EXPERIMENT- PART A (Inverting Amplifier)

Helpful Hints:

- One of the principal aims of this experiment is to reconcile your results in the laboratory with the theoretical model. You will save a lot of time if you are able to determine **on the spot** whether your results are correct and measurements are successful. Hence, it is essential for the preliminary calculations to be ready before the laboratory session.
- **Power Supply** – Two voltage rails are required, +15 V and –15 V. For convenience, especially for easier trouble-shooting, colour-code the leads as follows
  - +15 V: red
  - Common/ground:
  - -15 V black
- The power supplies provided in the laboratory have two DC sources which can be configured as either independent, series, or parallel. To obtain a dual supply rails from the power supply, the power supply can be configured in series mode [**one button down and another button up, if unsure ask the demonstrator]**. In this configuration, the negative terminal of one source will be connected to the positive terminal of the other internally as shown in Figure 5, and the connected terminals will define the analogue ground of the circuit (common). The other two terminals can define +15V and -15V rails as indicated in Figure 5 when the voltage output is adjusted to 15V. **[please ask the demonstrator to check the configuration before turning on the power]**:

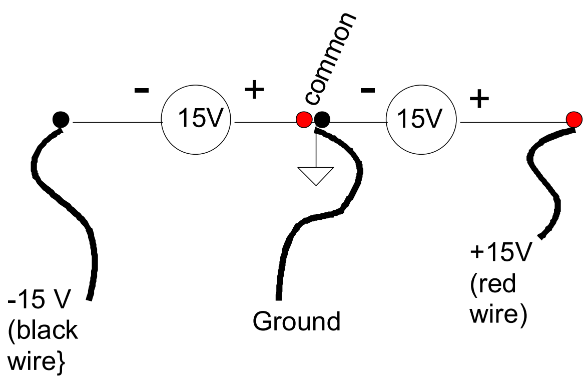


Figure 5: Dual supply rail power supply.

- **Frequency Compensation** – Unless otherwise stated, start of by using a 30 pF capacitor for C_c.
- **Golden Rule**:
  - ✓ When connecting or disconnecting components on the circuit bread board, **power supply or input signals should be switched off.**
  - ✓ Always switch on power supply **first before** switching on the input signals.
  - ✓ Always switch off the input signals **first before** switching off the power supply.

- Damage to your circuit will result in inconvenience and loss of valuable time for trouble-shooting and component replacement.
- **Warning**: ensure the op-amp output is not slew-rate limited, i.e., the rate-of-change at which you are trying to drive the output of the op-amp does not exceed its slew rate, as specified on the data sheet. The slew rate depends on C_c and the biasing current in the input stage of the op-amp. For a C_c = 30pf in the LM301, the slew rate is typically 1V/μs. You can easily observe if your op-amp is slew-rate limited from the shape of the output signal. If the output signal becomes triangular while your input is still sinusoidal, then your op-amp is slew-rate limited and measurement of gain or phase shift will be wrong. You can avoid slew-rate by either reducing the magnitude or frequency of input signal.
- It is important to monitor the output of the amplifier at all times on an oscilloscope so that saturation, overload or oscillation conditions can be detected immediately; measurements made in the presence of these conditions are mostly meaningless, and, at best, difficult. For example, if the gain should need to be measured in the presence of a low-level high-frequency parasitic oscillation, the use of an oscilloscope can make it possible to compensate visually for the effect of the oscillation. With a DVM (digital volt meter) alone, the parasitic oscillation would not be detected, and an incorrect measurement would likely result.

- Each student will be supplied with a pair of oscilloscope probes with low input capacitance. These probes must be returned to the lab attendant after each session.
- Before investing a lot of effort in measurement work, satisfy yourself that the parameters of your operational amplifier are reasonably close to those you have assumed in your theoretical preparations. In some cases, it may be necessary to vary some of the numerical values suggested in the instructions below. **If in doubt, consult a laboratory demonstrator without delay.**

Setups

For remote labs, the software interface used to control the relays (or switches) on the board and its circuitry is shown in Figure R1. It is very important to have **Power Switch ON** before providing an input signal to the circuit, controlled by **S1.** Conversely, always turn **S1 OFF** before turning **Power Switch OFF**.

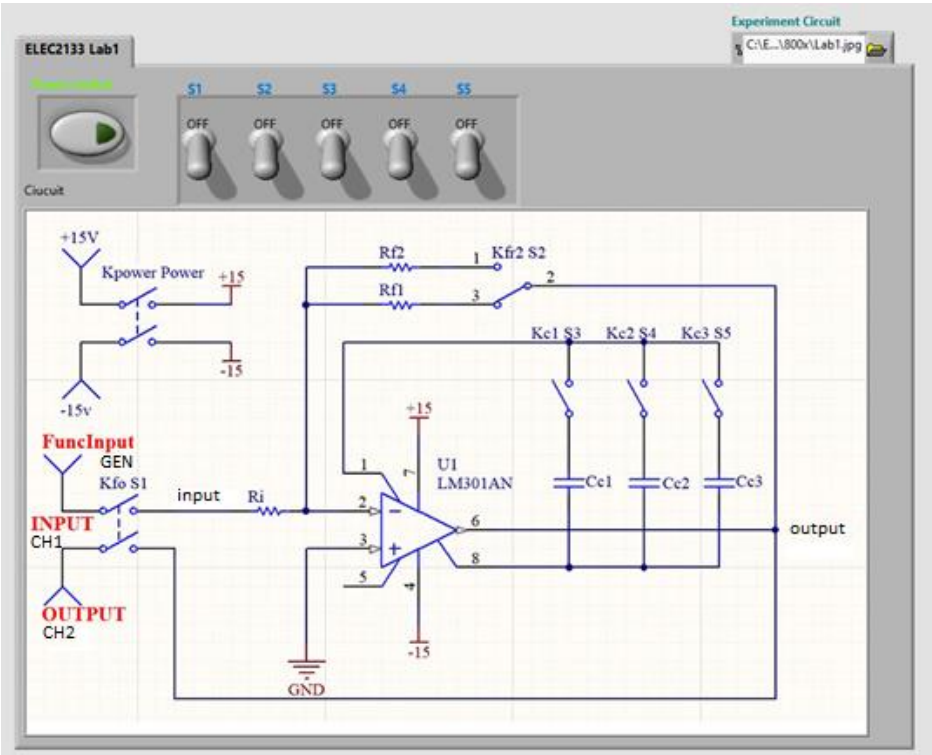


Figure R1: Remote Lab Setup for Lab 1. CH1 and CH2 represent CHANNEL 1 and CHANNEL 2 of the oscilloscope respectively. GEN represents the signal generator.

Demo

- Configure the DC power supply as dual rail power supply with +15V, -15V, and GND. Refer to the section above on helpful hints if you are unsure. **You must get this part right; otherwise you may destroy the LM301 IC**. Seek help from the lab demonstrators if you are still unsure.
- Use DVM or Oscilloscope to confirm that your DC power supply is configured right and supplying the required voltages. If you are unsure or have any problem, seek help from the lab demonstrator. Once you convince yourself the DC power supply is properly configured and giving out the required voltage, switch off the power supply.
- Make sure that the power supply is OFF. Connect the +15V, -15V, GND wires from the power supply to the corresponding pins on the PCB (on the left section of the PCB, Lab1 Operational amplifier).

Student

S2 OFF

- Plug-in the resistor values (Ri and Rf) in the spots provided on the PC board to obtain an inverting gain of 50 and input impedance of 10-20 kΩ as per your preliminary preparatory work. Before you plug in the resistors, measure their resistance values with DVM or the bridge meter in the laboratory and confirm that you have the correct values. **Be careful not to swap R_i and R_f when you plug-in the resistors.**

S3 ON

- Plug-in a compensation capacitor (C_c) of 30 pF (the *recommended compensation* capacitor value for this op-amp) into the spot provided on the PCB. Confirm that you have picked the right capacitor value by measuring its capacitance with the bridge meter in the lab.

Measure

- Set up a signal generator to generate 1kHz sinusoidal voltage with an amplitude of 100mV. Connect a signal generator to CHANNEL 1 of an oscilloscope to set the desired amplitude. Measure the amplitude of the signal using DVM (make sure that you set the DVM for AC and Voltage measurement). Is it different from 100mV? Why?

PS ON

- Switch ON the DC power supply. Note that the power supply is already connected to the corresponding pins on the PCB.

S1 ON

- Connect the signal generator as an input signal to the op-amp. The positive end of the signal generator (red) will be connected to V_i pin on the board and negative terminal (black) to GND.

S1 ON

- Connect an oscilloscope to the input (CHANNEL 1) and output (CHANNEL 2) using the probes provided. The positive terminal of CHANNEL 1 is to be connected to V_i pin on the PCB and the negative terminal of CHANNEL 1 will be connected to GND on the PCB. The positive terminal of CHANNEL 2 is to be connected to V_o pin on the PCB. You may leave the negative pin of CHANNEL 2 unconnected as the GND points of the two channels are internally connected in the oscilloscope.

Measurements

1. The Gain A = v_o/v_i of the circuit at 1 kHz:

   (i) Check that your 1 kHz sinusoidal input voltage amplitude is below 100mV and the output voltage is also sinusoidal (not slew rate limited). Measure the gain.

V_i (peak-to-peak)	V_o(peak-to-peak)	Gain (V_o/V_i)

Is the measured gain close to your theoretical calculation or design (i.e 50)? If not, what are the possible reasons for any discrepancy? (if your gain is significantly different from 50, your design values are either wrong or you have wrong component values (R_f, and R_i)). If you need to change resistance or capacitance values, follow the **GOLDEN Rules** outlined in helpful hints section. Switch OFF signal generator first and then switch OFF the DC power supply. After you change the plug-in component value, switch ON the DC power supply first and then switch ON the signal generator. Adjust the magnitude and frequency of the input signal and re-do (i).

(ii) Sketch the input and output waveform on the same time scale, noting their phase relationship. Write down an explanation of your observation.

(iii) Increase the input voltage amplitude to well above 100mV (for example 350mV or above) record the shape of the output waveform at 1 kHz. Give an explanation for the shape of the output waveform as the amplitude is increased.

(iv) Decrease the input amplitude to 200mV at 1kHz, then vary the frequency until the output begins to look like a triangular waveform. Estimate the slew rate of the op-amp from the slope of the ramp. Explain what is happening to the waveform?

2. Determine the input impedance R_{input} of the circuit at 1 kHz:

   There are two ways of measuring the input resistance of this circuit.

   (i) Using a multimeter to measure the ac input current, determine the input resistance. Connect Digital Multimeter (DM) configured to measure current in series with R_i. How?

   - ✓ Switch off signal generator and then DC power supply. Unplug left end of R_i while the right end is still plugged-in (The left end is connected to the input pin V_i).
   - ✓ Connect the positive terminal of the DM to the left side of the plug-in where R_i is unplugged from and the negative terminal of the DM to unplugged end of the resistor, R_i..
   - ✓ Switch ON DC power supply and then signal generator.
   - ✓ You may need to adjust the input signal to 100mV sinusoidal amplitude at 1 kHz. [Caution: Are the current and voltage readings in true RMS or peak value?]. If the measurement was done at a much higher frequency, would it be a problem?
   - ✓ Record DM measured currents for various input voltages (in pp) in the table below and calculate the input resistance.

V_i (in pp) from OS	100mV	200mV	300mV	400mV
V_i (in RMS) from OS				
I_i (in RMS) from DM				
Input resistance				

   (ii) **(You do not have to do this)** Place a 20kΩ variable resister R_v between R_i and the signal generator. Adjust R_v until the measured gain is ½ of what was obtained in the previous Gain measurement done above without R_v. Remove R_v and measure its resistance which should give R_{input} . Show algebraically that this is the case.

3. The 3dB bandwidth of the circuit:

   (i) **[For this part of the experiment, please remove the DM from your circuit and revert back to the original configuration before you proceed further].** Keep the <u>input amplitude at 100mV</u>, perform a quick frequency sweep to determine roughly the frequency range where the gain begins to decrease. You will notice that the gain does not change in the frequency range from dc to about 1 kHz and thus you only need to record the gain at every decade of frequency. However, you will need to measure the gain at closer frequency intervals in the critical region so that when you plot the gain versus frequency curve with sufficient data points to put a smooth curve through. Plot the gain-frequency curve in your lab book. Use the following tables and log-log chart to record and plot the curve.

Rough measurement (fill out all the measurements)

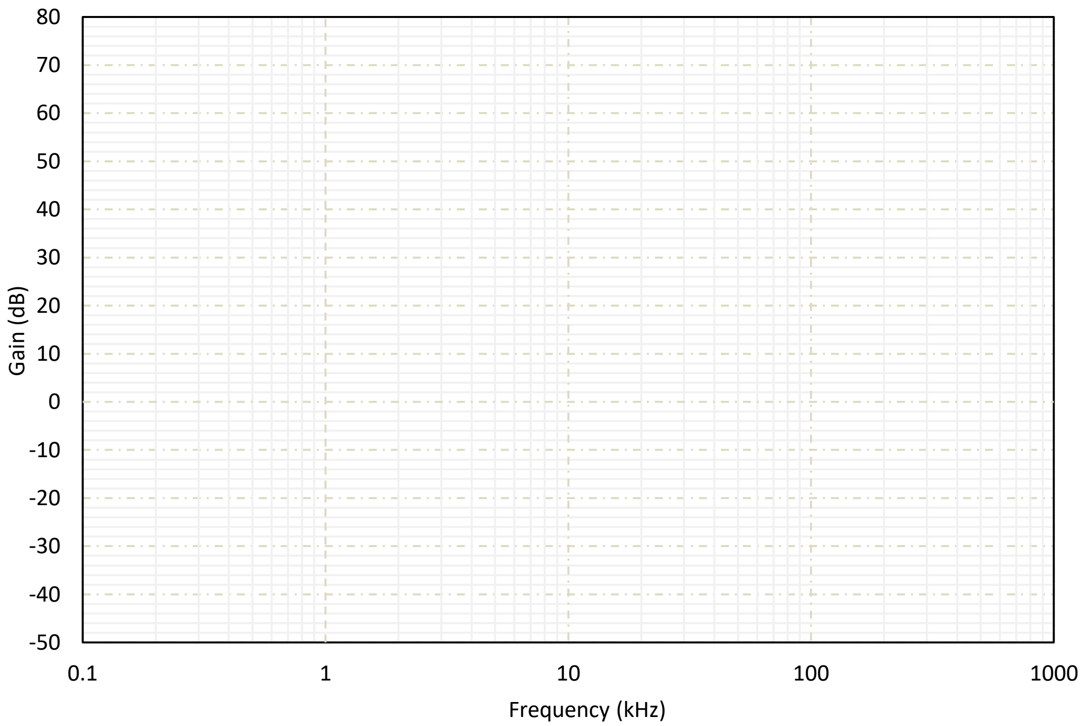
Frequency (kHz)	0.1	1	10	20	30	40
V_i (pp)						
V_o (pp)						
Gain (V_o/V_i)						
20log (Vo/Vi) in dB						

Frequency (kHz)	50	60	70	80	90	100	200	300
V_i (pp)								
V_o (pp)								
Gain (V_o/V_i)								
20log (Vo/Vi) in dB								

Refined measurement (measure at smaller frequency intervals, e.g., at every 1 kHz to determine the frequency when the gain starts to drop and locate the 3dB bandwidth frequency)

Frequency (kHz)								
V_i (pp)								
V_o (pp)								
Gain (V_o/V_i)								
20log (Vo/Vi) in dB								

Frequency (kHz)								
V_i (pp)								
V_o (pp)								
Gain (V_o/V_i)								
20log (Vo/Vi) in dB								



4. The frequency at which the gain falls to 0 dB:
   (i) Continue with the previous gain-frequency measurements until the gain reaches 0dB. Determine the gain-bandwidth product (GBP) the amplifier and compare with GBP of the op-amp calculated earlier.

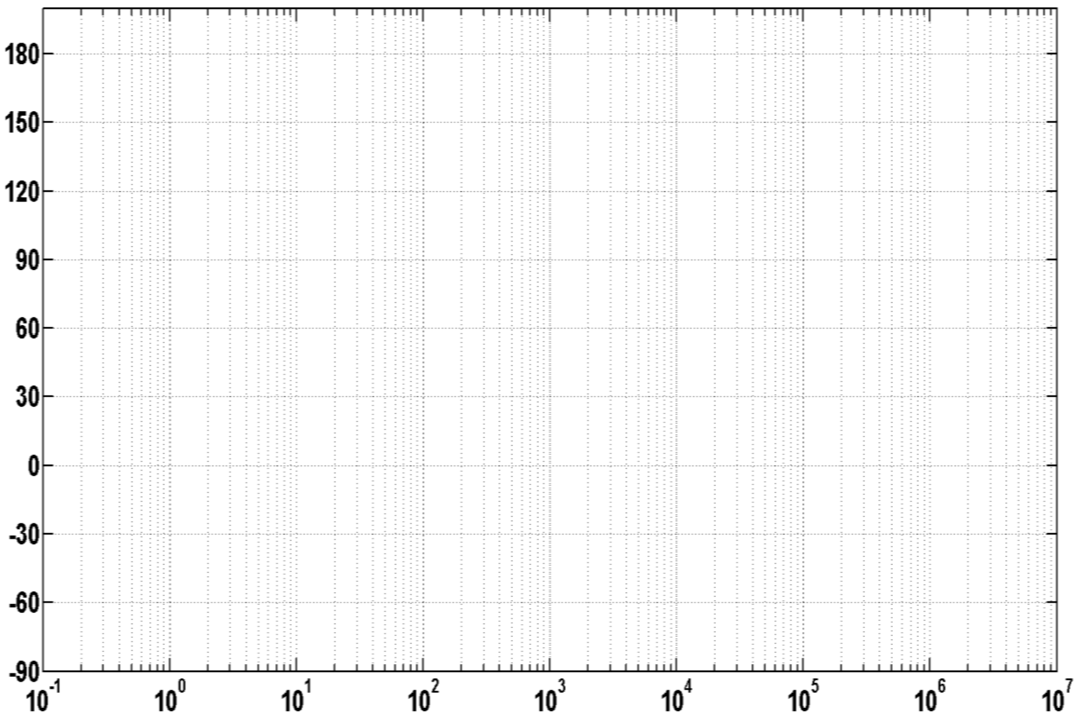
Frequency (kHz)	400	500	600	700	800	900	1000
V_i (pp)							
V_o (pp)							
Gain (V_o/V_i)							
20log (Vo/Vi) in dB							

5. Plot phase-frequency response. Display both input and output signals at the same time scale and measure the time difference (delay, T_d) between the peaks of the input and output. The phase difference is calculated as $(T_d/T)*360$, where T is the period of the signal. Vary the frequency, record T_d and T, and calculate phase and plot phase-frequency response. Use the table and linear-log scale chart provided below for recording and plotting the response.

Frequency (kHz)	0.1	1	10	20	30	40
T_d						
T (1/f)						
Phase (T_d*360/T)						

Frequency (kHz)	50	60	70	80	90	100	200	300
T_d								
T (1/f)								
Phase (T_d*360/T)								

Frequency (KHz)	400	500	600	700	800	900	1000
T_d							
T (1/f)							
Phase (Td*360/T)							



Compare your experimental results with theory and reconcile any differences. Is the actual gain-bandwidth product (GBP) of your amplifier, with standard compensation, as good as that claimed in the specifications?

Checkpoint 1.2	**Assessor**	**Marks**	**Date**