**Lab 6B: Op amp part 2 – inverting amplifier, voltage limitation**

**Objectives**

1) Become familiar with the inverting amplifier – its topology, advantages, and disadvantages.

2) Use the inverting amplifier to investigate the limitation of the op amp output voltage.

3) Optional – investigate the op amp’s slew rate and bandwidth.

**Part 1: single input circuits – inverting amplifier**

Construct the following inverting amplifier circuit. Pay attention to the DC signal input Vin. The circuit diagram shows a power source Vs, but you cannot use a power supply channel to implement Vs (think about why). Instead, you need to use a potentiometer and the existing power rails to implement Vs.

A diagram of a circuit

Description automatically generated

**Derive:** the gain formula (based on Rf and R1) of this inverting amplifier. Then verify it with actual measurements below.

**Measure and record:** Now apply a DC input signal Vin. Use the potentiometer to set Vin to be ±0.1V, ±0.2V, ±0.5V, ±1V, and ±1.5V. Measure the corresponding output voltages of Vout. Plot the voltage transfer curve (VTC).

**Determine** the gain Vout/Vin, and compare it with the theoretical gain.

**Discuss:** The advantages and disadvantages of the inverting amplifier topology.

**Explore:** Furtherincrease the input voltage Vin to be beyond ±1.5V and observe the output voltage Vout. The output will saturate when the input reaches a certain value. What are the Vin and Vout (positive and negative) at saturation? Revise the VTC with these saturation data points. Comment on the symmetry of the positive and negative saturation levels. Are they symmetrical?

Part 1: inverting amplifier data table:

|  |  |
| --- | --- |
| Derive the gain formula |  |
| Theoretical gain |  |
| Measured gain |  |
| Discuss the advantages and disadvantages of this inverting amplifier |  |
| At saturation, what is Vin (positive)? |  |
| At saturation, what is Vin (negative)? |  |
| At saturation, what is Vout (positive)? |  |
| At saturation, what is Vout (negative)? |  |
| Plot the VTC (including saturation) |  |
| Comment on the symmetry of the saturation levels. Are they symmetrical? |  |

**Part 2: output voltage saturation; bandwidth limitation (optional, not graded); slew rate (optional, not graded)**

Continue to use the inverting amplifier circuit as before, but change the input signal source from DC (implemented with a potentiometer and the power rails) to AC (implemented with a function generator). The input signal Vs is a sine wave, 0.2Vpp, 1kHz.

Diagram

Description automatically generated

1) Output voltage limitation (saturation):

**Tricky issue:** The function generator’s offset voltage may be slightly off, so setting a 0Vdc offset to the function generator may not actually create a 0Vdc offset signal. Use the scope to observe and help to adjust the Vin signal (e.g., -40mVdc) to create a Vin signal with zero offset. Then send this zero-offset signal into the op amp circuit.

**Observe:** Maintain the input signal frequency at 1kHz, and increase the input signal amplitude until the output waveform saturates. Record the input and output waveforms (superimposed) at saturation. At what input signal amplitude does the output signal begin to saturate? (should be around 2.8Vpp)

**Measure:** What are the upper and lower limits of output voltage?

**Comment** on the symmetry of the output voltage limits. Are they symmetrical?

Part 2: op amp output voltage saturation:

|  |  |
| --- | --- |
| Superimposed input and output waveforms at saturation |  |
| Upper limit of Vout |  |
| Lower limit of Vout |  |
| Comment of the symmetry of the two limits |  |

2) Bandwidth limitation **(optional, not graded)**

Use the same op amp circuit as before.

**Measure:** Maintain the input signal amplitude at 0.2Vpp and increase the signal frequency from 1kHz to higher values. Increase the frequency on logarithmic scale (e.g., 2 or 3 values per decade). Measure the gain of the circuit. Measure a few gains at several input signal frequencies. Plot the gain against the input frequency on a log-log scale (the Bode plot).

**Measure:** the exact -3dB cutoff frequency of this op amp circuit, based on the Bode plot? (e.g., ~90kHz)

**Comment:** Does the op amp resemble a HPF or LPF?

**Explain:** What causes the bandwidth limitation of the op amp?

Part 2 optional: bandwidth limitation

|  |  |
| --- | --- |
| Bode plot |  |
| Identify the cutoff frequency |  |
| Is this op amp circuit a HPF or LPF? |  |
| What causes the bandwidth limitation of the op amp? |  |

3) Slew rate limitation **(optional, not graded)**

Use the same op amp circuit as before.

**Measure:** Set the input as 1 kHz, square wave (50% duty cycles), with 4 input amplitude scenarios of 0.2Vpp, 1Vpp, 2Vpp and 2.8Vpp. Obtain the input and output waveforms. For each output wave, use the scope’s horizontal and vertical cursors to measure the slew rate (ΔV/Δt) (e. g., expected to see generally about 0.6 V/us, and then reducing to about 0.5 V/us).

**Repeat** the above steps with 10kHz input; organize your results to compare.

**Explain:** What causes the slew rate of the op amp?

Part 2 optional: slew rate limitation

|  |  |  |
| --- | --- | --- |
|  | 1kHz input signal | 10kHz input signal |
| Slew rate at 0.2 Vpp input |  |  |
| Slew rate at 1 Vpp input |  |  |
| Slew rate at 2 Vpp input |  |  |
| Slew rate at 2.8 Vpp input |  |  |
| What causes the slew rate of the op amp? | |  |

Scope image capture of the superimposed input and output waveforms (8 scenarios):

|  |  |  |
| --- | --- | --- |
|  | 1kHz input signal | 10kHz input signal |
| 0.2 Vpp input |  |  |
| 1 Vpp input |  |  |
| 2 Vpp input |  |  |
| 2.8 Vpp input |  |  |

**Data tables and scope image captures**

Part 1: inverting amplifier data table:

|  |  |
| --- | --- |
| Derive the gain formula |  |
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| Discuss the advantages and disadvantages of this inverting amplifier |  |
| At saturation, what is Vin (positive)? |  |
| At saturation, what is Vin (negative)? |  |
| At saturation, what is Vout (positive)? |  |
| At saturation, what is Vout (negative)? |  |
| Plot the VTC (including saturation) |  |
| Comment on the symmetry of the saturation levels. Are they symmetrical? |  |

Part 2: op amp output voltage saturation:

|  |  |
| --- | --- |
| Superimposed input and output waveforms at saturation |  |
| Upper limit of Vout |  |
| Lower limit of Vout |  |
| Comment of the symmetry of the two limits |  |