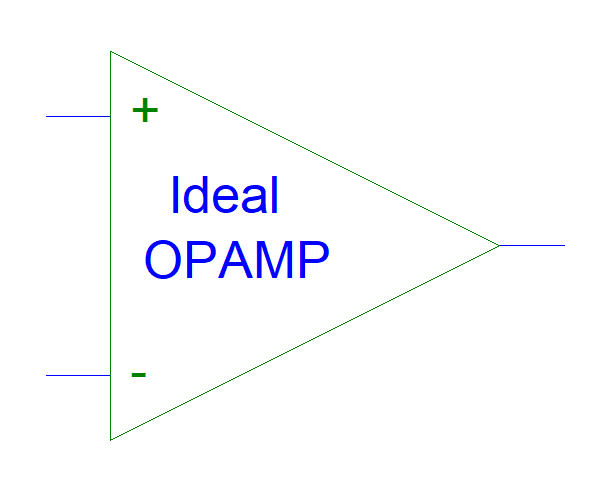
Operational Amplifiers

1. **Introduction**

Operational amplifier is a type of a differential amplifier that amplifies the difference between two inputs.

****

**Figure 1:** Operational Amplifier Symbol

Operational amplifiers were invented in the 1970s. For many years there were used for the following applications:

|  |  |  |
| --- | --- | --- |
| **Applications** | **1970s** | **Today’s** |
| Analogue Filtering | Operational Amplifiers | Digital Filtering with Microprocessors and Microcontrollers |
| Low Frequency Oscillators | Operational Amplifiers, Timer ICs (LM555, LM556) | Microprocessors and Microcontrollers |
| Instrumentation Amplification (medical, voltmeters) | Operational Amplifiers | Instrumentation Amplifier ICs |
| Educational Purposes | Transistors, Operational Amplifiers | Transistors, Operational Amplifiers |
| Voltage Reference | Operational Amplifiers, Voltage Regulators | Voltage Regulators |
| Integrators/Differentiators | Operational Amplifiers | Microprocessors and Microcontrollers |
| Schmitt Triggers | Operational Amplifiers | Microprocessors and Microcontrollers |
| Comparators | Operational Amplifiers, Comparator ICs | Microprocessors and Microcontrollers |
| Load Drivers (Motors, LEDs, Speakers) | Audio Power Amplifiers | Power Amplifiers and Power Operational Amplifiers, LED drivers, Motor Drivers |

**Table 1:** Operational Amplifier Applications

**2. Ideal Operational Amplifier**

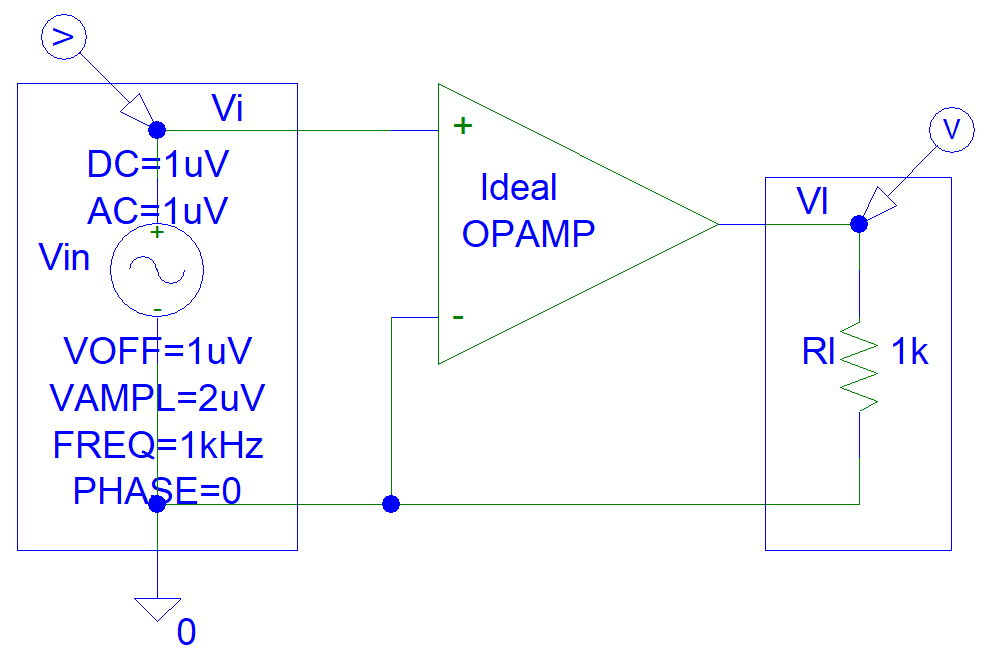
## 2.1 Characteristics

Ideal operational amplifier characteristics:

* Infinite:
  + Gain (Ad), Vo = Ad \* (V1 - V2),
  + Bandwidth (fb),
  + Gain bandwidth product (Ad\*fb),
  + Current output supply,
  + Common Mode Rejection Ratio (CMRR) (CMRR = Ad/Ac),
  + Input impedance (Zin).
* Zero:
  + Output impedance (Zo),
  + Common mode gain (Ac), (Vo = Ac \* (V1 + V2)/2)
  + Offset voltage (Vo), offset current (Vb), offset current (Io), bias current (Ib), output when the input is zero.

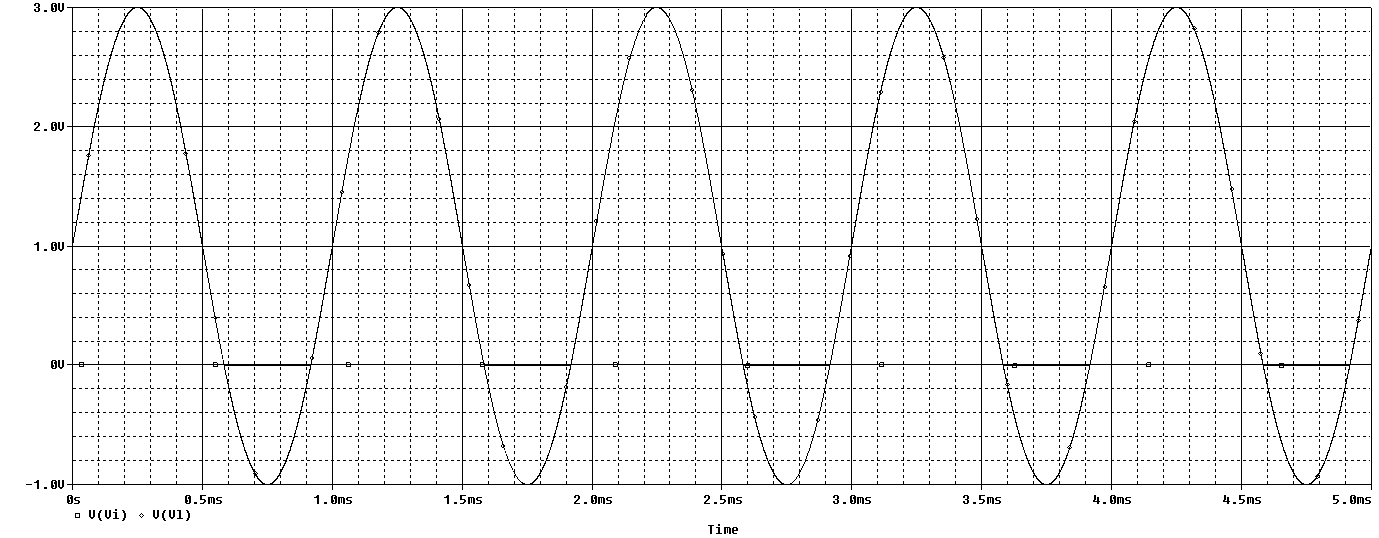
## 2.2 Ideal Operational Amplifier Circuit

*PSpice drawing:*



**Figure 2:** Ideal Operational Amplifier Circuit

*PSpice simulations:*



**Figure 3:** Operational Amplifier Time Domain Simulations



**Figure 4:** Operational Amplifier Frequency Simulations

**3. Practical Operational Amplifier**

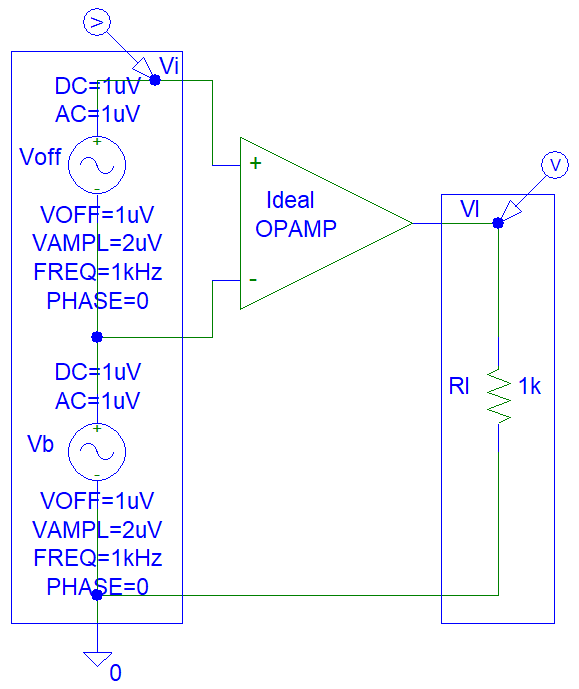
## 3.1 Characteristics

Typical operational amplifier characteristics:

* Limited:
  + Gain (Ad) = 1\*10^6 (at 1 Hz frequency),
  + Bandwidth (fb) = 1\*10^6 (at gain of “1”),
  + Gain bandwidth product (Ad\*fb) = 1\*10^6,
  + Current output supply (maximum 10 mA),
  + Common Mode Rejection Ratio (CMRR) (Ad/Ac) = 90 dB,
  + Input impedance (Zin) = 1 Megohm.
* Non-zero:
  + Output impedance (Zo) = 50 ohms,
  + Common mode gain (Ac), (Vo = Ac \* (V1 + V2)/2)
  + Offset voltage (Vo), offset current (Vb), offset current (Io), bias current (Ib), output when the input is zero.

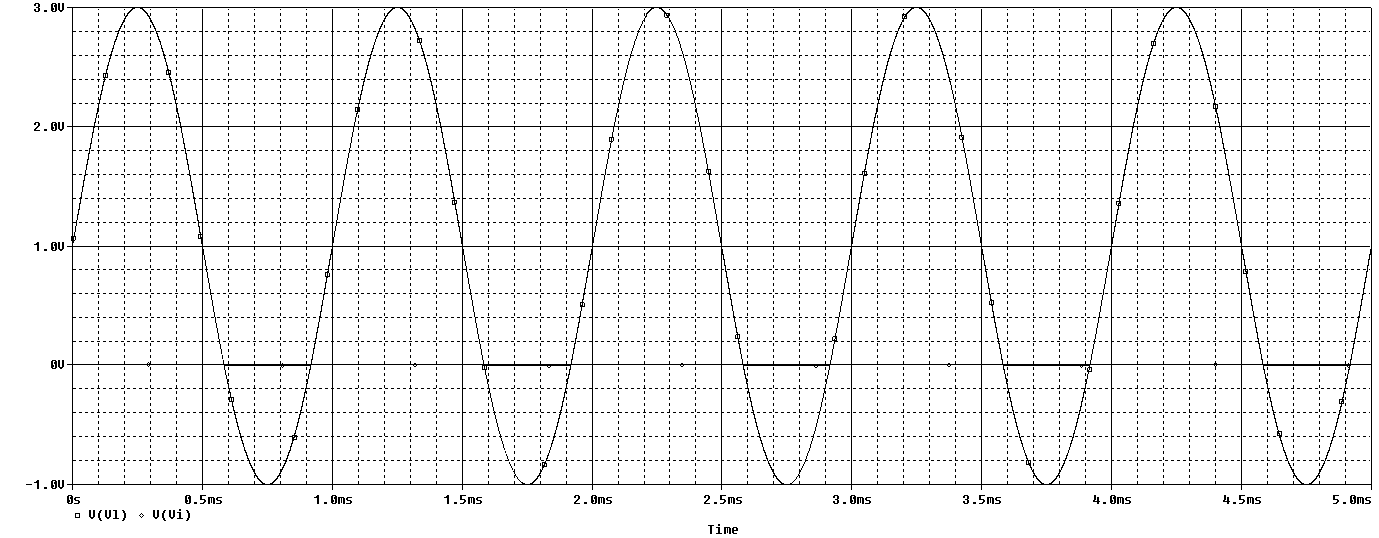
## 3.2 Offset Voltage Model

Op-amp offset voltage circuit:

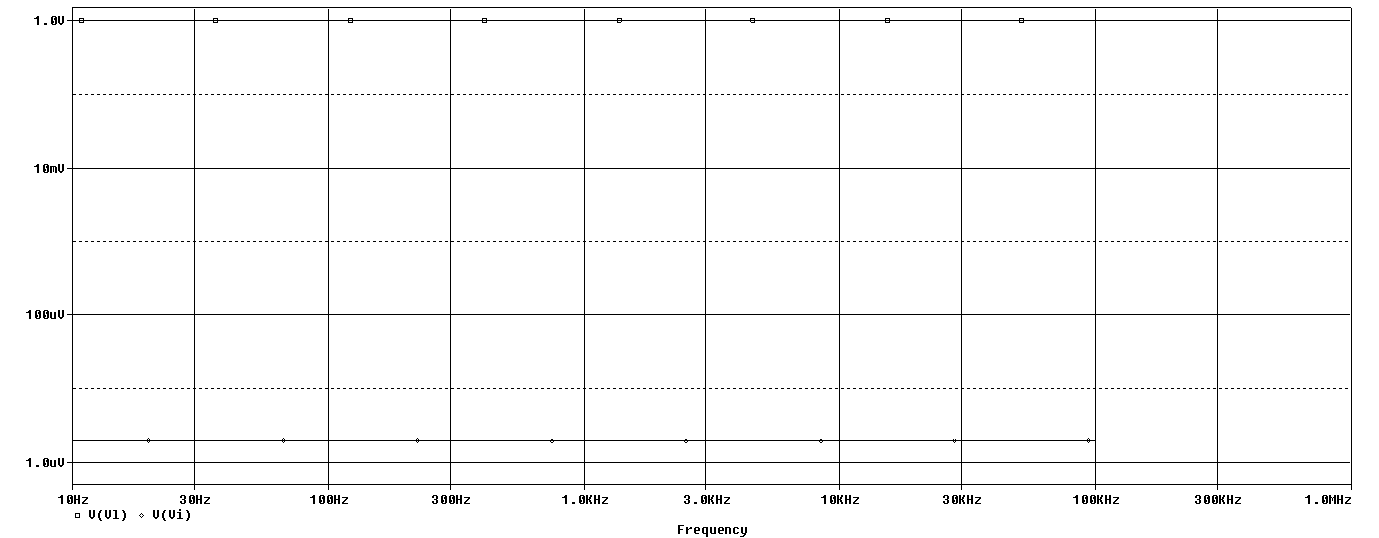


**Figure 5:** Practical Operational Amplifier Offset Voltage Model

*PSpice simulations:*



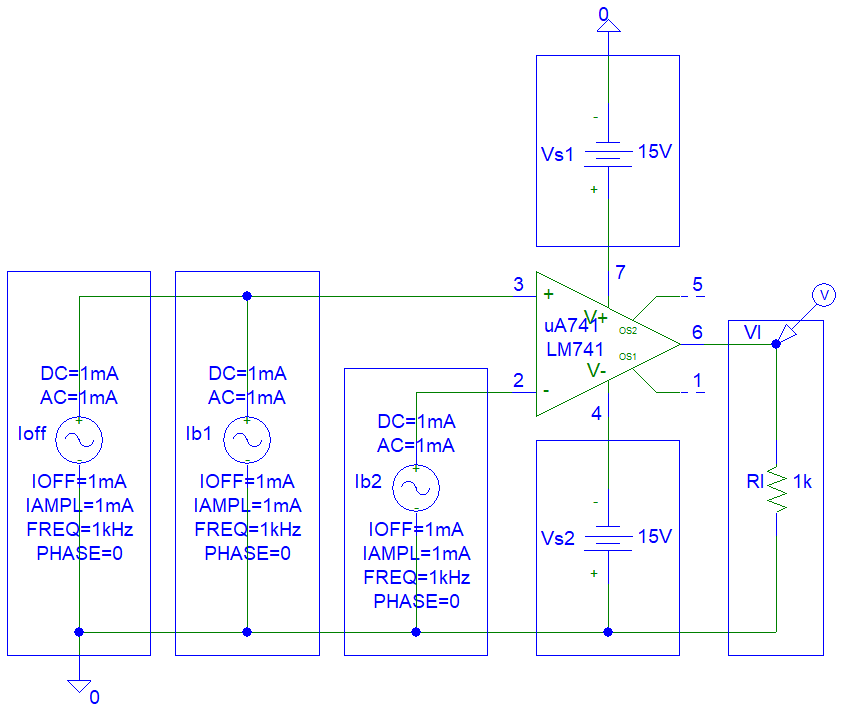
**Figure 6:** Practical Operational Amplifier Time Domain Simulations



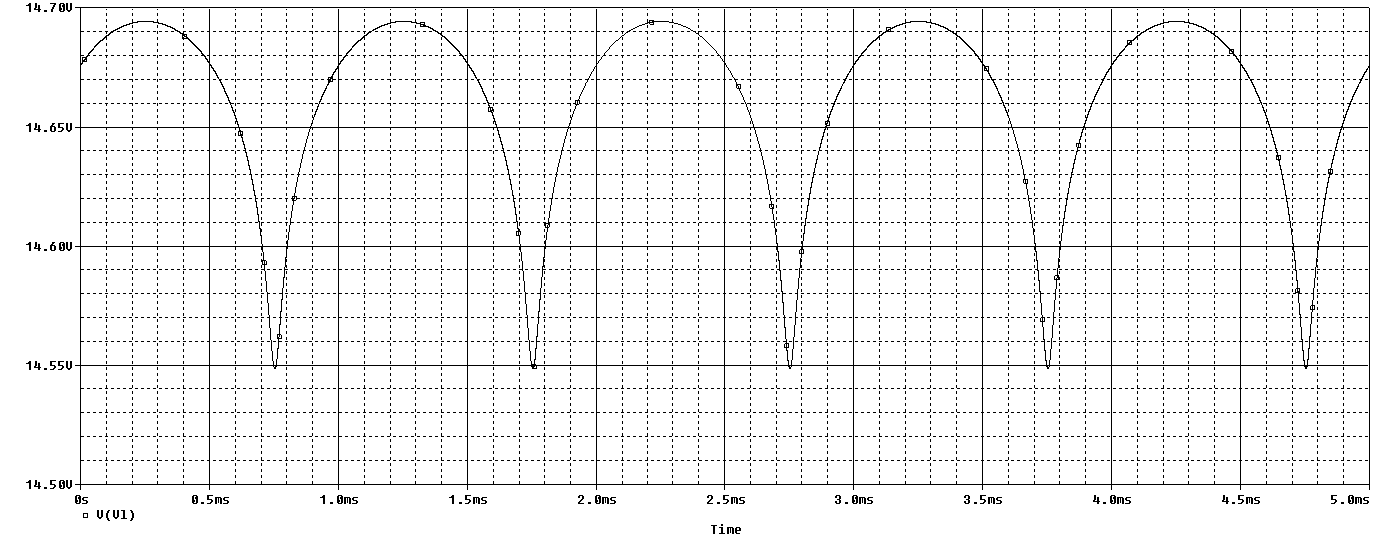
**Figure 7:** Practical Operational Amplifier Frequency Simulations

## 3.3. Offset Current Model

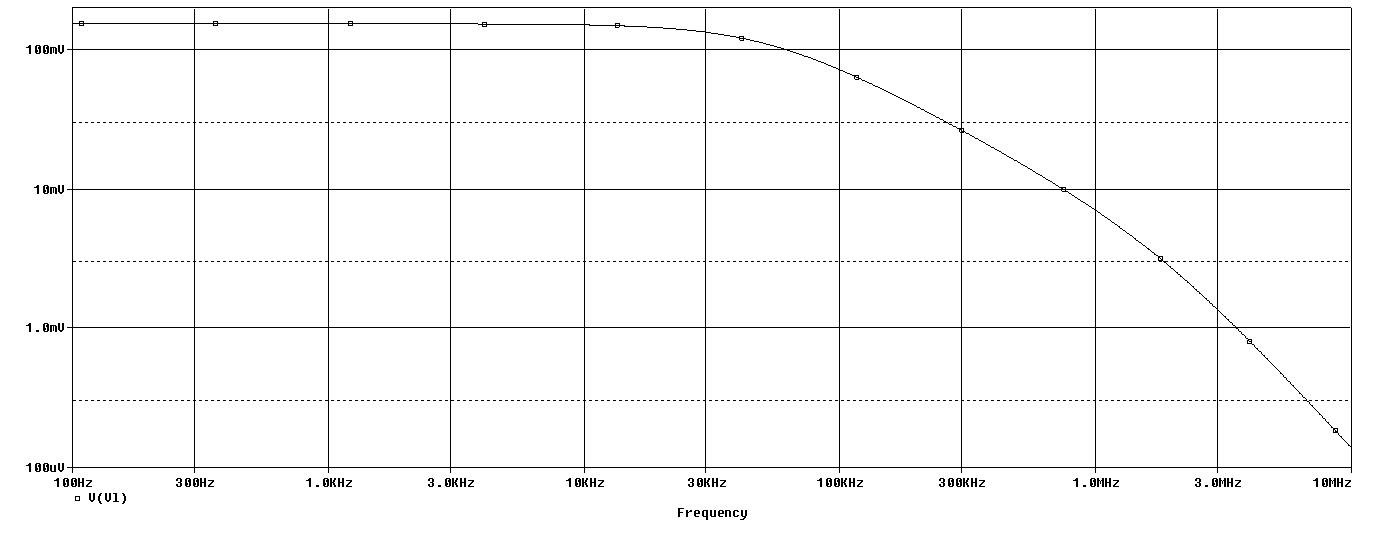
Op-amp offset current circuit:

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**Figure 8:** Practical Operational Amplifier Offset Current Model



**Figure 9:** Practical Operational Amplifier Time Domain Simulations



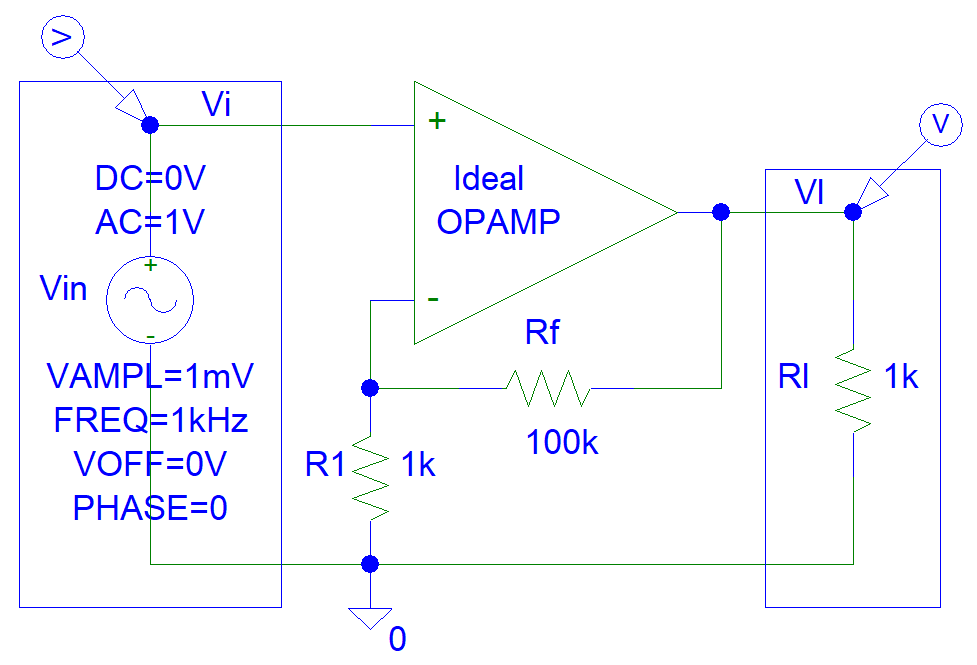
**Figure 10:** Practical Operational Amplifier Frequency Simulations

**4. Applications**

## 4.1 Amplifiers

### 4.1.1 Non-Inverting Amplifier

This is a non-inverting amplifier circuit for ideal op-amps:



**Figure 11:** Non-Inverting Ideal Operational Amplifier Circuit

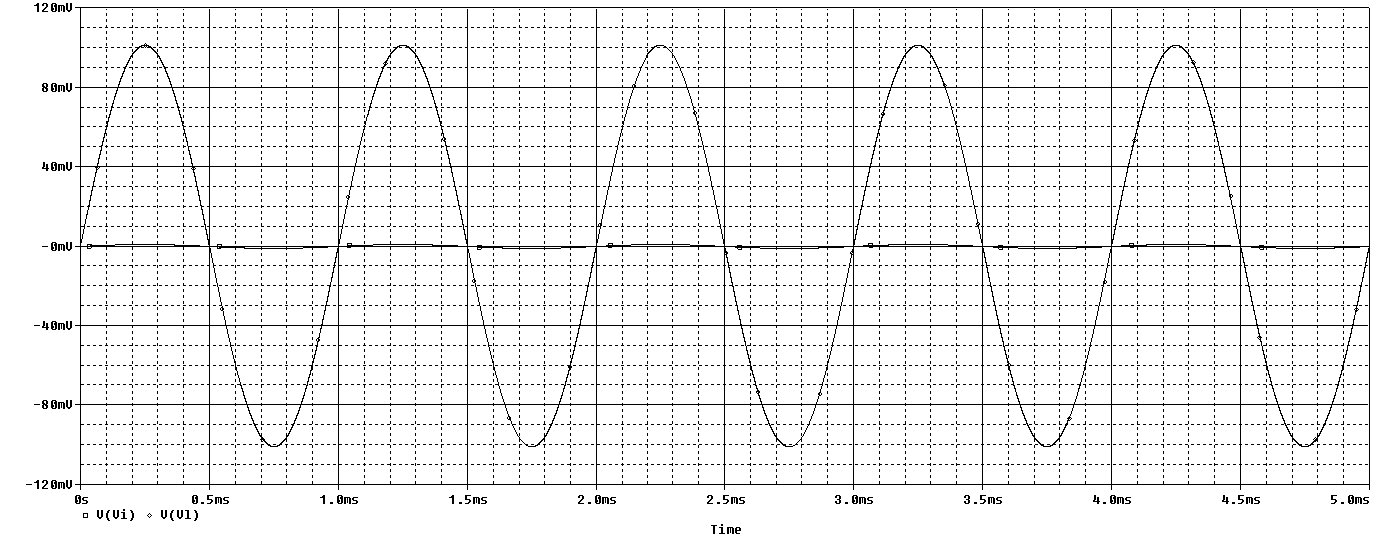
Gain derivations:

Vin = Vo \* R1 / (Rf + R1)

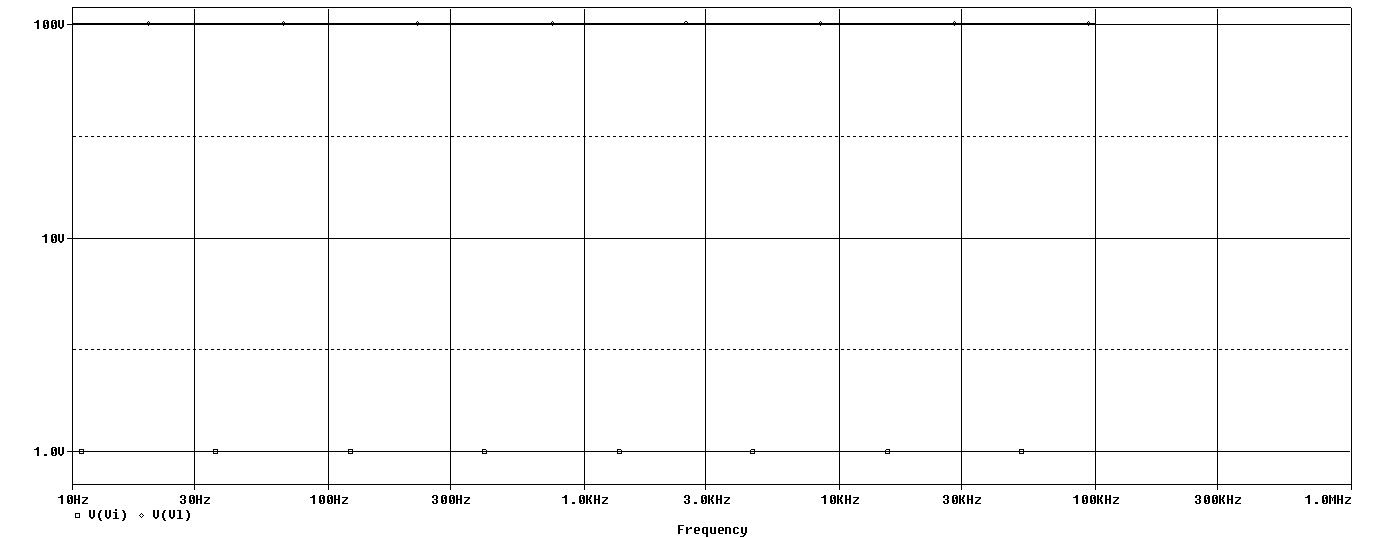
Vo = Vin \* (Rf + R1) / R1

Vo = Vin \* Ad

Ad = Rf / R1 + 1

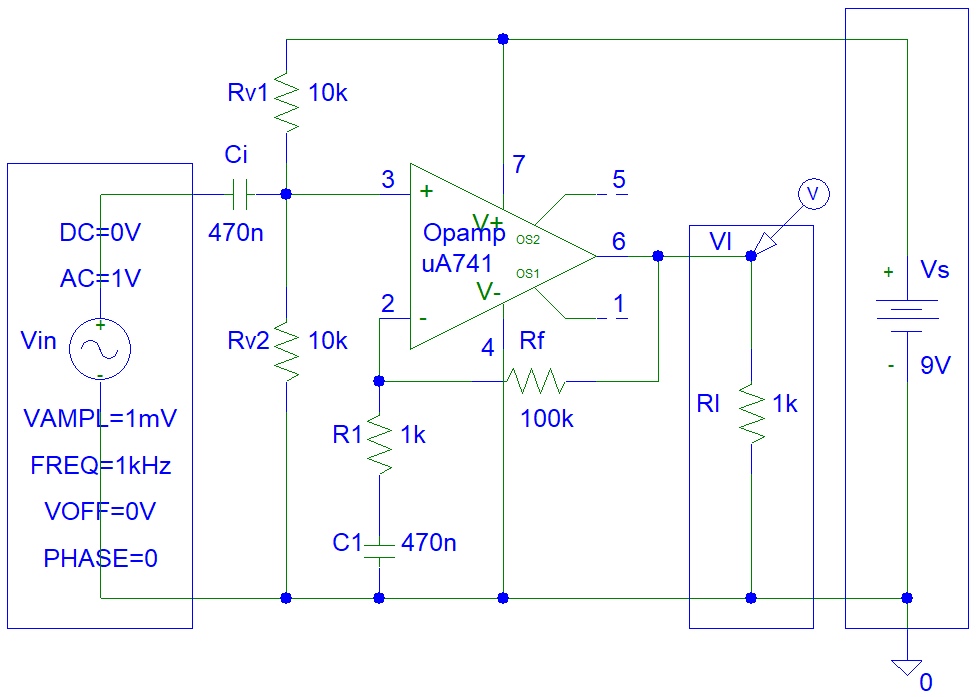
****

**Figure 12:** Non-Inverting Ideal Operational Amplifier Time Domain Simulations



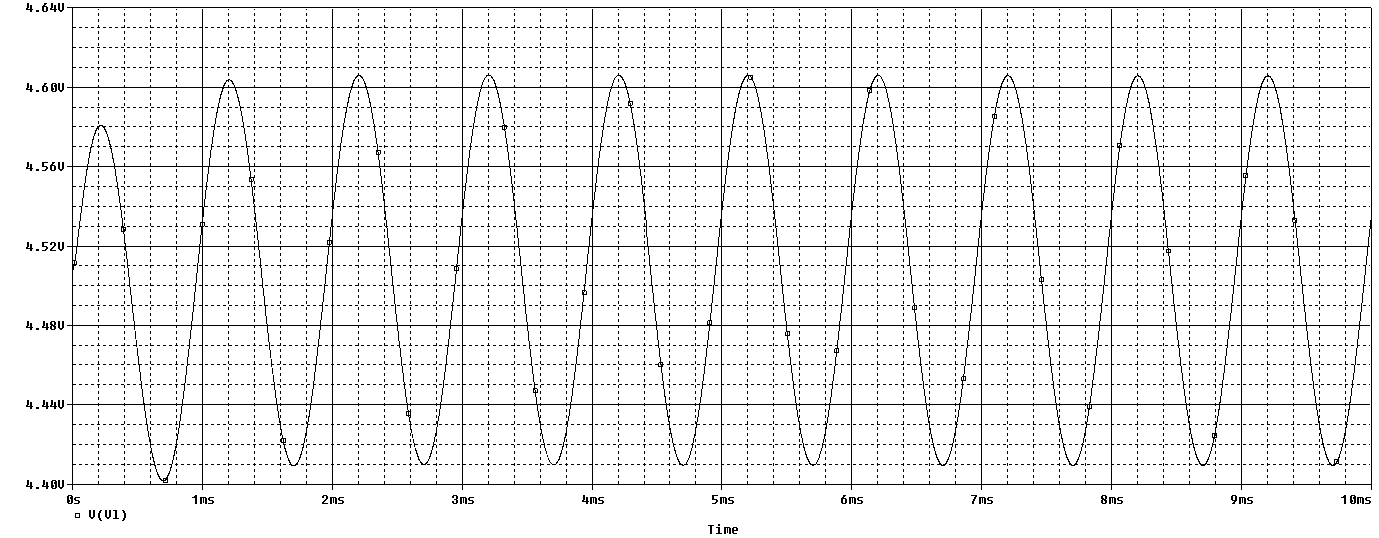
**Figure 13:** Non-Inverting Ideal Operational Amplifier Frequency Domain Simulations

This is a biased non-inverting amplifier with a single supply.

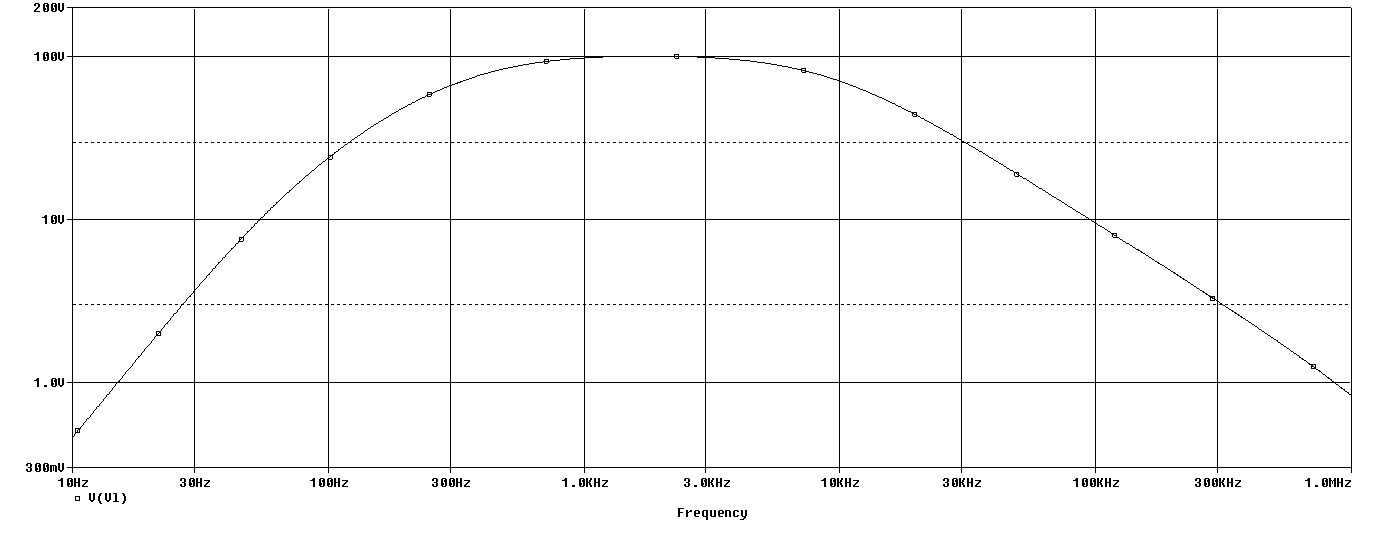


**Figure 14:** Non-inverting amplifier

*PSpice simulations:*



**Figure 15:** Non-inverting Amplifier Time Domain Simulations

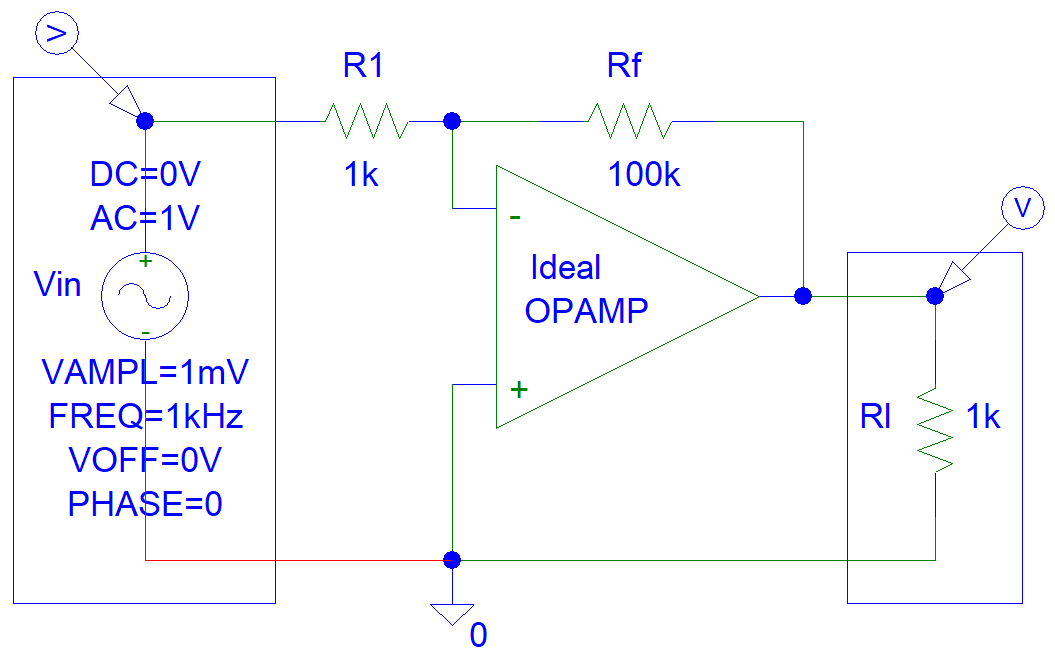


**Figure 16:** Non-inverting Amplifier Frequency Simulations

### 

### 4.1.2 Inverting Amplifier

This is a inverting amplifier circuit for ideal op-amps:



**Figure 17:** Inverting Ideal Operational Amplifier Circuit

Gain derivations:

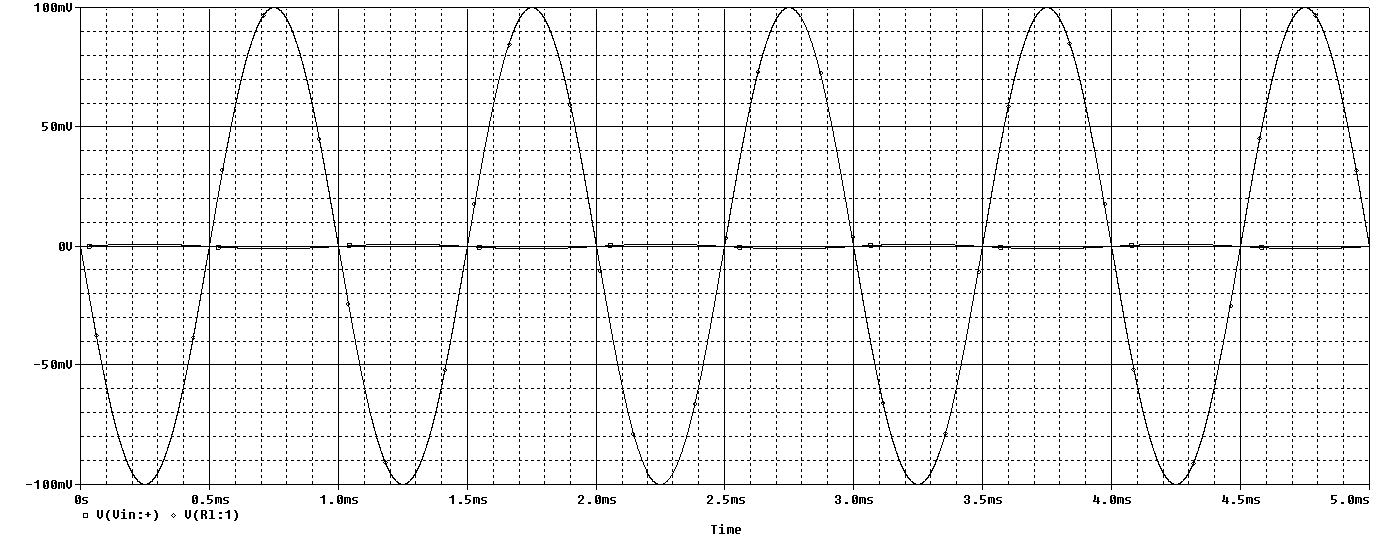
Vin / R1 = -Vo / Rf

Vo = Vin \* (-Rf / R1)

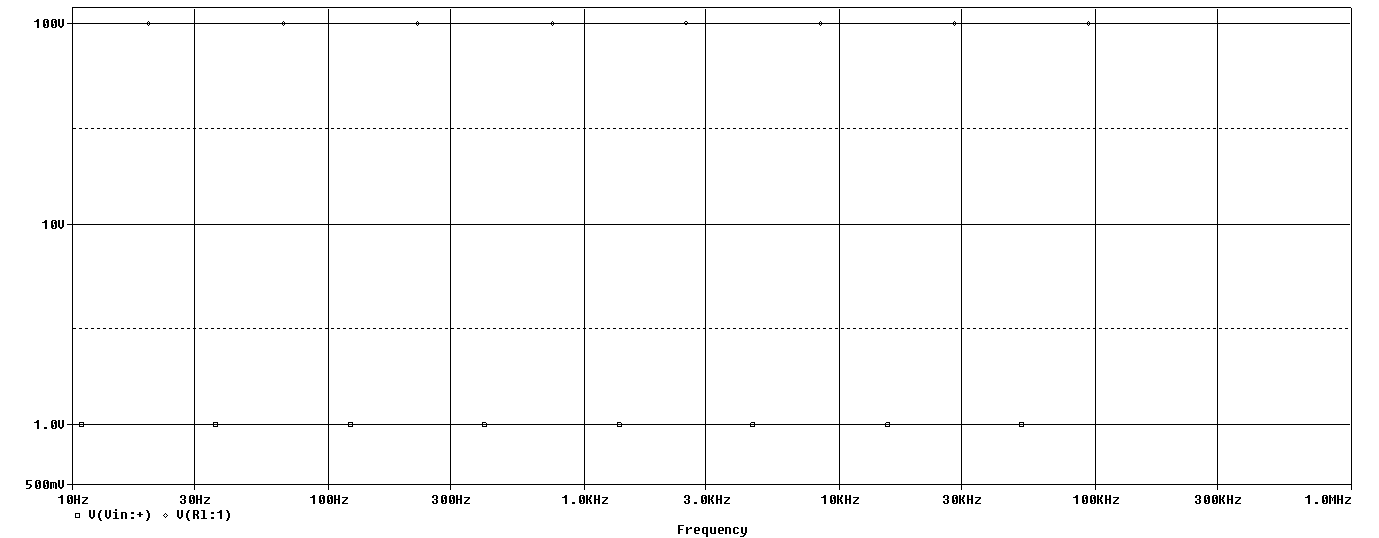
Vo = Vin \* Ad

Ad = -Rf / R1

*PSpice simulations:*

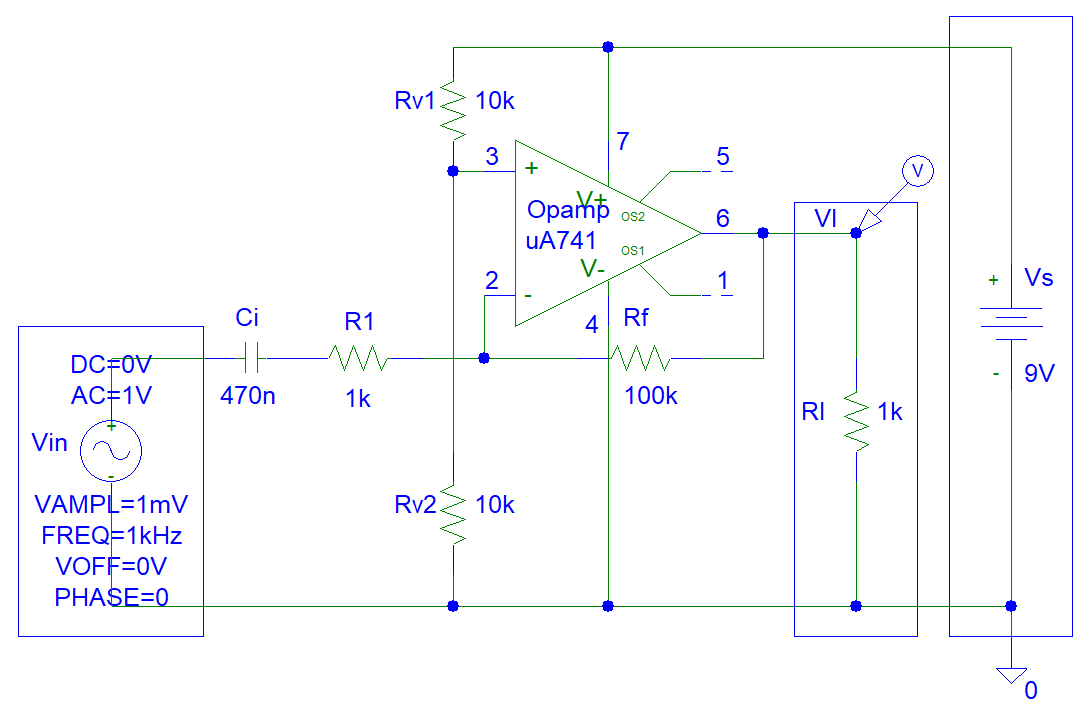


**Figure 18:** Inverting Ideal Operational Amplifier Time Domain Simulations



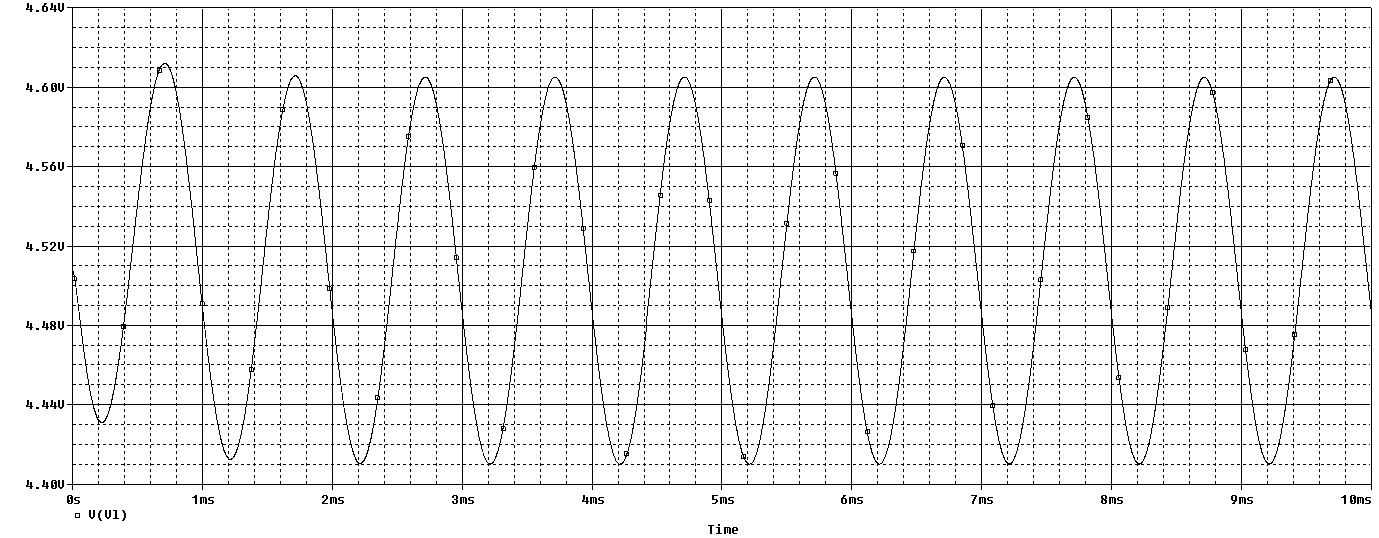
**Figure 19:** Inverting Ideal Operational Amplifier Frequency Domain Simulations

This is a biased inverting amplifier with a single supply:

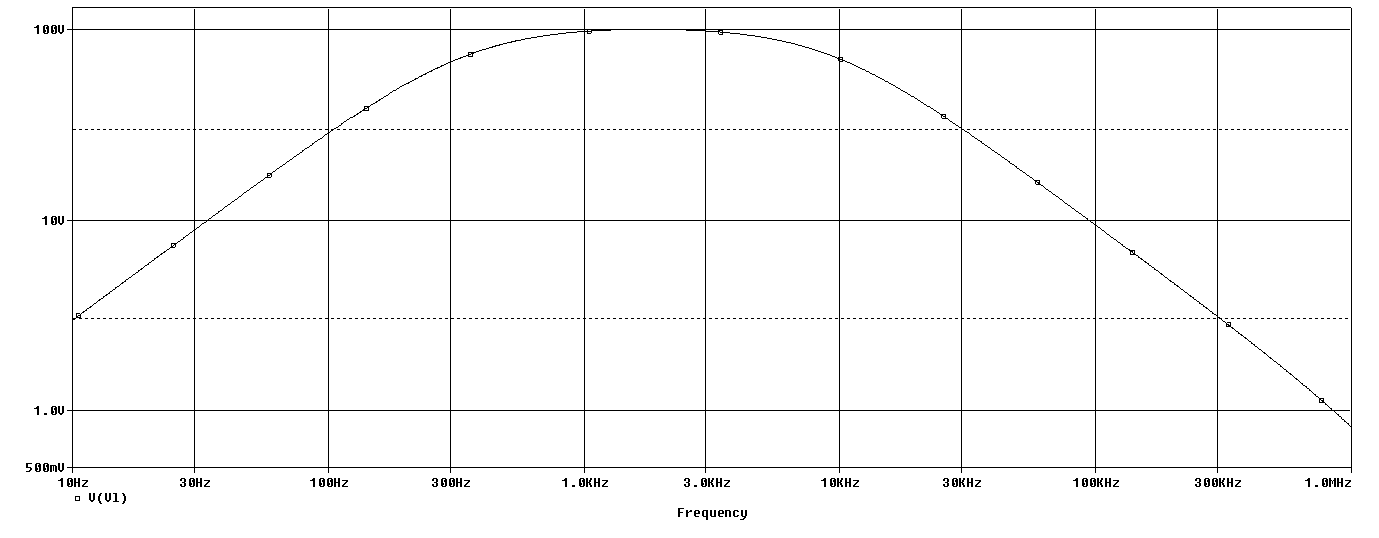
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**Figure 20:** Inverting amplifier

*PSpice simulations:*



**Figure 21:** Non-inverting Amplifier Time Domain Simulations

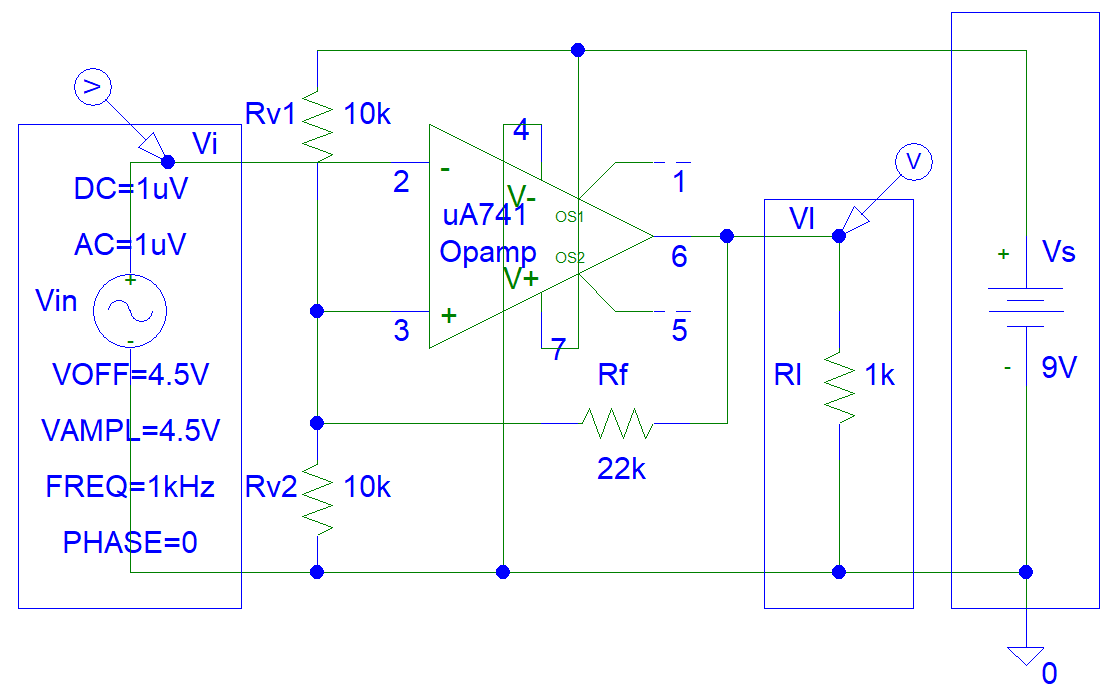


**Figure 22:** Non-inverting Amplifier Frequency Simulations

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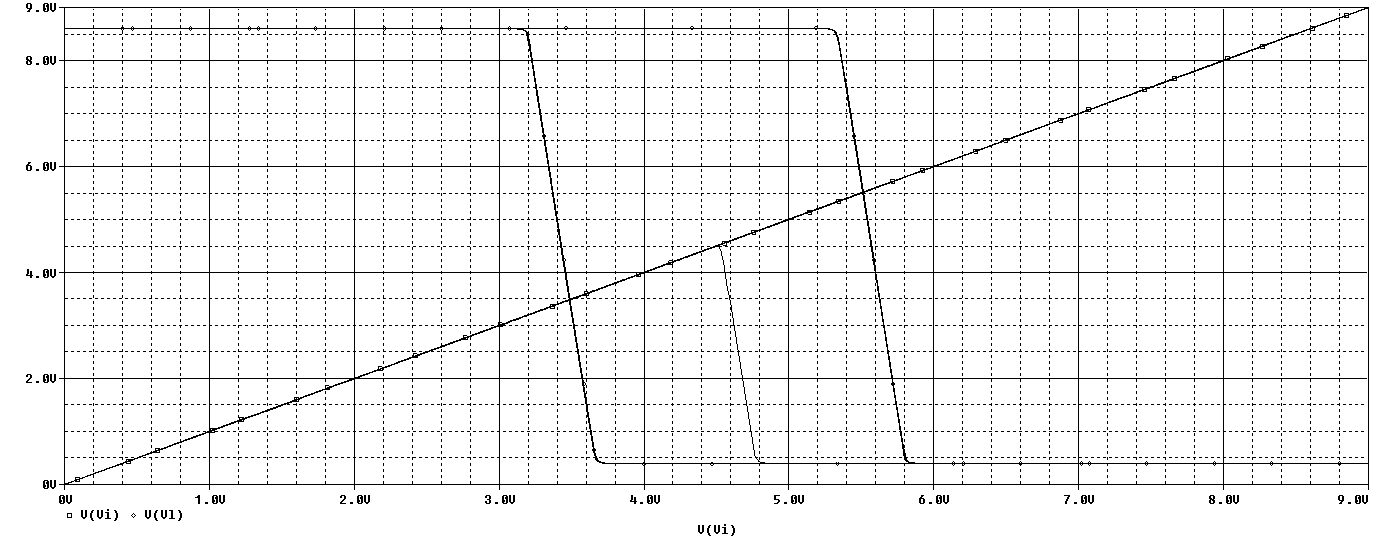
## 4.2 Schmitt Triggers

This ia a biased op-amp Schmitt Trigger design:

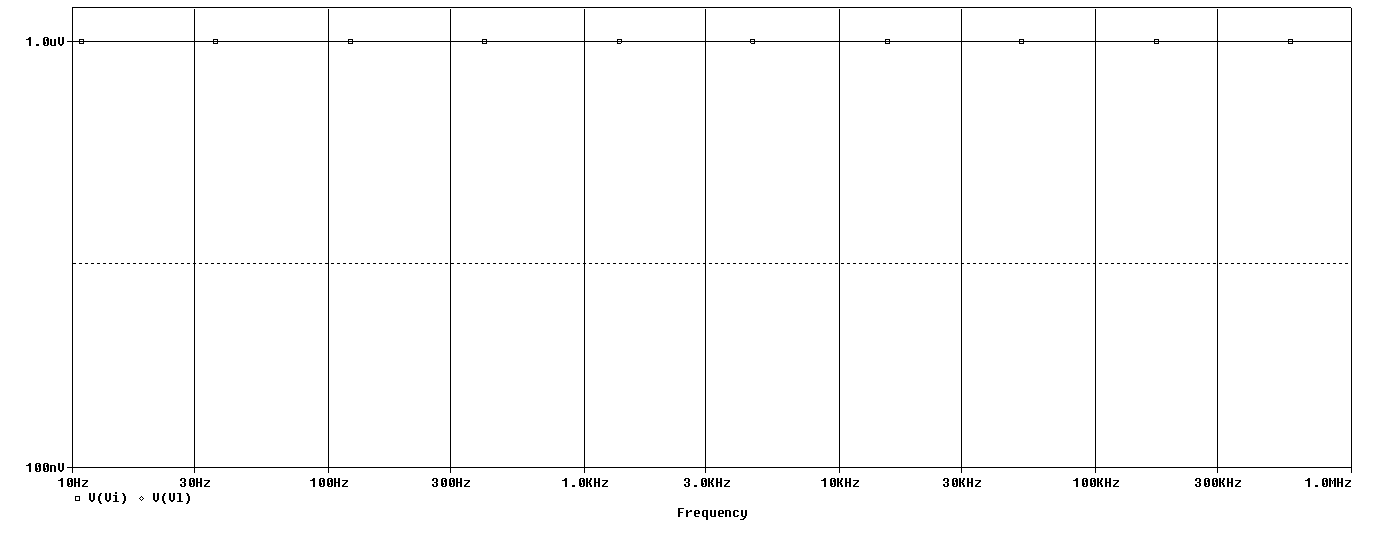


**Figure 23:** Schmitt Trigger Circuit

*PSpice Simulations:*

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**Figure 24:** Schmitt Trigger Time Domain Simulations

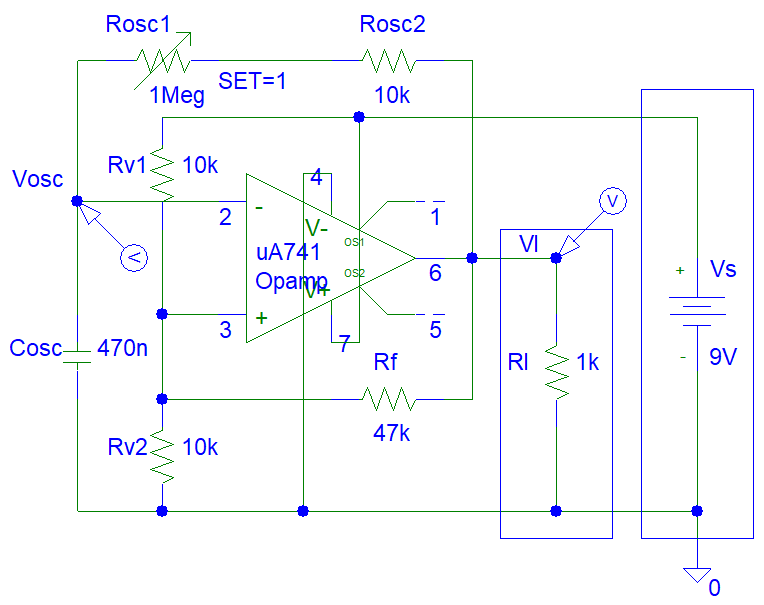


**Figure 25:** Schmitt Trigger Frequency Simulations

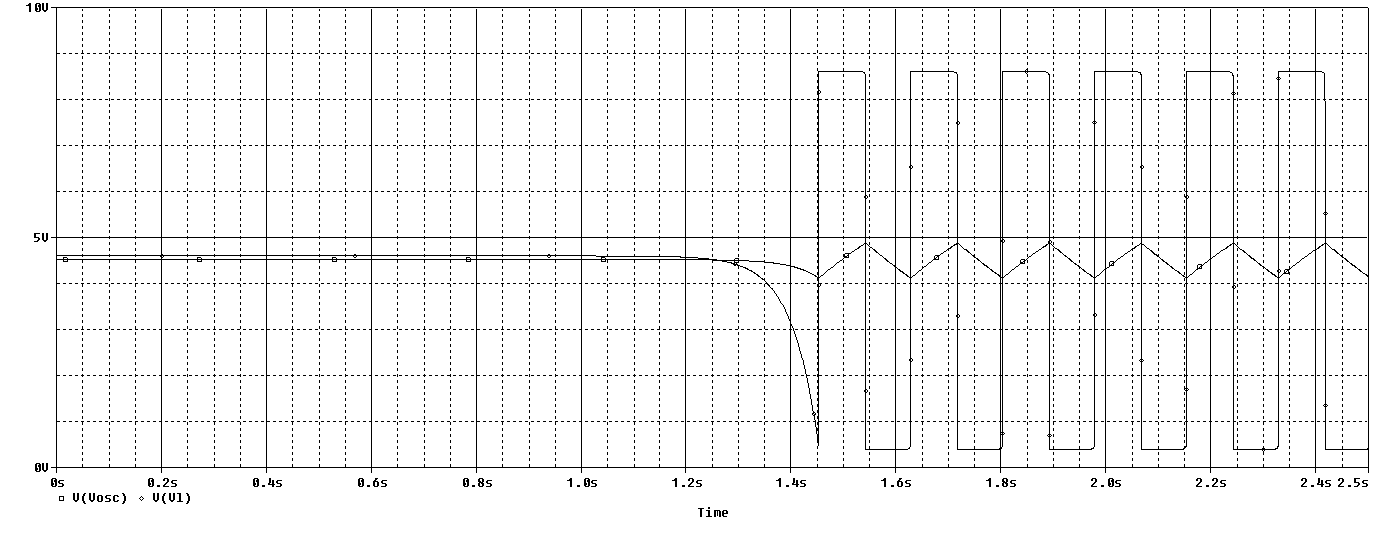
## 

## 4.3 Op-amp Schmitt Trigger Oscillators

This is biased Schmitt Trigger op-amp oscillator circuit:

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**Figure 26:** Op-amp Oscillator Circuit

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**Figure 27:** Op-amp Oscillator Circuit Simulations

## 

## 

## 

**5. Conclusion**

You can click on the references link and read the article about operational amplifier mixer circuits.

**6. References**

1. <https://www.electronics-notes.com/articles/analogue_circuits/operational-amplifier-op-amp/virtual-earth-mixer-summing-amplifier.php>
2. <https://www.electronicshub.org/light-sensors/>
3. <https://www.electronics-tutorials.ws/opamp/opamp_2.html>
4. <https://en.wikipedia.org/wiki/Schmitt_trigger>
5. <https://www.homemade-circuits.com/how-oscillators-work/>