Operational Amplifiers

1. Introduction

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

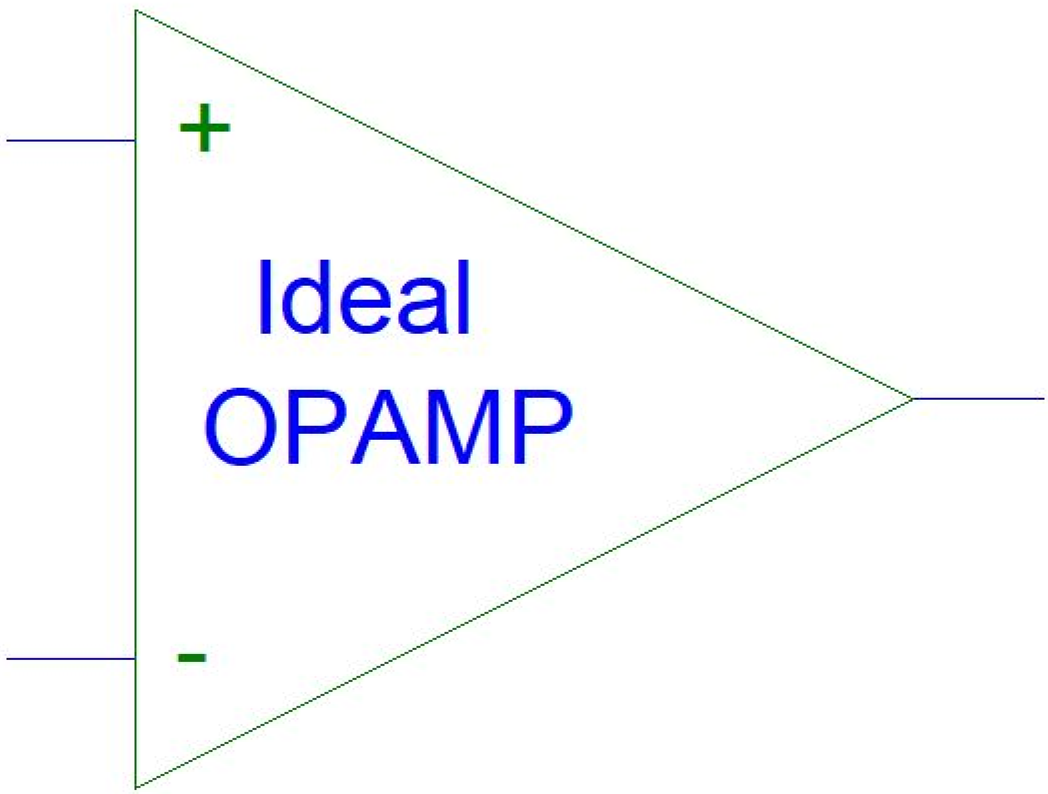

Figure 1: Operational Amplifier Symbol

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:

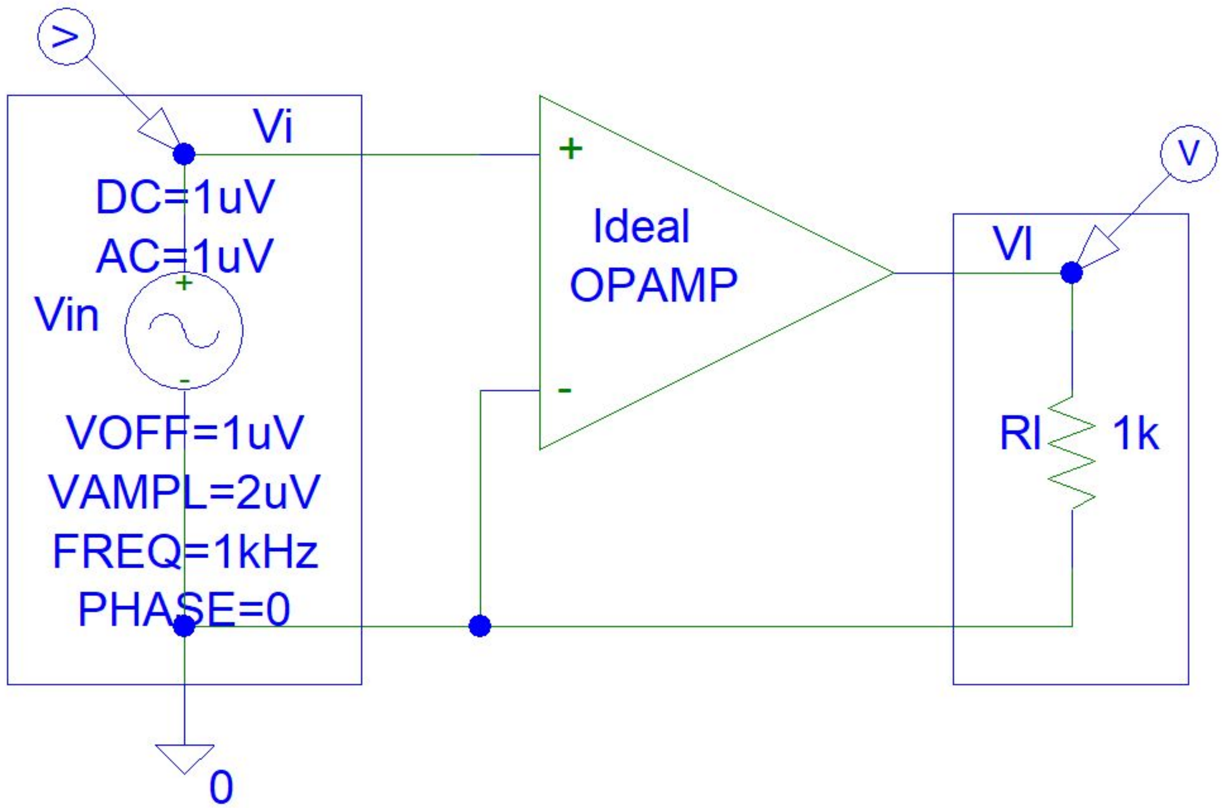

Figure 2: Ideal Operational Amplifier Circuit

PSpice simulations:

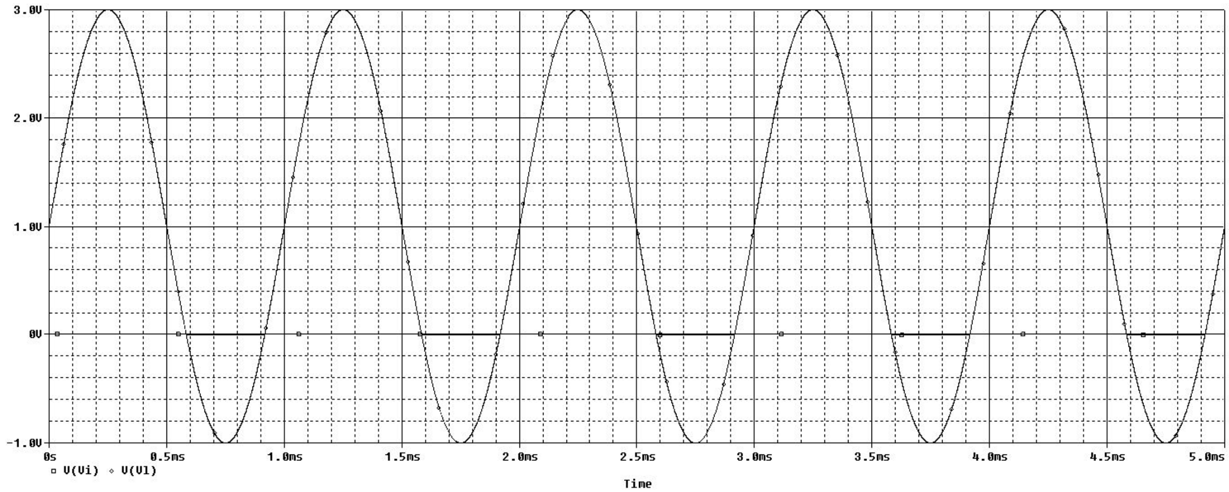

Figure 3: Operational Amplifier Time Domain Simulations

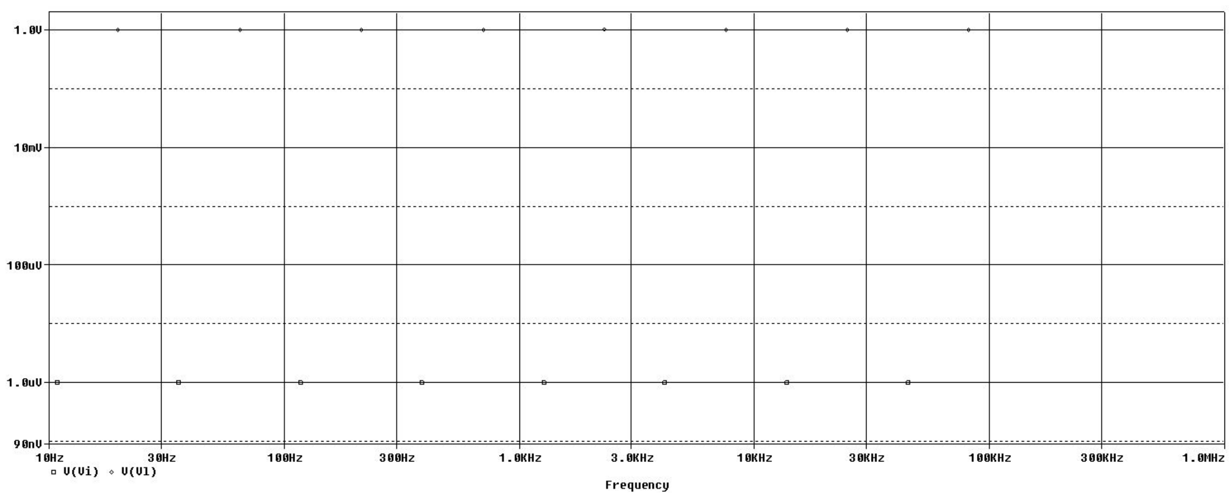

Figure 4: Operational Amplifier Frequency Simulations

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:

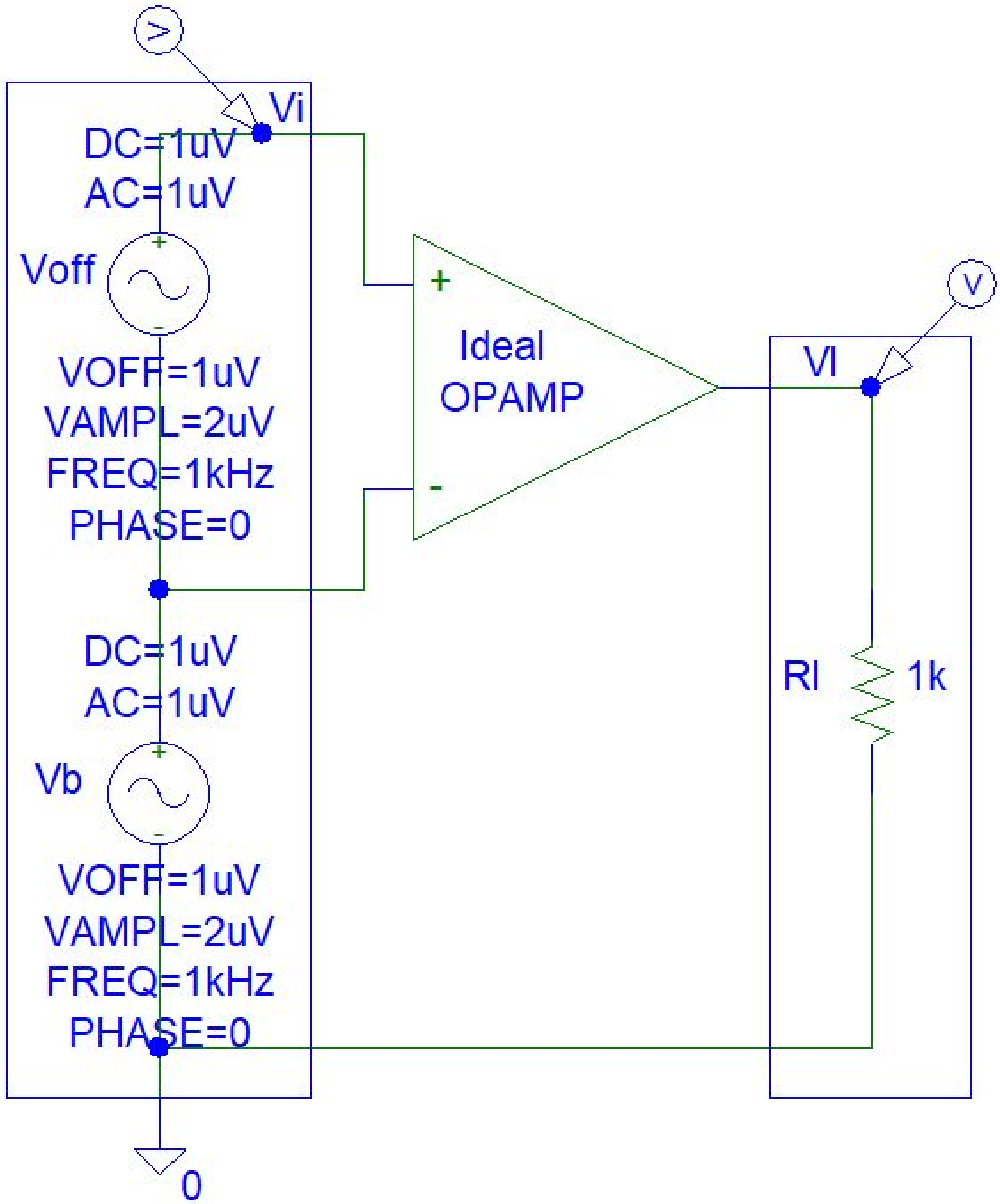

Figure 5: Practical Operational Amplifier Offset Voltage Model

PSpice simulations:

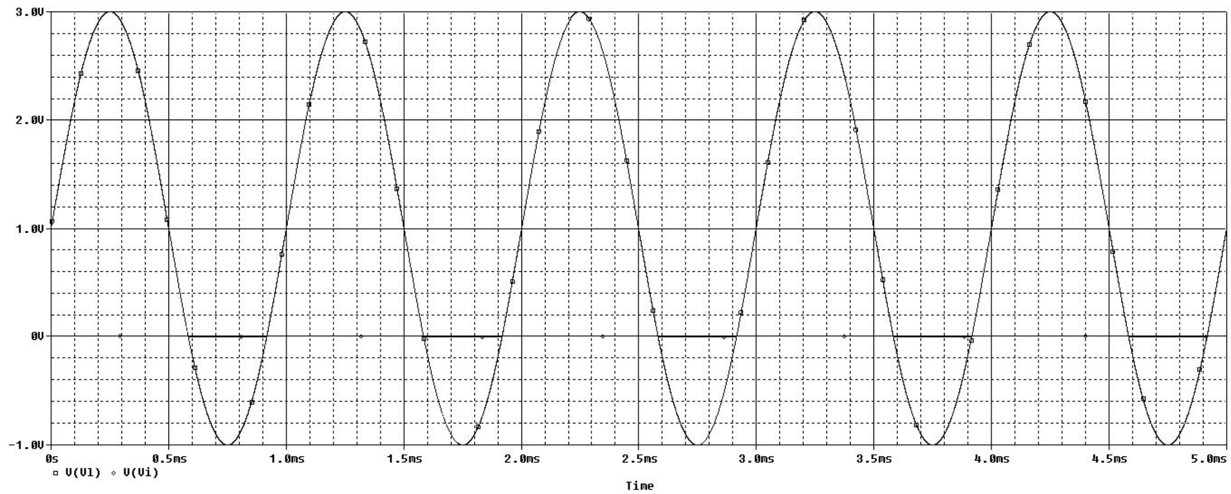

Figure 6: Practical Operational Amplifier Time Domain Simulations

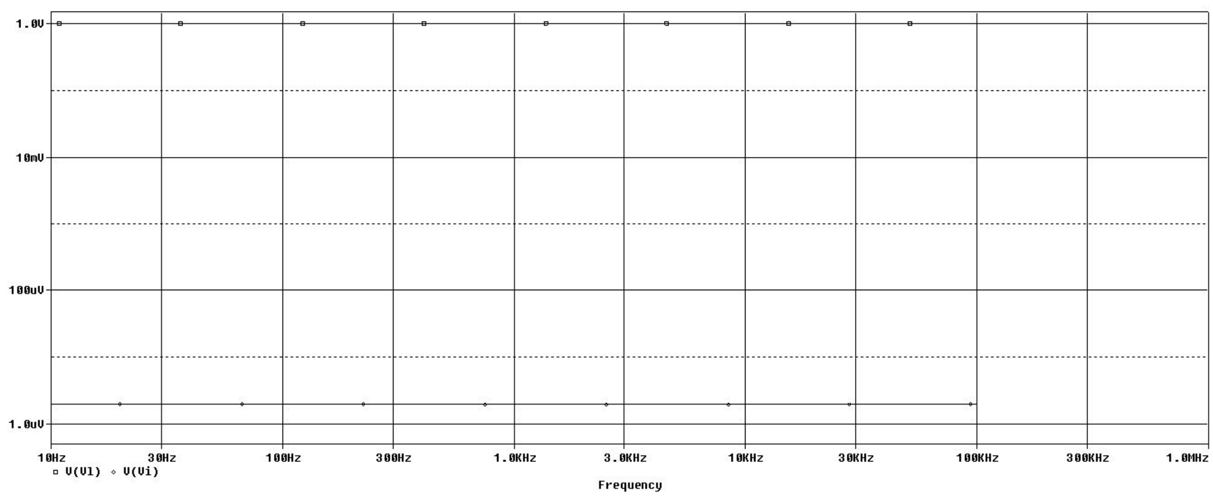

Figure 7: Practical Operational Amplifier Frequency Simulations

3.3. Offset Current Model

Op-amp offset current circuit:

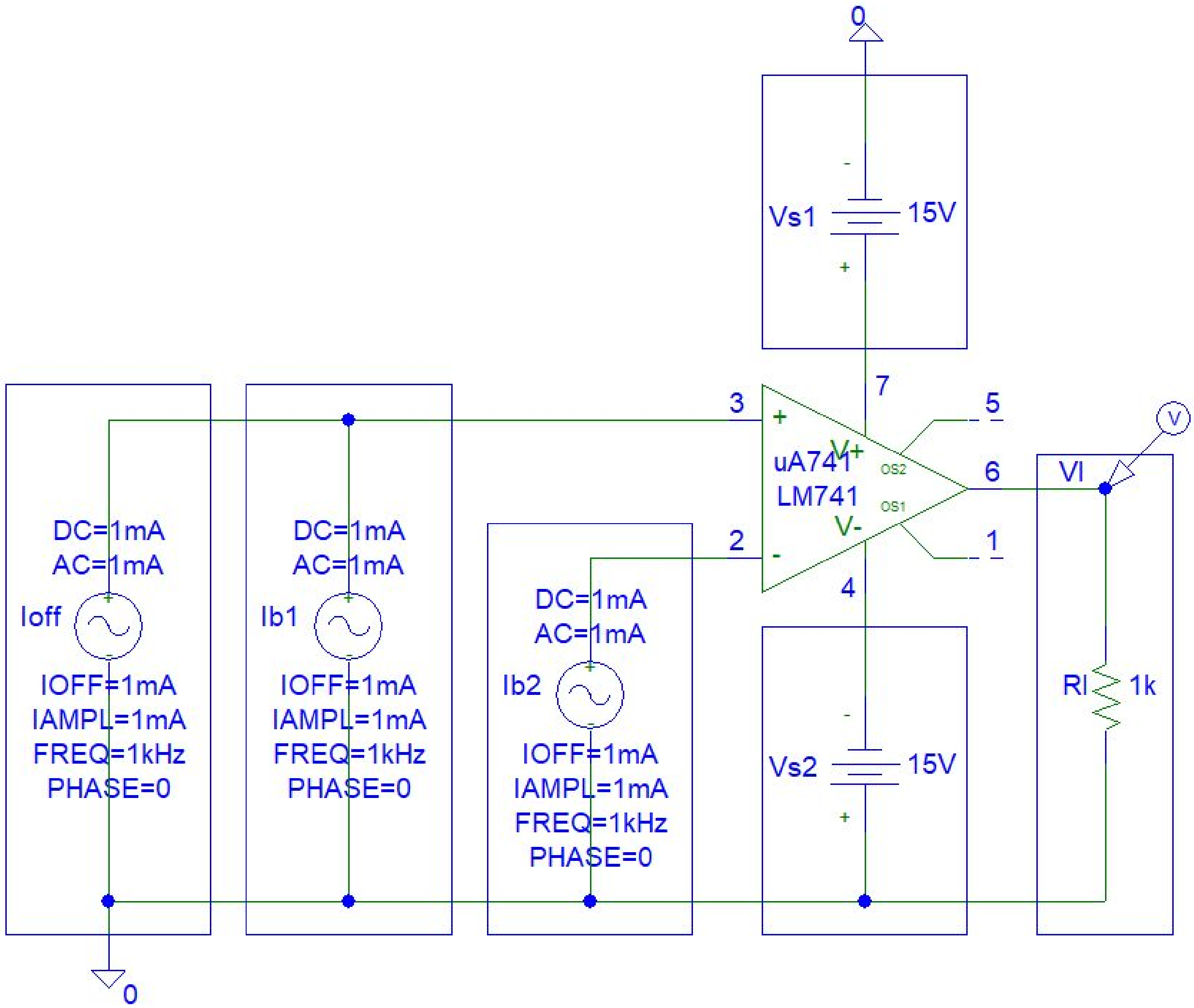

Figure 8: Practical Operational Amplifier Offset Current Model

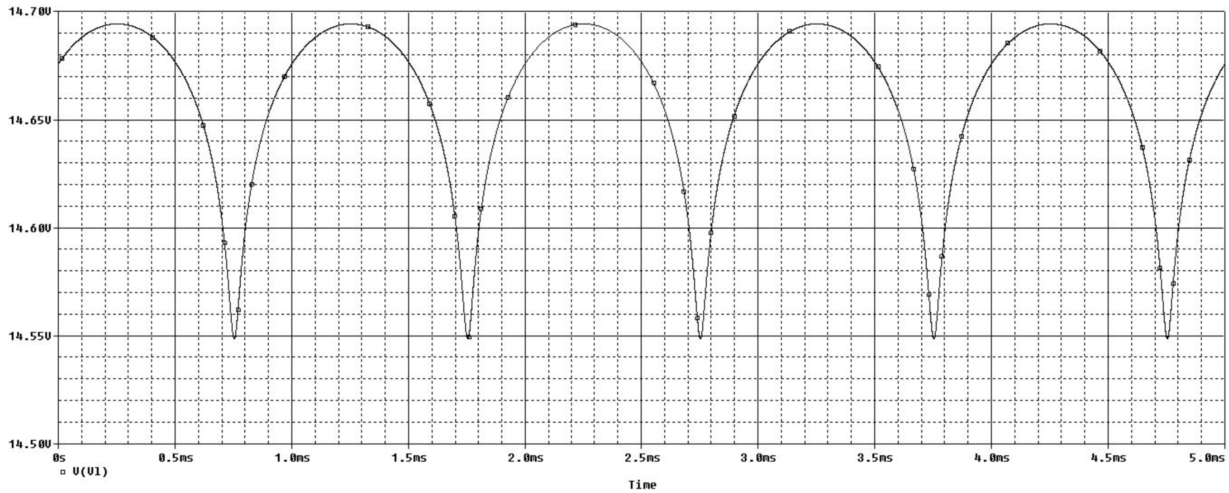

Figure 9: Practical Operational Amplifier Time Domain Simulations

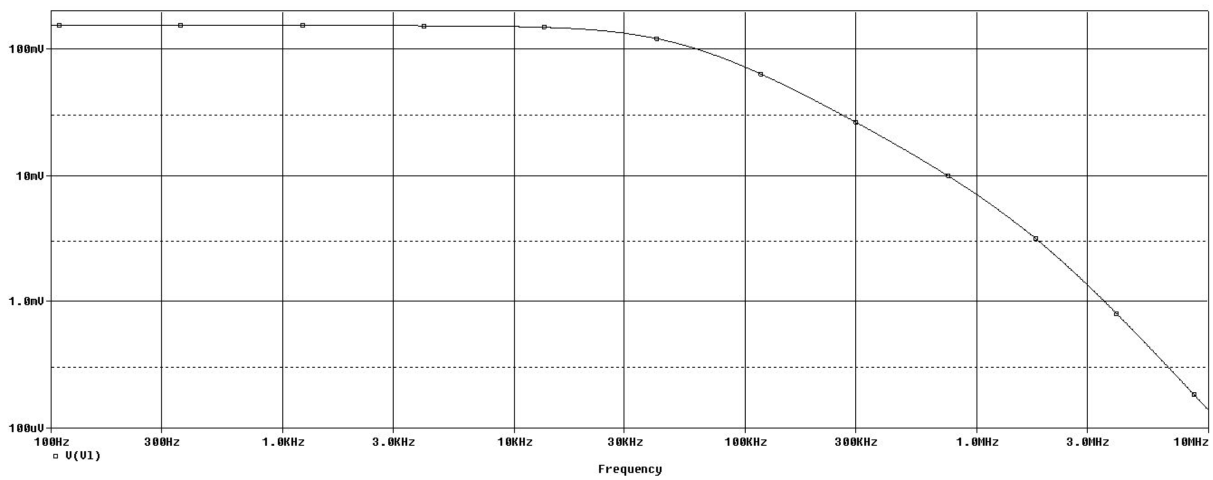

Figure 10: Practical Operational Amplifier Frequency Simulations

4. Applications

4.1 Amplifiers

4.1.1 Non-Inverting Amplifier

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

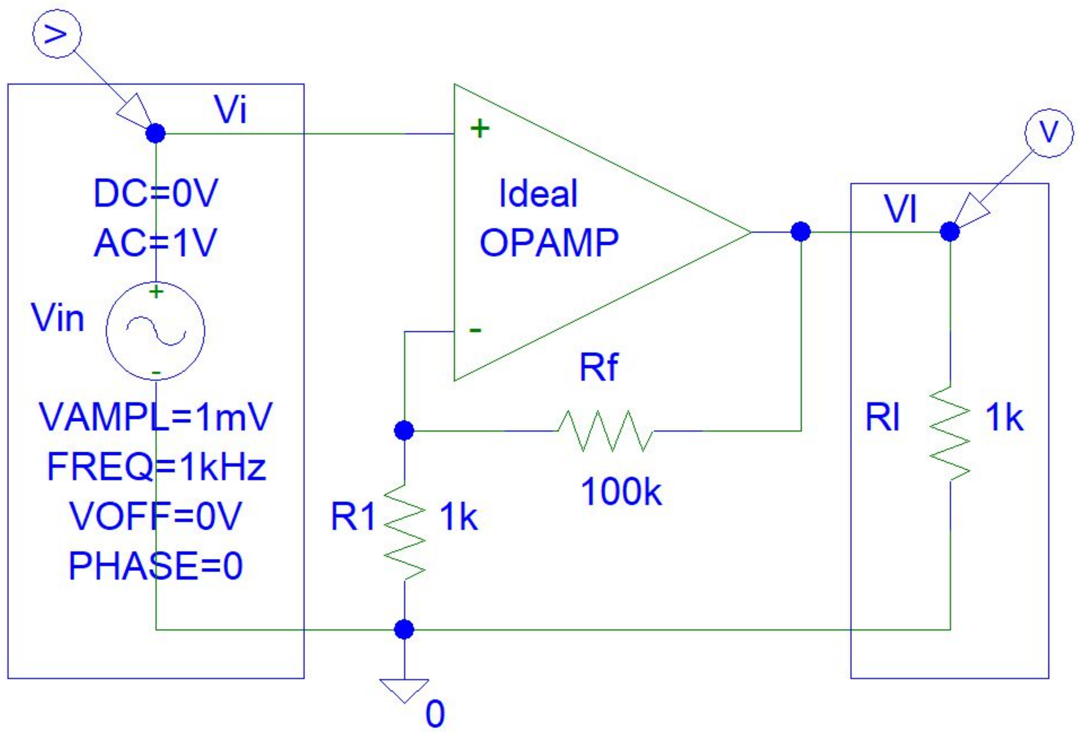

Figure 11: Non-Inverting Ideal Operational Amplifier Circuit

Gain derivations:

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

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

$$Vo = Vin * Ad$$

$$Ad = Rf / R1 + 1$$

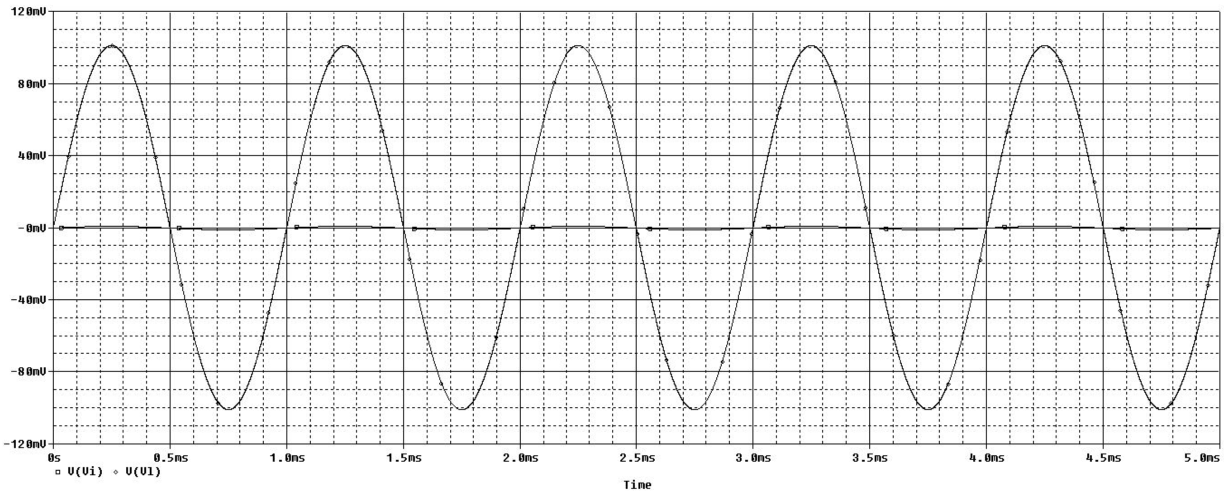

Figure 12: Non-Inverting Ideal Operational Amplifier Time Domain Simulations

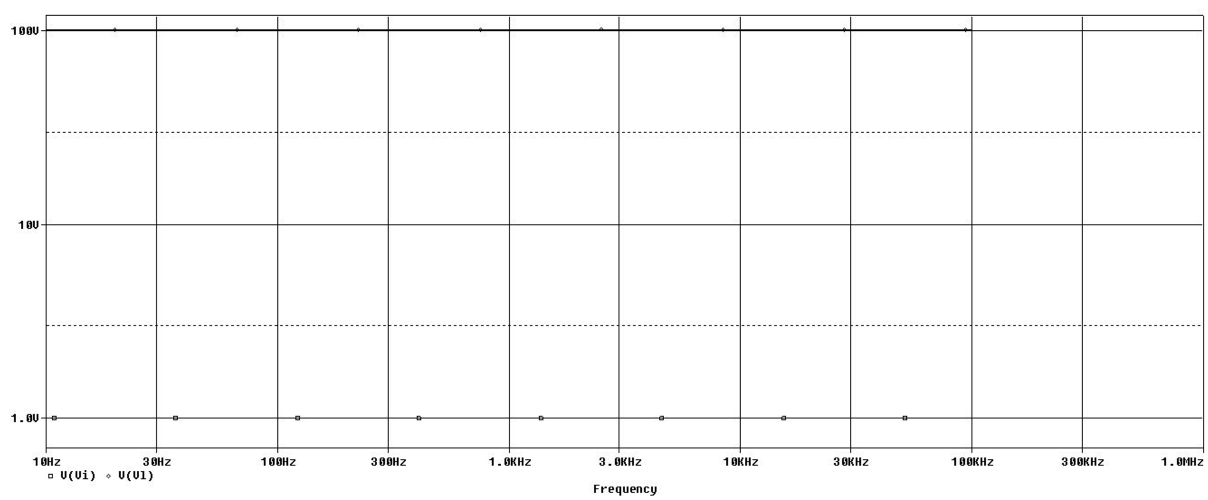

Figure 13: Non-Inverting Ideal Operational Amplifier Frequency Domain Simulations

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

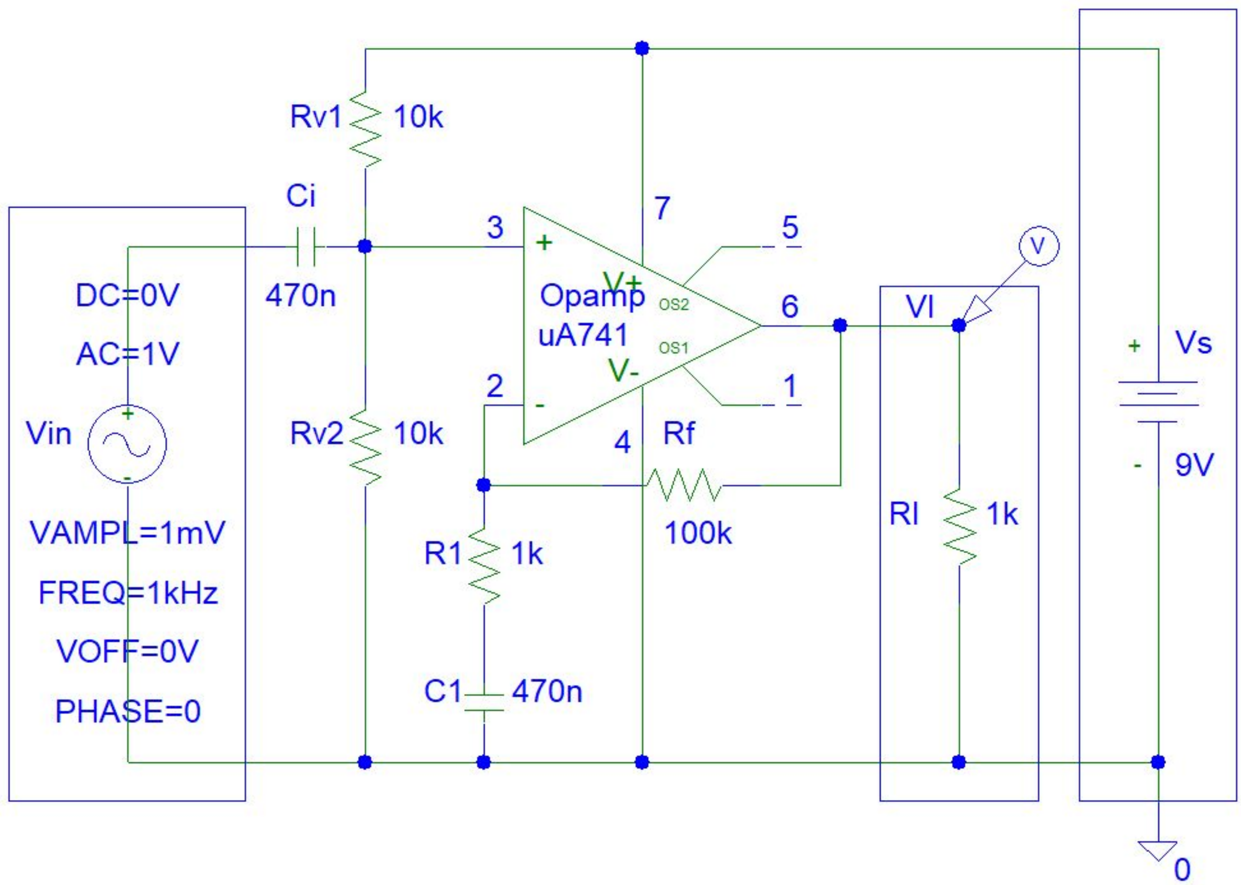

Figure 14: Non-inverting amplifier

PSpice simulations:

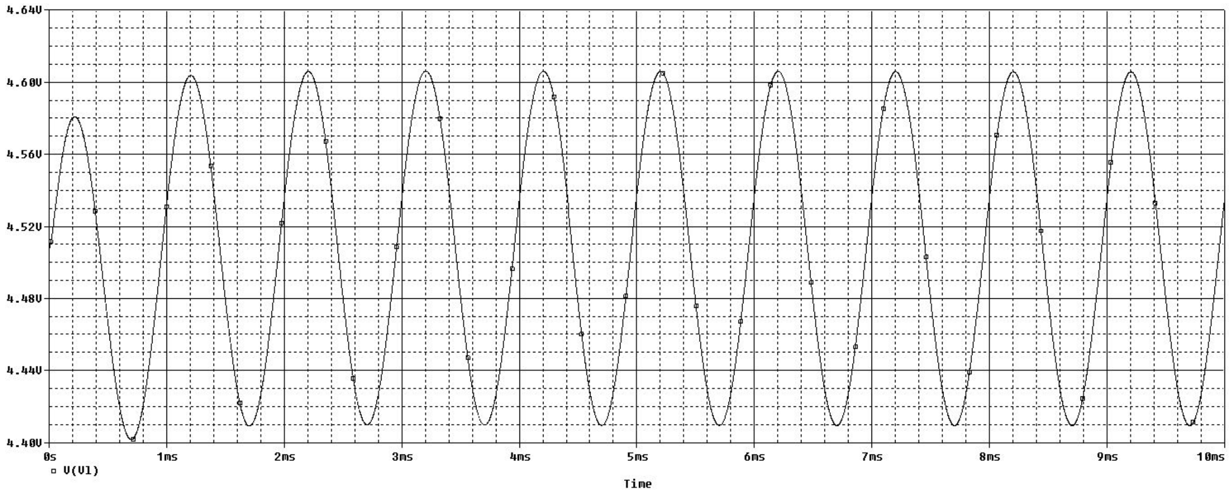

Figure 15: Non-inverting Amplifier Time Domain Simulations

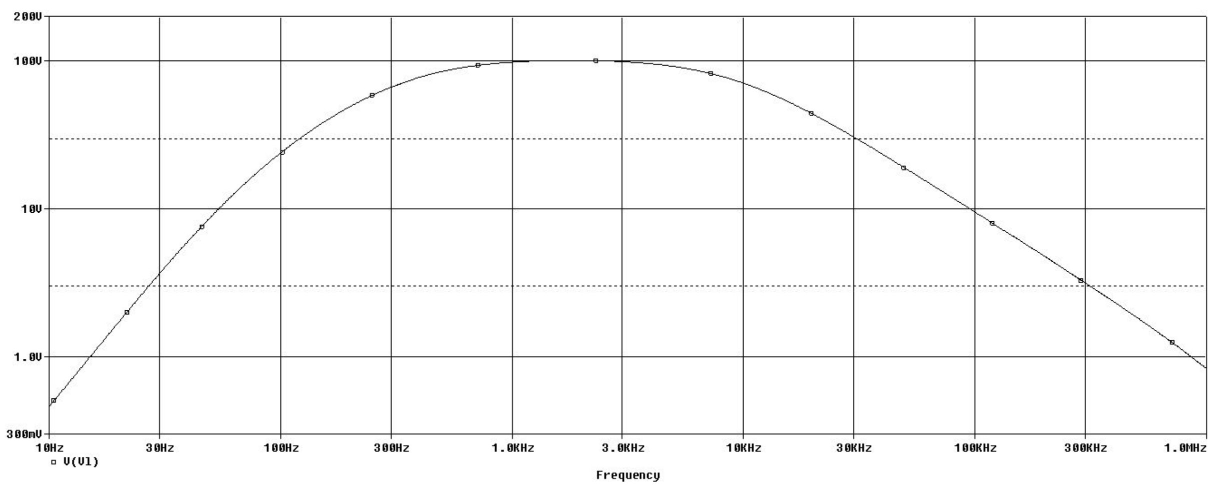

Figure 16: Non-inverting Amplifier Frequency Simulations

4.1.2 Inverting Amplifier

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

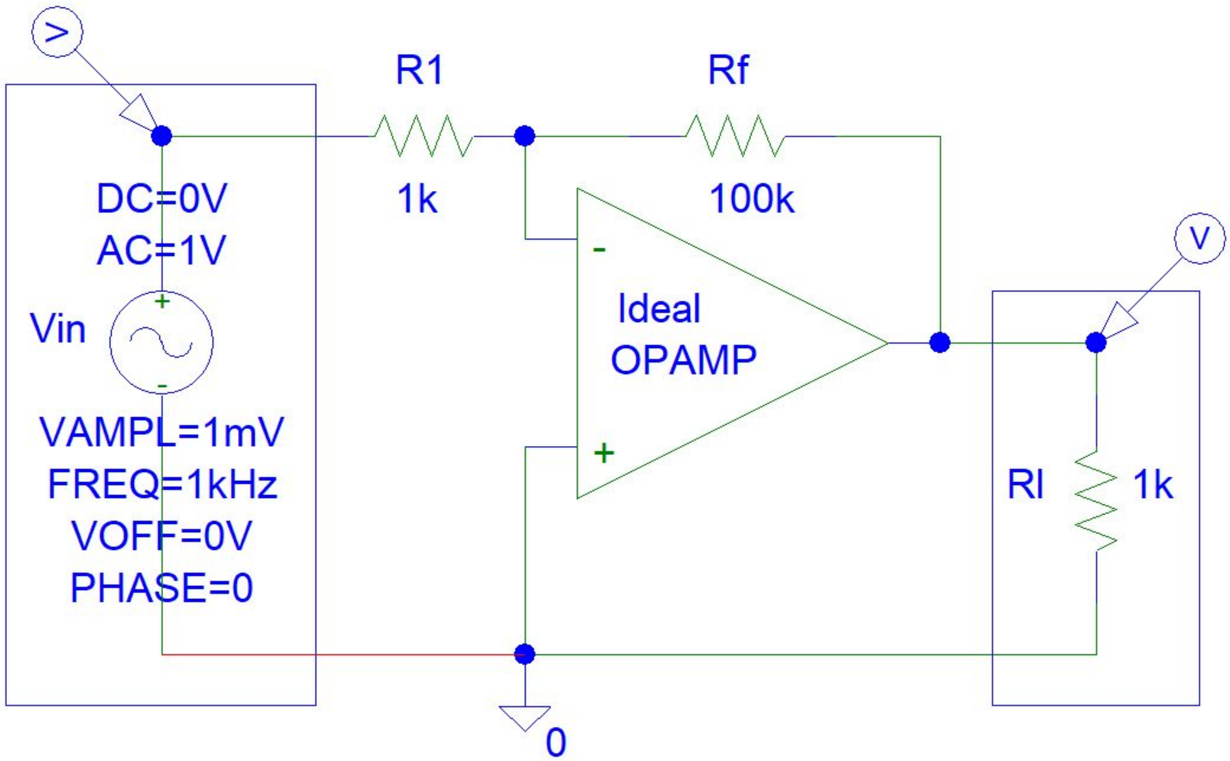

Figure 17: Inverting Ideal Operational Amplifier Circuit

Gain derivations:

$$Vin / R1 = -Vo / Rf$$
$$Vo = Vin * (-Rf / R1)$$
$$Vo = Vin * Ad$$
$$Ad = -Rf / R1$$

PSpice simulations:

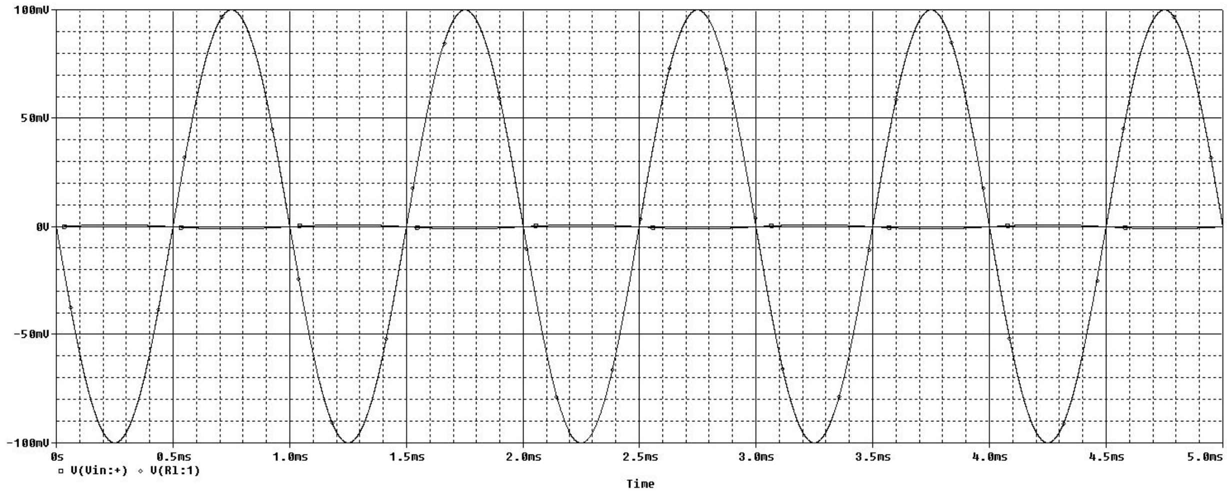

Figure 18: Inverting Ideal Operational Amplifier Time Domain Simulations

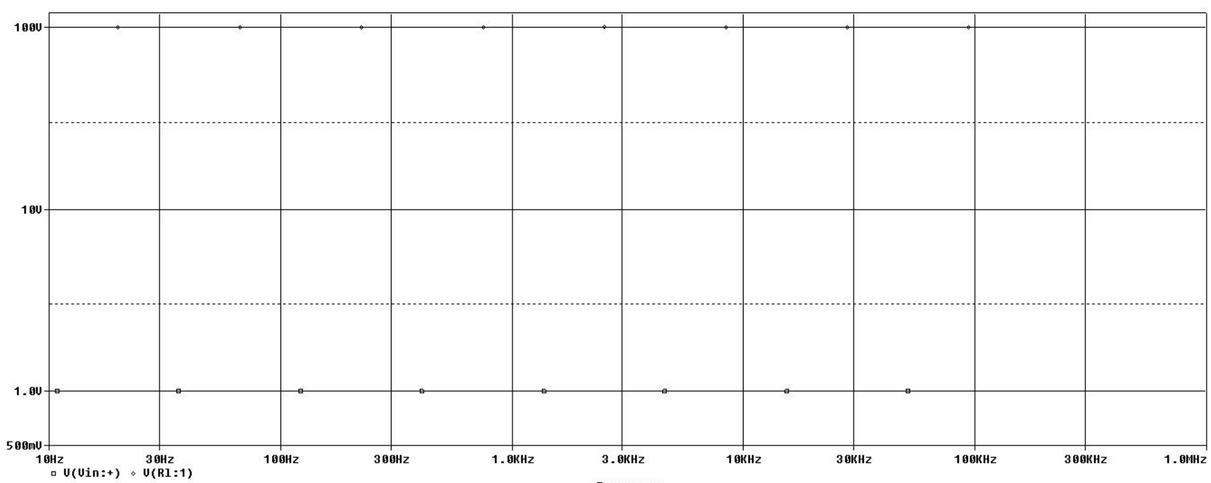

Figure 19: Inverting Ideal Operational Amplifier Frequency Domain Simulations

This is a biased inverting amplifier with a single supply:

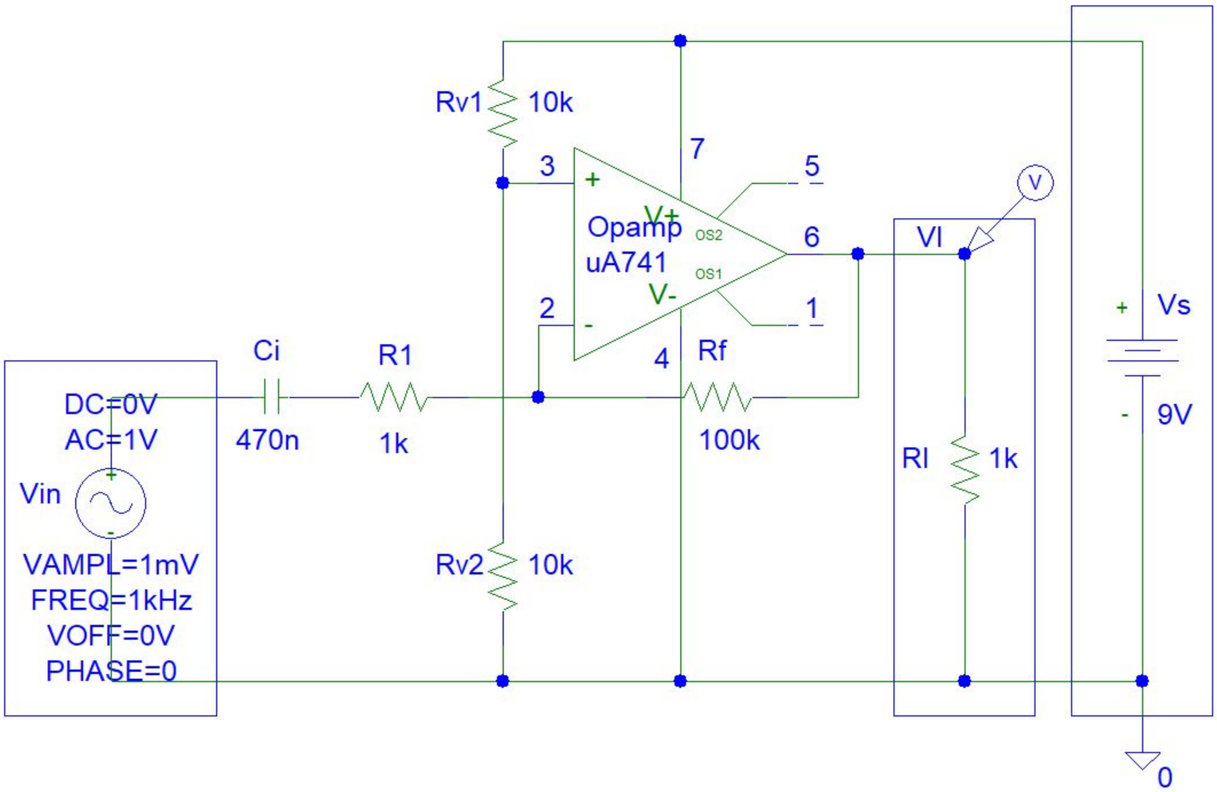

Figure 20: Inverting amplifier

PSpice simulations:

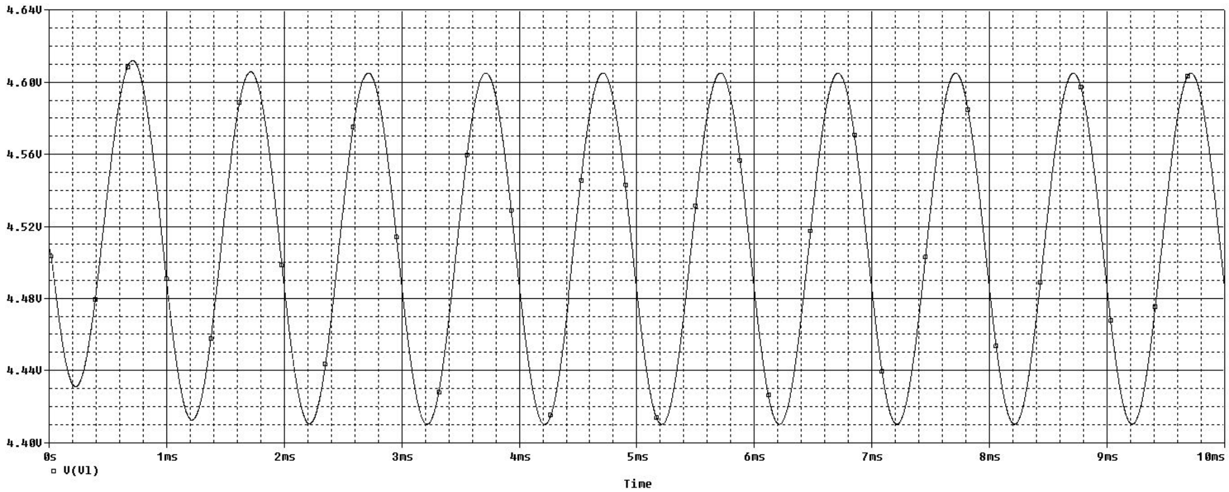

Figure 21: Non-inverting Amplifier Time Domain Simulations

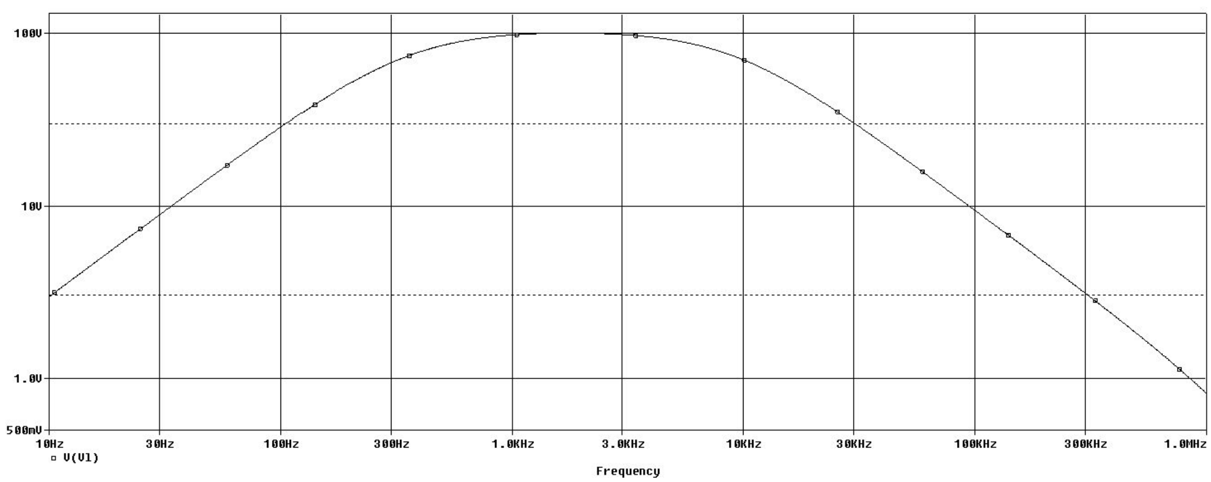

Figure 22: Non-inverting Amplifier Frequency Simulations

4.2 Schmitt Triggers

This ia a biased op-amp Schmitt Trigger design:

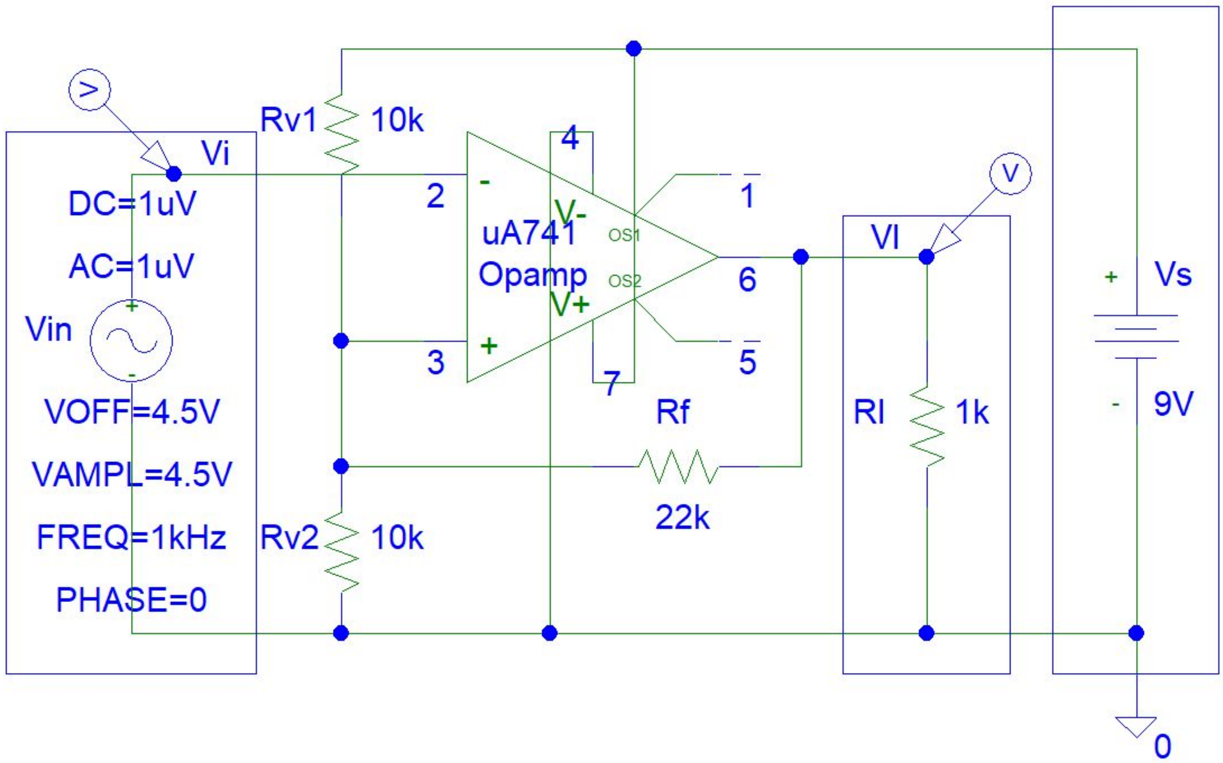

Figure 23: Schmitt Trigger Circuit

PSpice Simulations:

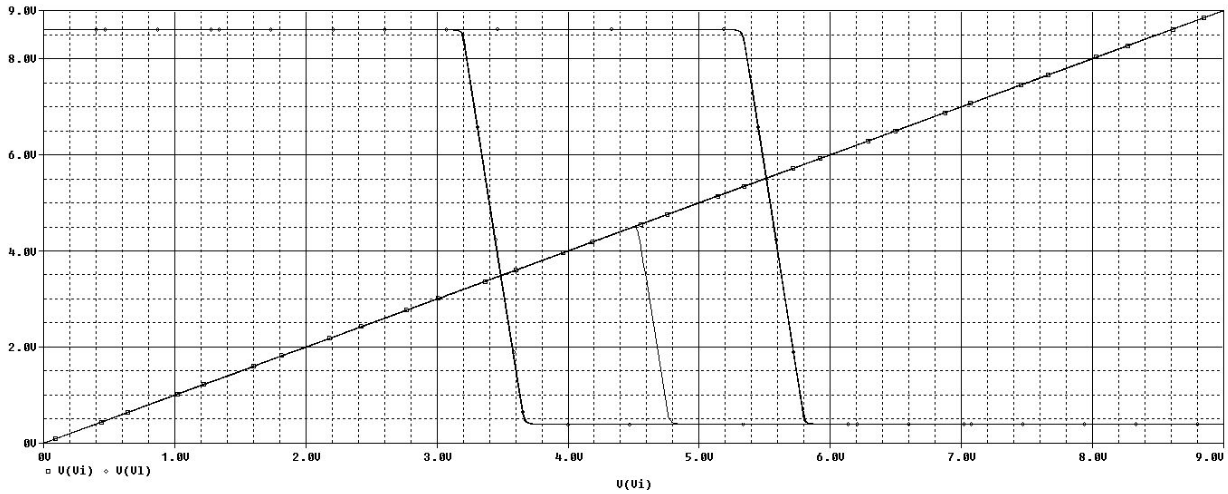

Figure 24: Schmitt Trigger Time Domain Simulations

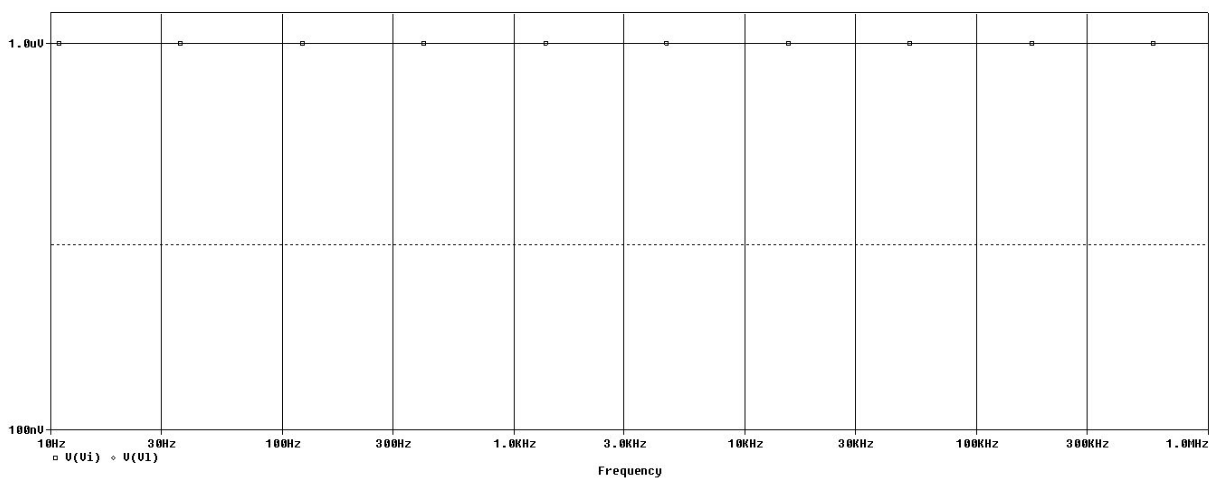

Figure 25: Schmitt Trigger Frequency Simulations

4.3 Op-amp Schmitt Trigger Oscillators

This is biased Schmitt Trigger op-amp oscillator circuit:

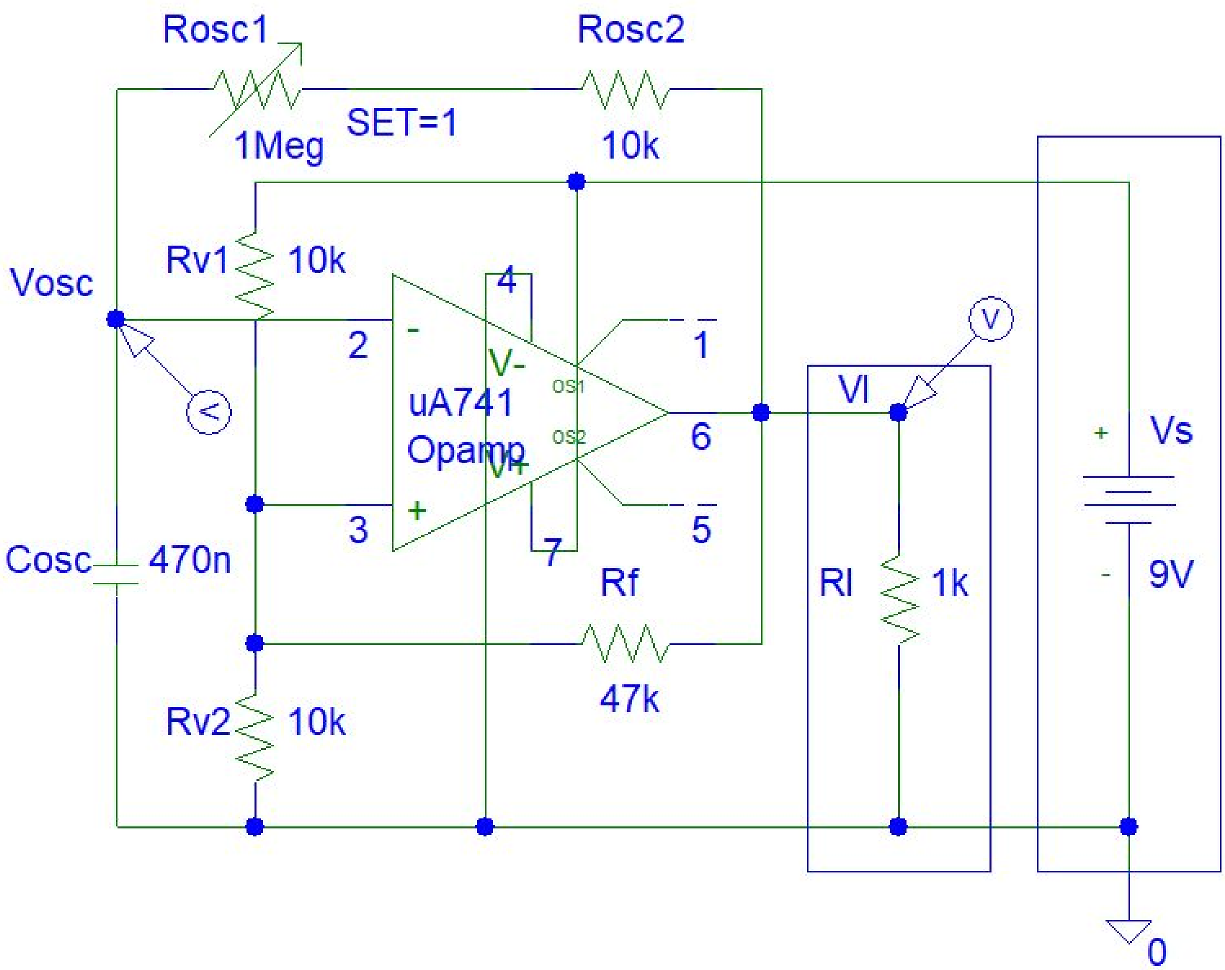

Figure 26: Op-amp Oscillator Circuit

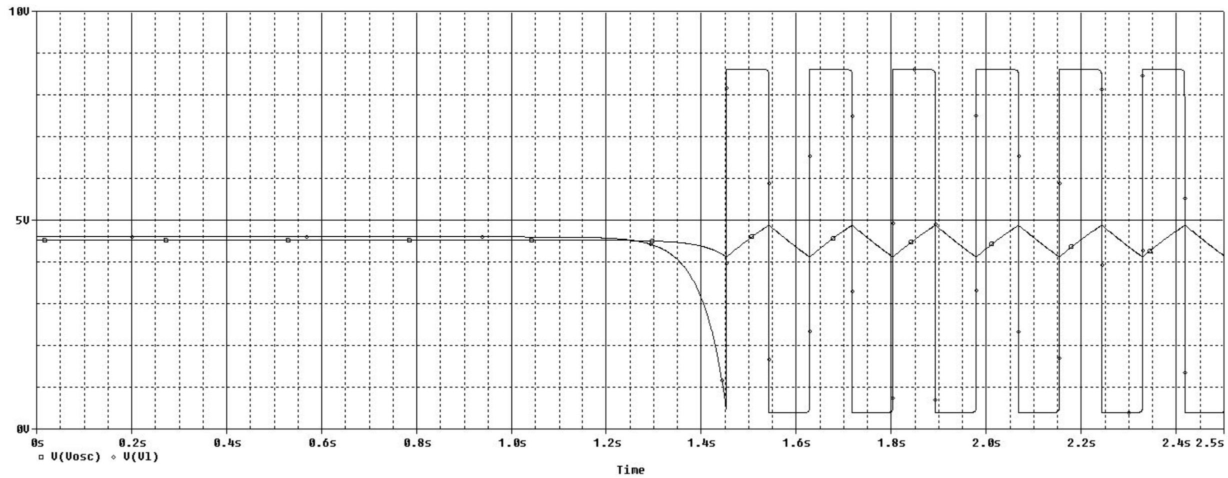

Figure 27: Op-amp Oscillator Circuit Simulations

5. Conclusion

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

6. References

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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/