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Sierra College	MECH 10 - Lab 25 Operational Amplifiers	Mechatronics Real Skills Real Jobs

BY:

[redacted]

Abstract

This series of experiments involved building several OpAmp circuits, both on the trainer board and in Electronics Workbench. Voltage gain was analyzed for open and closed loop circuits and a loaded closed loop circuit. The phase relationship between input and output signals of inverting and non-inverting OpAmps were noted. Cutoff frequencies were calculated for a simulated audio OpAmp and were illustrated in a Bode Plot.

Introduction

Learning objectives:

- Build and test negative feedback OpAmp circuits
- Use negative feedback to control gain
- Realize proportional effects of input and feedback resistors on OpAmp voltage gains

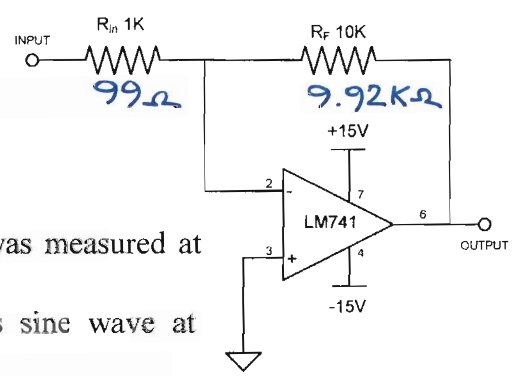
Materials required:

Quantity	Description
1	1kΩ resistor
1	10kΩ resistor
1	20kΩ resistor
1	3kΩ resistor
1	3.6kΩ resistor

Quantity	Description
1	LM741 OpAmp
1	GS Trainer
1	Digital Oscilloscope
1	Digital Multimeter
1	Electronics Workbench

Lab Procedure

Circuit 1 ~ Inverting Amplifier



CIRCUIT 1

1. All resistor values were measured with the DMM and are recorded on the schematics. These values were used for all calculations.
2. Circuit 1 was assembled.
3. Power rails were set to +15V and -15V on the trainer.
4. The input lead was connected to ground and V_{out} was measured at 0.5mV.
5. The input ground was removed and a 100mV_{RMS} sine wave at 100Hz was applied from the function generator.
6. The expected closed loop voltage gain was calculated as 9.99V.

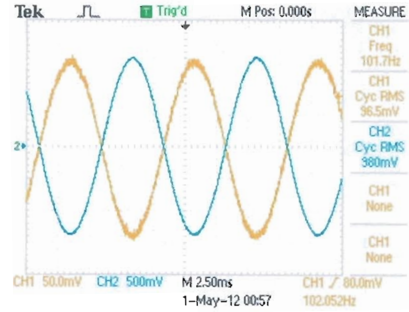
$$A_V = \frac{R_f}{R_{in}}$$

Where;
A_V = voltage gain
R_f = negative feedback resistor
R_{in} = input resistor

9.92E3/993
9.989929507

[redacted]

7. A screen shot from the scope shows the V_{inRMS} at 97mV and V_{outRMS} at 979mV.



8. The measured closed loop gain was calculated as 10.

$$A_V = \frac{V_{out}}{V_{in}}$$

Where;
A_V = voltage gain
V_{out} = output voltage
V_{in} = input voltage

```
980E-3/96.5E-3
        10.15544041
```

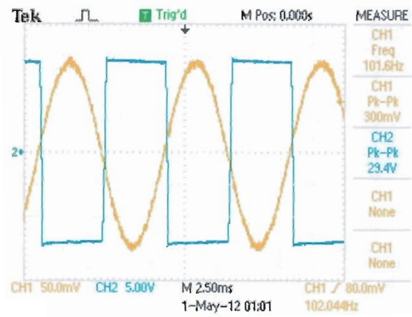
The percent error between the expected and measured gain values was 1.66%.

$$\%Error = \frac{measured - expected}{expected} x100\%$$

Where;
% Error = % change between measured and expected values
measured = a value taken from direct measurement
expected = a value taken from calculated value or process specifications

```
10.155-9.989
                .166
Ans/9.989
          .0166182801
Ans*100
          1.661828011
```

9. The dual trace mode of the scope shows a 180° phase shift between the input signal and the output signal of this inverting amplifier.
10. The feedback resistor, R_F, was removed from the circuit, creating an open loop gain amplifier. V_{ppIN} was 300mV and the output was 29.4V_{ppOUT}.



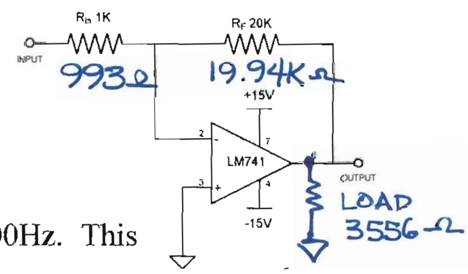
11. The scope image indicates severe clipping. This is because the output gain has exceeded the voltage rails. The clipped open loop gain was calculated as 98.

$$A_V = \frac{V_{out}}{V_{in}}$$

Where;
A_V = voltage gain
V_{out} = output voltage
V_{in} = input voltage

```
29.4/300E-3
                    98
```

Circuit 2~ Inverting Amplifier



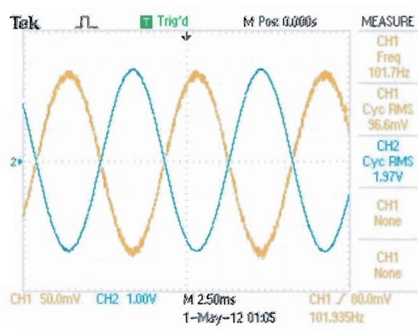
12. Actual resistor values were measured with the DMM, recorded on the schematic, and used for all calculations.
13. Circuit 2 was assembled on the trainer board.
14. Power supply voltages were again set to +15V and -15V.
15. The function generator was set to a 100mV_{RMS} sine wave at 100Hz. This was applied to the input of the circuit.
16. The expected closed loop voltage gain was calculated at 20.08.

$$A_V = \frac{R_f}{R_{in}}$$

Where;
A_V = voltage gain
R_f = negative feedback resistor
R_{in} = input resistor

```
19.94E3/993
        20.08056395
```

17. A scope shot shows the measured input RMS voltage as 96.6mV and the output RMS voltage as 1.97V.



18. The measured closed loop gain was calculated as 20.39.

$$A_V = \frac{V_{out}}{V_{in}}$$

Where;
A_V = voltage gain
V_{out} = output voltage
V_{in} = input voltage

```
1.97/96.6E-3
        20.39337474
```

The percent error between expected and measured gain values was calculated as 1.5%.

$$\%Error = \frac{measured - expected}{expected} x100\%$$

Where;
% Error = % change between measured and expected values
measured = a value taken from direct measurement
expected = a value taken from calculated value or process specifications

```
20.39-20.08
                .31
Ans/20.08
          .015438247
Ans*100
          1.543824701
```

19. A 3.6KΩ load resistor was connected between the output and ground.

20. The scope shot shows the measured input and output voltages in RMS values.
21. The measured, loaded closed loop voltage gain was calculated as 20.35.

$$A_V = \frac{V_{out}}{V_{in}}$$

Where;
A_V = voltage gain
V_{out} = output voltage
V_{in} = input voltage

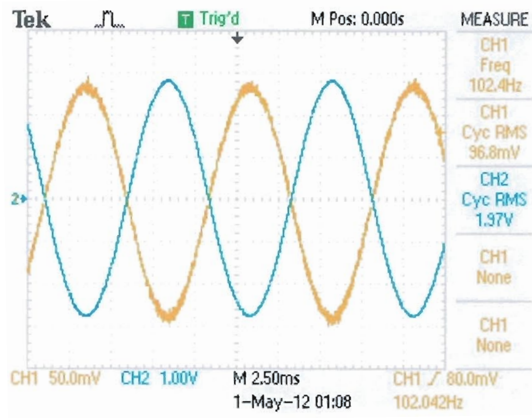
```
1.97/96.8E-3
            20.35123967
```

The percent change between unloaded and loaded voltage gain was calculated as 0.2%. *Very stable.*

$$\%Error = \frac{measured - expected}{expected} x100\%$$

Where;
%Error = % change between measured and expected values
measured = a value taken from direct measurement
expected = a value taken from calculated value or process specifications

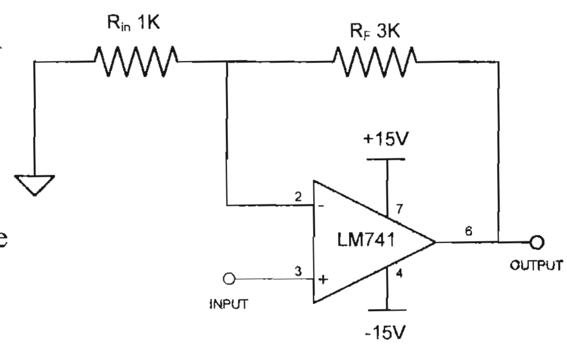
```
20.39-20.35
                    .04
Ans/20.35
            .001965602
Ans*100
            .1965601966
```



22. No cold spray was available, so the temperature test was not applied. It is assumed that temperature would have little or no effect on this circuitry.

Circuit 3 ~ Non-Inverting Amplifier

23. Resistor values were measured and recorded on the schematic. These values were used for all calculations.
24. Power supply rails were set to ±15V.
25. Circuit 3 was built on the trainer.
26. The input signal remained the same as the previous circuits: 100mVRMS at 100Hz.
27. The expected closed loop voltage gain was calculated as 4.10.



CIRCUIT 3

$$A_V = \frac{R_f}{R_{in}} + 1$$

Where;
A_V = voltage gain
V_{out} = output voltage
V_{in} = input voltage

```
3080/993
            3.101711984
Ans+1
            4.101711984
```

28. RMS input and output voltages were captured on the scope. V_{inRMS} = 103mV and V_{outRMS} = 420mV.
29. The measured closed loop gain was calculated as 4.07.

$$A_V = \frac{V_{out}}{V_{in}} + 1$$

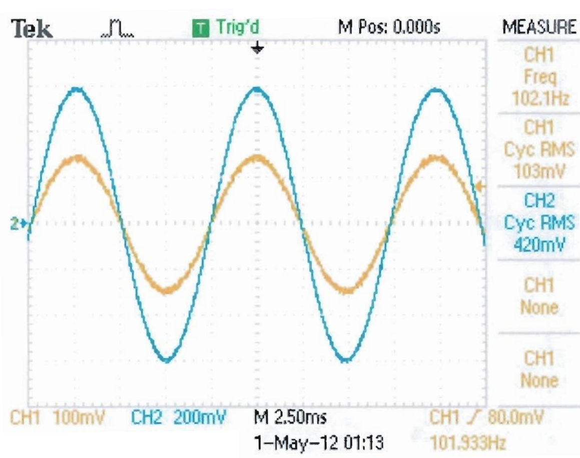
Where;
A_V = voltage gain
V_{out} = output voltage
V_{in} = input voltage

```
420E-3/103E-3
            4.077669903
```

The percent error between expected and measured gain was 0.7%.

$$\%Error = \frac{measured - expected}{expected} x100\%$$

```
4.07-4.10
                  -.03
Ans/4.10
        -.0073170732
Ans*100
        -.7317073171
```



30. The scope shot shows that input and output signals in a non-inverting circuit are in phase.

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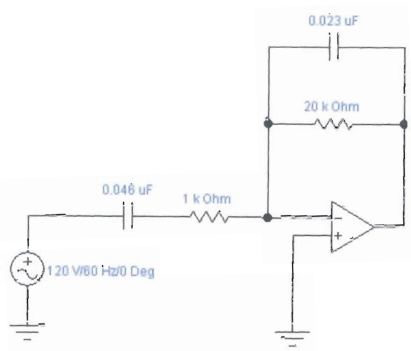
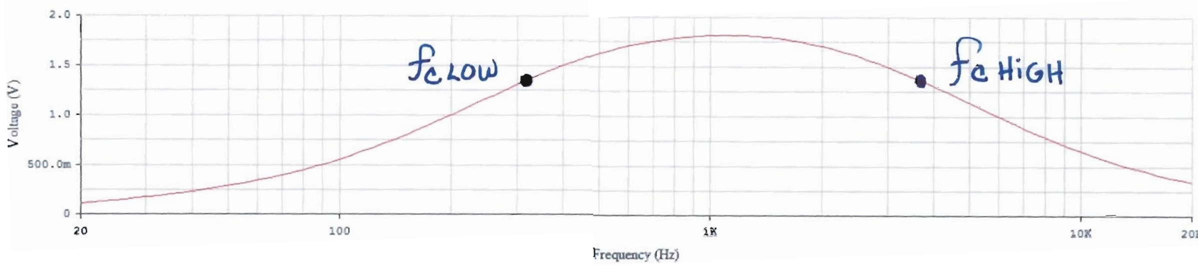
Circuit 4 ~ Band Pass Filter Amplifier



31. Circuit 4 was constructed in Electronic Workbench.
32. A 741 generic OpAmp was selected and component values were set as shown in the schematic.
33. Nodes were assigned to the circuit wires.
34. AC Frequency was analyzed at the output, setting the range from 20Hz to 20kHz and choosing a linear vertical scale.
35. A Bode Plot was created for this circuit.



36. Low frequency cutoff point was calculated as 346Hz. High frequency cutoff point was calculated as 3460Hz. These points are marked on the Bode Plot at -3dB.

$$f_c = \frac{1}{2\pi RC}$$

Where;
Fc = cutoff frequency (Hertz)
π = pi (3.14159...)
R = resistance (Ohms)
C = capacitance (Farads)

```
2π*.023E-6*20E3
        .0028902652
Ans⁻¹
        345.9890067 ←Low
```

```
2π*.046E-6*1E3
        2.890265241E-4
Ans⁻¹
        3459.890067 ←High
```

Data Results

Quantity	AVexp	AVmeas	%Error / Change
Circuit 1 ~ Closed Loop	9.99	10.1	1.66%
Circuit 1 ~ Open Loop	200,000	98	99.99%
Circuit 2 ~ Closed Loop	20.08	20.39	1.54%
Circuit 2 ~ Loaded	NA	20.35	0.196%
Circuit 3 ~ Closed Loop	4.10	4.07	0.73%

Conclusions

Operational amplifiers have an extremely high open loop gain. By adding a feedback resistor that is ten times the value of the input resistor the gain can be stabilized to 10. Gain is directly proportional to the feedback resistance and indirectly proportional to the input resistance. This allows a more precise gain control than that of an open loop amp. The stability of the open loop amp is terrible, as observed in the screen shot that shows how the output signal is severely clipped. An inverting OpAmp will have a 180° phase shift between the input and output signals, while the non-inverting OpAmp will be in phase. When constructing a circuit with a simulation program, such as Electronic Workbench, values and conditions are precise and allow for more accurate, theoretical measurements. This is very useful when comparing value changes, creating simulations, and plotting data for a circuit. However, my preference is to hardwire the circuit with real components. I find the construction itself to be an interesting activity, and enjoy it when the "real world" circuitry behaves as expected.

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