For this project three different op-amps were considered. The goal was to see the effect of the resistors value choices vs. the bandwidth and gain of the op-amp circuitry. The gain was -4, and the op-amps used were: LM-741, LF347BN, and OPA2604AP. Simulation in Mentor Graphics also performed using LM741 op-amp. Bode magnitude plots were obtained using the simulation. Figure 1 showed the op-amp amplifier circuit used.

\[
V_{\text{out}} = V_{\text{in}} \left( -\frac{R_2}{R_1} \right)
\]

Figure 1. Amplifier Circuit

Even though it looked as a voltage amplifier, this circuit was a shunt-shunt configuration. Where the transfer function was

\[
A_{\text{df}} = \frac{V_{\text{out}}}{I_{\text{in}}} = -R_2
\]
Figure 2. Equivalent circuit of shunt-shunt feedback configuration

For Figure 1, and the resistor values were 10 ohms, 8k, 8k2, 80k2, and 8M2 for R2. These values of resistors gave the voltage amplification of -4, in the low frequency region. As the frequency was increased, the gain stayed constant up to a certain cut-off (fc) frequency. The cut-off frequency varied with the size of the resistors used. Figures 2-5 showed the magnitude and phase plots of the transfer functions for the four simulated circuits. The results were summarised in Table 1.

<table>
<thead>
<tr>
<th>R1 [Ω]</th>
<th>R2 [Ω]</th>
<th>fc [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8</td>
<td>40.4</td>
</tr>
<tr>
<td>2×10^3</td>
<td>8×10^3</td>
<td>250</td>
</tr>
<tr>
<td>2×10^4</td>
<td>8×10^5</td>
<td>246</td>
</tr>
<tr>
<td>2×10^6</td>
<td>8×10^6</td>
<td>83</td>
</tr>
</tbody>
</table>

Table 1. MicroCap Simulation results
Figure 2. LM741 simulation plot 2Ω and 8Ω resistors

Figure 3. LM741 simulation plot 2kΩ and 8kΩ resistors
Figure 4. LM741 simulation plot 20kΩ and 80kΩ resistors

Figure 5. LM741 simulation plot 2MΩ and 8MΩ resistors
Figure 6. LM-741 with 2Ω and 8Ω resistors at 1kHz and cut-off frequency

Figure 7. LM-741 with 2kΩ and 8kΩ resistors at 1kHz and cut-off frequency

Figure 8. LM-741 with 20kΩ and 80kΩ resistors at 1kHz and cut-off frequency

Figure 9. LM-741 with 2MΩ and 80MΩ resistors at 1kHz and cut-off frequency
Figure 10. LF-347 with 2Ω and 8Ω resistors at 1kHz and cut-off frequency

Figure 11. LF-347 with 2kΩ and 8kΩ resistors at 1kHz and cut-off frequency

Figure 12. LF-347 with 20kΩ and 80kΩ resistors at 1kHz and cut-off frequency

Figure 13. LF-347 with 2MΩ and 8MΩ resistors at 1kHz and cut-off frequency
Figure 14. OPA2604 with 2Ω and 8Ω resistors at 1kHz (cut-off was not discernable)

Figure 15. OPA2604 with 2kΩ and 8kΩ resistors at 1kHz and cut-off frequency

Figure 16. OPA2604 with 20kΩ and 80kΩ resistors at 1kHz and cut-off frequency

Figure 17. OPA2604 with 2MΩ and 8MΩ resistors at 1kHz and cut-off frequency
The increase was more from the use of a parallel amplifier as well expected. The results were different, but their high frequency output, low cut-off of 0.4, and very noisy signal in case of 0.01 were hard to explain for the low values of R1 and R2. Only plausible explanation was a possibility of loading effect, since the source used had a series resistance of 50Ω.
Figure 18. Cut-off frequency vs. $R_2$ values

<table>
<thead>
<tr>
<th>Op-Amp</th>
<th>$R_1$</th>
<th>$R_2$</th>
<th>$f_c$ [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM-741</td>
<td>2Ω</td>
<td>8Ω</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>2kΩ</td>
<td>8kΩ</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>20kΩ</td>
<td>80kΩ</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>2MΩ</td>
<td>8MΩ</td>
<td>28</td>
</tr>
<tr>
<td>LF-347</td>
<td>2Ω</td>
<td>8Ω</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>2kΩ</td>
<td>8kΩ</td>
<td>780</td>
</tr>
<tr>
<td></td>
<td>20kΩ</td>
<td>80kΩ</td>
<td>323</td>
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<tr>
<td></td>
<td>2MΩ</td>
<td>8MΩ</td>
<td>2</td>
</tr>
<tr>
<td>OPA2604</td>
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<td>8Ω</td>
<td>unknown</td>
</tr>
<tr>
<td></td>
<td>2kΩ</td>
<td>8kΩ</td>
<td>1160</td>
</tr>
<tr>
<td></td>
<td>20kΩ</td>
<td>80kΩ</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>2MΩ</td>
<td>8MΩ</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 2. Cut-off frequency for various op-amps and resistors used