Ryerson University

**Department of Electrical**
**& Computer Engineering**
Faculty of Engineering & Architectural Science

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| **Instructor:** | **Dr. Fei Yuan** |

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| *Assignment/Lab Number:* | 8 |
| *Assignment/Lab Title:* | Amplifier Design Project |

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## 1. Introduction

The report for the Amplifier Design Project is presented herein. The lab session for this experiment took place on April 1, 2021.

## 2. Objectives

The objective of this project was to design a BJT amplifier with accordance to the proposed requirements in the project manual. All specifications and additional details are presented below.

**Specifications**:

- Power supply: $+\mathbf{10V}$ relative to the ground;
- Total quiescent current drawn from the power supply: **no larger than 10 $mA$;**
- No-load voltage gain (at 1 $kHz$): $|\boldsymbol{Avo}|$ = $\mathbf{50}$ (± $\mathbf{10}$%);
- Maximum no-load output voltage swing (at 1 $kHz$): **no smaller than 8 V peak to peak;**
- Loaded voltage gain (at 1 $kHz$ and with $RL$ = 1 $k\Omega$): **no smaller than 90% of the no-load voltage gain;**
- Maximum loaded output voltage swing (at 1 $kHz$ and $RL$ = 1 $k\Omega$): **no smaller than 4 V peak to peak;**
- Input resistance (at 1 $kHz$): no smaller than $\mathbf{20\ k\Omega}$;
- Amplifier type: **inverting or non-inverting;**
- Frequency response: **20 Hz to 50 kHz** ($-\mathbf{3dB}$ response);
- Type of transistors: **BJT;**
- Number of transistors (stages): **no more than 3;**
- Resistances permitted: **values smaller than $\mathbf{220\ k\Omega}$ from the E24 series;**
- Capacitors permitted: $\mathbf{0.1\ \mu F}$, $\mathbf{1.0\ \mu F}$, $\mathbf{2.2\ \mu F}$, $\mathbf{4.7\ \mu F}$, $\mathbf{10\ \mu F}$, $\mathbf{47\ \mu F}$, $\mathbf{100\ \mu F}$, $\mathbf{220\ \mu F}$;
- Other components (BJTs, diodes, Zener diodes, etc.): **only from your ELE404 lab kit**

**Notes:**

- The output voltage must be free from distortions (clipping, etc.) in all test conditions.
- The source resistance, $Rs$ , must be 600 Ω for all tests.

**Assumptions:**

- $V_{BE,ON} = 0.7$V
- $V_{CE,SAT} = 0.3$V
- $V_T = 0.026$V
- $\beta = 150$

## 3. Description of Amplifiers

For this project, the Common Collector (CC) and Common Emitter (CE) amplifiers are used to construct the multistage amplifier. There are 3 modes of operation for the amplifiers: Cutoff mode ($V_{CE,SAT} < 0.3$V), Saturation mode ($0.1 < V_{CE,SAT} < 0.3$V), and Active mode ($V_{CE} > V_{CE,SAT}$). For an NPN BJT (Bipolar Junction Transistor), $V_{CE,NPN} = V_C - V_E$, and for a PNP BJT, $V_{CE,PNP} = V_E - V_C$.

The Common Collector (CC) amplifier has the following characteristics:

- The voltage gain, with or without load, is approximately equal to 1
- The input resistance, $R_{in}$, is a relatively small value
- The output resistance, $R_o$, is a very small value

The Common Emitter (CE) amplifier has the following characteristics:

- The voltage gain is relatively large when compared to the CC amplifier's gain
- $V_{CE,SAT} = 0.3$V
- The input resistance, $R_{in}$, is a relatively large value
- The output resistance, $R_o$, is dependant on the emitter resistance, $R_E$, and is usually a relatively large value

## 4. Approach used for the project

For this project, a three-stage amplifier is used in the following order of BJT amplifiers: CC stage, CE stage and CC stage. The first two stages are in the order of CC-CE because the minimum value of the input resistance value (20 KΩ) could not be achieved using a CE-CC stage combination.

First, the CC amplifier stage is picked to obtain a voltage gain of approximately 1, or unity, and also having a minimum input resistance of 20 kΩ. Next, the CE amplifier stage is used to produce a high voltage gain, which in this project is approximately 50 for its input resistance. Finally, the second CC stage ensures that the voltage gain is again constant, thus maintaining the high input resistance and low output resistance values.

In terms of the resistance values picked for this project, the values were picked arbitrarily to help make the calculations more accurate and precise. Some of the values were picked from previous labs to ensure consistency in all resistor values. Through the performed manual calculations, it was determined that the picked values meet all specifications required from the project manual. The use of resistors in each amplifier stage is explained below.

**1) CC amplifier stage:** First, the resistor values were treated as unknown, or 0 Ω. Then, by placing a voltage probe between $R_2$, $R_3$and the BJT, the voltage is found to be 5 Volts at that place. Through voltage division, the values of $R_2$ and $R_3$are determined, since it is already known that $V_{CC}$is 10 Volts and V is 5 Volts. Through calculations, $R_2$ and $R_3$are in a 1-to-1 ratio and they have the same resistance value. To compensate for the small input resistance, $R_4$is also set to the same value as $R_2$ and $R_3$.

**2) CE amplifier stage:** The resistor values are initially treated as unknown. Then, by placing a voltage probe between $R_5$, $R_6$and the BJT, the voltage is found to be 5 Volts at that place. Through voltage division, the values of $R_5$ and $R_6$are determined, since it is already known that $V_{CC}$is 10 Volts and V is 5 Volts. Through calculations, $R_5$ and $R_6$are in a 1-to-1 ratio and they have the same resistance value. As for $R_7$, $R_8$, and $R_5$,the resistor values were picked to accommodate for the output voltage being half of the amplitude of the input voltage.

**3) Second CC amplifier stage:** The same values from the first CC stage are used to maintain the voltage gain. In the circuit of **Figure 5.2**, the load resistance of 1 KΩ us used to prevent gain loss in the circuit and ensure a small output resistance.

## 5. Circuit Configurations and Waveforms

There are two circuits under examination for this project. Each circuit represents a three-stage amplifier with the CC, CE and CC stages in order. **Figure 5.1** represents the three-stage amplifier with no load resistance and **Figure 5.2** represents the same amplifier with a load resistor of 1 KΩ. These circuits are constructed using the Multisim software environment, and a range of 20 Hz to 50 KHz was used in the Bode Plot machine to show the relationship between the magnitude and phase plots. The function generator has frequency of 20 KHz and amplitude of 5 milli-Volts, peak-to-peak. A small amplitude is used to avoid distortion for the output voltage's waveform.

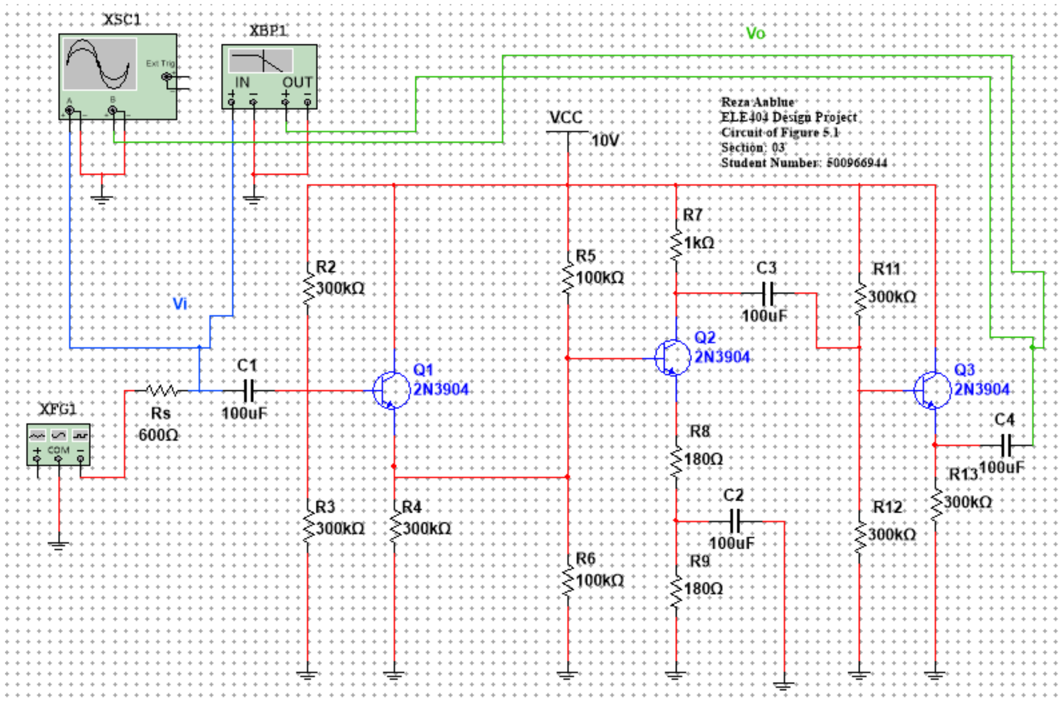



**Figure 5.1: Multisim circuit schematic for the three-stage amplifier without load resistance.**

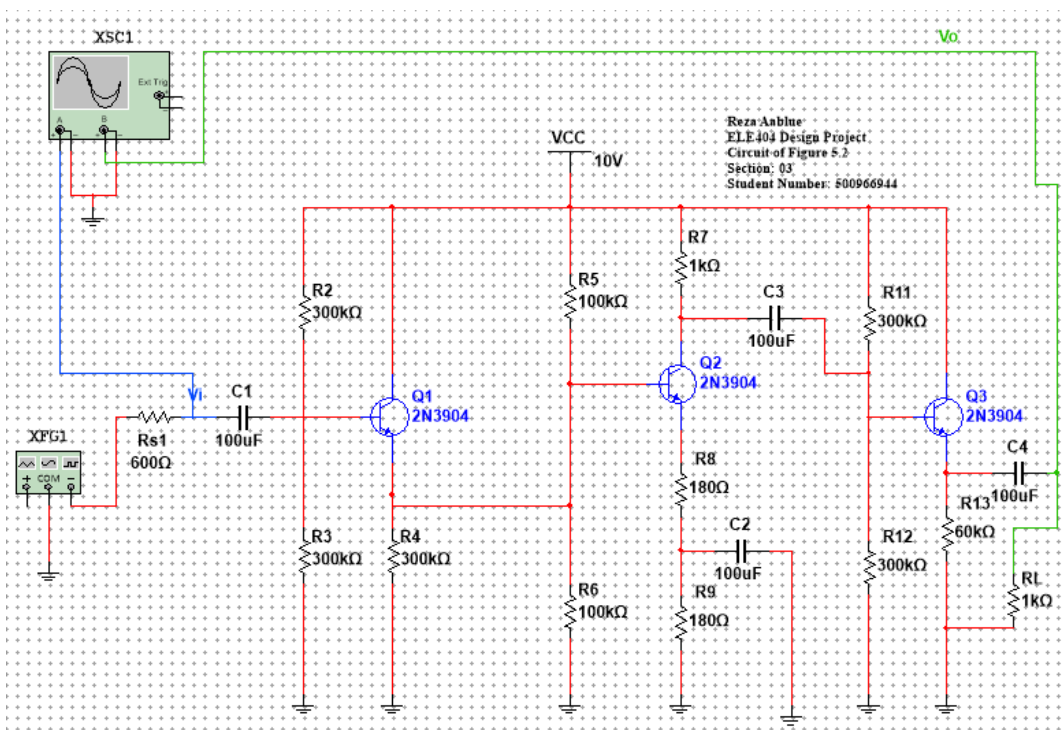
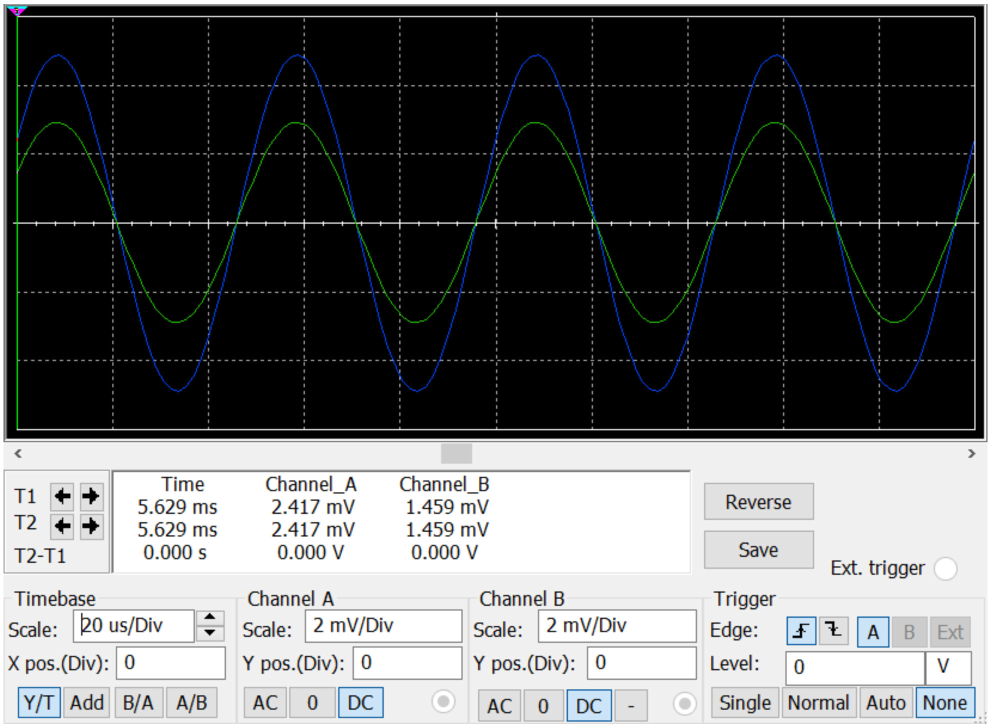
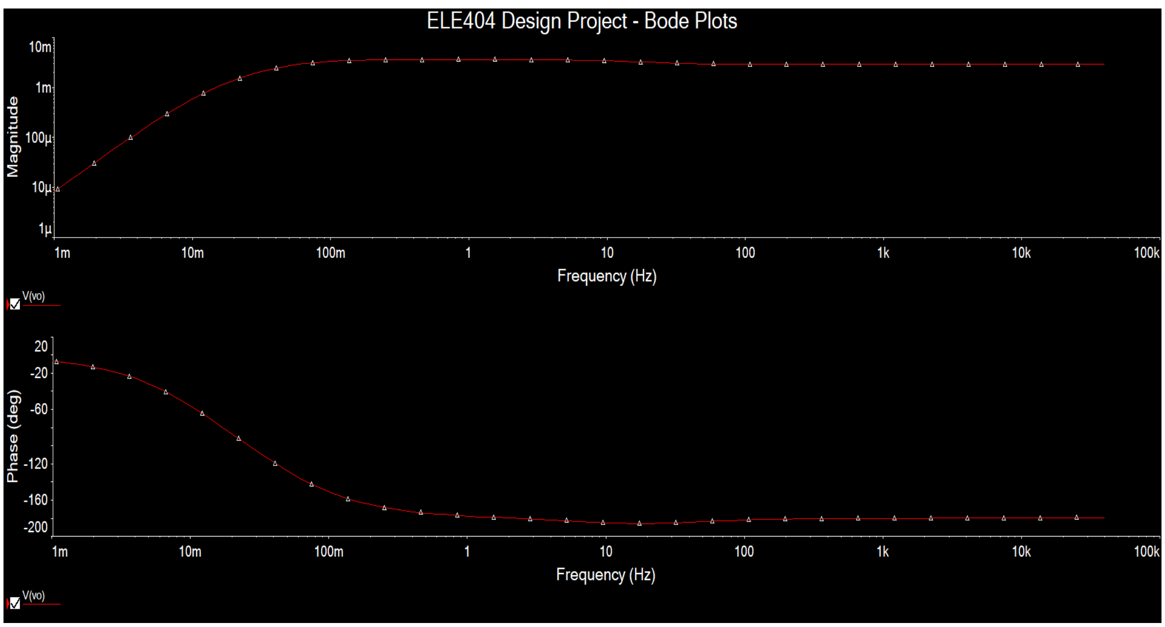


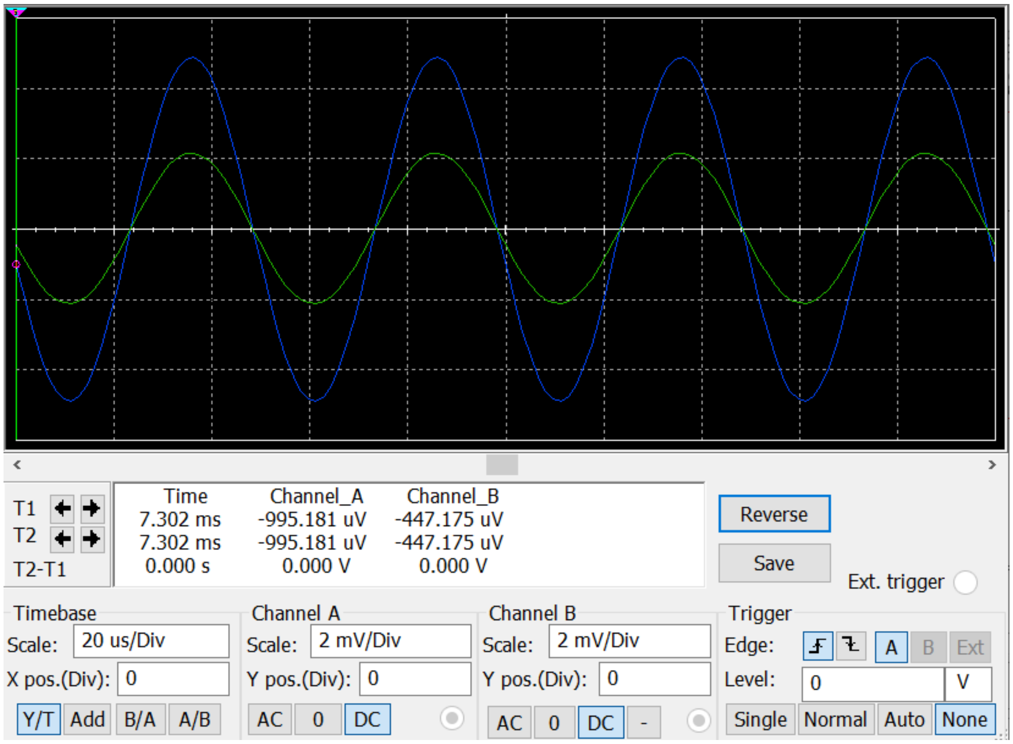

**Figure 5.2: Multisim circuit schematic for the three-stage amplifier with load resistance.**




**Graph 5.1: Input (BLUE colour) and output (GREEN colour) voltages of the circuit of Figure 5.1.**




**Graph 5.2: Bode plot waveforms of the circuit of Figure 5.1 for the output voltage.**




**Graph 5.3: Input (BLUE colour) and output (GREEN colour) voltages of the circuit of Figure 5.2.**

There is however, some discrepancies in the circuits. First, the value of β is set to 150, affecting the voltage gain and its quiescent currents. The BJT's current has some discrepancy as the resistors used are not ideal and the capacitors have internal resistances which also affect the BJT's current. Despite this, the multistage amplifier meets all the requirements.

## 6. Manual Calculations

The manual calculations for the three-stage amplifier are presented below. For the calculations, the DC and AC analysis parts are separated into sub-sections.

### ***Part 1: DC Analysis***

**Analysis for stage 1 (CC amplifier)**

$V_{B1} = V_{CC}\left(\frac{R_2}{R_2 + R_3}\right)$ **Equation #1**

$V_{B1} = (10\,V) * \left(\frac{300\ \mathrm{k\Omega}}{600\ \mathrm{k\Omega}}\right)$

$V_{B1} =$ 5 Volts

$V_{E1} = V_{B1} - V_{BE,\,ON}$ **Equation #2**

$V_{E1} = 5V - 0.7V$

$V_{E1} = 4.3$Volts

$I_{E1} = \frac{V_{E1}}{R_4}$ **Equation #3**

$I_{E1} = \frac{4.3V}{300\ \mathrm{k\Omega}}$

$I_{E1} = 14.3$ μ- Amperes

$I_{C1} = \left(\frac{\beta}{\beta+1}\right)I_{E1}$ **Equation #4**

$I_{C1} = 0.99338\,(14.3\ \mu A)$

$I_{C1} = 14.205$ μ- Amperes

$g_{m1} = \frac{I_{C1}}{V_T}$ **Equation #5**

$g_{m1} = \frac{14.205\ \mu A}{0.026\ V}$

$g_{m1} = 0.546$ mS

$r_{\pi 1} = \frac{\beta}{g_{m1}}$ **Equation #6**

$r_{\pi 1} = \frac{150}{0.546\ mS}$

$r_{\pi 1} = 274,725.28\Omega$

$r_{e1} = \frac{r_{\pi 1}}{\beta+1}$ **Equation #7**

$r_{e1} = 1819.37\Omega$

**Analysis for stage 2 (CE amplifier)**

$V_{B2} = V_{CC}\left(\frac{R_5}{R_5 + R_6}\right)$ **Equation #8**

$V_{B2} = 5\text{Volts}$

$V_{E2} = V_{B2} - V_{BE,\,ON}$ **Equation #9**

$V_{E2} = 4.3\text{Volts}$

$I_{E2} = \frac{V_{E2}}{R_8 + R_9}$ **Equation #10**

$I_{E2} = 11.94\text{milli - Amperes}$

$I_{C2} = \left(\frac{\beta}{\beta + 1}\right)I_{E2}$ **Equation #11**

$I_{C2} = 11.86\text{milli - Amperes}$

$g_{m2} = \frac{I_{C2}}{V_T}$ **Equation #12**

$g_{m2} = 0.433\text{S}$

$r_{\pi 2} = \frac{\beta}{g_{m2}}$ **Equation #13**

$r_{\pi 2} = 346.42\Omega$

$r_{e2} = \frac{r_{\pi 2}}{\beta+1}$ **Equation #14**

$r_{e2} = 2.294\Omega$

**Analysis for stage 3 (CC amplifier)**

$V_{B3} = V_{CC}\left(\frac{R_{11}}{R_{11} + R_{12}}\right)$ **Equation #15**

$V_{B3} = 5\text{Volts}$

$V_{E3} = V_{B3} - V_{BE}$ **Equation #16**

$V_{E3} = 4.3\text{Volts}$

$I_{E3} = \frac{V_{E3}}{R_{13}}$ **Equation #17**

$I_{E3} = 14.33\text{micro - Amperes}$

$I_{C3} = (\frac{\beta}{\beta+1})I_{E3}$ **Equation #18**

$I_{C3} = 14.24$micro - Amperes

$g_{m3} = \frac{I_{C3}}{V_T}$ **Equation #19**

$g_{m3} = 0.548$mS

$r_{\pi3} = \frac{\beta}{g_{m3}}$ **Equation #20**

$r_{\pi3} = 273,722.63\Omega$

$r_{e3} = \frac{r_{\pi 3}}{\beta+1}$ **Equation #21**

$r_{e3} = 1812.73\Omega$

***Part 2: AC Analysis***

$R_{in1} = r_{\pi1} + (\beta + 1)R_4$ **Equation #22**

$R_{in1} = 45,574,725.28\Omega$

$R_{in2} = r_{\pi2} + (\beta + 1)R_8$ **Equation #23**

$R_{in2} = 27,526.42\Omega$

$R_{in3} = r_{\pi3} + (\beta + 1)R_{13}$ **Equation #24**

$R_{in3} = 45,573,722.63\Omega$

$R_{in} = R_2 \,||\, R_3 \,||\, R_{in1}$ **Equation #25**

$R_{in} = 149.51\mathrm{K}\Omega$

$\frac{V_{B2}}{V_i} = \frac{g_{m1}(R_4 || R_5 || R_6 || R_{in2})}{1 + g_{m1}(R_4 || R_5 || R_6 || R_{in2})}$ **Equation #26**

$\frac{V_{B2}}{V_i} = 0.901$

$\frac{V_{B3}}{V_{B2}} = \frac{g_{m2}(R_7 || R_{11} || R_{12} || R_{in3})}{1 + g_{m2}(R_7 || R_{11} || R_{in3})}$ **Equation #27**

$\frac{V_{B3}}{V_{B2}} = 0.9944$

$\frac{V_O}{V_{B3}} = \frac{g_{m3}(R_{13})}{1 + g_{m3}(R_{13})}$ **Equation #28**

$\frac{V_O}{V_{B3}} = 0.9940$

$\frac{V_O}{V_i} = \frac{V_O}{V_{B3}} \; * \; \frac{V_{B3}}{V_{B2}} \; * \frac{V_{B2}}{V_I}$ **Equation #29**

$\frac{V_O}{V_i} = 0.8906$