Task 5: Voltage Amplifier

Optical Uplink

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Abstract

The design, simulation and construction of an amplifier circuit are described. In task 5 of the optical uplink project, a voltage amplifier will increase the signal from the active bandpass filter from a low voltage range, possibly in mV, to 5V. Two ways are explored to accomplish this task. The first is using a common source NMOS circuit. The second is using a NPN BJT common emitter circuit.

Electrical and Computer Engineering
University of Maine
ECE - 342
December 4, 2017

Contents

List of Figures

List of Tables

1 Introduction

This report describes design, implementation and test of two voltage amplifiers. One consisting of negative metal oxide semconducting field effect transistors (NMOS). The other comprised of bipolar junction transistors. Figure 1 demonstrates where in the optical uplink project the voltage amplifier is placed.

Figure 1: Block diagram for optical uplink [1]

The voltage amplifier is required by the optical uplink project. The output signal from the multi-feedback bandpass filter (MFBP) is in the hundreds of millivolt range. In order to make a more easily detectable signal, a voltage amplifier is required. This can achieved through the use of either a common source or common emitter amplifier. The specifications for this lab are summarized in Table 1.

Table 1: LED driver specifications

Specifications	Required
Peak gain, with load	21 dB $\pm$ 1dB%
Bias current for N_1	1mA
Lower cut-off frequency	$\geq$100 mA
Upper cut-off frequency	at least 200 kHz
R_in, small signal	at least 1 MΩ
R_out, small signal	at least 3 kΩ
$2^(nd)$ Harmonic distortion @ 1kHz	¡2%
Supply voltages	$\pm$12 V

The voltage amplifier circuit receives the voltage signal from the MFBP and increases the amplitude of the voltage wavefrom. The desired final output being 5 V. This is achieved with either the use of a NMOS common source amplifier or an NPN BJT common emitter amplifier.

Section 2 of this report describes the design and simulations of the common source amplifier and the common emitter amplifier. Experimental results are addressed in section 3. A discussion of the results, sources of error, and areas of possible improvement are outlined in section 4. Section 5 concludes this report.

2 Circuit Development

This section covers the design choices associated with the various circuits constructed. The individual circuits designed were a Schmitt trigger configured op amp as the signal conditioner and an op amp driving a BJT for the current driver. The input waveform was generated using the ring oscillator from Lab 3. A voltage regulator supplied a steady 5V from a 9V battery source.

The order in which the circuits are discussed is as follows: first the signal conditioner, then the current driver, and then finally the voltage regulator.

2.1 NMOS common source

The current driver for this lab was created using an MCP6004 op amp. The op amp is to act as the driver for the gate of a 2N3904 Bipolar Junction Transistor (BJT). The generic circuit for the current driver is shown in Figure 2.

CircuitDevelopment/ledgeneric.png

Figure 2: Generic current driver circuit [1]

The key to operation of the current driver is the BJT. A BJT, in contrast with the metal oxide semi-conducting field effect transistor (MOSFET), is capable of producing current by both types of Charge Carriers. This effectively allows the BJT to behave as a NPN or PNP transistor depending on the size of the input current. This also allows the BJT to use a smaller current signal to control a larger current.

The electrical properties of a BJT are paramount for this lab. The MCP6004 is only capable of outputting around 20mA of current. The IR LED in use, however, has a forward current of 100mA [2]. A much larger current has to generated in order for the LED to operate. Figure 3 shows the IV curve for the IR1503 LED.

Figure 3: The IV characteristic of the IR1503 [2]

The MCP6004 is used to set the node voltage for R_{sense}. The op amp is assumed to be ideal, so $V_- = V_+$. In order to ensure that the LED is forward biased, the node voltage should be less than the sum of the voltage drops from V_{supply} over the BJT and the diode [?]. The lab briefing [?] states to set V_- less then 3V.

In order to attain a suitable voltage, a voltage divider is placed at the input to the op amp. The source voltage is the output from the signal conditioner, and was found to be 5V. In order to be less than 3V, a

50/50 voltage divider was used in order to create an input of 2.5V. With this voltage, and the maximum forward current of 200mA, the value for R_{sense} can solved using Ohm's Law. The final value for R_{sense} is 12Ω. The simulated circuit for current driver is seen in Figure 4.

Figure 4: Simulated LED driver circuit

The circuit required no changes from design to simulation. The current through the LED can be seen in Figure 5. The simulation was performed using a transient analysis in NGSpice integrated with Matlab.

Figure 5: Simulated current through the LED

The current through the LED matched the calculated value of 200mA. The LED is in an operational state. The LED also operates with the correct frequency and duty-cycle from the signal conditioner.

2.2 BJT common emitter

The CMOS ring oscillator consists of three CMOS inverters connected in series with the output of the last inverter connected to the input of the first inverter. The ring oscillator will also have a capacitor at each output connected to ground. The schematic for the CMOS ring oscillator can be seen in Figure 6.

CircuitDevelopment/RingOscillatorCMOSexp.png

Figure 6: CMOS ring oscillator schematic

The operation of the ring oscillator uses a series of inverters. The output of one inverter inverts the input signal. Therefore, if there are a series of inverters, then each odd inverter will have the same inverted output as the first. In this instance, there are three stages of inverters used, with the output of the third inverter being fed back into the input of the first inverter. This feedback from the output to the input causes an oscillation. The simulated output of the ring oscillator is depicted in Figure 7.

CircuitDevelopment/ringoscsimlab4.jpg

Figure 7: Simulated CMOS ring oscillator output

The output of the ring oscillator seen in Figure 7 is not a square wave, but instead a distorted sinusoid. However, the signal will be converted into a square wave by using a schmitt trigger. The resulting signal will be used to drive the LED driver circuit.

2.3 Simulated summary

The final simulated circuit is shown in Figure 8.

Figure 8: Simulated LED driver

The simulated circuit did require any changes from calculations. One of the most significant margins of error for simulations is that the operation of the simulations is quite dependent on which simulation model for the 2N3904 is used. The "SP3" model from ON Semiconductor was utilized for these simulations [**?**]. Different models are capable of behaving in unexpected ways due to their interaction with the NGSpice simulation software. The summary of simulated results from this circuit is shown in Table 2.

Table 2: Simulated Results

Component	Simulated Values
Conditioned Voltage	5V
Conditioned Frequency	20kHz
Conditioned Duty-Cycle	48%
Output Current	200mA
R_{sense}	12Ω

The simulated signal conditioner outputted only a 48% duty-cycle directly and is slightly less than the required 50%. However, the final waveform through the LED operated with a 50% duty-cycle as required by specifications. The simulated circuit operated as expected and provided enough current in order to drive the LED. The resulting waveform through the LED is the correct frequency and duty-cycle.

3 Experimental Implementation

The final circuit is shown in Figure 9.

In order to meet specifications, several minor changes to all circuits were made. The individual changes are discussed in their respective subsection as follows, the signal conditioner then the current driver.

4 Discussion

After several minor changes, the circuit operated correctly. This lab served as introduction to circuits that include both transistors and op amps. The two types of components have been studied separately, but never in conjunction. The specifications are outlined in Table 4.

Table 3: Driver specifications

Specifications	Required
Frequency	20kHz±5%
Duty-cycle	50%
Amplitude	≥100mA

Notably, the ring oscillator had to have the its output frequency increased. This was due, in part, because of parasitic inductances and capacitances from the board and jumper wires. The propagation of the signal from the oscillator to output resulted in a decrease of frequency. Therefore, increasing the input frequency resulted in a correct output of the LED driver.

Another factor that determined the operating frequency is the fact that most of the components are temperature dependent. The MCP6004 IC, with increasing temperature, has an increased frequency output. The voltage regulator's efficiency, however, decreases with increasing temperature. The current through the LED is also a function of temperature. The behavior of this circuit can be heavily dependent on ambient temperature. This is a vital stipulation as, depending on the bandwidth of the MFBP filter designed before, the LED signal may fall inside the stopband of the MFBP filter. The receiver would then fail to

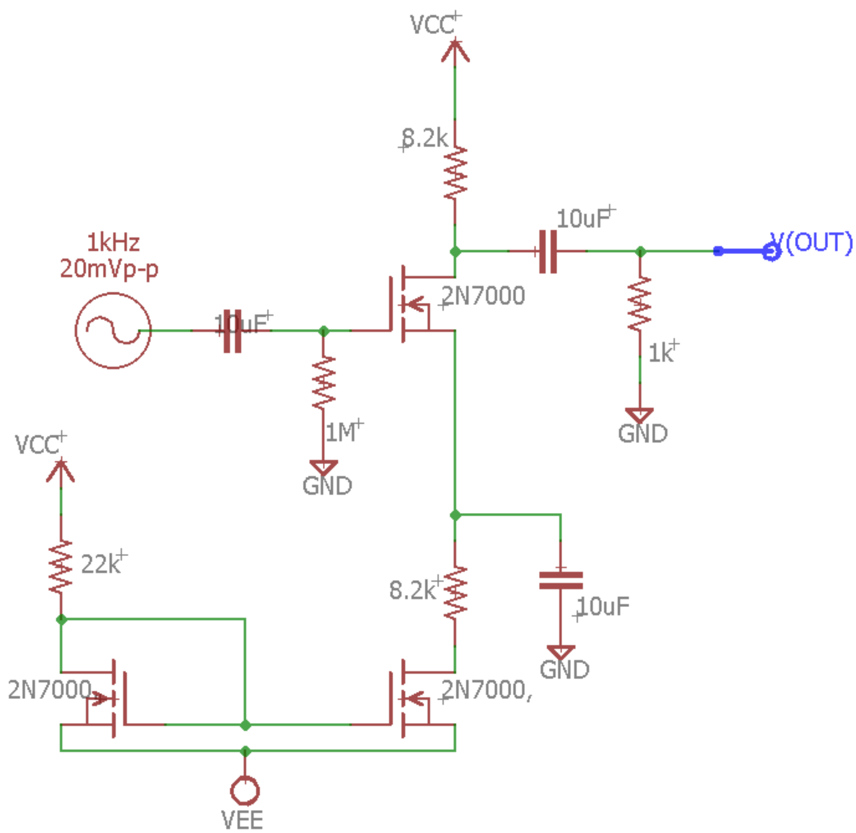

Figure 9

Figure 10

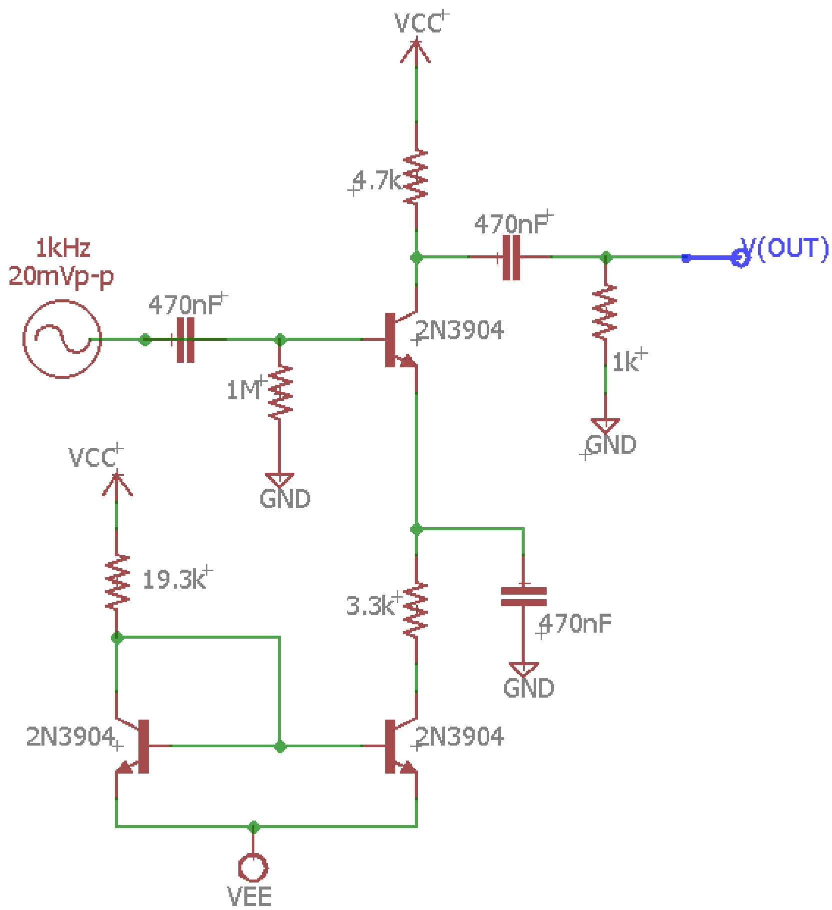

Figure 11

Figure 12

receive the LED signal and the optical uplink would not operate. The summary of the final results can be seen in Table 5.

Table 4: Simulated vs. experimental results

Component Values	Simulated	Experimental
Output Current	200mA	150mA
Output Frequency	20kHz	20.1kHz
Output Duty-cycle	48%	50.1%

The final circuit fell well within specifications and operated correctly after several component alterations.

5 Conclusion

The design, simulation, and implementation of the LED driver have been explained. Lab specification required that the signal generator have a frequency of approximately 20kHz, a duty-cycle of approximately 50%, and an amplitude of at least 100mA. The LED driver takes a sinuisoidal waveform of variable duty-cycle and outputs a 50% durt-cycle square wave. The waveform is then converted to a suffeciently large driving current by the current driver. The LED driver was constructed using the following parts: a 10kΩ, 100kΩ, 470Ω, 1kΩ, 12Ω and a 10kΩ potentiometer; a MCP6004 quadrature operation amplifier; an IR1503 LED; and finally a 2N3904 BJT. A 9V battery supply is stepped down to 5V with an LM7805 voltage regulator. The frequency was 20.1kHz, with a duty-cycle of 50.1%, and an amplitude of 150mA. An important lesson about the behavior circuits including both op amps and transistors was learned. The meshing of op amps and transistors provide novel solutions to real world problems

References

[1] D.E. Kotecki Lab.(2017) Lab #5 Voltage Amplifier [Online]. Available: http://davidkotecki.com/ECE342/labs/ECE342_2017_Lab5.pdf

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[3] ON Semiconductor. (2017) LM7805 [Online]. Available: https://www.sparkfun.com/datasheets/Components/LM7805.pdf