# Photoamplification for an IR Reciever

Alex Short
*Computer Engineering Department*
*California Polytechnic State University*
San Luis Obispo, United States of America

***Abstract*—Operational amplifiers (op-amps) are some of the most useful integrated circuits (ICs) in modern circuit applications. The ability to amplify an input voltage is incredibly practical for use in measuring analog signals in real-world applications. In this report I examine basic op-amp circuits to measure and demonstrate their gain capabilities, and then apply the amplification circuitry to the detection of an IR signal. The results of this report will demonstrate how the op-amp circuitry benefits this type of detector, and how different op-amp circuits are used together.**

***Index Terms*—Operational amplifier, gain, photodiode, photoamplifier, transimpedance amplifier, noninverting amplifier**

## I. Introduction

### A. Basic Theory of Operational Amplifiers

The operational amplifier is an integrate circuit (meaning it is made up of other more basic components, mostly capacitors and transistors) that takes in two inputs, an 'inverting' and a 'noninverting' input, denoted by $-$ and $+$ respectively. The op-amp also requires supply voltages that are both high and low, denoted by $V_+$ and $V_-$ respectively, and these are usually external sources.

The number one rule of an op-amp is that the device requires the input currents to be practically zero. When the negative input is connected to the output, this is called 'negative feedback', and the op-amp will hold the input voltages to the same value. Using these properties, we can solve circuits containing op-amps.

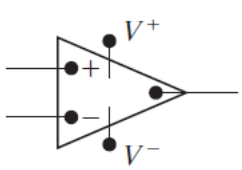


Fig. 1. high level diagram of an operational amplifier, containing labels for the input and supply voltages. Image taken from [1]

### B. The Noninverting Amplifier

One of the main circuits designed in this report is called the non-inverting amplifier. This circuit simply amplifies an input voltage by a calcuable gain, and does not invert the input signal.

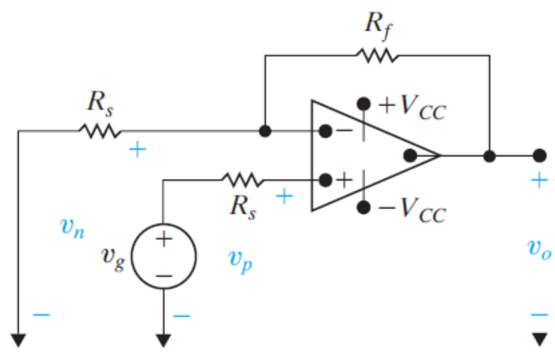


Fig. 2. the noninverting amplifier schematic, showing resistors and voltage sources. Image taken from [1]

Since this circuit has negative feedback, it is easily solved to demonstrate that the output, $v_o$ is given by the equation:

$$v_o = (1 + \frac{R_f}{R_s})v_g \tag{1}$$

Where $v_g$ represents the input voltage into the noninverting terminal. This circuit can be used to amplify very small signals, which is very useful in circuits that interact with the outside world.

### C. The IR Reciever

To design the IR receiver, we used a photodiode that could detect the input IR light and convert it into a current. In other words, we had a current source. This fed into what is called a transimpedance amplifier (Fig. 3), a circuit that makes use of negative feedback to convert a current source into a voltage output. This voltage can then be amplified.

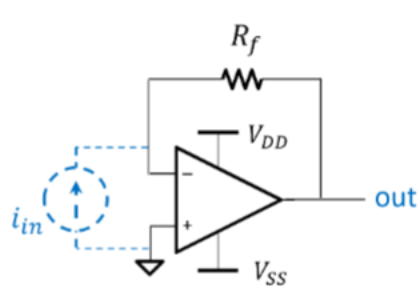


Fig. 3. transimpedance amplifier used to convert an input current from a photodiode to an output voltage. Image from [2]

The grounded non-inverting terminal creates a 'virtual ground' at the inverting terminal, as there is negative feedback. All of the current from $I_{in}$ goes through the feedback loop, due to the first rule discussed in section 1.A, and therefore the voltage output can be describes as:

$$V_{out} = I_{in} R_f \tag{2}$$

However, the input current will be very small, as is normal for photodiodes, and so we connect the transimpedance amplifier to a noninverting amplifier. This will create a clear signal as an output, which will be used to drive an LED indicator.

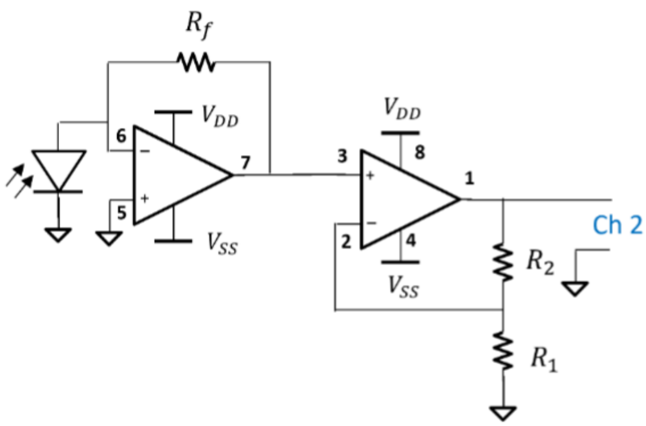


Fig. 4. the full IR reciever circuit complete with a transimpedance amplifier and a noninverting amplifier [2]

The current drawn by the photodiode is converted into voltage as per equation (2), and that voltage is fed through a noninverting amplifier with a gain given by equation (1). Thus the full output, as a function of the photodiode current is given in the following equation:

$$V_{out} = (1 + \frac{R_2}{R_1}) I_{in} R_f \tag{3}$$

By choosing the correct resistors one can draw a signal from an IR transmitter, for applications in remote sensing and more.

## II. Experimental Procedures and Results

### A. Noninverting Amplification

The circuit depicted in figure (2) was constructed using an LM358P operational amplifier (TI, [3]), which offers two op-amps in one IC chip. Supply voltages were generated by a DC power supply (Keysight, [4]) at $\pm 5$ V. The resistor values (names shown in figure (2)) were measured to be $R_f = 220.18\ k\Omega$ and $R_s = 21.96 k\Omega$, which means the theoretical gain would be 11.03.

To verify this, we used a function generator (Keysight, [5]) to generate a sinusoidal waveform with a frequency of 10 kHz and a range of small peak-to-peak voltages. The output waveforms were viewed against the input waveform on an oscilloscope. The following table contains the measured values, along with the calculate gain.

TABLE I
NONINVERTING AMPLIFIER

| **Input** $V_p$ | **100 mV** | **150 mV** | **200 mV** | **250 mV** |
|---|---|---|---|---|
| **V**$_{\text{in,RMS}}$ $[mV_{RMS}]$ | 35.2 | 52.7 | 70.3 | 87.8 |
| **V**$_{\text{out,RMS}}$ $[mV_{RMS}]$ | 382 | 571 | 768 | 960 |
| **Gain** $[mV/mV]$ | 10.76 | 10.77 | 10.97 | 10.92 |

[a]Measured outputs of a noninverting amplifier


Fig. 5. four waveforms showing the input voltage (yellow) and the output (green) for the four inputs in table (1), clearly showing the gain of the amplifier. Note the scale factors for each channel in the top left of each image

The measured gain is very close to the theoretical one, demonstrating the accuracy of the theory. This gain will be very useful when attempting to measure an IR signal.

### B. IR Reciever Using Amplification

After verification of the noninverting amplifier, we constructed the circuit in figure (4). To verify the circuit worked, we used the function generator to create a square wave signal, and to prevent damage the LED, the signal ranged from 0 volts to 5 volts, with a 50% duty cycle. This current was drawn across an IR LED (Everlight, [6]) which would then be registered by the photodiode (Everlight, [7]).

The reciever was tested with the square wave at different separation distances between the IR LED and the photodiode. This allowed us to understand the limits of our design and potential improvements.

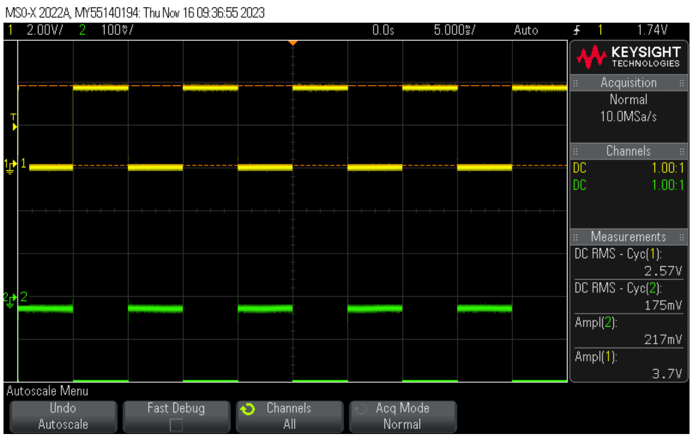


Fig. 6. input (yellow) and output (green) signals of the IR reciever when the IR LED and photodiode are incredibly close to each other

We started by placing the IR LED and photodiode practically touching, separated by around 1-2 mm, and the result is seen in figure (6). The reciever almost perfectly replicated the signal (inverted of course), and this was to be expected. Next, we moved the IR LED farther away, creating a separation of around 4 cm, which generated the output seen in figure (7).

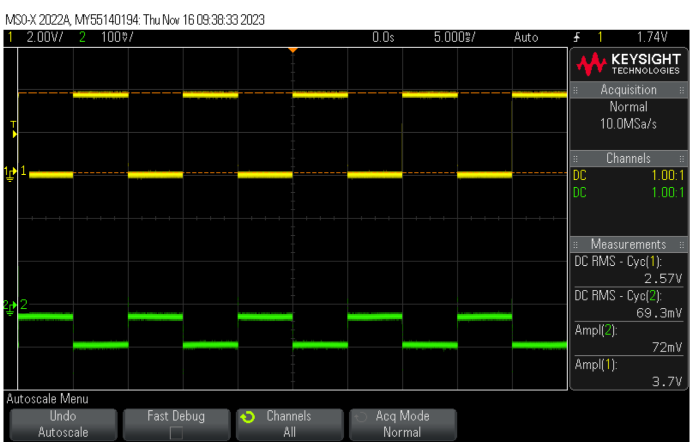


Fig. 7. input (yellow) and output (green) signals of the IR reciever when the IR LED and photodiode are a medium distance from each other

The output is slightly smaller, but still noticeable. Finally, we separated the LED and photodiode about 10 cm, which generated an output signal that demonstrated that the photodiode was not picking up any signal, or at least a very small signal.

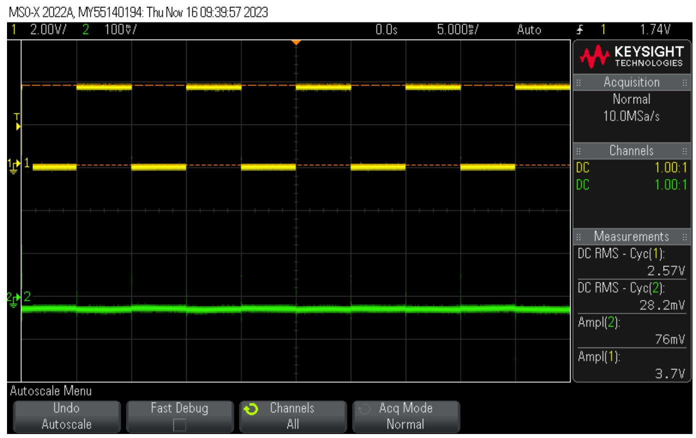


Fig. 8. input (yellow) and output (green) signals of the IR reciever when the IR LED and photodiode are far from each other

## III. Conclusion

The results of this report demonstrate the possibilities of signal amplification, and the applications sensing and recieving signals. Without the operational amplifiers, the photodiode signal would be too small to be useful. When using circuitry to interact with physical phenomena such as light, the analog nature of such signals requires proper scaling, which amplifier circuits provide.

The noninverting amplifier was predicted to have a gain of around 11, which was exhibited in the experimental results for multiple different input waveforms. This circuit amplifies a small signal into a larger, more observable one. This becomes useful when applied to the IR Reciever.

A reciever was constructed to detect an IR signal from an LED, and convert it into an observable signal. This required a transimpedance amplifer connected to a noninverting amplifier, and produced promising results. The reciever detected the LED signal from multiple centimeters away. These two designs demonstrate the capabilities of amplification circuitry and the uses in physical detection and transduction.

## References

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