Introduction

This project is designed to establish one-way data communication from a transmitter to a receiver over the infrared optical medium. More specifically, the project will communicate a modulated message over infrared to a receiver, which will filter and demodulate the signal and be processed in a micro-controller and output the message. Over the years, infrared data communications has been a common use for short range, low-bandwidth data transfers, where most products are used in the one-to-five foot range and speeds in the kilobits range. Some uses of infrared communication also run into extreme ranges, while still using a similar format to that of this project. The product line Laser-Tag, is another similar format, where some of the products are short range, one can reach about 1000 feet.

This project can send an infinite text string at a distance of 14 feet and at a speed of 19.2 kilobits per second (kbps). In the original specifications, the project must be able to send 10 ASCII characters at a speed of 9.6 kbps to a distance of 10 feet. These specifications are noted in the Project Proposal in Appendix A. Once power is supplied, the transmitter automatically sends the message, while the receiver waits until a signal is detected, and then it processes the signal with filtration and amplification.

In terms of limitations, there are only two. First, as mentioned before, the maximum distance that can be achieved is 14 feet because some of the amplifiers are at maximum operations in terms of gain without causing signal corruption by noise. The other limitation is that a fixed voltage of +/-10 Volts must be used on both circuits due to device operations in the transimpedance amplifier in the receiver and for proper operation of the LM7805 Voltage Regulator, which is on both circuits.

This report will give an overall description of the project in both hardware and software design, explaining justification and calculations of parts used in the project. Results and conclusions will follow, which include any improvements and issues that were encountered during the design and build phases of the project.

The Breakdown

This section will provide an overview for the hardware and the software of the transmitter and receiver contained in the project. The following sections will go into greater detail of the the transmitter and the receiver both in terms of hardware and in terms of software.

Transmitter

The five main components of the transmitter (Figure 1: top) will be explained in the Details section on page 6. The five main components of the receiver (Figure 1: bottom) will also be explained in the Details section starting on page 11. The complete schematics can be found in Appendixes B & D for the Transmitter and Receiver respectively on pages 22 & 24. Each board has several different stages that the signal goes through, as shown below.

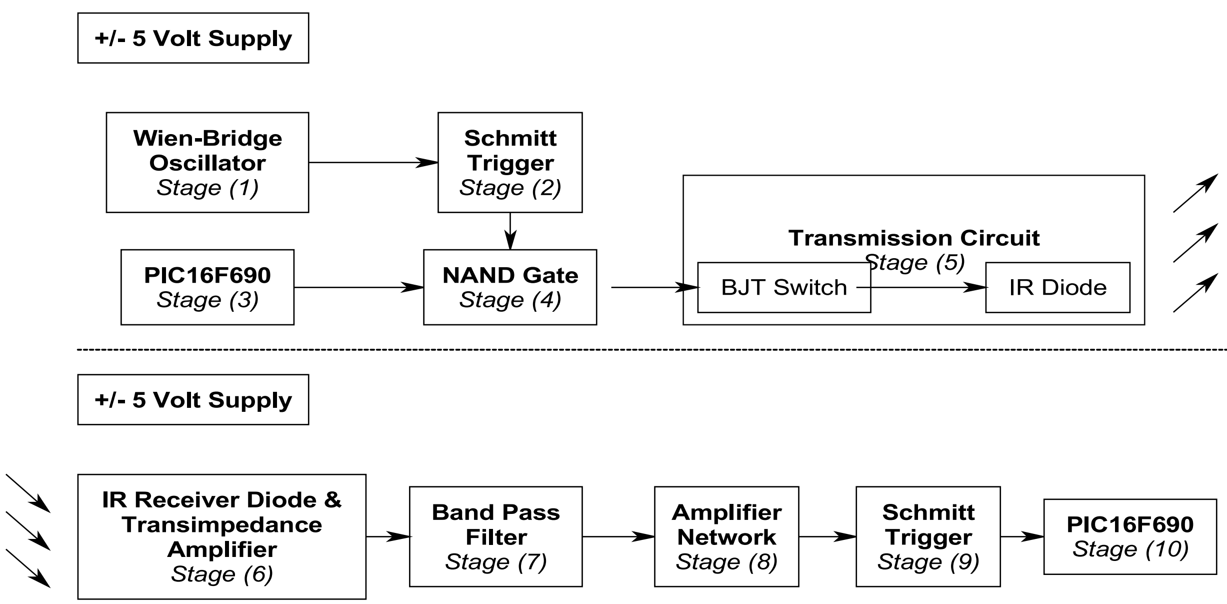


Figure 1: Block Diagram (above: Transmitter; below: Receiver)

+/-5 Volt Supply

Since the overall circuit will require a sustained voltage level of both positive and negative five volts, voltage regulators are used. The requirement of these regulators is important since the final application of the circuits would be battery-powered and require more voltage for long term usage. This stage is identical in both circuits, so it will be only explained once.

Stages (1) & (2): Wien-Bridge Oscillator & Schmitt Trigger

The oscillator creates a carrier frequency that transmits a modulated data signal. The purpose of the carrier frequency is to remove the influence of other infrared noise by placing the transmission frequency well above it, thus ensuring a clean and definitive signal. The oscillator's frequency was generated by pairs of .1nF capacitors and 20KΩ resistors. The gain of the oscillator is like any other amplifier, but includes a pair of diodes to help the oscillator maintain a constant amplitude. The Schmitt Trigger is an Operational Amplifier (Op-Amp) based design, which will modify the oscillator signal to become a perfect square wave, and thus improving the switching of the NAND gate. The Schmitt Trigger design used is the inverting design and the 58KΩ and 430Ω resistors are used on the positive feedback component of the circuit.

Stage (3): PIC16F690

The PIC16F690 Microcontroller is used to send a message as a Pulse Modulated Signal (PWM) with a duty cycle of 25% to representing a "zero" bit and a 75% duty cycle representing a "one" bit. The justification for such a method of transmitting, versus transmitting the signal in the Universal Synchronous Asynchronous Receiver/Transmitter (USART) format, is to insure there is some way of accurately determining that particular bit when repeated zeros or ones are sent. One advantage to the PWM scheme is that it doesn't require synchronizing the two boards for an accurate timing to determine if there are multiple zeros or ones. A flow chart of the transmitter will be found on page 6 along with the receiver's flow chart.

Stage (4): NAND Gate

The purpose of the NAND gate is to mix both the PWM signal from the PIC16F690 and the carrier frequency from the Wien-Bridge Oscillator/Schmitt Trigger stages creating the discrete pulses to be sent. The output creates one pulse for a "zero" and three pulses for a "one." This stage was made using discrete transistors from the CD4007 CMOS chip package.

Stage (5): Transmission Circuit

This circuit contains two components, the Bipolar Junction Transistors (BJT) and the Infrared (IR) Diodes. The BJT is being used as a current switch. When the NAND gate outputs a pulse the transistor will turn on and supply current to the diodes. The IR diodes were selected for a specific high-speed capability which will be explained in greater detail. It is from here that the actual signal is converted to IR energy and transmitted to the receiver.

Receiver

+/- 5 Volt Supply

The purpose of the +/- 5 Volt Supply is the same reason stated on page 2; however, another reason is due to the fact that Stages 6 through 8 are operating on a different voltage level to allow as much gain as possible in the Transimpedance Amplifier.

Stage (6): IR Receiver Diode & Transimpedance Amplifier

When an IR signal is being received, the photo diode will create a current. A current is useless to analyze for processing the signal. A transimpedance Amplifier is used to convert the current to a voltage. Unlike most other stages, this stage uses +/- 10 volts rails instead of +/- 5 volts to allow for higher gains, leading to longer distances being obtained. The use of the 2MΩ resistor will allow a huge gain and amplify almost any signal detectable by the photo diode. The photo diode used in is designed for high speed applications, which ensures high signal quality.

Stage (7): Band Pass Filter

This stage is a cascaded low-pass, high-pass filter network which will filter any noise that is not relevant to the data signal. The filter is designed to remove any noise that is more than 10KHz greater and less than the 78.6 KHz carrier frequency. In addition, this stage removes the DC offset that was present in the input signal to the filter stage. The supply rails for this stage was also +/- 10 Volts.

Stage (8): Amplifier Network

This stage contains a single non-inverting amplifier which will amplify the filtered input signal to a point so that the Schmitt Trigger can create discrete pulses, while not having other noise of the current signal interfere with the signal. The output of this stage will set the Schmitt Trigger's threshold values. This stage will use the +/- 5 volt rails, so that the voltage can be limited for the Schmitt Trigger and the later PIC chip. The gain of this stage was 29.8 dB, which will offset the 5 dB attenuation in the bandpass stage.

Stage (9): Schmitt Trigger

This Schmitt Trigger has the same function as the one used in the transmitter; however, this trigger is considerably more sensitive than the trigger in the transmitter circuit. Since the PIC chip cannot support negative voltages either, the signal must be rectified to remove any negative voltages and have only positive voltages pass through. The way to achieve this is a diode with a pull-down resistor to create the required input signal like ones shown in Figure 6.

Stage (10): PIC16F690

The main function of the PIC16F690 is to take the signal from the previous stages and demodulate it to something that is readable. To do this the PIC uses two different methods of determining if a bit that it receives is a one or zero. The first method is latching the value after a set amount of time and the second is to use pulse counting. The software does this eight times to receive a whole bit and then sends the value to the output.

The following figure are the flow charts for both the transmitter and receiver PIC chips.

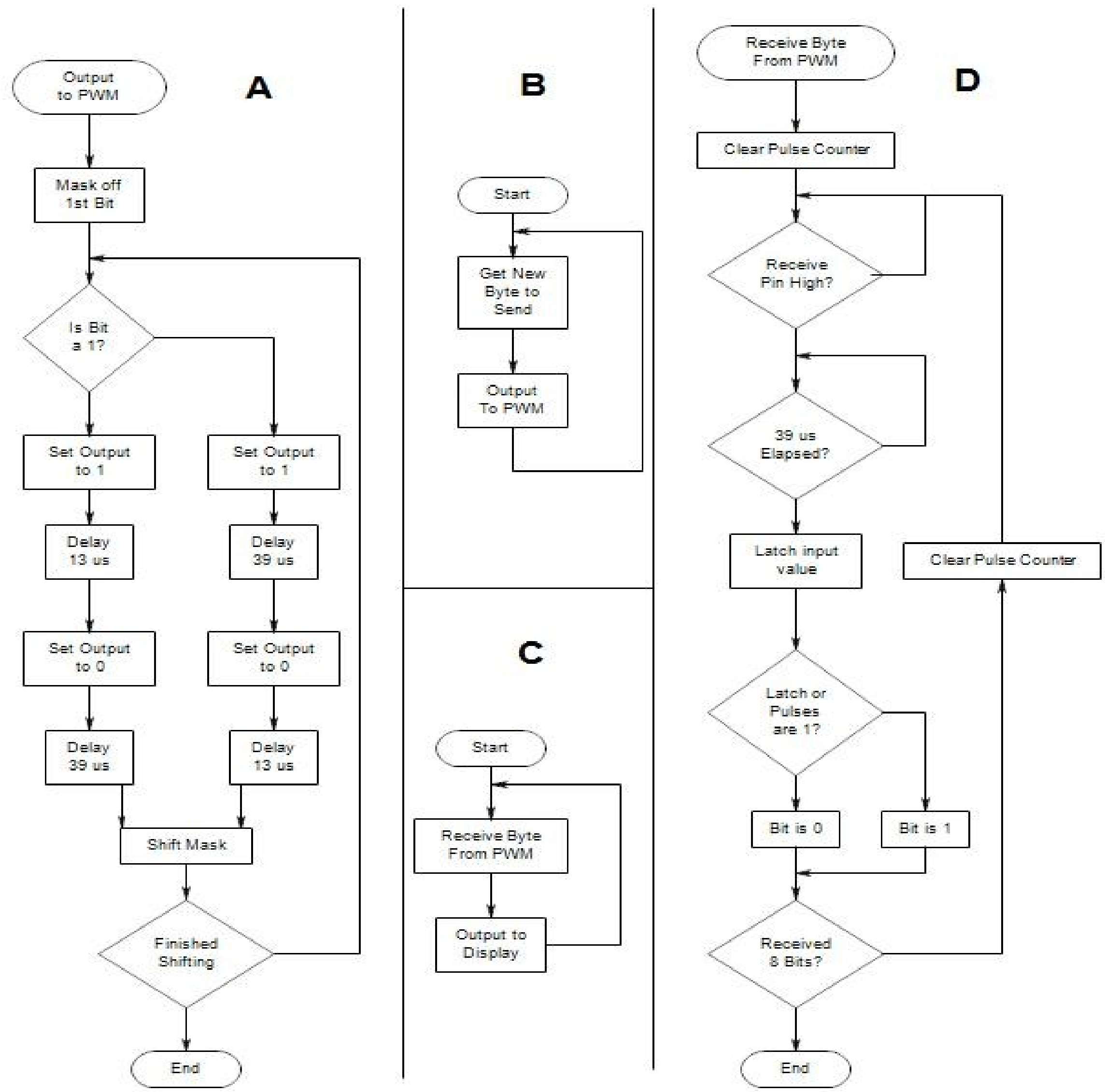


Figure 2: (A)Transmitter "Output to PWM" flow chart; (B) Transmitter "Main" flow chart; (C)Receiver "Main" flow chart; (D)Receiver "Receive Byte from PWM" flow chart

Details

The following section will be broken into four sub-sections, first starting with the hardware of both the transmitter and receiver and then the software of both circuits.

Transmitter Hardware

+/-5 Volt Supply

To allow for multiple voltage levels, and potential battery-powered operations, the LM7805 and LM7905 were used for a positive and negative (respectively) 5 volt supply. The purpose of the regulators is to set a constant voltage output no matter what the input is. These regulators were used properly as specified in the data sheet. One thing that was not known about these regulators, was that there is a minimum voltage of 7.5 Volts which must be considered for proper operations.

Stage (1): Wien-Bridge Oscillator

For transmission, the goal was to produce a signal that would not be corrupted by other infrared radiation from lights and other sources. The concept of creating a modulated signal using a carrier frequency will allow the receiver to filter out any other noise and get the desired signal, thus requiring an oscillator. Of the class of oscillators available, the Wien-Bridge Oscillator proved to be the most useful because it allowed for easier customization as the carrier frequency when the original specifications of the project were increased. The advantage of this frequency change also improves the bandwidth of the project.

Since the project requires a fast performing components for signal clarity and the Wien-Bridge needs an op-amp, the AD829 from Analog Devices Inc. was used in all components that contained an Op-Amp because of the higher slew rate (230 V/μs). Unlike other amplifiers, the AD829 requires an external compensation capacitor to make it stable at low gains, which was the case with the oscillator and the bandpass filter in the receiver circuit.

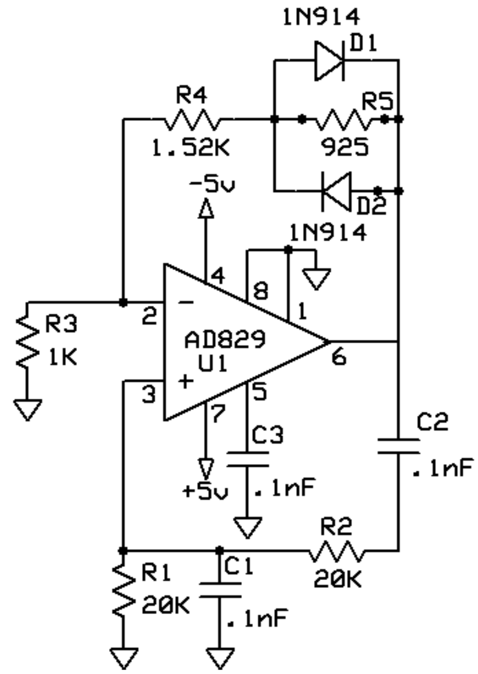


Figure 3: Wien-Bridge Oscillator

In determining the frequency, the Laplace Transformation of the oscillator circuit is found. Then substituting s=Jω as seen in equation (1) and where setting the loop gain to be real, the frequency is found to be equation (2) (Note that "R" in equations (1 & 2) represents both R_1 and R_2 in the circuit, and "C" in equations (1 & 2) represents C_1 and C_2)

$$\frac{V_p(J\omega)}{V_o(J\omega)} = \frac{1 + \frac{R_2}{R_3}}{3 + J\left(\omega \cdot C \cdot R - \frac{1}{\omega \cdot R \cdot C}\right)} \qquad \text{Equation 1}$$

$$\omega = \frac{1}{R \cdot C} \qquad \text{Equation 2}$$

To set the frequency of 76.8 KHz, the capacitors were selected to be .1nF, thus the resistances were calculated to be 20.25KΩ.

Now to set the amplitude, using equation (1) at the given frequency, it is found that the sum of R_4+R_5 over R_3 is equal to 2. However, setting this value to be slightly higher will ensure oscillations. The diodes around R_5 are used to ensure stable oscillations so the signal does not amplify to rail or attenuate to zero volts. To determine the gain required, the minimum voltage required for the transistor of the NAND gate to turn on must be larger than the threshold voltage of the transistors. For safe measure, an amplitude of four volts were used. The following equations (3 & 4) were used to determine the resistor values of R_4 & R_5, since R_3 will be set at 1KΩ. Other values to consider are that V_o= 2.5, V_n= 1/3, and V_x= .7 (the voltage drop across a diode).

$$1 + \frac{(R_4 + R_5)}{1000} = 3.51 \quad \text{Equation 3}$$

$$V_x = \frac{(V_o - V_n) R_5}{2.5 \cdot R_3} \quad \text{Equation 4}$$

Once applied, the resistors values are 1.52KΩ for R_4 and 1.9KΩ for R_5.

In testing, it was found that the first diodes used, the 1N4004, operated too slowly thus leading to the wrong frequency. When the diodes were switched to the 1N914, the signal was corrected and the frequency error initially found was corrected. Any other frequency errors were due to variations cause of the tolerance in the resistors and capacitors.

Stage (2): Schmitt Trigger

When considering the strength of the modulated signal, pulses that lasted longer will have a better chance in being received. In addition, as the sine wave is passed into the NAND gate, any voltage less than the threshold voltage will be lost and the pulses from the NAND gate will be shorter, thus increasing the risk that the signal could be lost. To prevent that, a Schmitt Trigger was implemented, which will set an output voltage when the input signal passes a certain reference voltage, which in this case was set near zero volts.

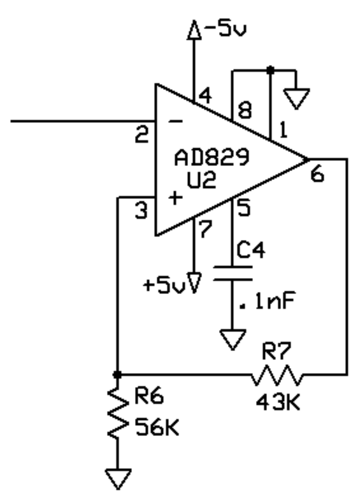


Figure 4: Inverting Schmitt Trigger

Using the equations (5-7), and setting the desired trigger voltages the resistor value can be found. The first is the nodal analysis of the circuit.

$$\frac{v_O - v_p}{R_7} = \frac{V_p}{R_6} \quad \text{Equation 5}$$

Then reorganizing the equation gives,

$$v_p = v_O \cdot \frac{R_6}{R_6 + R_7} \quad \text{Equation 6}$$

Then by setting $v_p = 2.82$ and $v_O = 5$, the desired resistor values are 56KΩ and 43KΩ for R6 and R7 respectively. Since the circuit is biased around ground, the threshold values are both positive and negative 2.82 volts. Keep in mind that this was in the inverted formation so the output will be inverted.

Stage (4): NAND Gate

The sole purpose of the NAND gate is to mix the PWM signal of the PIC16F690 with the carrier frequency from the oscillator. The intended output is a pulse based signal that outputs one pulse for a "0" bit, and three pulses for a "1" bit. Each pulse will be 6 microseconds long. These transistors are of the CD4007 CMOS chip package, thus giving a one chip solution. To minimize the number of components, the use of a NAND was more logical over an AND (4 transistors vs 6). In addition, the use of a NAND gate has a lower propagation delay than an AND gate. These decisions affected how the transmission section is designed.

Stage (5): Transmission Circuit

As mentioned earlier, the use of the NAND circuit determined how the transmission circuit was to be designed. Since current is the key factor in determining how much infrared power is transmitted, a pnp BJT is used to supply as much current to the diodes.

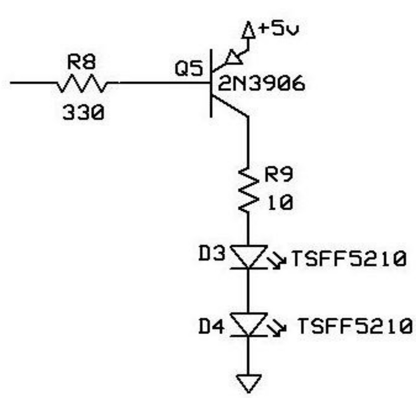


Figure 5: Transmission Circuit

The 330Ω resistor was used to bias the transistor to prevent damage. The 10Ω resistor was calculated by using the equation (7), where the 1.5 V drops are the voltage difference across the two TSFF5210. To find the correct resistor value, the current must be set to a minimum of 100mA.

$$I = \frac{(5 - 1.5 \cdot 2)}{R} \quad \text{Equation 7}$$

It was found that using multiple IR emitting diodes in series will allow more infrared energy to be created, thus a stronger signal will be received on the Receiver. The function of Resistor 9 is to bias the diodes to supply the most current without damaging the diodes, which has a maximum of 100mA sustained current according to the data sheet.

The TSFF5210 IR Diode from Vishay was selected because it had the fastest rise/fall time (15ns), a narrow angle of half intensity (10 degrees), and a radiant intensity of 180mW/sr. The TSFF5410 is identical to the 5210 with the exception of a wider range, but less radiant intensity therefore less infrared energy. It was these features and capabilities that led to the decision on which diode will be used.

The pnp 2N3906 BJT transistor was selected for suppling the most current possible, as well as inverting the pulse signals leaving the NAND gate so that only short pulses were sent, thus protecting the IR diodes. According to the data sheets of the diodes there is a maximum sustained current of 100 mA for 100 microseconds, which is not much of a concern in this project, so the diodes are guaranteed to be protected.

Simulation and Testing of the Transmitter Hardware

One limitation that is present in making simulations due to a lack of a model of any IR Diode (and the TSFF5210) in Micro-Cap 9. It is due to this limitation that an accurate value of the current cannot be obtained, as seen in the output of the current across the diodes (Appendix C, Graph C.1). Also it is seen is that there are sets of 2 or 3 pulses is due to the PWM generator source operating at 50% duty cycle. In normal operation the number of pulses would be 1 or 2 pulses for a “zero” or a 3 or 4 pulses for a “one”. In testing, and using an actual signal, it was found that the concept of operation that the simulation showed worked. The problem that was noticed is the current that is flowing through the diodes was not 100 mA like calculated, but instead less. (Appendix C, Graph C.2) This likely due to the BJT operating in Saturation versus Forward Active, thus the in correct current would being supplied.

Receiver Hardware

+/- 5 Volt Supply

The purpose, design, and operations of this stage are identical to the other supply mentioned on page 6. However, there is a larger significance because both Transimpedance Amplifier and Bandpass Filter stages are using +/- 10 Volts.

Stage (6): IR Receiver Photo Diode & Transimpedance Amplifier

For the receiver circuit, the first stage is the photo diode and transimpedance amplifier. Due to the high speed capability that was considered in the transmission diode, the same was considered in the selection of the photo diode. PIN photo diodes were chosen over regular photo diodes and photo transistors for its extremely fast speed capabilities. PIN diodes are like regular diodes, except they include another layer of intrinsic silicon in between the p and n type materials, which allows for faster transitions at much higher operating frequencies[1]. As a basic function of IR photo diodes, the photo diode will generate a current when an IR signal is received. A transimpedance amplifier must be used to convert the current to a voltage for processing. Using an Op-Amp design, the next goal was to produce a gain that is extremely high, such that if as little as one microamp of current was produced by the photo diode, it would be reflected on the output. Using nodal analysis, the gain of the transimpedance amplifier is:

$$v_o = -I_{in} \cdot R \qquad \text{Equation 8}$$

For the given amount of current mentioned, a resistor value of greater than 1 MΩ was used. In testing, it was found that a resistor of 2MΩ was the most ideal for supplying the largest gain without deteriorating the signal.

Stage (7): Bandpass Filter

For this stage of the receiver circuit, it is just a basic cascaded active high-pass-low-pass filter. For the filter design, the passband is +/- 10Khz from the carrier frequency, which places it from 66.8KHz to 86.8KHz. This bandpass filter will remove any errant noise that could have been from any other infrared sources. From the transfer function, the frequency is found by the equation below.

$$\omega = \frac{1}{R \cdot C} \qquad \text{Equation 9}$$

Using a .1nF capacitor, the resistors found are 18KΩ for the low pass, and 24KΩ for the high pass.

This stage also removes any and all DC offset, which existed in the output of the transimpedance amplifier and low pass filter. This is extremely useful for it will make our signal easier to amplify and will not require a DC restoration circuit to be implemented to remove the offset.

Stage (8): Amplifier Network

This stage is a single non-inverting amplifier. Unlike some cases, in which the signal can be amplified to +/- 5 Volt rails, this amplifier is set only so that the Schmitt Trigger can take the signal and create the desired square wave pulse signal. However, the gain cannot be so high that noise is also triggered. Testing was used to set the exact value of the gain so that the noise was low enough not to cause a problem. The gain of the amplifier can be calculated by equation (10), where R_f is Resistor 16 and R_s is Resistor 15. For simplicity, R_s is set to 1KΩ, and with that, R_f is found to be a 30KΩ resistor, thus the gain of the stage is 29.82 dB.

$$1 + \frac{R_f}{R_s} = \text{gain} \qquad \text{Equation 10}$$

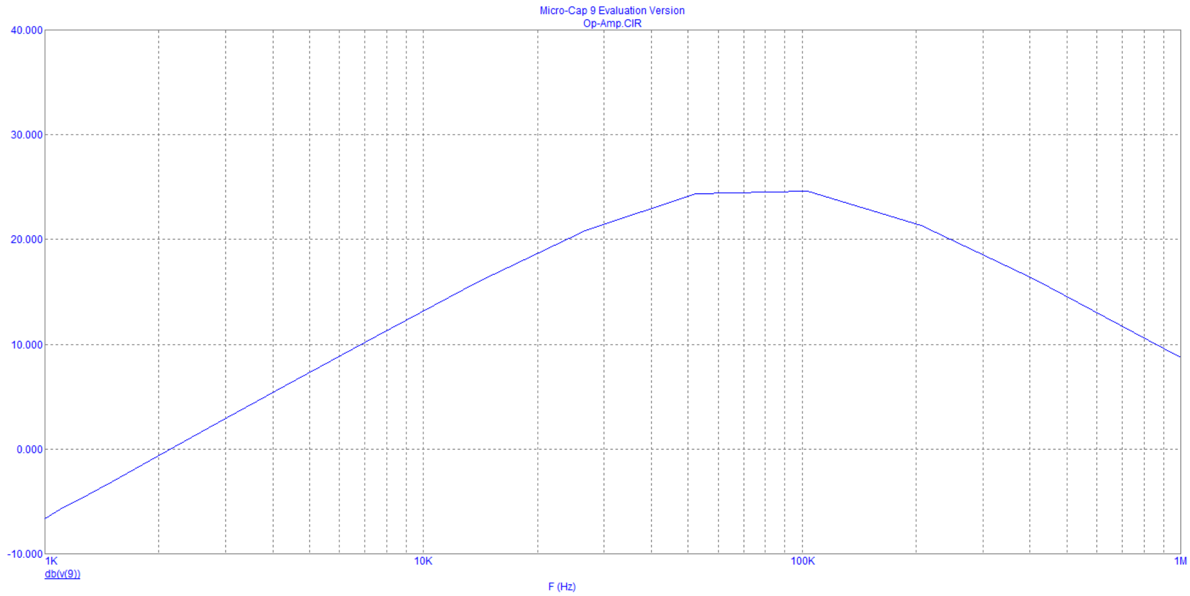
Stage (9): Schmitt Trigger and Rectifier

This last stage before the PIC chip is designed to take the signal from the amplifier stage and create a perfect square wave because before this stage, the signal was basically an amplified, intermittent sine wave. The Schmitt Trigger needed to be sensitive enough to trigger on the actual signal and not the noise. In order to do that, the same equations from page 9 (equations 5-7) of the earlier Schmitt Trigger (page 8) were used, and the resistance values obtained were 20KΩ and 1KΩ. As mentioned earlier, a rectifier diode is needed to remove any negative voltages.

Simulation of Receiver Hardware

The main point of issue of the receiver was the filtration and amplification networks, to ensure that they worked correctly from the simulation to the tested result. For simulation, Micro-Cap 9 was used. As seen on the simulation in Graph 1 (next page), the overall gain was simulated to be lower than what was actually calculated. In further study of the AC analysis, there is an attenuation 5dB of the signal found in the passband of the bandpass filter stage. This was confirmed in testing as the output of the bandpass stage was found to be in the millivolts range. Under ideal cases, the gain of the bandpass filter stage should be 0dB. The reason is because the cut-off frequencies are close together such that there is going to be an attenuation of

2 to 2.5 dB per filter at the carrier frequency.



Graph 1: AC Analysis of Bandpass and Amplifier Stages

Transmitter Software

In designing the transmitter circuit, choosing which parts to use was the first thing to be considered. The main component of this is the PIC chip that will be sending the pulse width modulated bits to the diode. In other classes three different PICs, the 877A, the 627A, and the 690, have been used. The 877A has a large number of I/O pins but no internal oscillator. The 627A does has an internal oscillator but significantly less I/O capability. This left the 690. The PIC16F690 is a relatively new chip. As such, it has hardware support for several new operations like the Enhanced-USART (EUSART) capability. The EUSART has hardware support for RS-232, so communicating with a computer is streamlined. Secondly, while most PIC chips have an internal 4 MHz oscillator, the 690 has a internal 8 MHz oscillator, which gives a instruction clock of 2 MHz and therefore an instruction time of .5 ns. By using this faster PIC, faster transmission speeds will be achievable. The 690 is a 20 pin chip, as opposed to the 627A, which only has 18 pins. More options for future expansion are possible by using the 690.

The start of the transmitter board is the PIC16F690 chip. The 690 compiles a message to be transmitted and then outputs each bit as a pulse width modulated version at the carrier frequency, which is 4 times our transmission rate. With the carrier frequency at 76.8 KHz, this gives a transmission speed of 19.2 kbps. Once a byte is received by the EUSART, it is sent to the pwm_byte routine, which converts each bit to a modulated width pulse and outputs it to the NAND gate. Two libraries are used to do this. The picserial library contains functions to read from and write to the serial port. The pwm library contain functions that send to and receive from an output and input pin.

The code calls the two initialization functions. Initserial() sets the baud rate for receiving from a computer and the correct input and output states for the pins that are used. The &= and |= operators are used for modifying the TRIS registers so that the direction of pins that are not used are not changed. The initpwm() routine sets the output state for the PWM as well as initialize Timer 2 for timing the transmit speed.

The code then infinitely gets a character from a pre-compiled string and then outputs the byte to the PWM pin. The getch() routine returns the next character from the string. The pwm_byte() routine modulates the given byte to the carrier frequency. As an overview, the routine will output at a 75% duty cycle if the bit is a “one” and output at a 25% duty cycleif the bit is a “zero.” It uses a for loop to shift through each bit. Inside the loop, Timer 2 is used to time setting the output high or low. For each case of “one” or “zero”, Timer 2 is loaded with the high time. The routine blocks until the timer hits zero and then blocks until the low time has elapsed. A prescaler of 1:4 is used so that the timer increments every 4 clock cycles or two nanoseconds. After each bit has been sent out, the routine exits.

Receiver Software

The PIC16F690 was chosen for the receiver for the same reasoning as on the sender. Another factor was the 690's external clock trigger, which is available on most PIC chips. For this project, it was how a pulse counter was implemented.

The PIC chip takes the filtered input signal and the demodulates it and sends the output to a display. To start, the main loops first calls the initserial() and initpwm() functions. As with the sender program, |= and &= operators are used to ensure that other output states are not accidentally changed. Once both the initializations are complete, an extra bit is enabled as an output for debugging. Then in an infinite loop, a character is received from the filters (using the pwm_ret routine) and then outputs the character to LEDS (using the putch routine). In between receiving and output, the debugging bit is toggled. It was monitored with an oscilloscope to ensure that no bits were being skipped on the receive.

Demodulating the signal took a few tricks to solve since the signal could be in one of several forms on the receiver due to frequency mismatch between the Wien-Bridge Oscillator and the PWM. A logic "zero" could be either one or two pulses and a logic "one" could be three or four pulses. To error check the received signal two methods of detection were used. First the signal is fed into the pulse counter. Because of the way that the hardware internal to the PIC chip is designed, there will be one less pulse in the pulse counter than the number that was received. If more than two pulses were received then the bit is determined to be a "one." The signal is also sampled at 32 microseconds, which is halfway through the third pulse of a "one." If the signal is high at that point, the bit is also determined to be a one. The two results are then OR-ed together to determine the final bit value. If the result of the OR is a "one", then the bit is declared a "one" otherwise it is a zero. This is repeated 7 more times so that a whole byte is received. The demodulation routine is in the pwm library, while the picserial library contains the routines serial communication. The figure on the next page shows the possible input patterns for a "zero" bit and a "one" bit.

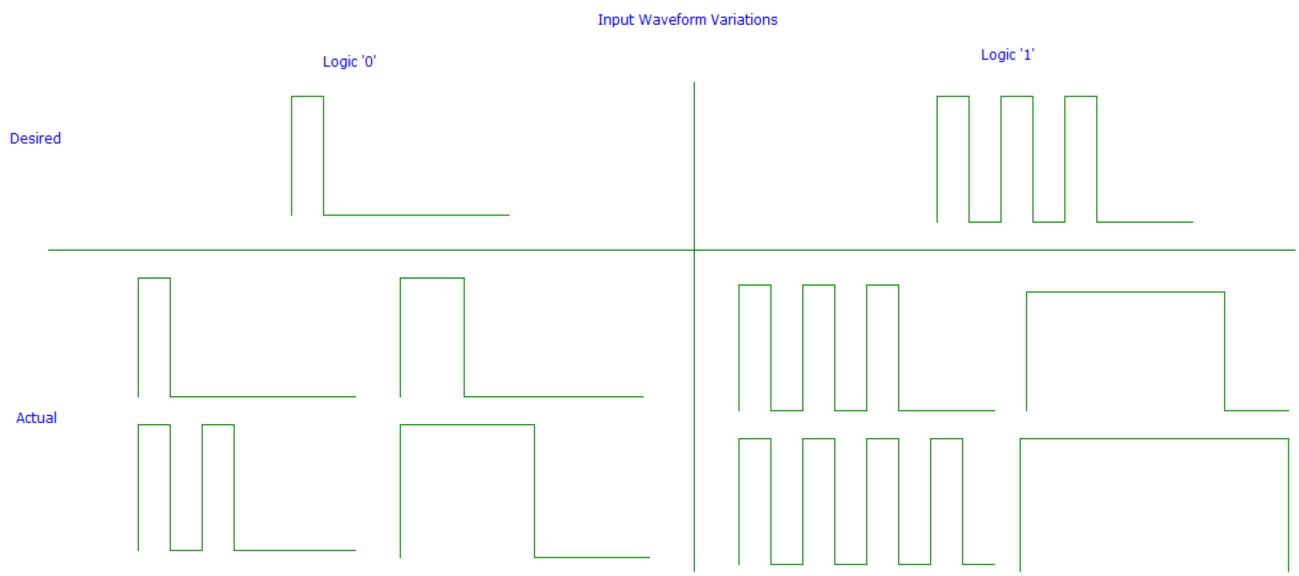


Figure 6: Desired and Actual examples of input patterns

Testing

For the transmitter, the testing process was taken to check each stage for proper operation. For testing the NAND gate and the transmission circuit, with out the use of a PIC chip to send the PWM signal, was using the function generator that generated a 0 to 5 Volt square wave with a 25% and 75% duty cycle to simulate a “zero” and “one” respectively. For confirming the correct current was being supplied, the voltage difference across the 10Ω was found, and using Ohm's Law, the current was found. In confirming the calculations, it was found that the max sustained current was fixed at 100 mA. The current never reached 200 mA like the calculations in the “Transmission Circuit” section on page 7 would have expected. Reading the voltage at this resistor, it was found that the ideal case of having either one or three pulses for a “zero” and “one” respectively was not possible because of a frequency mismatch between the carrier frequency and the PWM, which was compensated for in the receiver programming. For the PIC chip, the testing process was to program the PWM to match the carrier frequency, and create a match of the duty cycle. To confirm that the speed requirements were met, on the oscilloscope, a screen capture was taken at that 10Ω resistor, and took time measurements between each set of pulses. Since that is the period of one bit, and by taking the reciprocal gives the transfer speed. For a transfer speed of 19.2 kbps, the maximum period had to be 52.08 microseconds.

In testing the receiver, the same process for testing each stage was used. The bandpass stage was tested by using a function generator, with the same settings that was used to simulate the PWM. A frequency sweep up to 100 KHz was conducted to confirm the correct filter parameters. For testing the transimpedance amplifier was to build the circuit directly, having the transmitter send an automated signal, and setting up the receiver circuit at point-blank range and moving the circuit further back until the amplifier's output signal is lost. Then any improvements on the amplifier was made until the range was in excess of ten feet. Since the only components remaining were the amplifier and Schmitt Trigger stages, those were just “connect and confirm” that the signal was maintained. This method was used to obtain the maximum distance for the project. For the receiver PIC, debug LEDs will show the byte transmitted, in addition to pins that were configured to pulse high when the correct byte is transmitted (the term “correct byte” means an ASCII character).

Results & Conclusion

The project meets the expectations as stated earlier. A comparison of the original specifications which were outlined in the project proposal in Appendix A, and the final specifications mentioned in the Introduction on page 1 is shown in Table 1. It can be seen that the speed was doubled from 9.6 kbps to 19.2 kbps, the distance was improved by 40%, and the ASCII String Length was proven to work for an infinite length.

Table 1: Comparison of Specifications and Results

	Speed	Distance	ASCII String Length
Original Specifications	9.6 kbits/s	10 feet	10
Final Results	19.2 kbits/s	14 feet	Infinite

Project Issues

Several problems were encountered in the development of the project. One major problem was the variety of ways that the signal could be received. Which was solved by using a pulse counter as well as value-latching on the receiver PIC as presented earlier. Another problem that was encountered was slew rate limitations of the 741 and 351 Op-Amps. This was solved by using the AD829 Op-Amp, which is designed for high speed video applications. The final major problem was noise in the output of the amplifier which was solved by adding a Schmitt Trigger. During the build phase, there were some wiring problems on the receiver board, but those were solved by stripping the board down and re-wiring it. One case was the capacitor in the low-pass filter which was not filtering correctly, instead of filtering high frequencies, it filtered all frequencies. The last issue was to change the specification of a 10 byte character string to just a 10 byte string. This would increase the flexibility of what the project could do.

Project Improvements

The first major improvement that can be done is what the project can do. Research revealed that there is a do-it-yourself laser tag system called Miles-Tag that it would be nice to integrate the project into. Switching the receiving display to an LCD for portability and readability is another improvement.

In terms of hardware, one major improvement would be to the use a single supply Op-Amp, that met or exceeded the same slew rate performances as the AD829. Without the use of a negative supply the diode in the last stage of the receiver would become useless. Another way to get around this issue is to use CMOS technology to build an Op-Amp, as it would not only get the required single supply design, but also get very high slew rate performance. However for high end operations, the transistors must be appropriately sized to allow for as much open-loop gain and slew rate as possible, therefore designing with the CD4007 was not an optimal idea. Another improvement would be to set the entire receiver to a consistent voltage. To clarify, the use of a +/-10 Volt power supply is kind of an unusual value, especially in terms of batteries. The idea would be to use a 9 Volt battery, or at most 12 Volts (using AA batteries) for a power source.

In terms of software on the transmitter, an improvement that would have fixed the frequency mismatch was to have the PIC chip interrupt driven, with the Oscillator as the interrupt source. Every pulse of the Oscillator would signal the PIC chip to send another bit. Doing so would increase the software complexity, but decrease the hardware complexity. In addition, faster speeds can be achieved on the same carrier frequency, as now the pulses would not have to be 25% and 75%, but 50% and 100%, thus needing only two pulses at most to represent a "one".

This report covered the design, analysis, and development of the Infrared Data Communications Senior Project. As shown, the project was not only able to meet the specifications outlined in the project proposal, but exceed them as much as possible. Also noted that several improvements can be made, which were not able to be executed due to limitations in the available hardware. With additional time these changes can be made to improve the overall project. In fact, the hardware of the receiver circuit, with the exception of the PIN diode, has being applied to an integrated circuit design in ECE 547, VLSI Design, which has capitalized on these hardware improvements and include additional flexibility in terms of operating at different carrier frequencies. The completed product has been "taped in" and will be ready for testing in the Fall 2008 semester.

Appendix A: Project Proposal

An Infrared Text Transmission System

Our proposed project will be a IR data transmission device that will be capable of transmitting a text string using an IR diode. A second device will receive this information and display it.

The input of the system will be a text string, and the output will be the received text string.

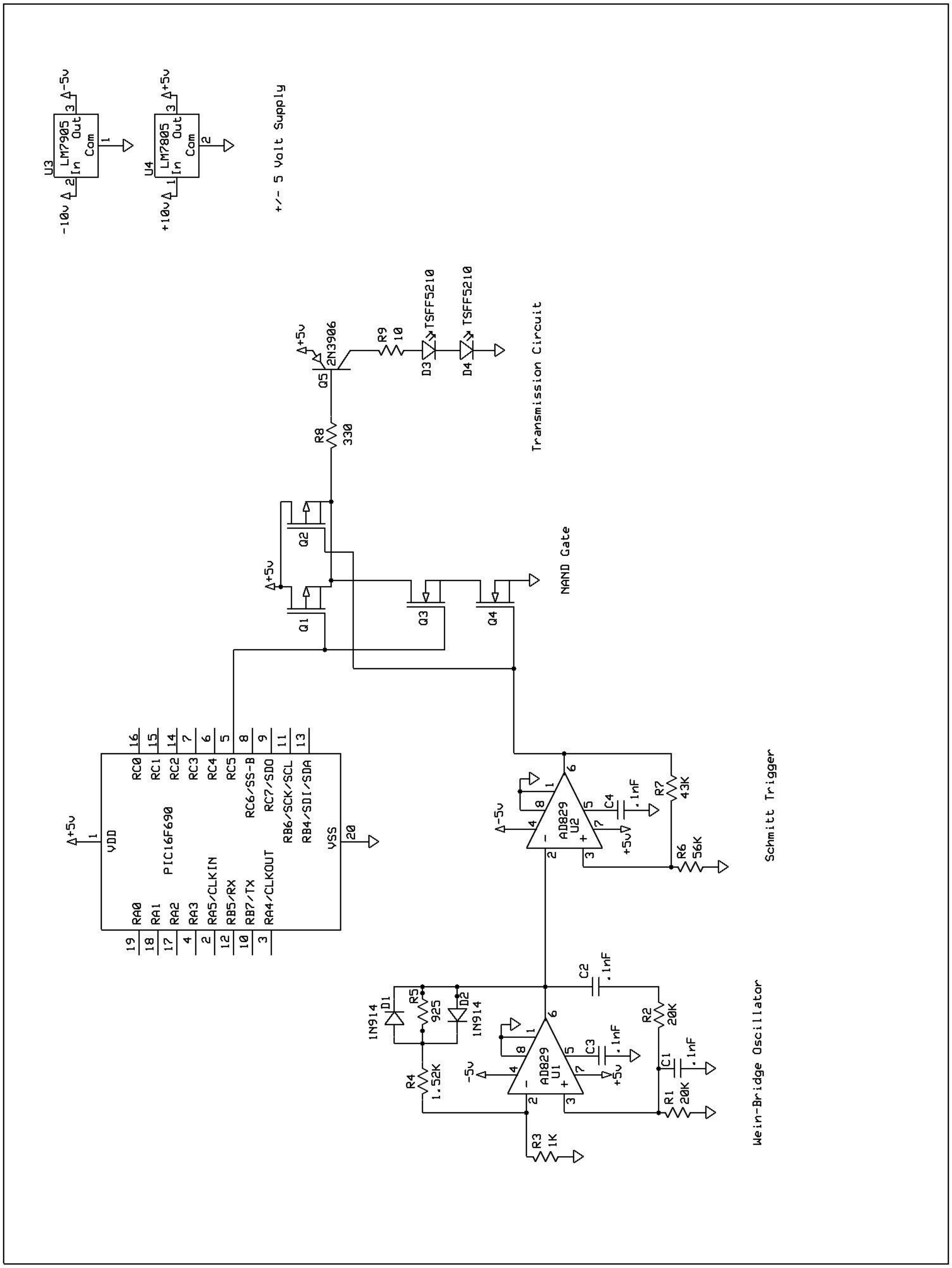
The specifications of the project are as follows:

1) The system will handle at least 10 ASCII characters.

2) A minimum transfer rate of 9600 bits per second will be achieved for transmission.

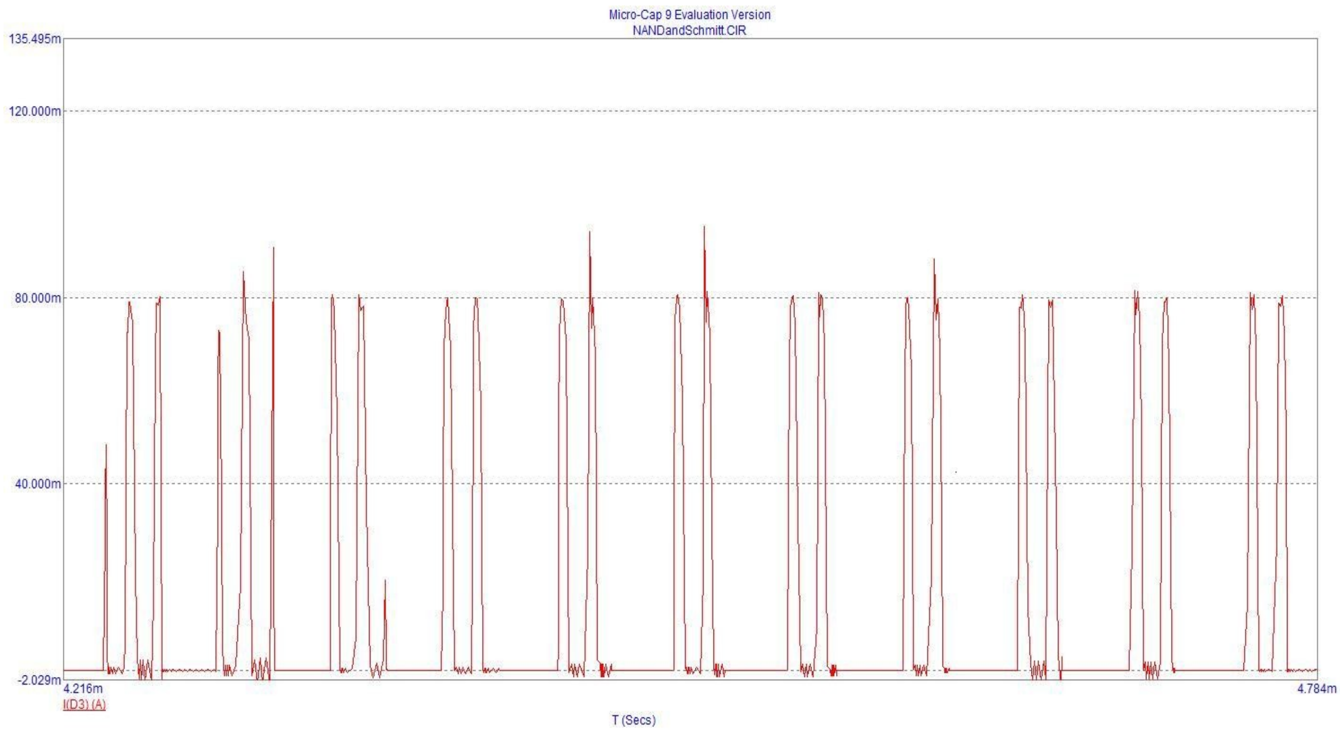
3) There will be a minimum range of 10 feet for the transmission.

Appendix B: Transmitter Complete Schematic



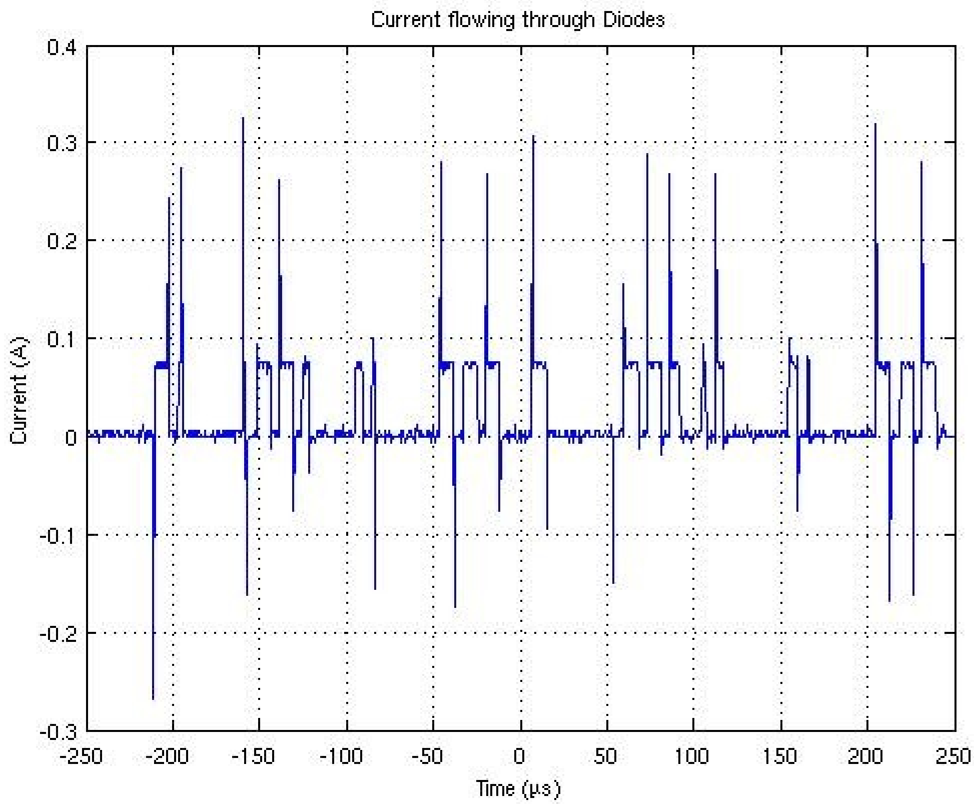
Appendix C: Transmitter Simulation & Results

Graph C.1 shows a simulated result of the current output that flows through the IR diodes in the transmission circuit. This was only a fixed duty cycle of the PWM example, and represents the intended signal format of sending pulses to represent bits.



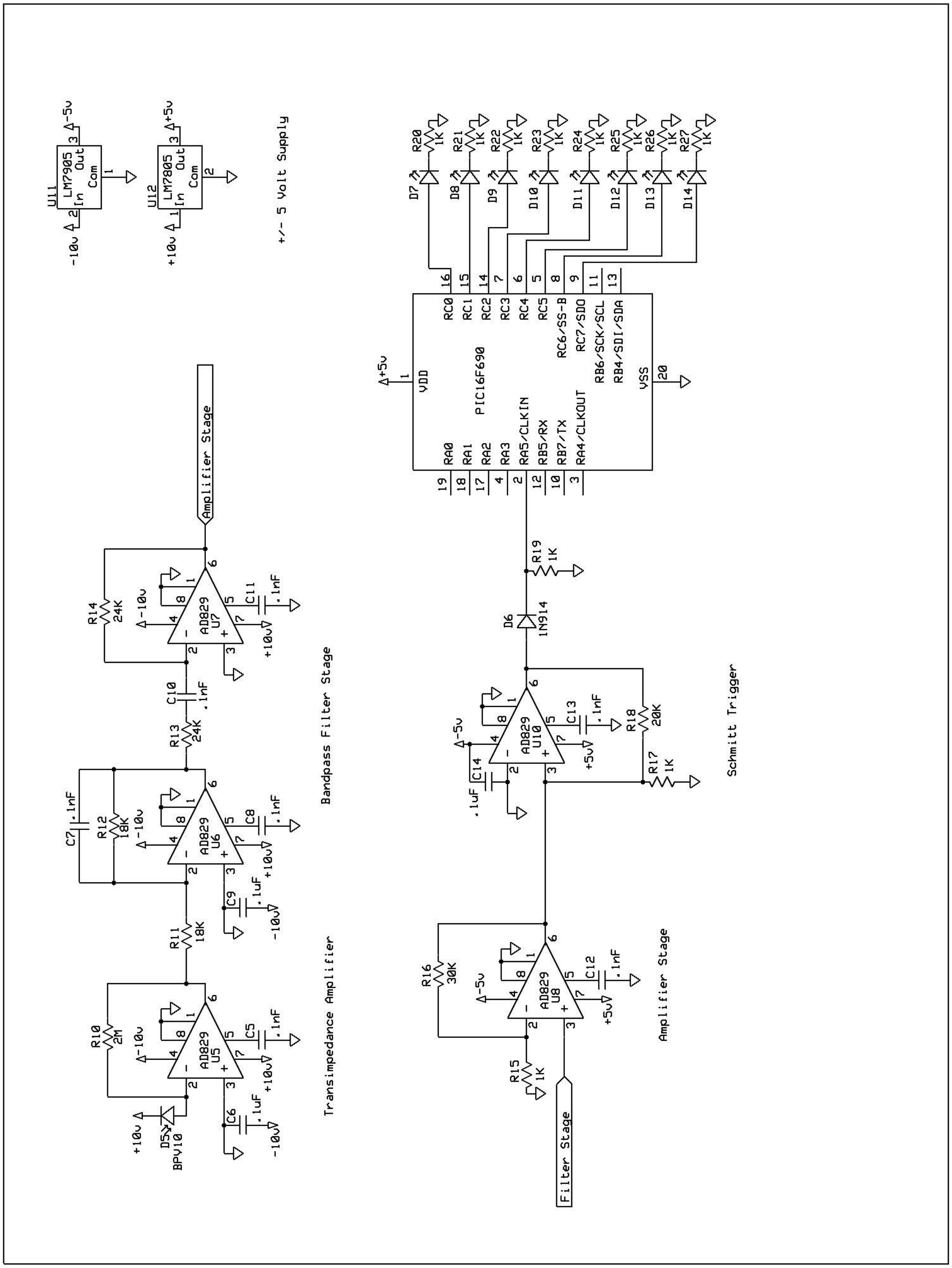
Graph C.1 Simulated Current Results

Graph C.2 shows the actual current flowing through the diodes. The data was taken using Oscope and processed with MatLab. The values were taken by capturing the voltages across Resistor 9 of the circuit stage, and using Ohm's Law gives the current. The spike shown are mathematical errors created in MatLab due to small variations in the data signal. The current is lower than expected due to the transistor not operating in Forward Active.



Graph C.2 Actual Current Results

Appendix D: Receiver Complete Schematic



Appendix E: Operating Instructions

For operating this device, the transmitter will be automatically transmitting upon being powered on. The receiver circuit will also automatically be ready to receive any signal upon being powered on. When the transmitter is not in use, the receiver will be on stand by, and the LEDs will be bright and not flicker. A message will be received when the LEDs are dimmed and flickering.

Appendix F: References

(1)MicroSemi, *MicroNotes Series 701: PIN Diode Fundamentals*, Aquired 21 February, 2008, Available from MicroSemi Website: http://www.microsemi.com/micnotes/701.pdf

Appendix G: Parts List

Transmitter

1 PIC16F690
3 .1nF Capacitors
2 1N914 High Speed Diodes
2 TSFF5210 High Speed Infrared Emitting Diodes
1 CD4007 CMOS Transistor
1 2N3906 pnp BJT Transistor
2 20KΩ Resistors
1 1KΩ Resistor
1 1.5KΩ Resistor
1 925Ω Resistor
1 56KΩ Resistor
1 43KΩ Resistor
1 330Ω Resistor
1 10Ω Resistor
2 AD829 High Speed Video Operational Amplifiers
1 LM7905 Negative 5 Volt Voltage Regulator
1 LM7805 Positive 5 Volt Voltage Regulator

Receiver

1 PIC16F690
10 .1nF Capacitors
1 1N914 High Speed Diode
1 BPV10 High Speed Photo PIN diode
1 2MΩ Resistors
2 18KΩ Resistors
2 24KΩ Resistors
3 1KΩ Resistors
1 30KΩ Resistor
1 20KΩ Resistor
5 AD829 High Speed Video Operational Amplifiers
1 LM7905 Negative 5 Volt Voltage Regulator
1 LM7805 Positive 5 Volt Voltage Regulator

Appendix H: Data Sheet of AD829

ANALOG DEVICES

High Speed, Low Noise Video Op Amp

AD829

FEATURES

High Speed
- 120 MHz Bandwidth, Gain = –1
- 230 V/μs Slew Rate
- 90 ns Settling Time to 0.1%

Ideal for Video Applications
- 0.02% Differential Gain
- 0.04° Differential Phase

Low Noise
- 1.7 nV/√Hz Input Voltage Noise
- 1.5 pA/√Hz Input Current Noise

Excellent DC Precision
- 1 mV Max Input Offset Voltage (Over Temp)
- 0.3 mV/°C Input Offset Drift

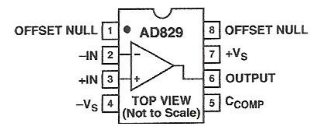
Flexible Operation
- Specified for ±5 V to ±15 V Operation
- ±3 V Output Swing into a 150 Ω Load
- External Compensation for Gains 1 to 20
- 5 mA Supply Current

Available in Tape and Reel in Accordance with EIA-481A Standard

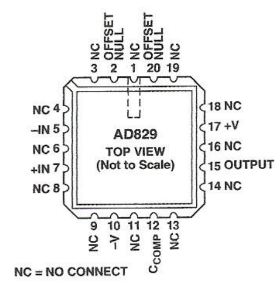
CONNECTION DIAGRAMS

8-Lead

PDIP(N), Cerdip (Q), and SOIC (R) Packages



20-Lead LCC Pinout



GENERAL DESCRIPTION

The AD829 is a low noise (1.7 nV/√Hz), high speed op amp with custom compensation that provides the user with gains of ±1 to ±20 while maintaining a bandwidth greater than 50 MHz. The AD829's 0.04° differential phase and 0.02% differential gain performance at 3.58 MHz and 4.43 MHz, driving reverse-terminated 50 Ω or 75 Ω cables, makes it ideally suited for professional video applications. The AD829 achieves its 230 V/μs uncompensated slew rate and 750 MHz gain bandwidth while requiring only 5 mA of current from power supplies.

The AD829's external compensation pin gives it exceptional versatility. For example, compensation can be selected to optimize the bandwidth for a given load and power supply voltage. As a gain-of-two line driver, the –3 dB bandwidth can be increased to 95 MHz at the expense of 1 dB of peaking. The AD829's output can also be clamped at its external compensation pin.

The AD829 exhibits excellent dc performance. It offers a minimum open-loop gain of 30 V/mV into loads as low as 500 Ω, low input voltage noise of 1.7 nV/√Hz, and a low input offset voltage of 1 mV maximum. Common-mode rejection and power supply rejection ratios are both 120 dB.

This op amp is also useful in multichannel, high speed data conversion where its fast (90 ns to 0.1%) settling time is important. In such applications, the AD829 serves as an input buffer for 8-bit to 10-bit A/D converters and as an output I/V converter for high speed DACs.

Operating as a traditional voltage feedback amplifier, the AD829 provides many of the advantages a transimpedance amplifier offers. A bandwidth greater than 50 MHz can be maintained for a range of gains through the replacement of the external compensation capacitor. The AD829 and the transimpedance amplifier are both unity gain stable and provide similar voltage noise performance (1.7 nV/√Hz); however, the current noise of the AD829 (1.5 pA/√Hz) is less than 10% of the noise of transimpedance amps. The inputs of the AD829 are symmetrical.

PRODUCT HIGHLIGHTS

1. Input voltage noise of 2 nV/√Hz, current noise of 1.5 pA/√Hz, and 50 MHz bandwidth, for gains of 1 to 20, make the AD829 an ideal preamp.
2. Differential phase error of 0.04° and a 0.02% differential gain error, at the 3.58 MHz NTSC and 4.43 MHz PAL and SECAM color subcarrier frequencies, make the op amp an outstanding video performer for driving reverse-terminated 50 Ω and 75 Ω cables to ±1 V (at their terminated end).
3. The AD829 can drive heavy capacitive loads.
4. Performance is fully specified for operation from ±5 V to ±15 V supplies.
5. The AD829 is available in plastic, CERDIP, and small outline packages. Chips and MIL-STD-883B parts are also available. The SOIC-8 package is available for the extended temperature range of –40°C to +125°C.

REV. G

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AD829–SPECIFICATIONS (@ T_A = 25°C and V_S = ±15 V dc, unless otherwise noted.)

Model	Conditions	V_S	AD829JR Min	AD829JR Typ	AD829JR Max	AD829AR Min	AD829AR Typ	AD829AR Max	AD829AQ/S Min	AD829AQ/S Typ	AD829AQ/S Max	Unit
INPUT OFFSET VOLTAGE		±5 V, ±15 V		0.2	1		0.2	1		0.1	0.5	mV
	T_{MIN} to T_{MAX}				1			1			0.5	mV
Offset Voltage Drift		±5 V, ±15 V		0.3			0.3			0.3		μV/°C
INPUT BIAS CURRENT		±5 V, ±15 V		3.3	7		3.3	7		3.3	7	μA
	T_{MIN} to T_{MAX}				8.2			9.5			9.5	μA
INPUT OFFSET CURRENT		±5 V, ±15 V		50	500		50	500		50	500	nA
	T_{MIN} to T_{MAX}				500			500			500	nA
Offset Current Drift		±5 V, ±15 V		0.5			0.5			0.5		nA/°C
OPEN-LOOP GAIN	V_O = ±2.5 V	±5 V										
	R_{LOAD} = 500 Ω		30	65		30	65		30	65		V/mV
	T_{MIN} to T_{MAX}		20			20			20			V/mV
	R_{LOAD} = 150 Ω			40			40			40		V/mV
	V_{OUT} = ±10 V	±15 V										
	R_{LOAD} = 1 kΩ		50	100		50	100		50	100		V/mV
	T_{MIN} to T_{MAX}		20			20			20			V/mV
	R_{LOAD} = 500 Ω			85			85			85		V/mV
DYNAMIC PERFORMANCE												
Gain Bandwidth Product		±5 V		600			600			600		MHz
		±15 V		750			750			750		MHz
Full Power Bandwidth[1, 2]	V_O = 2 V p-p											
	R_{LOAD} = 500 Ω	±5 V		25			25			25		MHz
	V_O = 20 V p-p											
	R_{LOAD} = 1 kΩ	±15 V		3.6			3.6			3.6		MHz
Slew Rate[2]	R_{LOAD} = 500 Ω	±5 V		150			150			150		V/μs
	R_{LOAD} = 1 kΩ	±15 V		230			230			230		V/μs
Settling Time to 0.1%	A_V = −19											
	−2.5 V to +2.5 V	±5 V		65			65			65		ns
	10 V Step	±15 V		90			90			90		ns
Phase Margin[2]	C_{LOAD} = 10 pF	±15 V										
	R_{LOAD} = 1 kΩ			60			60			60		Degrees
DIFFERENTIAL GAIN ERROR[3]	R_{LOAD} = 100 Ω	±15 V										
	C_{COMP} = 30 pF			0.02			0.02			0.02		%
DIFFERENTIAL PHASE ERROR[3]	R_{LOAD} = 100 Ω	±15 V										
	C_{COMP} = 30 pF			0.04			0.04			0.04		Degrees
COMMON-MODE REJECTION	V_{CM} = ±2.5 V	±5 V	100	120		100	120		100	120		dB
	V_{CM} = ±12 V	±15 V	100	120		100	120		100	120		dB
	T_{MIN} to T_{MAX}		96			96			96			dB
POWER SUPPLY REJECTION	V_S = ±4.5 V to ±18 V		98	120		98	120		98	120		dB
	T_{MIN} to T_{MAX}		94			94			94			dB
INPUT VOLTAGE NOISE	f = 1 kHz	±15 V		1.7	2		1.7	2		1.7	2	nV/√Hz
INPUT CURRENT NOISE	f = 1 kHz	±15 V		1.5			1.5			1.5		pA/√Hz
INPUT COMMON-MODE VOLTAGE RANGE		±5 V		+4.3			+4.3			+4.3		V
				−3.8			−3.8			−3.8		V
		±15 V		+14.3			+14.3			+14.3		V
				−13.8			−13.8			−13.8		V
OUTPUT VOLTAGE SWING	R_{LOAD} = 500 Ω	±5 V	±3.0	±3.6		±3.0	±3.6		±3.0	±3.6		V
	R_{LOAD} = 150 Ω	±5 V	±2.5	±3.0		±2.5	±3.0		±2.5	±3.0		V
	R_{LOAD} = 50 Ω	±5 V		±1.4			±1.4			±1.4		V
	R_{LOAD} = 1 kΩ	±15 V	±12	±13.3		±12	±13.3		±12	±13.3		V
	R_{LOAD} = 500 Ω	±15 V	±10	±12.2		±10	±12.2		±10	±12.2		V
Short Circuit Current		±5 V, ±15 V		32			32			32		mA
INPUT CHARACTERISTICS												
Input Resistance (Differential)				13			13			13		kΩ
Input Capacitance (Differential)[4]				5			5			5		pF
Input Capacitance (Common Mode)				1.5			1.5			1.5		pF
CLOSED-LOOP OUTPUT RESISTANCE	A_V = +1, f = 1 kHz			2			2			2		mΩ

Model	Conditions	V_S	AD829JR Min	AD829JR Typ	AD829JR Max	AD829AR Min	AD829AR Typ	AD829AR Max	AD829AQ/S Min	AD829AQ/S Typ	AD829AQ/S Max	Unit
POWER SUPPLY												
Operating Range			±4.5		±18	±4.5		±18	±4.5		±18	V
Quiescent Current		±15 V		5	6.5		5	6.5		5	6.5	mA
	T_{MIN} to T_{MAX}				8.0			8.0			8.2/8.7	mA
		±15 V		5.3	6.8		5.3	6.8		5.3	6.8	mA
	T_{MIN} to T_{MAX}				8.3			9.0			8.5/9.0	mA
TRANSISTOR COUNT	Number of Transistors			46			46			46		

NOTES
[1]Full Power Bandwidth = Slew Rate/2 π V_{PEAK}.
[2]Tested at Gain = +20, C_{COMP} = 0 pF.
[3]3.58 MHz (NTSC) and 4.43 MHz (PAL and SECAM).
[4]Differential input capacitance consists of 1.5 pF package capacitance plus 3.5 pF from the input differential pair.

Specifications subject to change without notice.