DESIGN AND TESTING OF A COMMUNICATIONS EDUCATIONAL EMBEDDED BOARD FOR TEACHING AND RESEARCH

by

Ishfan Vakil

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Approved by:

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Dr. James M. Conrad

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Dr. Ivan L. Howitt

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Dr. Thomas P. Weldon

DEDICATION

To my parents for their endless love and support.

ABSTRACT

ISHFAN VAKIL. Design and testing of a communications educational embedded board for teaching and research. (Under the direction of DR JAMES M. CONRAD)

A communications educational embedded system board has been designed and tested for use in teaching and research. The motivation lies in the desire to design a board capable of data communication using optical fiber, infrared, serial RS-232 and USB. The board will be used for research and teaching purposes in the field of embedded systems. There has been significant technological development in the field of data communications. Many embedded systems which are integrated as a part of many high technology devices and home appliances use the most recently developed and advanced means of data communication for faster and reliable data transfer. Optical communication using either optical fiber or infrared have been widely used in industry and integrated into modern devices for efficient and faster data communication. The embedded systems engineer needs to have the knowledge about the working of such data communication technologies. The main aim of this project is to develop a communication board which handles data communication using optical fiber and Infrared. The board can be used in class room teaching for learning embedded systems and at the same time give the embedded systems engineering student the hands on experience to handle optical communication.

ACKNOWLEDGEMENTS

As with any endeavor, this research project could not have been completed without the help and support of others. Foremost, I wish to thank my research advisor Dr James M. Conrad for his guidance throughout the course of this thesis. Without his efforts and guidance this thesis would have never been completed. His systematic approach and management skills along with encouragement at every step of this thesis were some of the major factors behind the completion of this thesis work.

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I would also like to thank the Charlotte Research Institute and Optics center for their generous financial support. And, in general, I would like to thank my professors and fellow students/colleagues here at University of North Carolina at Charlotte they have consistently been of high caliber and it was a pleasure working with you all. Finally, I would like to thank my family and friends for their support and encouragement.

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LIST OF ABREVATIONS

ALU	Arithmetic Logic Unit
ATmega 128L	AVR ATMEL 8 bit Microcontroller
AVR	RISC Microcontroller family from ATMEL.
ADC	Analog to Digital Converter.
BOM	Bill of Materials
CISC	Complex Instruction Set Computing
DRC	Design Rule Check
EEPROM	Electrically Erasable Programmable Read only Memory
EMI	Electro Magnetic Induction
FT232BM	USB to Serial Transceiver IC
FIFO	First In First Out
HFBR	Agilent Technologies Optical Fiber Transceivers
I/O	Input/Output
IR	Infrared
IDE	Integrated Development Environment
JTAG	Joint Test Action Group
KBPS	Kilo bytes per second
LCD	Liquid Crystal Display
MBPS	Mega bytes per second
MAX202	RS-232 transceiver IC
NRZI	Non Return to Zero, Inverted.
PWM	Pulse Width Modulation.

RS-232	Standard for Serial communication
RISC	Reduced Instruction Set Computing
RTC	Real Time Counter.
RS	Recommended Standards.
RWW	Read While Write.
SIR	Serial Infrared
SIE	Serial Interface Engine.
TFDU4100	Vishay Semiconductors Infar Red Transceivers
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus

CHAPTER 1: INTRODUCTION

1.1 Introduction to the Thesis

Data communication is one of the most important and fundamental part of any electronic or electric equipment in use today. Transfer of data in the form of radio waves, voltages and light signals is taking place all around us. Two parts of the same electrical equipment controlling a given process send and receive control signals in the form of electrical data. Control systems that are embedded inside industrial grade high technology equipment or as a part of many household electrical appliances require data communication either within the system, between the various components involved in that system or outside the system. It would be safe to say that data communication forms the backbone for any electronic system. Data may be carried to a distance of less than a fraction of an inch on a printed circuit board to as far as a few hundred miles through long wires. Different devices based on the requirements and the type of device use different methods of data communication. The basic aim of each device capable of data communications is to transmit and/or receive data at the highest possible transmission speed with the lowest possible transmission error, consume lowest possible power, and cost the least amount of money possible.

Data is transmitted through communication channels, which are pathways through which data flows from the transmitter to the receiver. Communication channels can vary depending upon the type of application and the transmission requirements. They can be either wire line or wireless channels. The wire line communication channels physically connect the transmitter to the receiver with a wire which could be a twisted pair, a coaxial

cable or an optical fiber. The wireless communication channel requires no physical connection between the transmitter and the receiver. Data is transmitted through air where the transmitter having an antenna radiates signals that can be received by another antenna at the receiving end.

The speed with which data can be transmitted between a transmitter and a receiver is called data transfer speed or simply data rate. In a digital communication channel, the data is represented by individual bits which may be combined to form multibit message units. A byte, which consists of eight bits, is an example of a message unit that data rates are measured in megabytes per second (Mbps), kilobytes per second (Kbps) or simply bytes per second (bps). The data transfer rate or simply data rate is also termed as throughput. The throughput of a device would thus be defined as the number of data bits transferred per second.

Embedded system is one of the fields where data communication holds a very important place. Embedded communication devices are integrated into different applications ranging from homeland security system to industry automation to simple home appliances. With these significant technological advancements in the field of data communication and the subsequent development of high technology equipment and gadgets comes the need for teaching the latest technology in data communication to the upcoming engineering students. Embedded system engineers have knowledge about computer architecture, microcontrollers and programming. The demand of embedded engineers having knowledge about data communication is going to be high. However there are very few development tools available for classroom teaching, so the engineering students usually do not learn much about different data communication technologies.

1.2 Work done in the past

Before the start of this thesis, much time was spent in understanding the basic requirements and need of the students to work with communication modules like the one being designed and tested. A lot of work has been done in the past to understand the learning curve of students working in embedded systems and how different lab exercises directly related to programming of the embedded microcontroller board along with communication modules like infrared and optical fiber helps them to better understand the subject of embedded systems programming, embedded systems hardware requirements and data communication.

Several papers related to the software and hardware tools for teaching communication and embedded systems concepts have been written by experienced faculties, who have been involved in teaching embedded systems and communication systems for several years.

One of the works worth mentioning is the research effort by Conrad and Howitt on software and hardware tools for teaching communication concepts and introducing students to low power wireless communication [12]. In this effort, the experiences of introducing board to board communication concepts and hardware to students have been covered. Communication concepts using optical fiber, infrared and low power wireless communication was introduced to students and the effort of the students was assessed based on the success of their assigned work.

Other major work done in the Department of Electrical and Computer Engineering, University of North Carolina at Charlotte was the introduction of optical

communication in the embedded systems course [6]. The students were made to do lab exercises on optical fiber and infrared communication and results were collected based on the speed of data transfer and other communication related concepts. More than 20 students were involved in various lab exercises which gave the researchers a thorough idea about the concept of introducing such labs into courses like embedded systems and how these exercises help the students to further strengthen their embedded systems programming , embedded systems hardware and communication theory concepts.

In one of the lab exercises performed by the students, throughput measurements were done under different conditions. The requirement was to push the optical fiber communication to its limit by using simple I/O interfacing in contrast to interfacing with the UART of the microcontroller. Data was collected from the different teams of students and compared. Results showed that speeds higher than expected through UART could be achieved using programmed I/O pins however with a compromise of increasing error rates.

Many related work in this field have shown that introducing experimental or lab related concepts in a teaching course improves the way a student learns about that subject [11]. Communication theory and analytical models are often considered dry by students, leading to poor retention of the material. Understanding these concepts is an important part of understanding approaches required to solve real world problems. Therefore, one of the goals of this research is to develop hands-on learning modules for communications courses. There is a substantial body of work relating to the advantages and approaches for integrating course work with laboratory investigation [16-23] in order to illustrate concepts in communications. Of particular interest is the three-level approach [16-18]

where the student is introduced to 1) component level, 2) sub-system level and then 3) system level experiments. It is anticipated this approach will be adopted for courses that use this communications hub board, and is one of the primary motivations for developing this board. The optical communication board will be the only microcontroller board and the first of its kind having optical fiber, infrared, USB and RS232 in one package that will be available for students

1.3 Motivation

The primary motivation for this work was the lack of commercially available low cost microcontroller boards that would have all the communication modules or components interfaced on it. Having a single board simplifies the design and reduces the need of using several different boards and components for performing research and experiments. The board being further used as a platform for teaching and learning embedded systems. Reducing the cost of the board as much as possible was one of the main design objectives. The target user groups for the communication board are the students and researchers in various universities and research labs. The other design objectives were robustness, reliability and functionality of the board. Most of the early technological learners such as high school students lack experience and expert knowledge for interfacing a controller board with other components. To prevent the learners from making errors, connectors on our board have been made foolproof (the user cannot damage the components of the board by plugging cables in the wrong sockets).

After reviewing the commercially available micro-controller boards with respect to their suitability as teaching tools, we concluded that none of the existing micro-controller boards met our requirements. We then designed a new controller board based on previous boards and added various communication modules to it.

The major uses of this embedded systems communication board can be summarized as follows:

- The board will be used as a teaching tool in embedded systems courses.
- The embedded systems course will cover the basic microcontroller programming and hardware details related to the board.
- Laboratory exercises form an essential part of any embedded system or communication course. This board will serve as basic learning module for the students performing programming, testing and other interfacing exercises in the lab.
- Research in the field of optical fiber and infrared communication can be performed on the basic level using this board. Measurement of the throughputs and calculating the maximum throughputs at different speeds and in different conditions can be an excellent research issue to work upon.
- Interfacing of different sensors on the board will allow the user to accumulate data from the sensor and transmit it through optical fiber over long distances of up to 2.7 Km.
- The board will provide enough resources for the researchers and developers to build applications on top of it by interfacing different technologies with it.

1.4 Organization of Thesis

The thesis has been organized into different sections for the ease of reading and understanding. Care has been taken to follow a particular pattern in such a way that things which are relevant at the beginning and are required to understand the later chapters have been discussed in the first few chapters. A reader having very little knowledge about the subject can easily follow the chapters and understand the details in the subsequent chapters.

Chapter 2 of the thesis provides a detail into the understanding of the specifications and functionalities that were required for the board. The entire design rests on the initial specifications set for the project. All throughout the design project these specifications and required functionalities were followed and kept in mind.

Chapter 3 of the thesis provides the details of the hardware used for the board design. The hardware detail of each module of the communication board has been discussed in this chapter. The specifications of the microcontroller followed by the hardware details of the optical communication modules and in the end the hardware details of the serial RS-232 and serial USB have been discussed in detail.

The Chapter 4 is the most important chapter of the thesis reflecting the maximum amount of work done on the project. The design details of each circuit, including the schematic design, have been discussed in this chapter. The entire design of the communication board has been divided into a number of important circuits for the ease of design and understanding. Each of these circuits has been discussed along with the interfacing techniques used. The interfacing of each module with the micro controller has been discussed in detail.

Chapter 5 of the thesis provides the details about the testing of the different modules used in the communication board. Each of the board modules was tested for its design correction and functionality. Testing forms a very important part of the project. The project can only go to the next stage of layout design and finally manufacturing if the test results are correct and favor the design.

Chapter 6 provides a small introduction to the layout specifications of the board and various footprints of some important modules of the board. This chapter discusses the importance of proper layout design for manufacturing of flawless microcontroller boards.

Chapter 7 of the thesis summarizes and concludes the work done in this project and discusses the future work needed on this project.

CHAPTER 2: BOARD DESIGN

2.1 Board Specification

The Communication Educational Board is a small sized communication hub capable of handling different types of data communication. Optical fiber, infrared, RS-232 and USB are some of the modules which can handle data communication on the board. Each of these modules is independent of each other and works at different baud rates depending upon their specification. The board is powered through a DC voltage supply between 9V to 15V. The board carries a voltage regulator which brings down the voltage to 5V. The board can also be alternatively powered through the USB port, giving the port additional functionality.

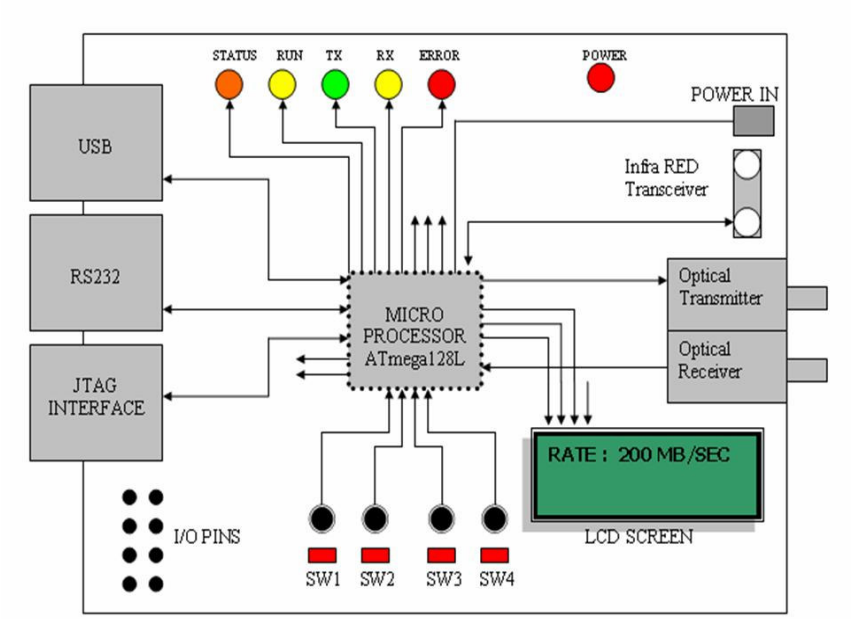


Figure 2.1: Diagram of the Embedded Communication Board

All the components on the board have been chosen in order to fit the voltage requirements. To make the board work as a low power communication hub, low power

consuming devices including the microcontroller have been chosen with no or very less compromise with the price.

The components have been chosen such that the size of the overall board does not increase beyond 4 square inches. Surface mount resistors and capacitors of standard size 0603(~1.6 mm) have been chosen. These components immensely reduce the over all complexity and the size of the board. The board has been equipped with a LCD screen, giving it an additional user friendly look. Baud rates, bit error and/or current state of the microcontroller are some of the things that can be displayed on the LCD screen by programming the board. The board comes along with a number of test and sample codes which can be downloaded on the board through the PC using a JTAG connector. The test codes will be able to test the functionality of each module on the board. A user will be able to alter and improve upon those test codes depending upon the requirement.

2.2 Board Functionalities

Before the design of the board was started we had to decide upon the different data communication modules that will be used on the communication educational board. The optical communication transceivers, which include both fiber optic and infrared transceivers, form the main data communication ports on the board. The entire board has been initially designed based upon these two data communication channels. However apart from the optical communication, the board will be capable of handling serial data communication through the serial RS-232 port. In addition to the serial port a USB port has also been provided. The USB port will be capable of handling data communication and in addition provide an alternate power source to the board. The JTAG (Joint Test

Action Group) interface present on the board is used for downloading code from the PC to program the microcontroller. The Board has been designed specifically for educational and research purposes. The board functionalities can be used to demonstrate data communication in embedded system or optical communication classes. Engineering students working with the communication educational board will get hands on experience in programming of the microcontroller for handling data communication using different communication channels present on the board. The board in general will be capable of handling data communication between the different modules of the board, between the PC and the board and between two PCs via the communication board.

CHAPTER 3: HARDWARE

3.1 Microcontroller

The microcontroller chosen for this board is the ATMEL ATmega128L. It is a high performance, low power, 8 bit AVR® microcontroller. It comes with a 128Kbytes of self programmable flash, 4Kbytes of EEPROM and 8Kbytes of internal SRAM. The microcontroller comes with a JTAG interface for programming. The processor speed ranges from 0 to 16 MHz in the voltage range of 4.5 to 5.5V. As far as the data communication is concerned, the ATmega128L carries two programmable UARTs. It is capable of Master/ Slave SPI interface and byte oriented 2-wire serial interface. It comes with two 8-bit and four 16-bit timers, four 8-bit PWM channels, 8-channel 10-bit ADC and 51 programmable I/O lines making it an ideal microcontroller for the communication hub.

Figure 3.1: Quad flat pack 64 pin ATmega128L [1]

Figure 3.1 shows the 64 pin quad flat package of the microcontroller which has been used for the data communication board. The ATmega128 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega128 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

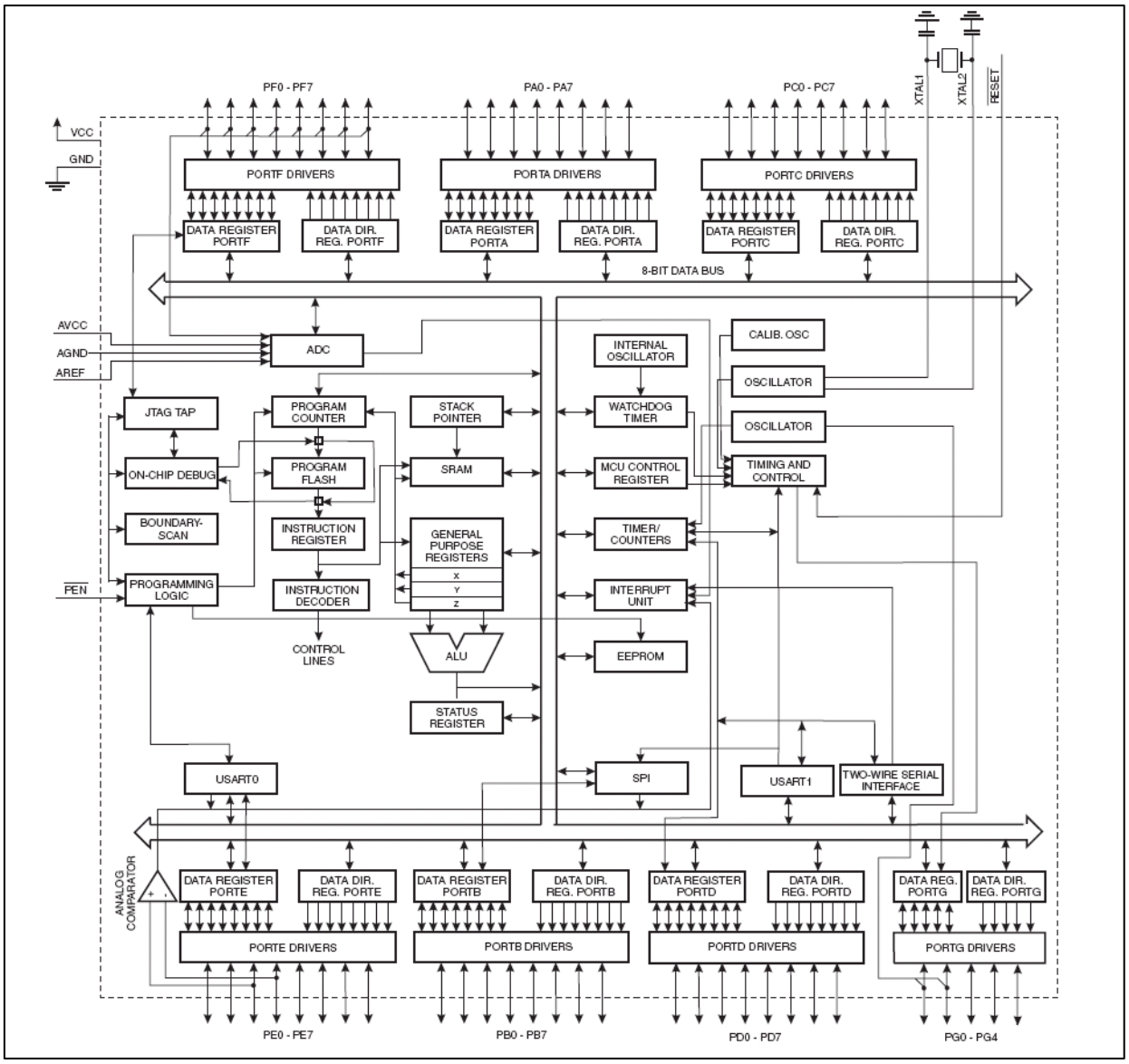


Figure 3.2: Block Diagram of ATmega128L [1]

The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega128 provides the following features: 128K bytes of In-System Programmable Flash with Read-While-Write capabilities, 4K bytes EEPROM, 4K bytes SRAM, 53 general purpose I/O lines, 32 general purpose working registers, Real Time Counter (RTC), four flexible Timer/Counters with compare modes and PWM, 2 USARTs, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain, programmable Watchdog Timer with Internal Oscillator, an SPI serial port, IEEE std. 1149.1 compliant JTAG test interface, also used for accessing the on-chip debug system for programming and six software selectable power saving modes. The idle mode stops the CPU while allowing SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The power down mode saves the register contents but freezes the oscillator, disabling all other chip functions until the next interrupt or hardware reset. In power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC noise reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In standby mode, the crystal/resonator oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low power consumption. In extended standby mode, both the main oscillator and the asynchronous timer continue to run. The device is manufactured using Atmel's high-density nonvolatile memory technology. The on-chip ISP flash allows the program memory to be reprogrammed in-system through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an on-chip boot program running on the AVR® core. The boot program can use any interface to download the application program in the

application flash memory. Software in the boot flash section will continue to run while the application flash section is updated, providing true Read-While-Write (RWW) operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega128 is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications. The ATmega128 AVR® is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kits. The microcontroller is programmed using AVR Studio®4. The AVR Studio® 4 is the professional Integrated Development Environment (IDE) for writing and debugging AVR® applications in Windows® 9x/NT/2000/XP environments. AVR Studio 4 includes an assembler and a simulator. A JTAGICE mkII connector [13] is connected between the PC and the board to download code to the ATmega128L microcontroller through the JTAG connector. The AVR JTAGICE mkII combined with AVR Studio® can program all AVR 8-bit RISC microcontrollers with a JTAG interface.

The AVR® JTAGICE mkII from Atmel® is a powerful development tool for on-chip Debugging of all AVR 8-bit RISC microcontrollers with IEEE 1149.1 compliant JTAG interface or debugWIRE Interface. DebugWIRE enables on-chip debug of AVR microcontrollers in small pin count packages, using only a single wire for the debug interface. The JTAGICE mkII and the AVR Studio® user interface give the user complete control of the internal resources of the microcontroller, helping to reduce development time by making debugging easier. The JTAGICE mkII performs real time emulation of the microcontroller while it is running in a target system. The JTAGICE mkII provides emulation capability at a fraction of the cost of traditional emulators. The

JTAGICE mkII allows access to all the powerful features of the AVR microcontroller. All AVR resources can be monitored namely, flash memory, EEPROM memory, SRAM memory, register file, program counter, fuse and lock bits, and all I/O modules. The JTAGICE mkII also offers extensive on-chip debug support for break conditions, including break on change of program memory flow, program memory break points on single address or address ranges and data memory break points on single address or address range.

Figure 3.3: AVR® JTAGICE mkII [14]

The Universal Synchronous and Asynchronous serial Receiver and Transmitter (USART) is a highly flexible serial interface device present in the microcontroller. It supports full duplex operation (independent serial receive and transmit registers), master or slave clocked synchronous operation and high resolution baud rate generator. It supports serial frames with 5,6,7,8 or 9 data bits and 1 or 2 stop bits. With all this serial

data communication support and more, it made the choice of the microcontroller for the communication board easy and un-debatable. Figure 3.4 shows the pin diagram of the ATMEL ATmega128L microcontroller.

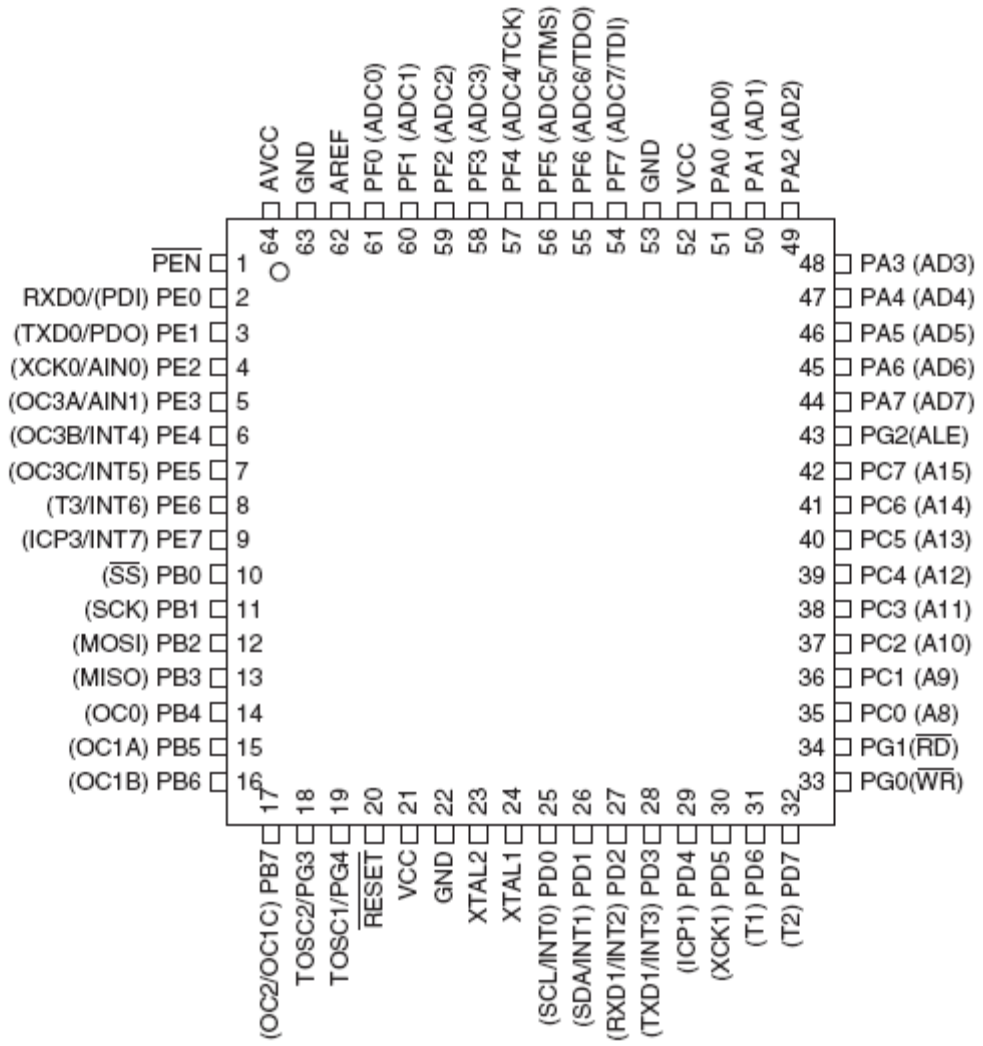


Figure 3.4: Pin Diagram of ATmega128L [1]

3.2 Optical Fiber Transmitter and Receiver

The optical fiber communication module used for the embedded systems communication board uses separate transmitter and receiver circuits. The module used is the Agilent technologies HFBR-1412 as the transmitter which is capable of speeds in excess of 10 Mbps (Mega bits per second) and HFBR-2412 as the receiver that is capable of speeds up to 5Mbps. The Agilent optical fiber transmitter and receiver are low solution for optical fiber data communication for up to distances of 2.7 km. All HFBR-0400 series transmitters and receivers are housed in a low-cost, dual-inline package that is made of high strength, heat resistant, chemically resistant, and UL94V-O flame retardant ULTEM® plastic. The transmitters are easily identified by the light grey color connector port. The receivers are easily identified by the dark grey color connector port, (black color for conductive port). The package is designed for auto-insertion and wave soldering so it is ideal for high volume production applications.

Figure 3.5: HFBR-14xx and HFBR-24xx package [7]

The HFBR-14xx fiber optic transmitter contains an 820 nm AlGaAs emitter capable of efficiently launching optical power into four different optical fiber sizes: 50/125 μm, 62.5/125 μm, 100/140μm, and 200 μm HCS®. This allows the designer

flexibility in choosing the fiber size. The HFBR-14xx is designed to operate with the Agilent HFBR-24xx fiber optic receivers. The HFBR-14xx transmitter's high coupling efficiency allows the emitter to be driven at low current levels resulting in low power consumption and increased reliability of the transmitter. The HFBR-14x4 high power transmitter is optimized for small size fiber and typically can launch -15.8 dBm optical power at 60 mA into 50/125 μm fiber and -12 dBm into 62.5/125 μm fiber. The HFBR-14x2 standard transmitter typically can launch -12 dBm of optical power at 60 mA into 100/140 μm fiber cable.

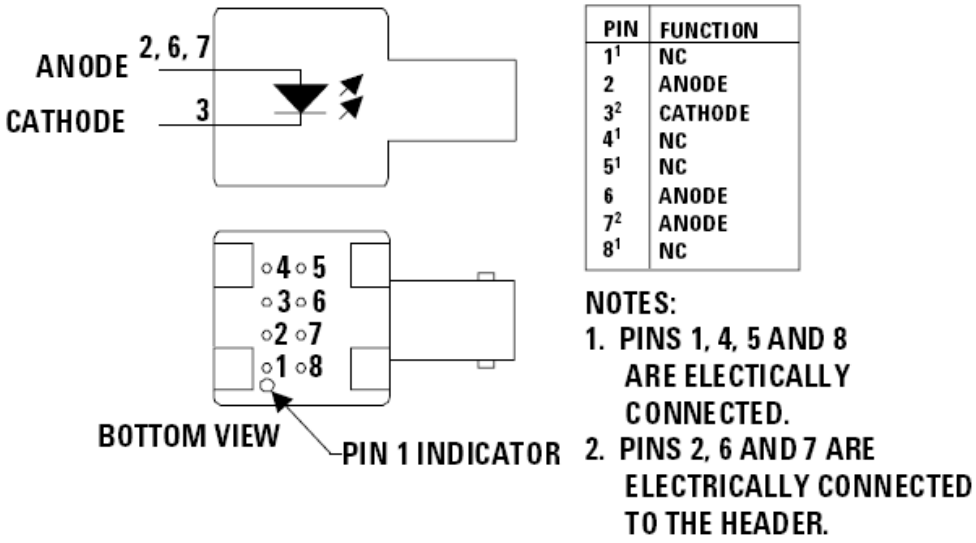
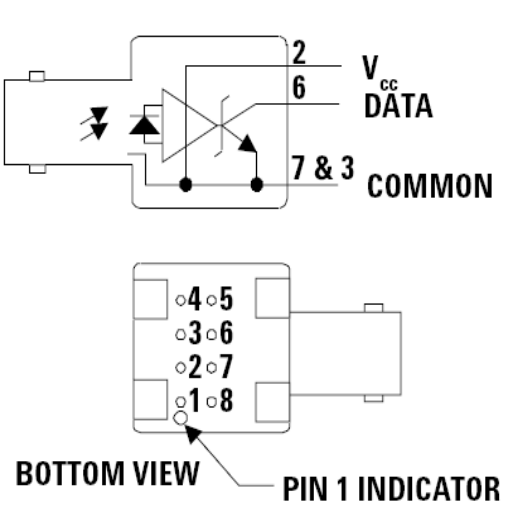


Figure 3.6: HFBR 14x 2 Transmitters [7]

It is ideal for large size fiber such as 100/140 μm. The high launched optical power level is useful for systems where star couplers, taps, or inline connectors create large fixed losses. Consistent coupling efficiency is assured by the double-lens optical system. Power coupled into any of the three fiber types varies less than 5 dB from part to part at a given

drive current and temperature. Consistent coupling efficiency reduces receiver dynamic range requirements which allows for longer link lengths.

The HFBR-24x2 fiber optic receiver is designed to operate with the Agilent HFBR-14xx fiber optic transmitter and 50/125 μm, 62.5/125 μm, 100/ 140μm, and 200 μm HCS® fiber optic cable. Consistent coupling into the receiver is assured by the lensed optical system. Response does not vary with fiber size ≤0.100 μm. The HFBR-24x 2 receivers incorporates an integrated photo IC containing a photo detector and dc amplifier driving an open collector schottky output transistor. The HFBR-24x2 is designed for direct interfacing to popular logic families. The absence of an internal pull-up resistor allows the open collector output to be used with logic families such as CMOS requiring voltage excursions much higher than VCC.



NOTES:
1. PINS 1, 4, 5 AND 8 ARE ELECTICALLY CONNECTED.
2. PINS 2, 6 AND 7 ARE ELECTRICALLY CONNECTED TO THE HEADER.

PIN	FUNCTION
1[1]	NC
2	V_{cc} (5 V)
3[2]	COMMON
4[1]	NC
5[1]	NC
6	DATA
7[2]	COMMON
8[1]	NC

Figure 3.7: HFBR 24x2Receiver [7]

Both the open-collector “data” output pin 6 and VCC pin 2 are referenced to “com” pin 3, 7. The “data” output allows busing, strobing and wired “OR” circuit configurations. The transmitter is designed to operate from a single +5 V supply. It is essential that a bypass

capacitor (0.1 mF ceramic) be connected from pin 2 (VCC) to pin 3 (circuit common) of the receiver.

3.3 Infrared Transceiver

Another optical communication module used in the data communication board is the infrared transceiver module. The IR transceiver used in the hub is the TFDU4100 Serial Infrared Transceiver (SIR) from Vishay Semiconductors. The TFDU4100 is an infrared transceiver module compliant with the IrDA (Infrared Data Association) standard for serial infrared (SIR) data communication, supporting speeds up to 115.2kbit/s. The transceiver module consists of a PIN photodiode, an infrared emitter (IRED), and a low-power analog control IC to provide a total front end solution in a single package.

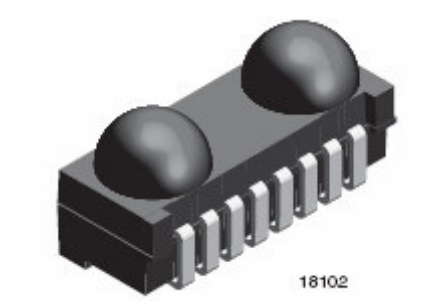


Figure 3.8: TFDU4100 Infrared Transceiver package [8]

The TFDU4100 SIR transceiver comes in a small baby face package. The transceiver is capable of directly interfacing with a wide variety of microcontrollers. The wide area of applications that the SIR can be used in makes it an ideal data communication module to be selected for the communication Hub for teaching purposes. Some of the examples

where the TFDU4100 SIR transceiver can be used are printers, fax machines, copiers, cellular phones, pagers, handhelds, medical and industrial data collecting devices, GPS and more.

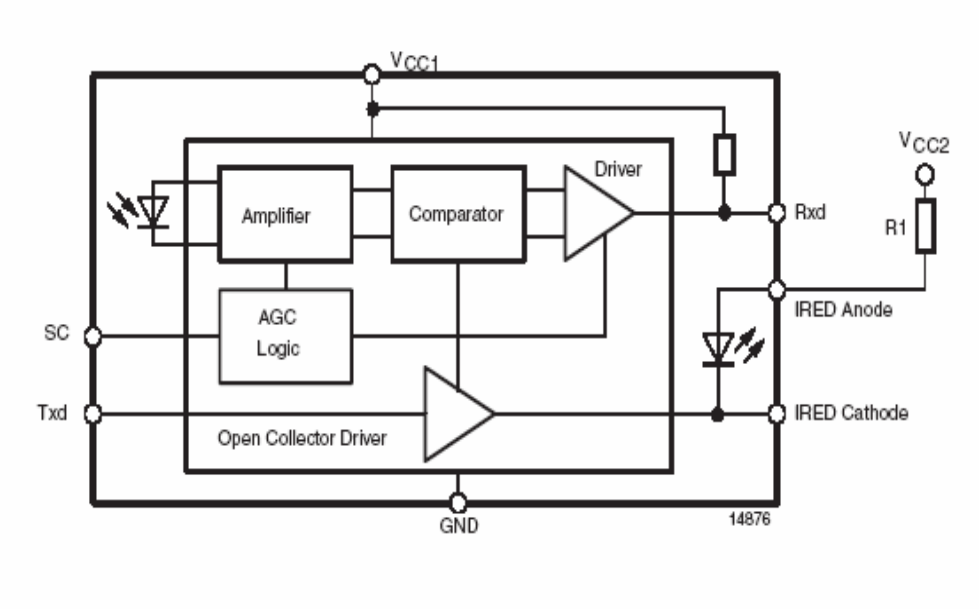


Figure 3.9: Functional Block Diagram of TFDU4100 [8]

The TFDU4100 is a very low power consumption (1.3mA supply current) surface mount transceiver with a wide operating voltage range between 2.7 to 5.5 V. It has an open collector receiver output with a 20kΩ internal pull up resistor. It has a built in EMI (Electro Magnetic Interference) protection, such that no external EMI shielding is required.

TABLE 3.1 Pin description TFDU4100

Pin Number	Function	Description	I/O	Active
1	IRED Anode	IRED anode, should be externally connected to VCC2 through a current control resistor.		
2	IRED Cathode	IRED cathode internally connected to driver transistor.		
3	Txd	Transmit Data Input.	I	HIGH
4	Rxd	Received Data Output, open collector. No external pull-up or pull-down resistor is required (20 kΩ resistor internal to device). Output data is invalid during transmission.	O	LOW
5	NC	No internal connection.		
6	VCC1	Supply Voltage.		
7	SC	Sensitivity control.	I	HIGH
8	GND	Ground.		

3.4 Serial RS-232

The RS-232 is a popular serial data communication protocol used to connect the PC with various data acquisition devices or microcontroller boards. The RS-232 device can be directly connected to the computer through its communication (COM) port. The main aim of the RS-232 port to be put on the communication educational board was to have an option of data communication between the PC and the board. Students working on the communication board will be able to send and receive data to and from the PC and

process it inside the microcontroller. RS which stands for recommended standard was developed in the 60's by a standards committee now known as the Electronic Industries Association to develop an interface to connect computer terminals to modems. RS-232 serial communication is a very simple data communication protocol which can be implemented using both software (if I/O pins of the microcontroller are used) and with hardware (if UART of the microcontroller is set). In the communication board the RS-232 port has been connected to the UART pins of the microcontroller. The RS-232 connector was originally developed to use 25 pins called the DB25 connector in which provisions were made for a secondary serial RS-232 communication channel. In practice, only one serial communication channel with accompanying handshaking is present. On personal computers, the smaller DB9 version is more commonly used today.

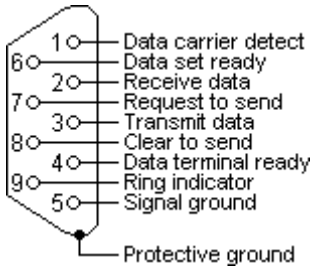


Figure 3.10: PIN configuration of a DB9 connector for RS-232 port

Figure 3.10 shows a DB9 connector pin out diagram used for RS-232 serial communication. The RS-232 standard is an asynchronous serial communication in which the information is sent one bit at a time. Being asynchronous the information is not sent in a predefined time slots and hence the data transfer can start at any given time. The RS-232 standard describes a communication protocol where the information or data is sent bit by bit on a physical channel. The information is broken up in data words. The length of a data word may vary between 5 and 8 bits typically. For proper transfer additional

bits are added for synchronization and error checking or detection purposes. It is important that the same number of bits be used by the transmitter and the receiver otherwise the data word may be misinterpreted, or not recognized at all. Each data word is starts with an attention bit, also known as the start bit. Directly following the start bit, the data bits are sent. For error detecting purposes, an extra bit is added to the data word automatically, called the parity bit. The transmitter calculates the value of the bit depending on the information sent. The receiver performs the same calculation and checks if the actual parity bit value corresponds to the calculated value. All the data bits and parity bit are contained in a frame of start and stop bits. The period of time between the start and stop bit is a constant defined by the baud rate. The start bit always has a space value (logic 0) and the stop bit always has a marking value (logic 1). If the receiver detects a value other than marking when the stop bit should be present on the line, it knows that there is a synchronization failure. This causes a framing error (frames not received correctly) condition in the receiving UART. The device then tries to resynchronize on new incoming bits. The signal level of the RS-232 pins can have two states. A high bit, or marking state is identified by a negative voltage and a low bit or space state uses a positive value. The voltage limits are shown below.

TABLE 3.2 Voltage limits of RS-232

LEVEL	**Transmitter capable(V)**	**Receiver capable(V)**
Space State(0)	+5…..+15	+3….+25
Mark State(1)	-5…..-15	-3….-25
Undefined	-	-3….+3

The RS-232 serial port is interfaced with the microcontroller through the RS-232 serial transceiver. In this board MAX202 is used as the transceiver driver chip. The MAX202 transceiver IC is designed for RS-232 communication interface for use in voltage levels less than 12V. The IC is used to level shift the board 5V to ±10V required for RS-232 output levels. It allows data rates in excess of 120kbps in standard conditions. It consumes around 8mA of current. The MAX202 comes in a 16 pin surface mount package. The output of the transceiver IC is interfaced through the UART1 pins of the microcontroller.

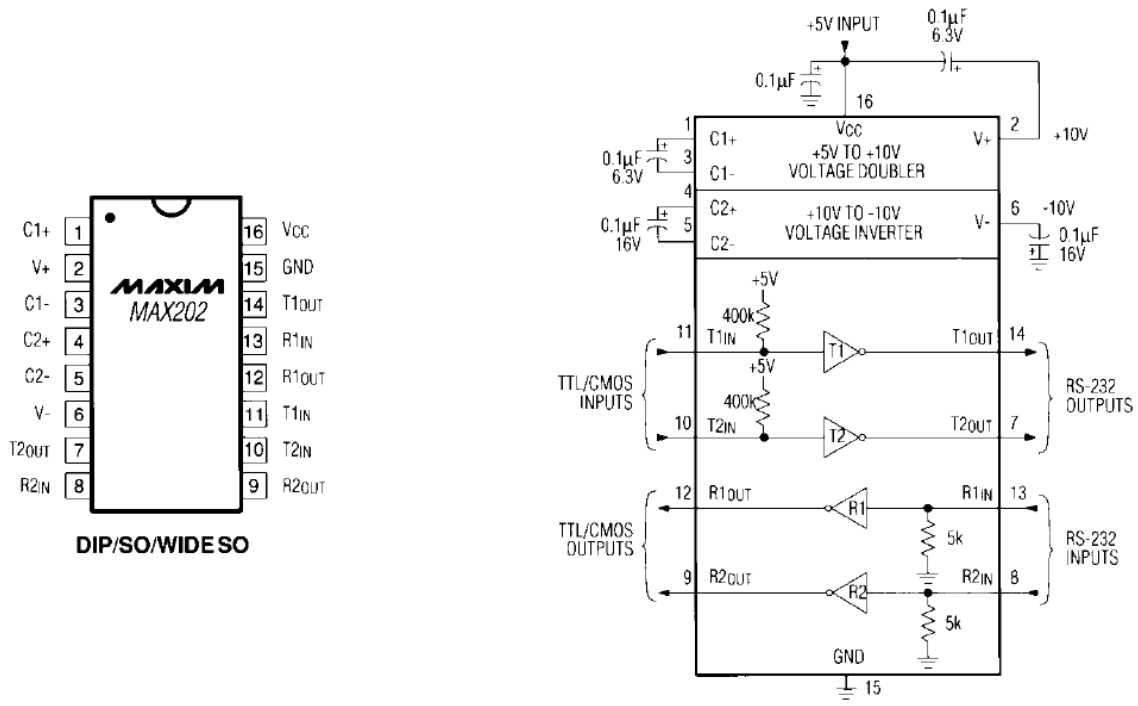


Figure3.11: The MAX202 Pin Configuration and Typical Operating Circuit [12]

The MAX202 consists of three sections; charge-pump voltage converter, drivers (transmitters) and receivers. The dual charge-pump voltage converter performs the +5V to ±10V conversion. This section of the IC consists of two voltage converters. The first converter uses capacitor C1 (shown in figure 3.12) to double +5V to +10V, storing +10V on the V+ output filter capacitor, C3. The second charge pump voltage converter uses capacitor C to invert the +10V to -10V, storing the -10V on the V- output filter capacitor, C4. Figure 3.12 shows the details of the dual charge pump inside the MAX202 transceiver IC.

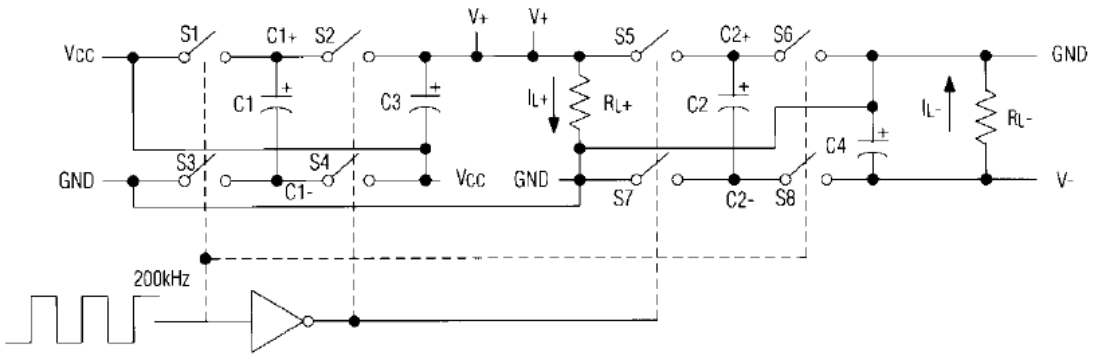


Figure3.12: Dual Charge pump inside the MAX202 transceiver.[12]

With VCC= 5V the typical driver (transmitter) output voltage swing is ± 8V when loaded with a normal 5kΩ RS-232 receiver. The output of drivers is inverted. The input thresholds are both CMOS and TTL compatible. The inputs of the unused drivers can be left unconnected. When in Low-power shut down mode, the driver outputs are turned off and their leakage current is less than 1μA. The receivers convert RS-232 signal to CMOS logic output levels. Receiver outputs are inverting, maintaining compatibility with the driver outputs.

3.4 Serial USB

A Universal Serial Bus or simply USB is one of the most popular and easy to use data communication ports in use these days. They are available in all PCs and most of the data acquisition devices, which makes them a good choice to be put on our communication educational board. USB ports are incredibly easier to use as compared to other connecting devices to the computer like serial RS-232 or parallel ports. The USB gives us the flexibility and ease to connect up to 127 devices to the PC. The USB gives us a maximum data rate of 480Mbits per second. The USB cable consists of two power lines, ground and +5V and a twisted pair which carries data. In the communication board the USB port has been interfaced with the microcontroller through the UART pins. The connection between the PC and the microcontroller UART via the USB takes place through a FT232BM USB UART IC, used for Asynchronous Serial Data Transfer. The chip supports 7 or 8 data bits, 1 or 2 stop bits and a parity bit. The chip uses an external 6 MHz crystal oscillator. The FT232BM IC has an integrated level converter to provide an output voltage of 3.3V. The USB port gives an additional power supply to the communication board. It provides a regulated 5V supply in addition to the main regulated power supply from the board's main power circuit.

The Figure 3.13 shows the functional block diagram of the FT232 BM. The 3.3V LDO Regulator generates the 3.3 volt reference voltage for driving the USB transceiver cell output buffers. It requires an external decoupling capacitor to be attached to the 3V3OUT regulator output pin. It also provides 3.3v power to the RSTOUT# pin. The main function of this block is to power the USB Transceiver and the reset generator cells rather than to power external logic. However, external circuitry requiring 3.3v nominal at

a current of not greater than 5mA could also draw its power from the 3V3OUT pin if required.

The USB transceiver cell provides the USB 1.1 / USB 2.0 full-speed physical interface to the USB cable. The output drivers provide 3.3 volt level slew rate control signaling, whilst a differential receiver and two single ended receivers provide USB data in, SEO and USB reset condition detection.

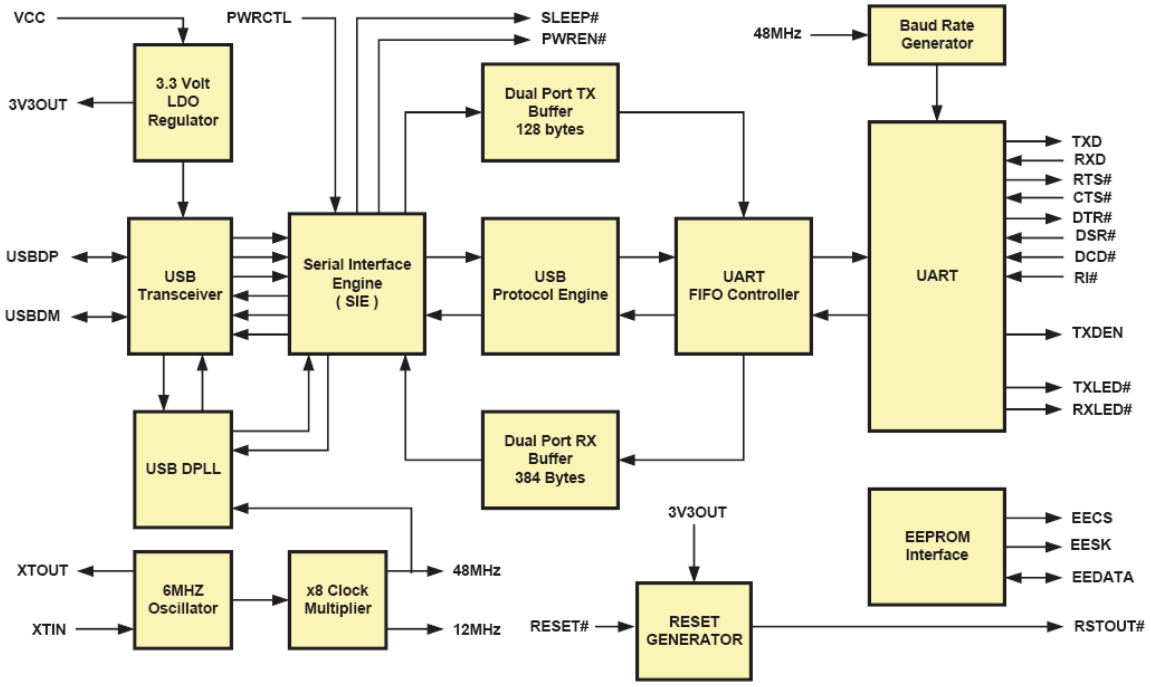


Figure3.13: Functional block diagram of FT232BM USB to serial IC [9]

The USB DPLL cell locks on to the incoming NRZI USB data and provides separate recovered clock and data signals to the SIE block. The 6MHz oscillator cell generates a 6MHz reference clock input to the x8 clock multiplier from an external 6MHz crystal or ceramic resonator. The x8 clock multiplier takes the 6MHz input from the oscillator cell

and generates a 12MHz reference clock for the SIE, USB protocol engine and UART FIFO controller blocks. It also generates a 48MHz reference clock for the USB DPPL and the baud rate generator blocks. The Serial Interface Engine (SIE) block performs the parallel to serial and serial to parallel conversion of the USB data. In accordance to the USB 1.1 specification, it performs bit stuffing / un-stuffing and CRC5 / CRC16 generation / checking on the USB data stream. Data from the USB data out endpoint is stored in the dual port TX buffer and removed from the buffer to the UART transmit register under control of the UART FIFO controller. Data from the UART receive register is stored in the dual port RX buffer prior to being removed by the SIE on a USB request for data from the device data in endpoint. The UART FIFO controller handles the transfer of data between the dual port RX and TX buffers and the UART transmit and receive registers.

The UART performs asynchronous 7 / 8 bit parallel to serial and serial to parallel conversion of the data on the RS-232 (RS422 and RS485) interface. Control signals supported by the UART include RTS, CTS, DSR, DTR, DCD and RI. The UART provides a transmitter enable control signal (TXDEN) to assist with interfacing to RS485 transceivers. The UART supports RTS/CTS, DSR/DTR and X-On/X-Off handshaking options. Handshaking, where required, is handled in hardware to ensure fast response times. The UART also supports the RS-232 break setting and detection conditions. The baud rate generator provides a x16 clock input to the UART from the 48MHz reference clock and consists of a 14 bit pre-scalar and 3 register bits which provide fine tuning of the baud rate (used to divide by a number plus a fraction). This determines the baud rate of the UART which is programmable from 183 baud to 3 million baud. The reset

generator cell provides a reliable power-on reset to the device internal circuitry on power up. The figure below (figure 3.14) shows the PIN-OUT diagram of the FT232BM IC and its schematic symbol.

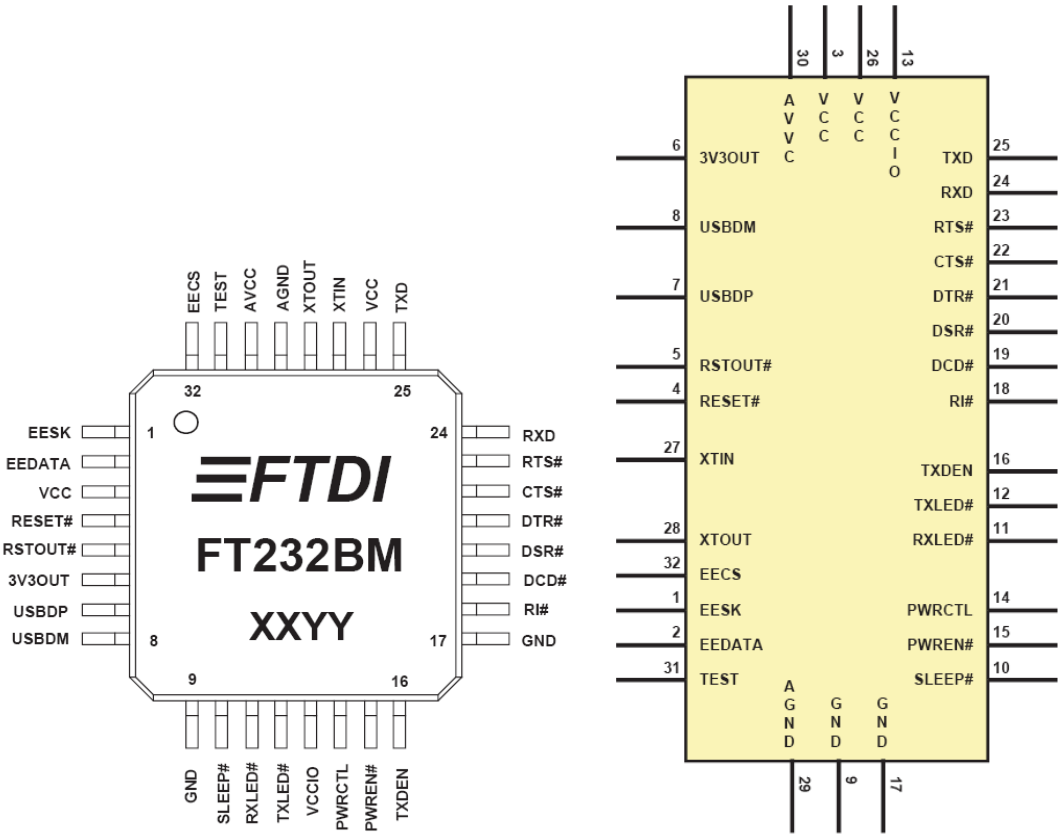


Figure3.14: FT232BM pin out and schematic symbol [9]

An additional RESET# input and RSTOUT# output are provided to allow other devices to reset the FT232BM or the FT232BM to reset other devices respectively. During reset, RSTOUT# is high-impedance otherwise it drives out at the 3.3v provided by the onboard regulator. It can also be used to reset other devices. RSTOUT# will stay high-impedance for approximately 5ms after VCC has risen above 3.5v and the device oscillator is running. RESET# should be tied to VCC unless it is a requirement to reset the device

from external logic or an external reset generator IC. Though the FT232BM will work without the optional EEPROM, an external 93C46 (93C56 or 93C66) EEPROM can be used to customize the USB VID, PID, serial number, product description strings and power descriptor value of the FT232BM for OEM applications. The EEPROM is also required for applications where multiple FT232BM's are connected to a single PC as the drivers rely on a unique serial number for each device to bind a unique virtual COM port to each individual device. The EEPROM should be a 16 bit wide configuration such as a MicroChip 93LC46B or equivalent capable of a 1Mb/s clock rate at VCC = 4.4v to 5.25v.

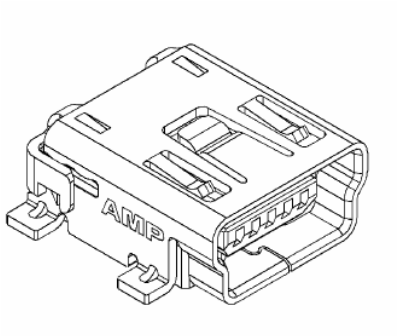


Figure 3.15: Mini USB B connector

Figure 3.15 shows the Mini USB B connector used on the communication board. It is a surface mount package having five connected surface mount pins on the back, four unconnected surface mount pins on the two sides of the package and two through hole solder posts for mechanical strength. Table 3.3 shows the pin functionality:

TABLE 3.3: USB Mini B connector Pin functionality

Pin No.	Symbol	Functionality
1	Vcc	+5V Vcc
2	D-	Data pin negative
3	D+	Data pin positive
4	Vss/GND	Ground pin
5	NC	Shield / not connected

3.5 Other Hardware

3.5.1 LCD module

The LCD module used for the board is the ACM0802C, from AZ, Displays, Inc. It is an 8x2 LCD module (8 characters and 2 lines). The ACM0802C was chosen for the communication board because of its simplicity of use.

Figure 3.16: ACM0802 LCD Module

Table 3.4 shows the pin assignment of the LCD module:

TABLE 3.4 ACM0802 LCD Pin functionality

Pin No.	Symbol	FUNCTION
1	Vss	Ground
2	Vdd	+5V
3	Vo	LCD contrast adjust
4	RS	Register select
5	R/W	Read/Write
6	E	Enable
7	DB0	Data bit 0
8	DB1	Data bit 1
9	DB2	Data bit 2
10	DB3	Data bit 3
11	DB4	Data bit 4
12	DB5	Data bit 5
13	DB6	Data bit 6
14	DB7	Data bit 7
+/A	BL+	Power supply for BL+
-/K	BL-	Power supply for BL-

3.5.2 Switches and LEDs

Switches and LEDs are provided on the board of debugging purposes. There are four switches and four LEDs present on the communication board. The switches used are the small 4mm J hook surface mount switches having a maximum current rating of 100mA. Figure 3.17 shows the drawing of the switch.

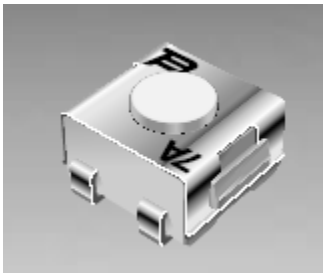


Figure 3.17: 4mm J hook surface mount switch

Apart from the four switches, there are four debugging LEDs present on the board. These LEDs can be programmed and used along with different transceiver modules to

perform or indicate different states of the board. The LEDs used for the board are small 635nm surface mount of the standard size 1206. Figure 3.18 shows the picture of a 1206 surface mount LED. LEDs of different color are used on the board to give it more functionality and better user interface. An additional LED used as a power LED is used on the board to indicate the power ON/OFF condition of the board.

Figure 3.18: Surface mount 635nm LED

CHAPTER 4: INTERFACING AND SCHEMATIC DESIGN

4.1 Overview of OrCAD Capture

The board schematic has been designed using cadence OrCAD capture® tools. OrCAD capture® is one of the software tools which forms a part of a large family of hardware design tools supported by OrCAD, namely OrCAD layout plus, OrCAD AD design, OrCAD circuit simulator etc. The OrCAD capture can be used to design various electrical circuits including analog and digital schematics. It further provides built in features for design verification and processing of the design for manufacture.

The OrCAD capture provides a very simple Windows® user interface for the designer. It allows the user to organize an entire project in the form of separate design sheets or windows. Each of these designs are a part of a single project, however for the ease of the designer and the clarity of the schematic any big project can be split into any number of pages while maintaining the overall continuity of the design. Separate schematic pages within a schematic folder are electrically connected and form a part of the whole design. Ofpage connectors are used to connect wire segments of the same name in different schematic pages. This allows electrical connectivity between components which are connected electrically but are present in different schematic pages. The OrCAD capture project manager forms an important part of any schematic design. Besides providing an organized view into the contents of the different design files and schematic pages, it also allows the user to view other related folders like the library folder, the design cache and the output folder. The library folder contains the information about component design libraries, the design cache contains an archive of each unique

part and symbol used in the design, while the output folder contains files generated through different auto generation tools namely the bill of materials or the netlist.

The netlist and bill of materials (BOMs) is created by the OrCAD tool by extracting information contained in the schematic database. The properties of each part or component can also be extracted in the form of a text file.

One important tool available with the OrCAD capture is the DRC (design rule check). As the name suggests it detects errors present in the schematic design. An error in the design may be in the form of a duplicate part, an invalid design packaging, unconnected or floating signals or wires, electrical design violations etc. The DRC allows a comprehensive verification of the design before the user moves to the final stage of generating the netlist (*.mnl) file. The netlist file is used to export the schematic design into OrCAD layout for the board layout design.

OrCAD tools provide facilities to design a new part or modify an already existing part from the library. The library holds thousands of different circuit parts which can be easily dragged and dropped on to the schematic page. Any alteration in the parts can be made by editing the part and its properties. The components can be easily moved, dragged, rotated or mirrored individually or as a part of a group using the mouse. The right click of the mouse over any component or object provides fast access to editing and properties for that component. Figure 4.1 shows a typical OrCAD schematic capture window.

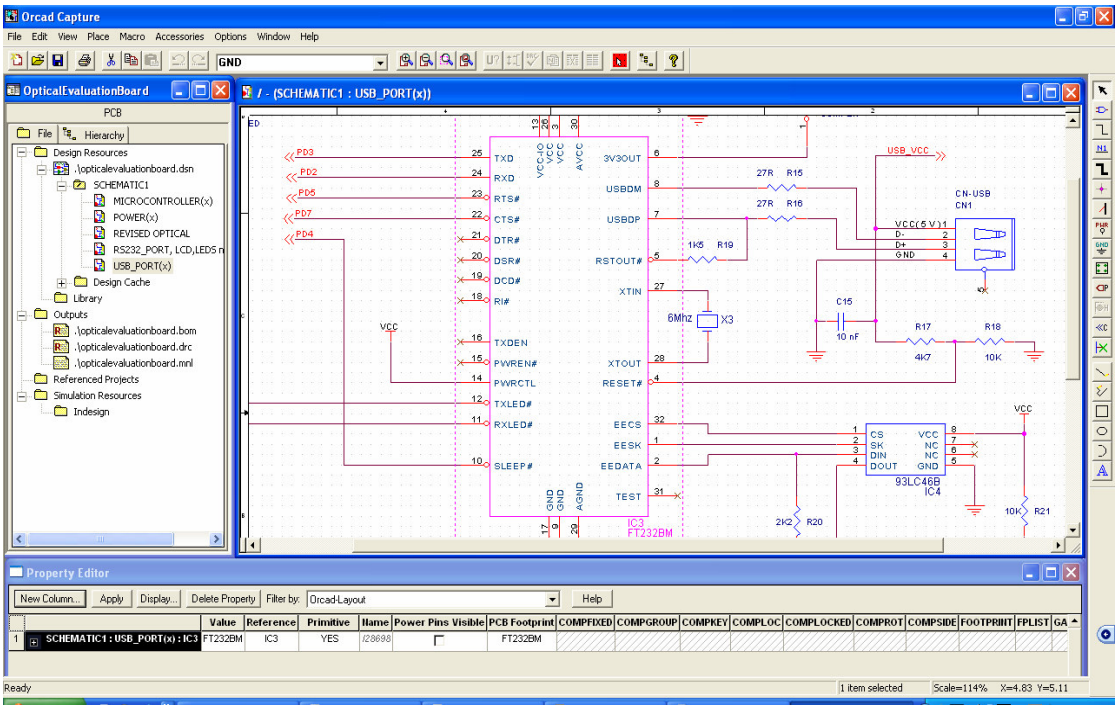


Figure 4.1: Capture design window

4.2 Microcontroller Circuit

The entire board design is divided into five parts for the ease of the design. The first part is the microcontroller schematic design. This part of the schematic carries the ATmega128L microcontroller and the related components. Two I/O connector sockets each of length 16x2 have been provided on the board for easy I/O interface with the board. Port A, B, and C are placed on the first I/O connector socket and ports D, E, F and G have been placed on the second connector socket. A total of 51 I/O pins have been made available on the board for interfacing

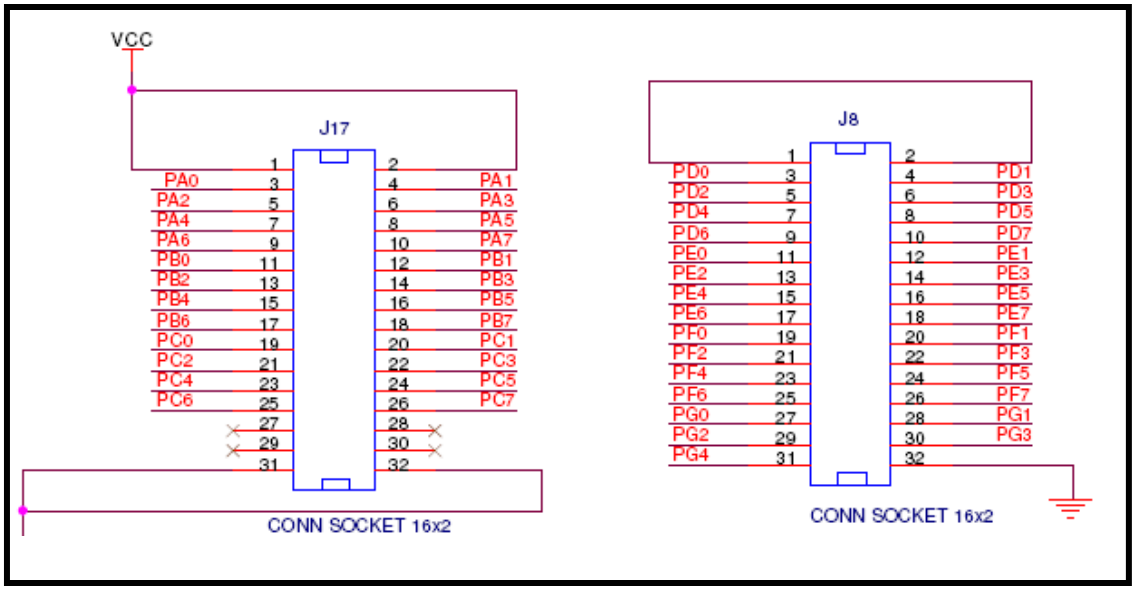


Figure 4.2: I/O connector sockets for future hardware interface

Two external crystal oscillators, 32.768 KHz and 8.0 MHz are connected to the microcontroller through selection jumpers. A 5x2 pin connector for JTAG interface is connected to the microcontroller for programming.

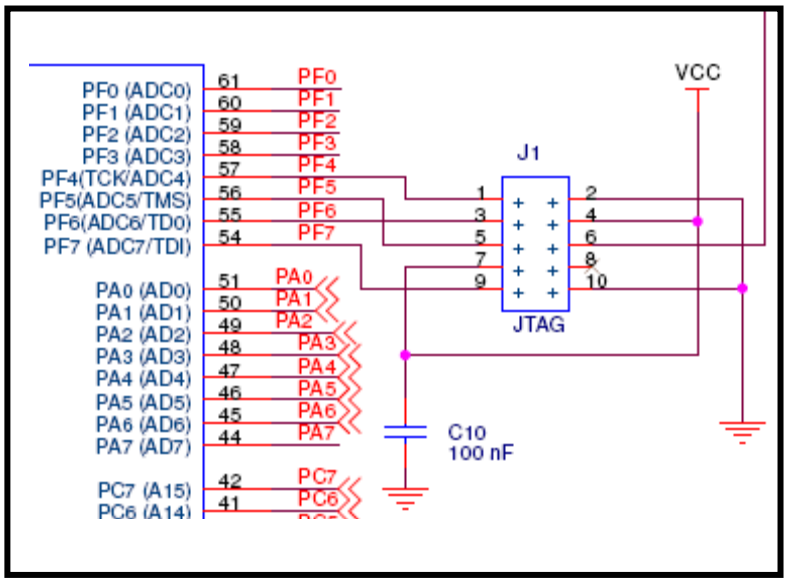


Figure 4.3: JTAG 10 pin connector schematic

Programming of AVR parts via JTAG is performed via the four-pin JTAG port, TCK, TMS, TDI, and TDO. The JTAG interface is accessed through these four AVR's pins. In JTAG terminology, these pins constitute the Test Access Port — TAP [26] , namely:

• TMS: Test mode select. This pin is used for navigating through the TAP-controller state machine.

• TCK: Test clock. JTAG operation is synchronous to TCK.

• TDI: Test Data In. Serial input data to be shifted in to the Instruction Register or Data Register (Scan Chains).

• TDO: Test Data Out. Serial output data from Instruction Register or Data Register.

These are the only pins that need to be controlled or observed to perform JTAG programming (in addition to power pins). It is not required to apply 12V externally. The JTAGEN fuse must be programmed and the JTD bit in the MCUCSR. Register must be cleared to enable the JTAG Test Access Port [26].

4.2 Optical Communication Circuit.

Figure 4.4 is the recommended coupling circuit for the HFBR optical fiber transmitter and receiver used on the board.

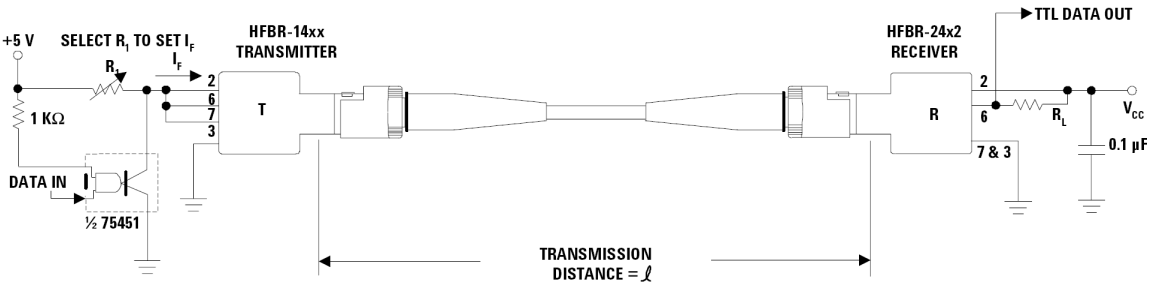


Figure 4.4: Typical Circuit configuration for HFBR 14xx and HFBR 24xx. [7]

If resistor R1 in Figure 2 is 70.4 W, a forward current IF of 48 mA is applied to the HFBR-14x4 LED transmitters. With IF = 48 mA the HFBR-14x4/24x2 logic link is guaranteed to work with 62.5/125 µm fiber optic cable over the entire range of 0 to 1750 meters at a data rate of up to 5 MBd (Mega baud = Mega bits per second), with arbitrary data format and pulse width distortion typically less than 25%. By setting R1=115 W, the transmitter can be driven with IF = 30 mA, if it is desired to economize on power or achieve lower pulse distortion. It is essential that a bypass capacitor (0.01 µF to 0.1 µF ceramic) be connected from pin 2 to pin 7 of the receiver. Total lead length between both ends of the capacitor and the pins should not exceed 20 mm.

The HFBR 1412 optical fiber transmitter is connected to the ATmega128 microcontroller through the UART0_tx pins (Port E 1 pin). In the part of the schematic shown in Figure 4.5 below the PIN 2 of the driver chip DS7545 is connected to Port E 1 of the microcontroller.

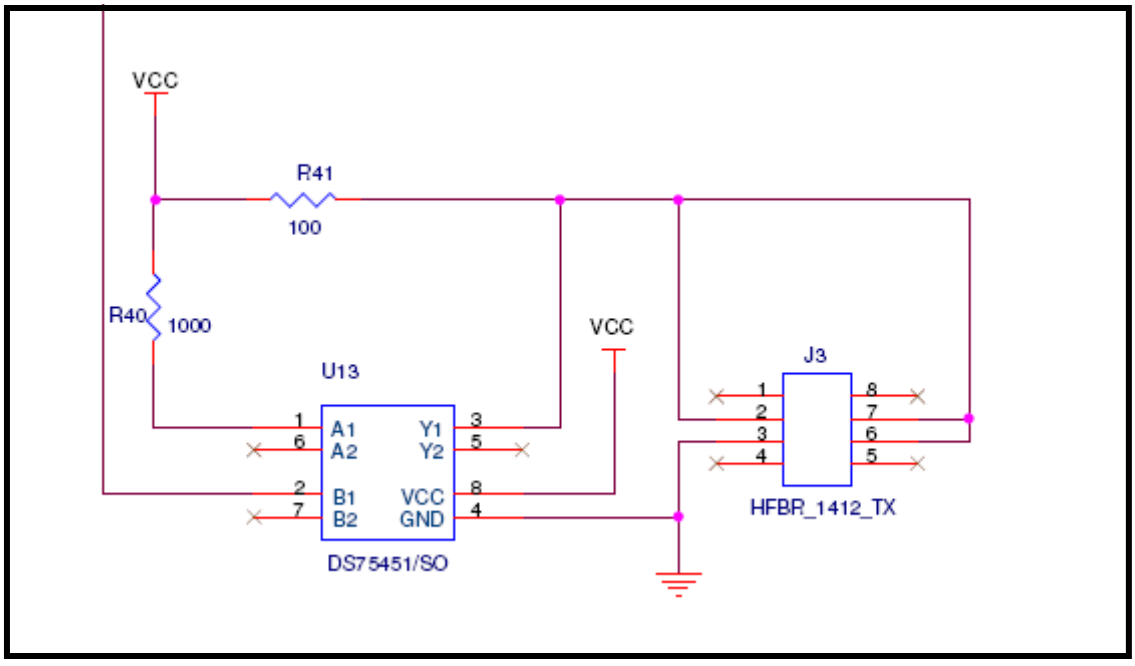


Figure 4.5: Optical fiber transmitter HFBR 1412 schematic

Figure 4.6 shows the coupling circuit for the HFBR 2412, optical fiber receiver. The output of the receiver is connected to the UART0 receive pin at PORT E 0 of the ATmega128L microcontroller. The output of the receiver is inverted so an inverter chip SN7404 is used between the microcontroller and the optical fiber receiver. For complete details of the optical fiber transmitter and receiver schematic circuits, see Appendix A at the end.

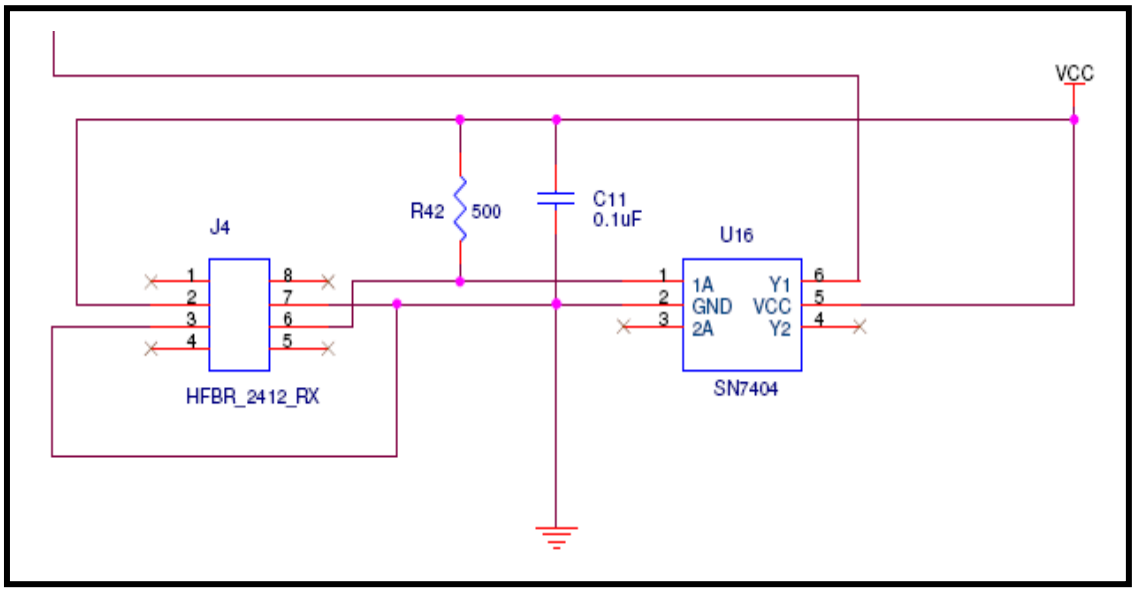


Figure 4.6: Optical fiber Receiver HFBR 2412 schematic

The second part of the optical communication circuit is the Infrared transceiver. The circuit shown in Figure 4.7 is the recommended schematic circuit for TFDU4100. The only required components for designing IR transceivers are a current limiting resistor to the IRED. However, depending on the entire system design and board layout, additional components may be required. It is recommended that the capacitors C1 and C2 are positioned as near as possible to the transceiver power supply pins. A tantalum

capacitor should be used for C1, while a ceramic capacitor should be used for C2 to suppress RF noise. Also, when connecting the described circuit to the power supply, low impedance wiring should be used.

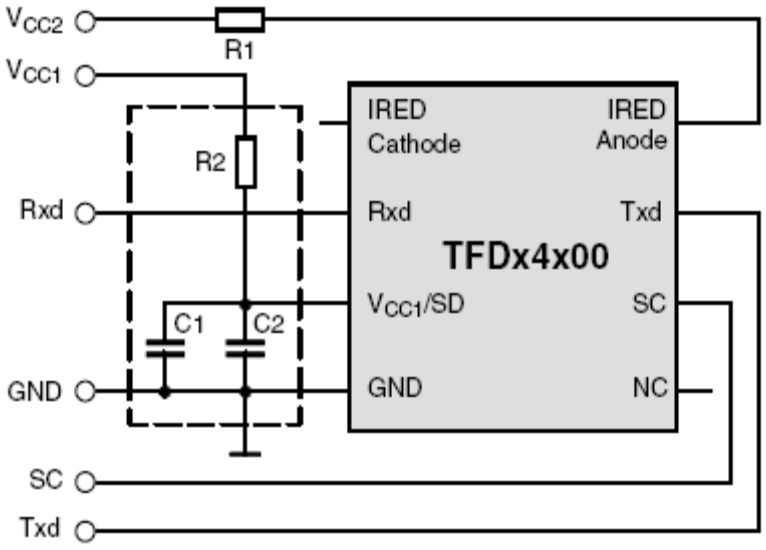


Figure 4.7: Recommended circuit for TFDU4100 Transceiver [8]

R1 is used for controlling the current through the IR emitter. For increasing the output power of the IRED, the value of the resistor should be reduced. Similarly, to reduce the output power of the IRED, the value of the resistor should be increased. R2, C1 and C2 are optional and dependent on the quality of the supply voltage VCC1 and injected noise. An unstable power supply with dropping voltage during transmission may reduce sensitivity (and transmission range) of the transceiver. Figure 4.8 shows the part of the schematic design for the infrared transceiver.

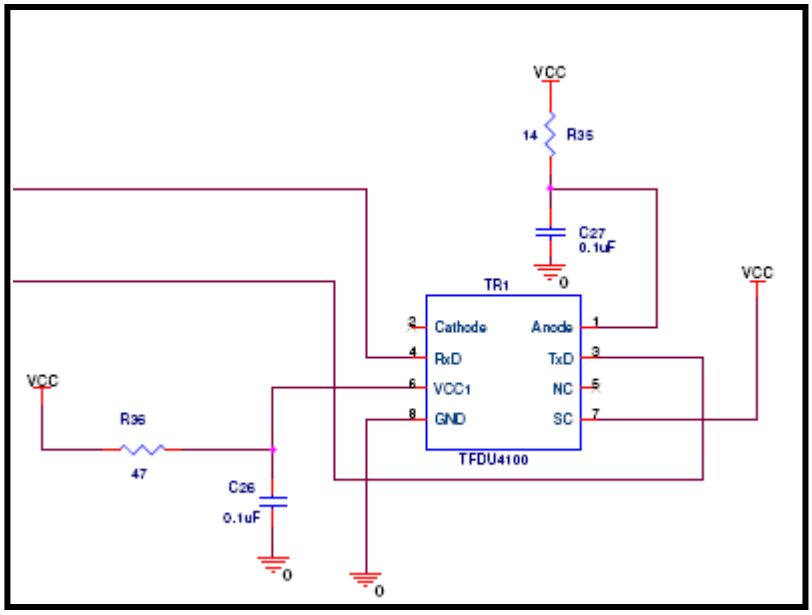


Figure 4.8: TFDU4100 Infra red Transceiver Schematic

4.3 Serial RS-232 Circuit

The third part of the schematic design consists of the RS-232 serial port design. The DB9 connector used for serial RS-232 communication as discussed in the earlier part of the paper is interfaced with the microcontroller through the MAX202 IC chip. The MAX202 transceiver IC is designed for RS-232 communication interface for use in voltage levels less than 12V. The IC is used to level shift the board 5V to ±10V required for RS-232 output levels. It allows data rates in excess of 120kbps in standard conditions. It consumes around 8mA of current. The MAX202 comes in a 16-pin surface mount package. The output of the transceiver IC is interfaced through the UART1 pins of the microcontroller.

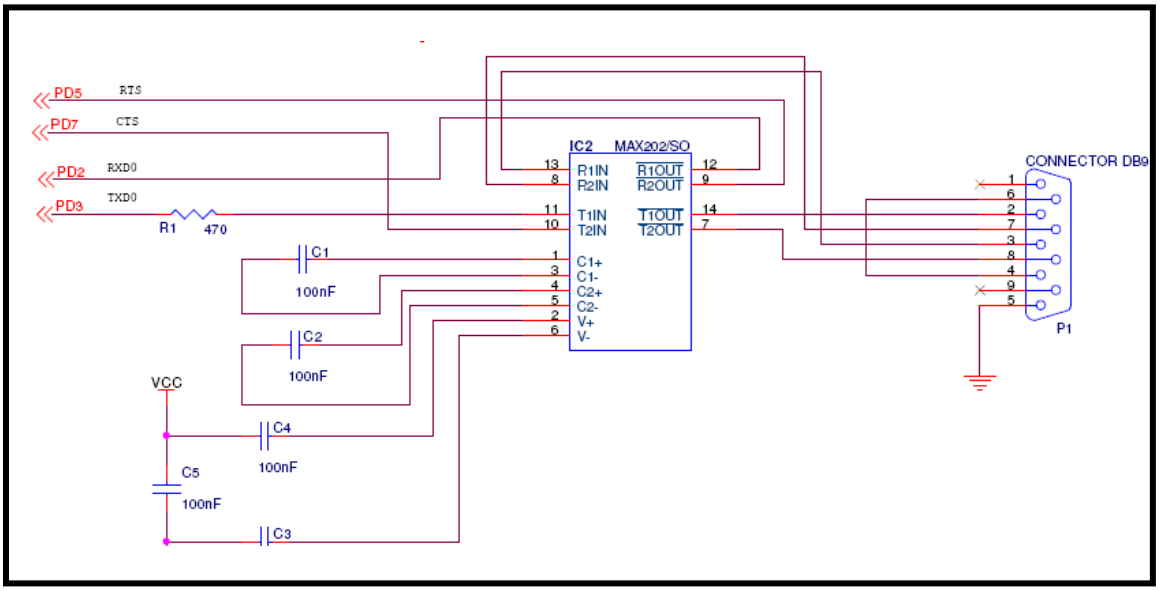


Figure 4.9: The DB9 connector and the serial driver IC MAX202 for serial interface

The RS-232_TD and RS-232_RTS pins of the serial DB9 connector are connected to the receiver input R1IN and R2IN. The other three receiver inputs are grounded. The driver outputs T1OUT and T2OUT are connected to the RS-232_RD and RS-232_CTS pins of the serial DB9 connector. The TXD1 and CTS pins of the microcontroller are connected to the driver inputs T1IN and T2IN of the MAX202. The RXD1 an RTS of the microcontroller are connected to the receiver output pins R1OUT and R2OUT. For detailed schematic see APPENDIX A.

4.4 Serial USB Circuit

The serial USB interface is the last communication module included on the board. The board used a USB mini B connector as discussed earlier in this document. The USB mini B connector is interfaced with the ATmega128L microcontroller through the FT232BM driver IC. Figure 4.10 shows how the USB mini B connector is connected to the FT232BM IC.

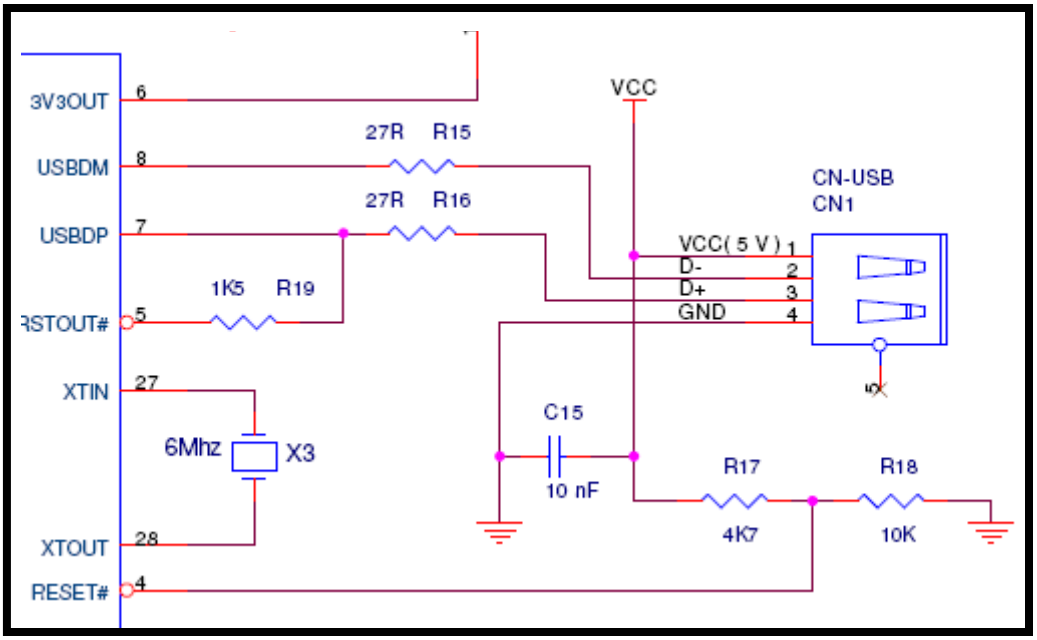


Figure 4.10: USB mini B connector interface with FT232BM driver IC

The D+ and D- pins of the USB connector are connected to the PIN 7(USBDP) & and PIN 8 (USBDM) of the UART USB to serial IC driver chip (FT232BM) through 27 ohm current limiting resistors. Figure 4.11 illustrates how the FT232BM is used with a 6MHz crystal or 2-Pin ceramic resonator. In this case, these devices do not have in-built loading capacitors so these have to be added between XTIN, XTOUT and GND as shown. A value of 27pF is shown as the capacitor in the Figure 4.11 – this has been recommended in the data sheet of the FT232BM as the standard value to be used.

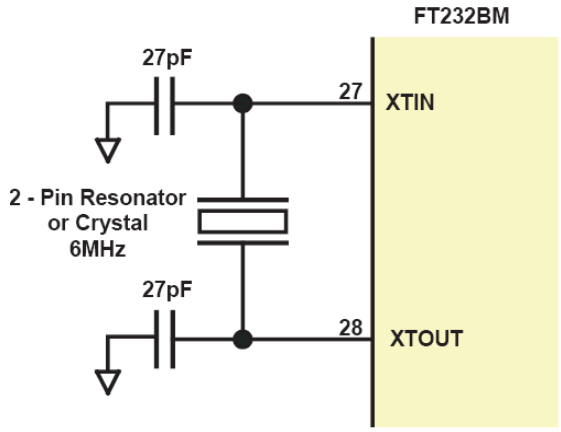


Figure 4.11: A two pin ceramic crystal configuration with the FT232BM driver IC

Figure 4.12 illustrates how to connect the FT232BM to the 93LC46B (93C56 or 93C66) EEPROM. EECS (pin 32) is directly connected to the chip select (CS) pin of the EEPROM. EESK (pin 1) is directly connected to the clock (SK) pin of the EEPROM. EEDATA (pin 2) is directly connected to the Data IN (DIN) pin of the EEPROM.

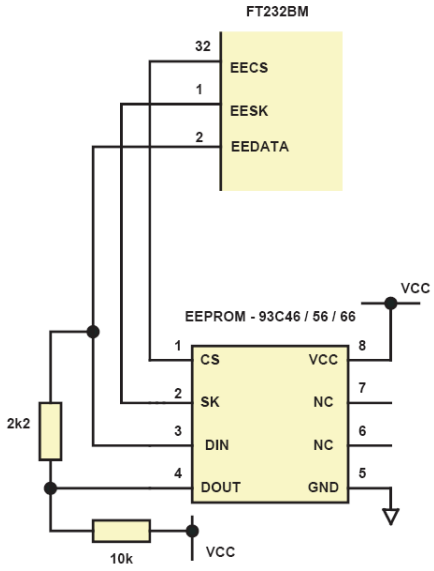


Figure 4.12 EEPROM 93C46 configuration with the FT232BM driver IC

There is a potential condition whereby both the Data Output (DOUT) of the EEPROM can drive out at the same time as the EEDATA pin of the FT232BM. To prevent potential data clash in this situation, the DOUT of the EEPROM is connected to EEDATA of the FT232BM via a 2.2K resistor. Following a power-on reset or a USB reset, the FT232BM will scan the EEPROM to find out if an EEPROM is attached to the Device and if the data in the device is valid. If both of these conditions are true, the FT232BM will use the data in the EEPROM, otherwise it will use the built-in default values. When a valid command is issued to the EEPROM from the FT232BM, the EEPROM will acknowledge the command by pulling the DOUT pin low. In order to check for this condition, it is necessary to pull DOUT high using a 10k resistor. If the command acknowledge doesn't happen then EEDATA will be pulled high by the 10k resistor during this part of the cycle and the device will detect an invalid command or no EEPROM present.

4.5 Power Circuit

The power circuit has been designed keeping in mind the voltage ratings and the different voltage ranges within which all the components present on the board work reliably. The DC connector can be hooked to a voltage source ranging between 9V to 15V DC. A power slide switch is provided on the board to allow manual control of power. The power slide switch used on the board is a two way sliding, surface mount six pin package switch. The voltage coming into the board between 9V to 15V DC needs to be brought down to an operating range of regulated 5V DC for the board to work.

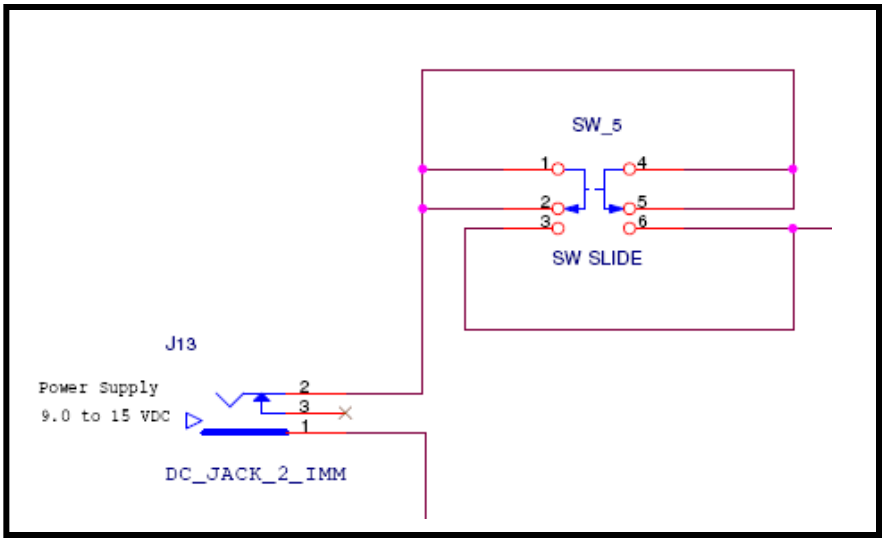


Figure 4.13: Schematic showing the DC jack and the sliding switch

A bridge rectifier circuit followed by a 5V DC regulator has been used for this purpose. The bridge rectifier is a standard DF10S surface mount IC chip, with high current and high surge current capabilities. The voltage regulator used is a standard 78M05A, positive regulator. It employs internal current limiting, thermal shutdown and safe area protection, making it essentially indestructible.

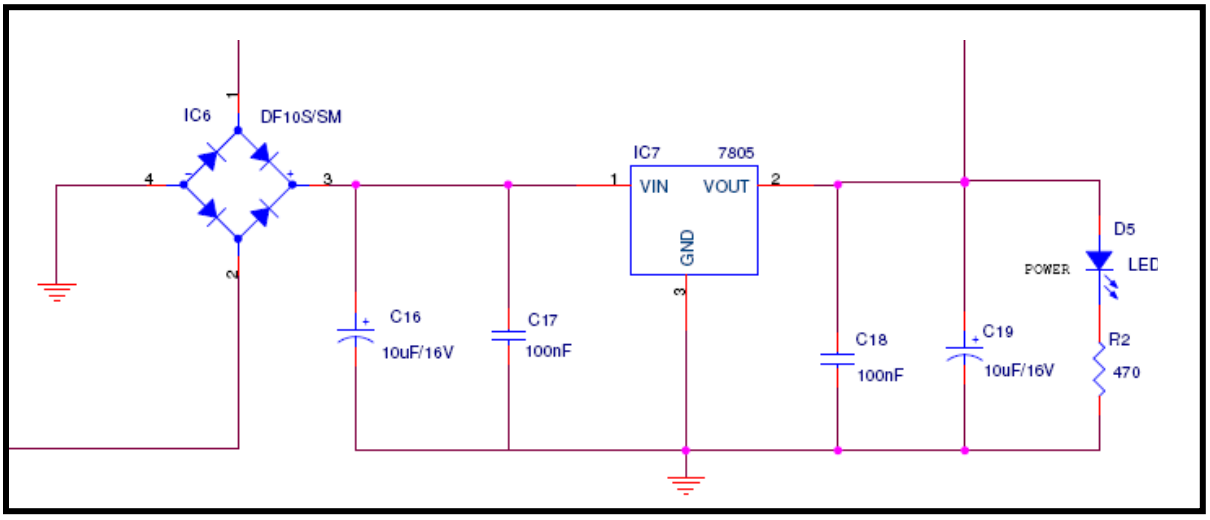


Figure 4.14 Schematic of the rectifier bridge and the 7805 voltage regulator.

The 7805 fixed voltage regulators are designed with Thermal Overload Protection [24] that shuts down the circuit when subjected to an excessive power overload condition, Internal Short-Circuit Protection that limits the maximum current the circuit will pass, and Output Transistor Safe-Area Compensation that reduces the output short-circuit as the voltage across the pass transistor is increased.

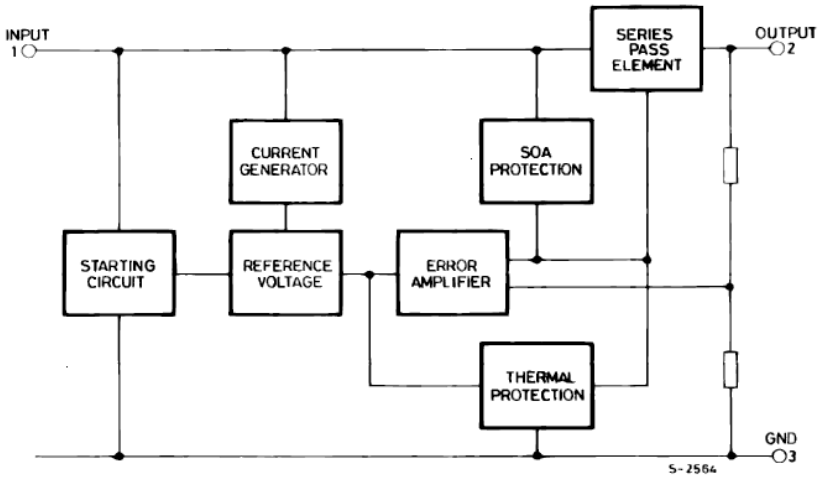


Figure 4.15 Block diagram of the 7805 voltage regulator.[24]

4.6 Circuit for On Board LCD Screen

The LCD module used for the board is the ACM0802C, from AZ Displays, Inc. The LCD module is easy to interface with any microcontroller. The LCD module has 8 data pins that are connected to the I/O pins of Port A of the microcontroller. Only four of the 8 data pins are connected to the Port A and the rest four are connected to the ground. The Pin 3 of the LCD module is connected to a 10K potentiometer for providing the LCD contrast. Pin 7, 8, 9 and 10 of the LCD module have been grounded as seen in the Figure 4.16. These pins represent the lower 4 data bits. The upper 4 data bits have been connected to the Port A of the microcontroller.

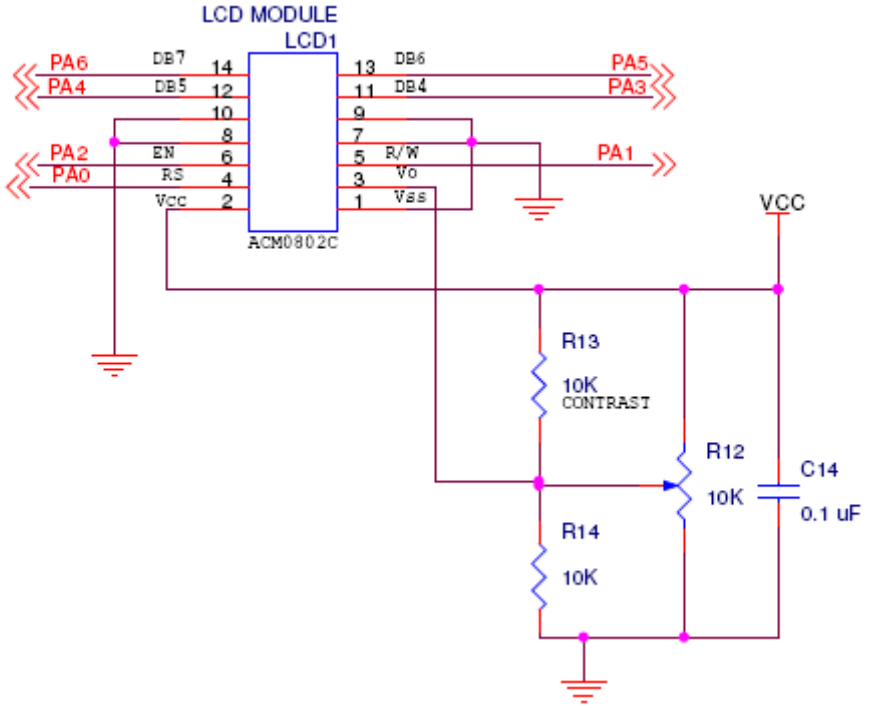


Figure 4.16 Schematic showing the LCD module.

4.7 Circuit for debugging LEDs and Switches

Switches and LEDs are provided on the board of debugging purposes. There are four switches and four LEDs present on the communication board. The switches used are the small 4mm J hook surface mount switches having a maximum current rating of 100mA. Each of the switches has been connected to a 10K pull up resistors. The LEDs are connected through a current limiting resistor of 470 ohms. All the LEDs and the Switches are connected to the port C of the microcontroller and each can be programmed for a particular user defined function.

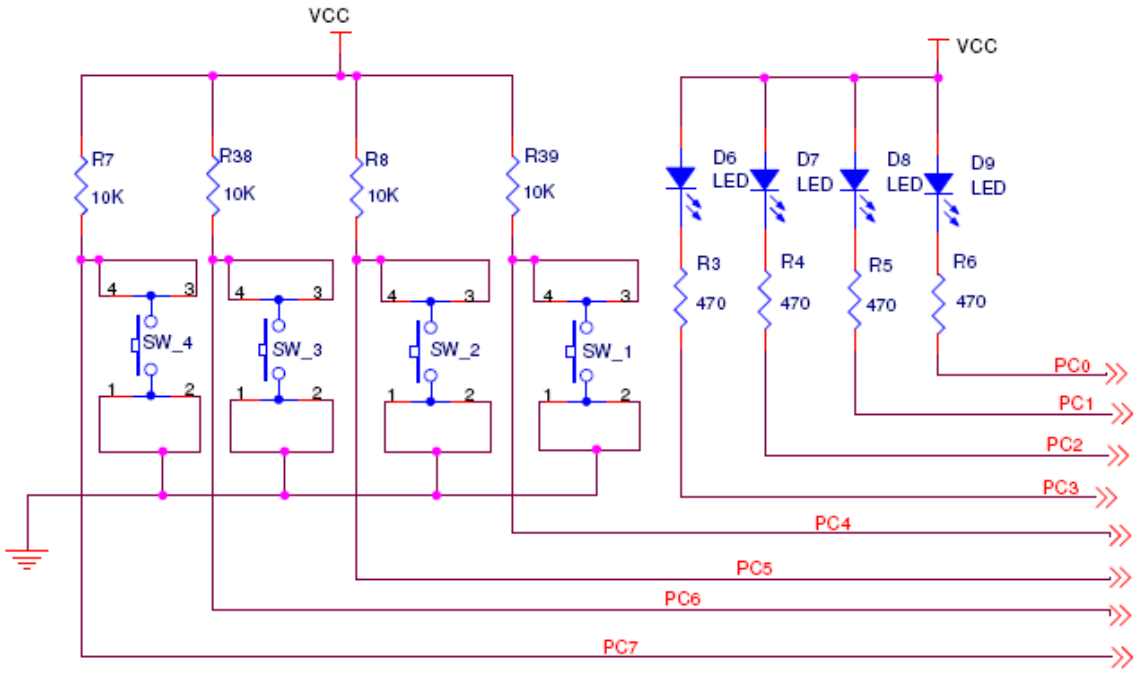


Figure 4.17 Schematic showing LEDs and Switches.

CHAPTER 5: TESTING

5.1 Programming of the Board

. The communication board comes with a JTAG interface for programming. The ATmega128 AVR is supported with a full suite of program and system development tools including: C compilers, macro assemblers, program debugger/simulators, in-circuit emulators, and evaluation kits. The microcontroller is programmed using AVR Studio4 and IAR Embedded workbench which also supports most of the AVRs. The AVR Studio® 4 is the professional Integrated Development Environment (IDE) for writing and debugging AVR® applications in Windows® 9x/NT/2000/XP environments. AVR Studio 4 includes an assembler and a simulator. A JTAGICE mkII connector is connected between the PC and the board to download code to the ATmega128L microcontroller through the JTAG connector.

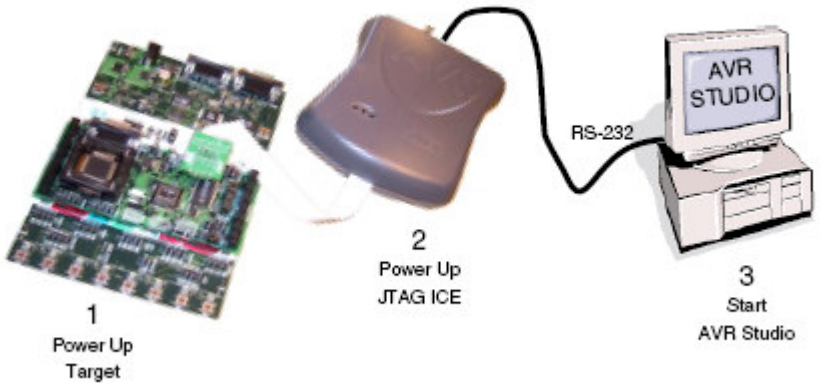


Figure 5.1 The setup to program AVR microcontroller using JTAG ICE

Since the testing of the various modules had to be done before the communication boards goes for manufacturing and further design processing, we had to use different evaluation boards readily available in the market for different modules for testing with the ATmega128 microcontroller. The subsequent sections will deal with the testing of the various modules using different evaluation boards and circuits available readily in the market. These evaluation boards or test boards have the same circuit and components as being used on the communication board. Testing the different modules using the evaluation boards is easier and less time consuming. To duplicate the whole schematic circuits comprising of hundreds of small components on a bread board and interfacing it with the ATmega128 microcontroller is not only difficult and time consuming but also highly susceptible to erroneous results because of possible imperfect and loose connections and mistakes in arranging the small parts correctly.

5.2 Testing for Microcontroller

The evaluation board used for testing the microcontroller ATmega128 is the STK 500 and the STK 501 daughter board. Figure 5.2 shows the detailed block level diagram of the STK board. The board comes with the 8 yellow LEDs and 8 push-button switches. The LEDs and switches are connected to debug headers that are separated from the rest of the board. They can be connected to the AVR devices with the supplied 10-wire cable to the pin header of the AVR I/O ports. The STK500 includes two RS-232 ports. One RS-232 port is used for communicating with AVR Studio. The other RS-232 can be used for communicating between the target AVR microcontroller in the socket and a PC serial port connected to the RS-232.

The daughter board STK501 which sits on the STK500 gives the board the support needed for testing most AVR microcontrollers, including ATmega128. The main aim of testing the microcontroller was to test a sample code and to see if the microcontroller can be programmed using a JTAG connector through the PC and further make use of the debugging LEDs and switches to confirm our results. The combination of the STK500 and the STK501 was used to test and program the ATmega128. Once correctly programmed using the PC and tested using the debugging LEDs we could further proceed to interface various communication modules with the microcontroller.

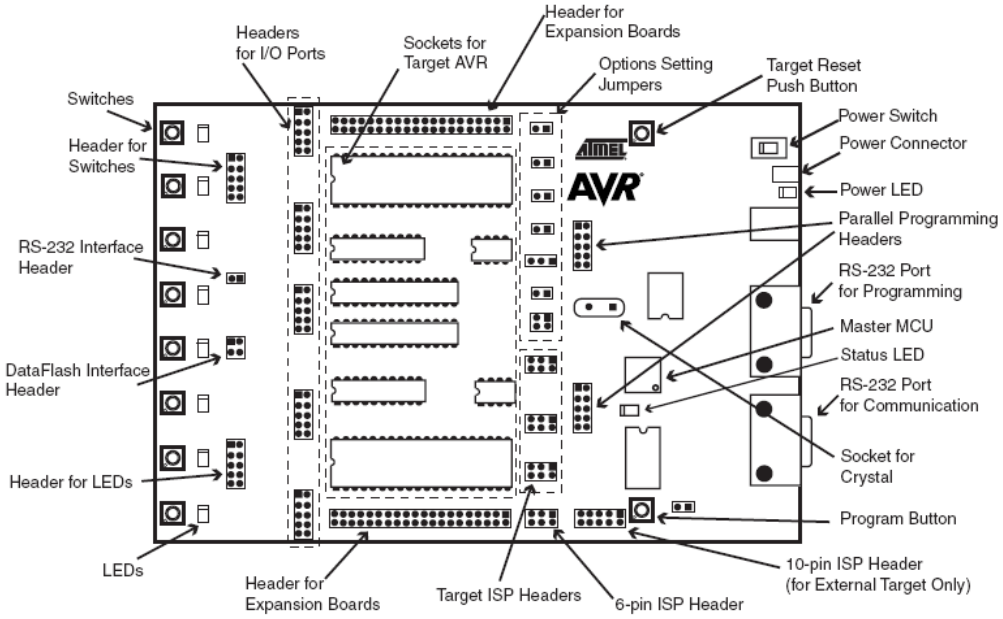


Figure 5.2 The components of the STK500 board [14]

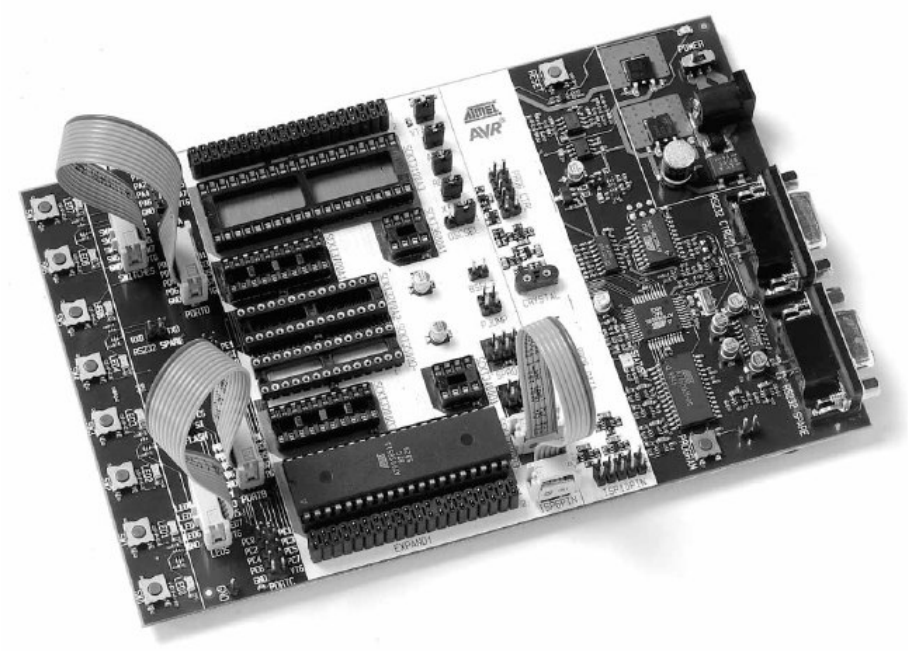


Figure 5.3 The STK500 board with default settings [14]

The STK501 board is a top module designed to add ATmega103 (L) and ATmega128 (L) support to the STK500 development board from Atmel Corporation.

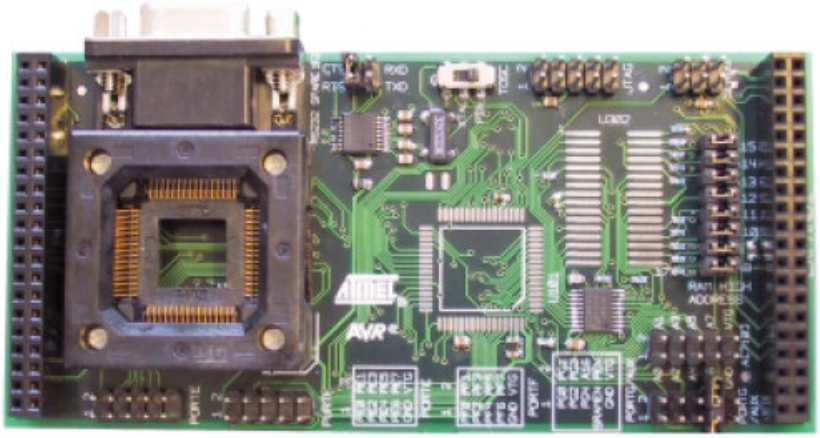


Figure 5.4 The STK501 board with the socket to hold the ATmega128 [15]

With this board the STK500 is extended to support all current AVR devices in a single development environment. The STK501 includes connectors, jumpers and hardware allowing full utilization of the new features of the ATmega128. The socket shown above in the Figure 5.4 holds the ATmega128 microcontroller. The 10-Pin JTAG connector on the top edge of the board is used for connecting the JTAG using the MKII connector to program the microcontroller using the PC.

A very simple C program was written to test the microcontroller by setting the I/O pins of the microcontroller to high or low and the output was connected to the debugging LEDs present on the STK500 board. The LEDs were made to glow alternately or on press of the switches. Once the program was downloaded through the JTAG and confirmed that the microcontroller was getting programmed properly using the JTAG connection, the second step was to hardware interface other communication modules and test their working with the microcontroller.

5.3 Testing for Optical Fiber Transceiver

The testing of the optical fiber communication module was done using the HFBR 0x400 series of optical fiber transmitter and receiver modules manufactured by Agilent technologies. The HFBR-0400 Series of components is designed to provide cost effective, high performance fiber optic communication links for information systems and industrial applications with link distances of up to 2.7 kilometers. With the HFBR-24x6, the 125 MHz analog receiver, data rates of up to 160 mega baud are attainable. Transmitters and receivers are directly compatible with popular “industry-standard” connectors: ST®, SMA, SC and FC.

These modules are readily available in the market in the form of a testing kit, which comprises of a HFBR 2412 receiver, a HFBR 1412 transmitter and a 2m long ST optical fiber cable.

Figure5.5: The Agilent HFBR 04x series Optical Fiber evaluation kit.

The pin diagram and hardware details of the optical fiber transmitter and receiver have already been discussed in Chapter 3 of this document. The testing of the optical fiber communication module was done by interfacing the appropriate pins with the microcontroller UART pins. Two small PCBs were designed to hold the transmitter and receiver along with the associated coupling circuit on it. Breadboard testing was not used to avoid lose connections and lose of signal and noise. Well soldered connections were

used on the PCB to obtain near perfect testing conditions to duplicate the exact scenario that would be present in the final optical communication board.

The interfacing part was followed by testing our hardware for its working along with the microcontroller. This was done by programming the microcontroller UART. A simple C program was written, which would send bytes regularly on its UART transmitter pin and the UART receiver pin was programmed to receive these bytes correctly and make a check if the received byte is received properly without any error. Due to very less available resources only one microcontroller circuit was used and the optical fiber was made to echo the bytes back to the microcontroller.

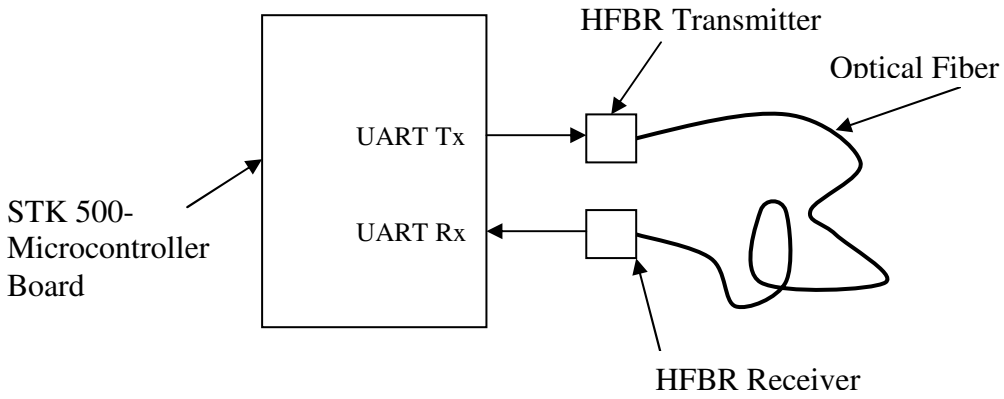


Figure 5.6 Block diagram showing testing of optical fiber module

The main aim of this testing was to identify any anomalies in our circuit design. Our test results showed that the bytes transmitted through the UART transmitter were able to be received without any errors at the other end of the optical fiber on the UART receiver pin.

5.4 Testing for Serial USB

The Serial USB communication module was tested to work with the ATmega128 by using a readily available evaluation kit. The USB2SER kit [25] is a USB to Serial converter kit manufactured by Parallax. The circuit on the USB2SER board is the same as used in our USB module for the communication board. This provides us an exact platform to test our USB circuit without having to create the setup on a breadboard. Using evaluation boards for testing helps in avoiding any possible errors and variation in results that could come into picture because of lose connections and larger size of components used on the breadboard. The USB2SER board provides a very easy way to connect the PC to the microcontroller.

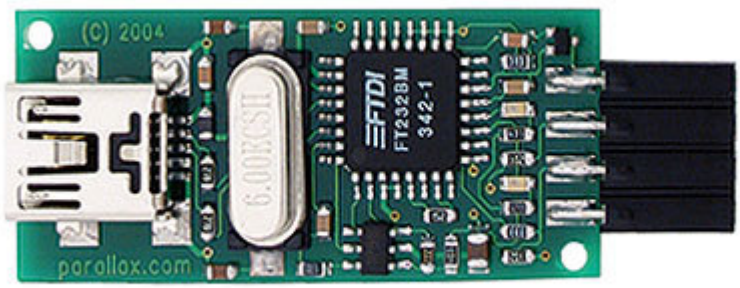


Figure 5.7: USB to serial converter used for testing the USB circuit.[25]

The USB2SER board bridges the PC's USB port to the logic level Rx and Tx signals that can connect directly to a microcontroller's I/O pins. To the PC it appears as a virtual COM port and to the microcontroller it appears as a true 3.3V – 5V serial connection consisting of Rx and Tx signals.

The hardware setup for testing the USB circuit consists of connecting the UART Tx and UART Rx signals with the corresponding connectors of the USB2SER board. The USB port of the converter is connected to the PC using a USB cable.

A simple UART program was written to test the USB circuit for its working. Characters where sent out on the UART transmit pin of the microcontroller and received on the PC using a hyper terminal. Similarly characters where sent from the PC on the USB to be received on the UART Rx pin of the microcontroller and verified by displaying on the LCD screen connected on the STK500 board.

This simple exercise of sending and receiving characters from the microcontroller to the PC and from the PC to the microcontroller gave us the proof of the working of the USB circuit with the ATmaga128 microcontroller. This test did not measure the speed and capabilities of the USB circuit involved in our communication board. However it only tested the working of the circuit on the hardware level, so that it could be approved for second stage of the design, i.e. board layout design.

CHAPTER 6: LAYOUT DESIGN

6.1 Overview

The layout design for the board was done using the ORCAD layout tools. Before we start work on the board layout a netlist file is created using the ORCAD Capture tools. The netlist (*.mnl) describes the interconnection of a schematic design using the names of the nets, components and pins. A netlist contains the following:

- Footprint names
- Electrical packaging
- Component names
- Net names
- The component pin for each net
- Net, pin and component property information.

Following steps are taken to make the board layout using OrCAD layout tools:

1. Ensure that a netlist with all footprints and other necessary information has been created.
2. Create a directory in which the schematic design, netlist, and board will coexist and put the schematic design and netlist in it. OrCAD provides a directory (ORCADWIN\LAYOUT\DESIGN) for this purpose.
3. From the Layout session frame's File menu, choose New. The Load Template File dialog box will be displayed.
4. Select a technology template (.TCH), and then choose the Open button. The Load Netlist Source dialog box will be displayed.

5. Select a netlist file (for example, *design_name.mnl*), then choose the Open button. The Save File As dialog box displays.

6. Specify a name for the new board (for example, COMM_BOARD.MAX), then chose the save button. The AutoECO process begins

7. If necessary, respond to the Link Footprint to Component dialog box.

Most of the components used in the communication board did not have footprints in the ORCAD standard library. All the footprints were made manually using the data sheet drawings and dimensional details of each component and saved in the ORCAD library before proceeding further with the LAYOUT design.

6.2 Design of New Footprints

Majority of the components used on the communication board are surface mount and very small in size. Creating new footprints for these components becomes even more challenging and difficult. Care must be taken to be as precise as possible, because even a fraction of an inch error in creating the footprint may cause problems while soldering the components on the board. Most of the footprints were designed using already present footprints in the library and modifying them according to the requirements and datasheet values.

The newly created footprints where then saved in the libraries and the name of the footprints updated in the schematic design under the property of each component. Note that the layout design will not be complete unless each component in the schematic capture design has a specific footprint present in the layout library. Care was taken to accurately update the properties of each component with their corresponding footprint

names in the layout library. When the netlist file (*.mnl) is created in the schematic , it holds the information about the footprints and other properties of the components and when we link the netlist in the OrCAD layout, the tools automatically picks up the corresponding footprint from the libraries to generate the initial board layout design.

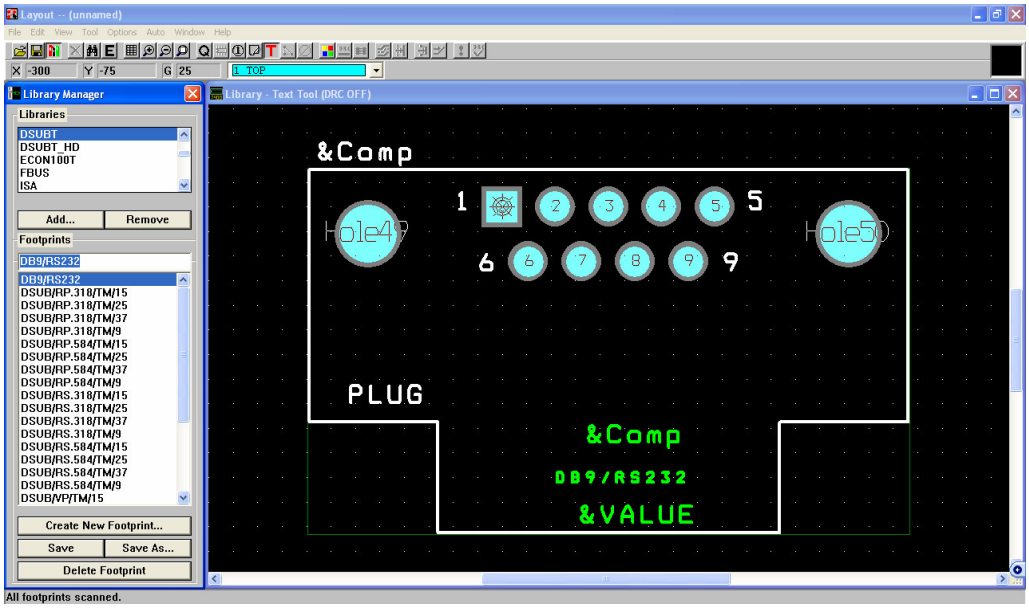


Figure 6.1 OrCAD Layout foot print: RS-232 Serial Port

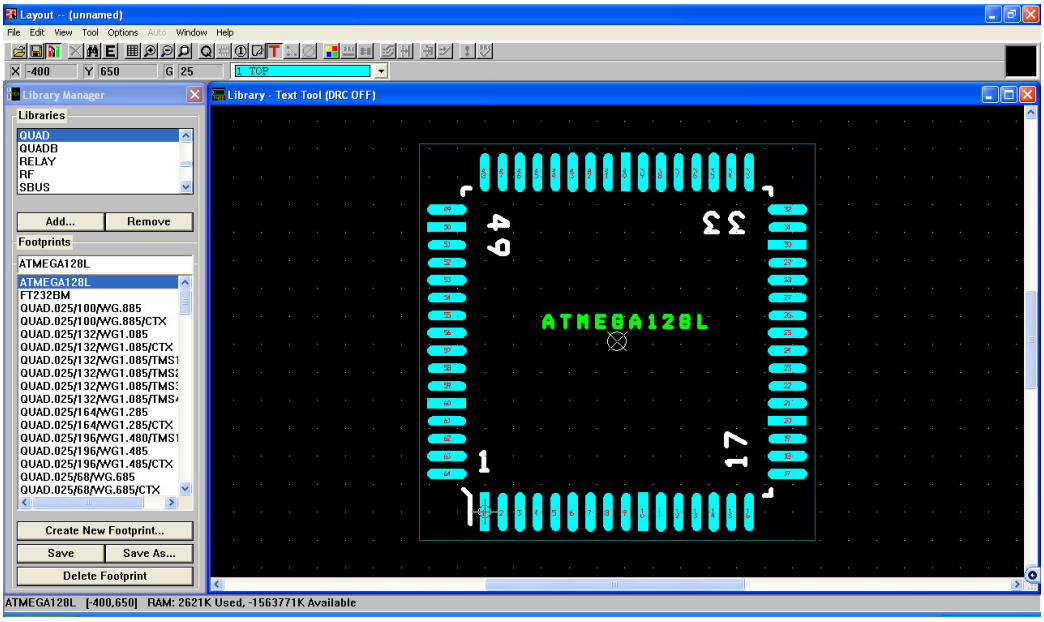


Figure 6.2 OrCAD Layout foot print: ATmega128 microcontroller

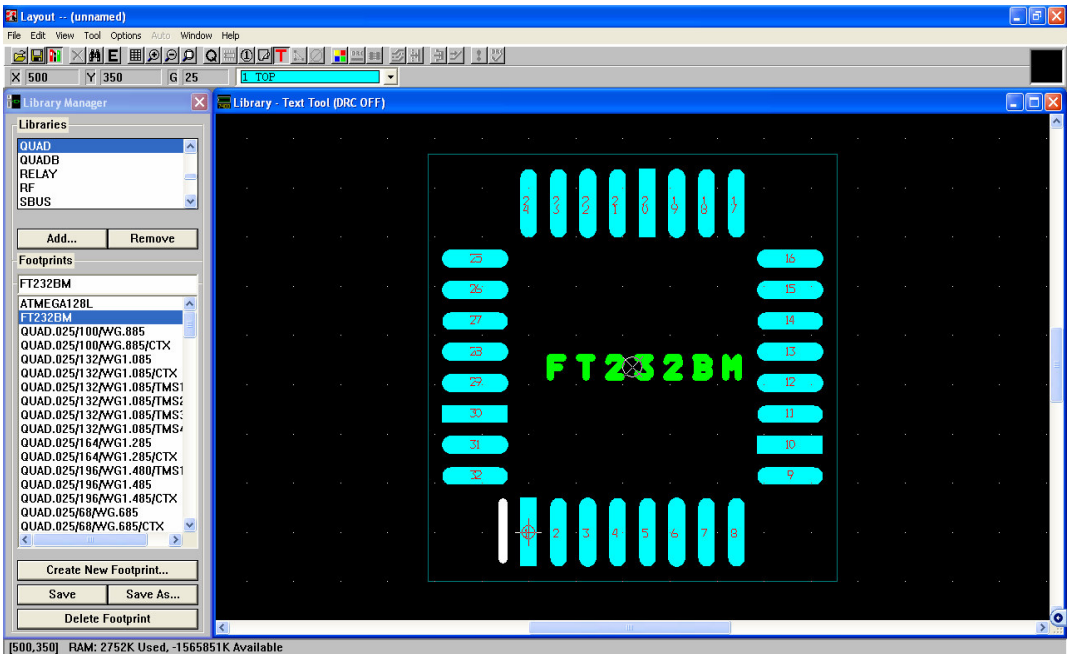


Figure 6.3 OrCAD Layout foot print: USB to serial IC driver chip (FT232BM).

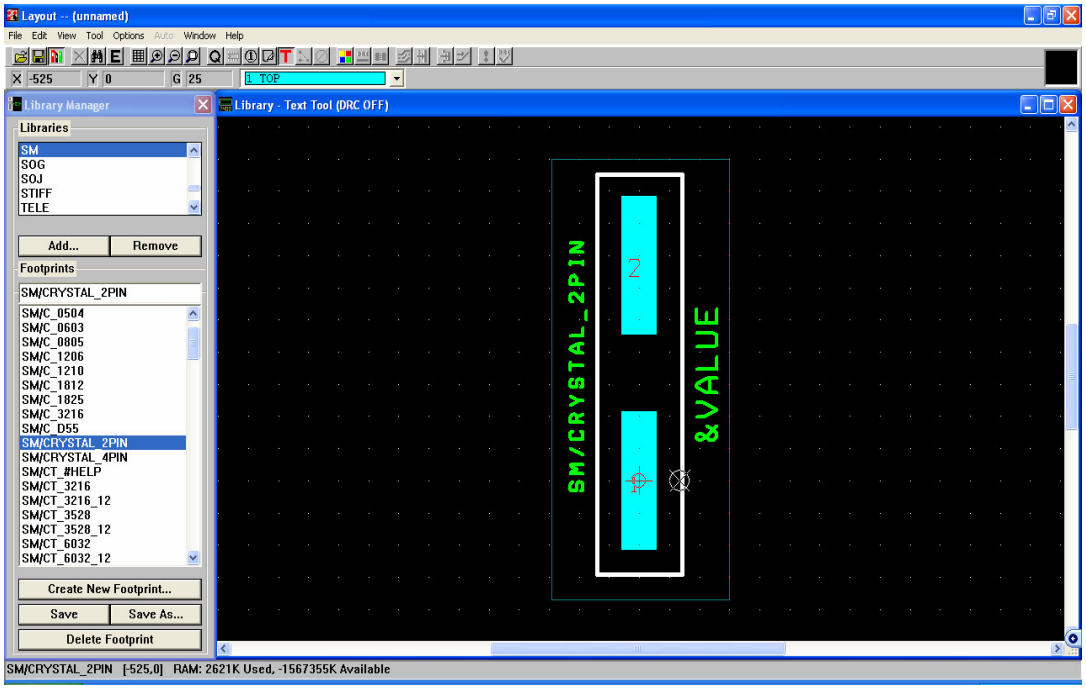


Figure 6.4 OrCAD Layout foot print: 2 Pin Crystal Oscillator

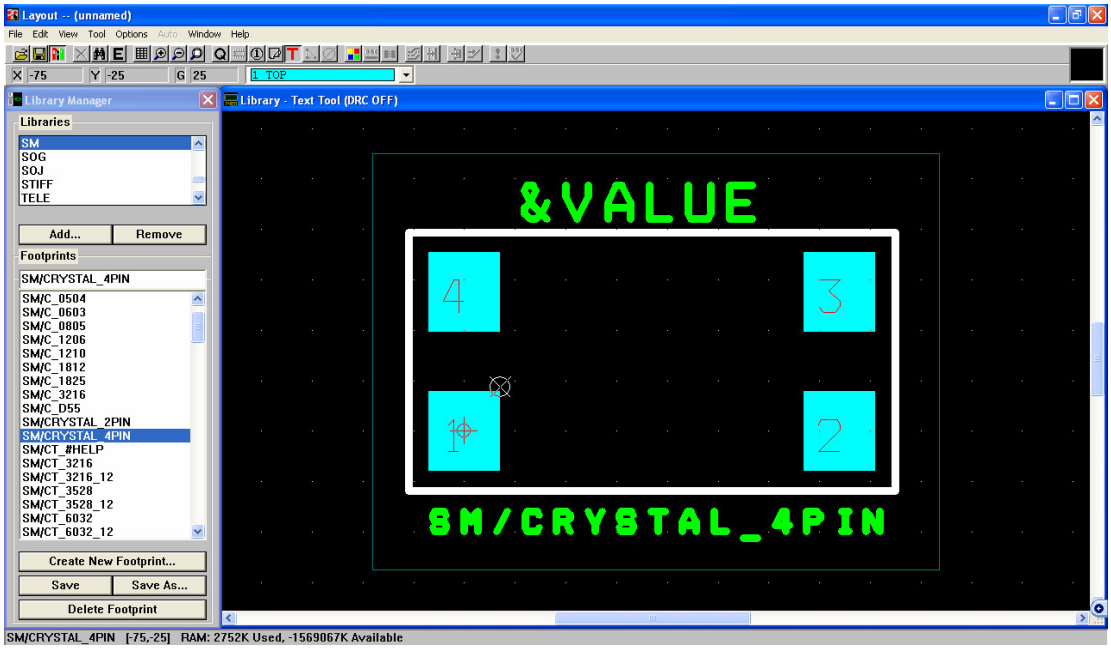


Figure 6.5 OrCAD Layout foot print: 4 Pin crystal oscillator.

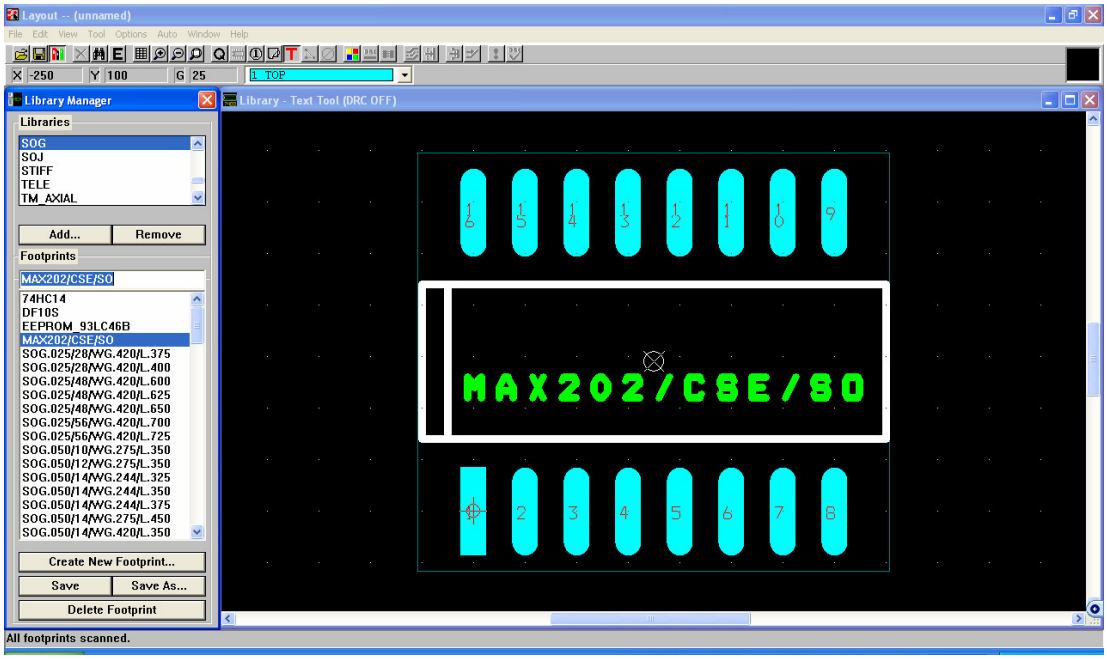


Figure 6.6 OrCAD Layout foot print: Serial UART transceiver IC (MAX202)

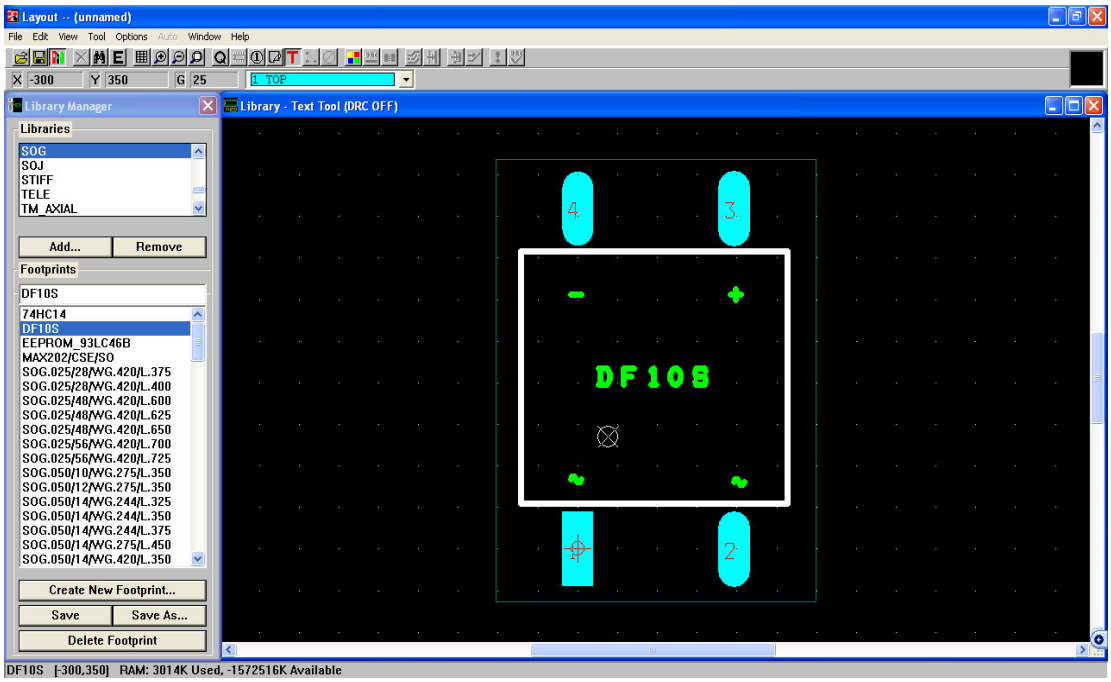


Figure 6.7 OrCAD Layout foot print: Surface mount Bridge rectifier (DF10S).

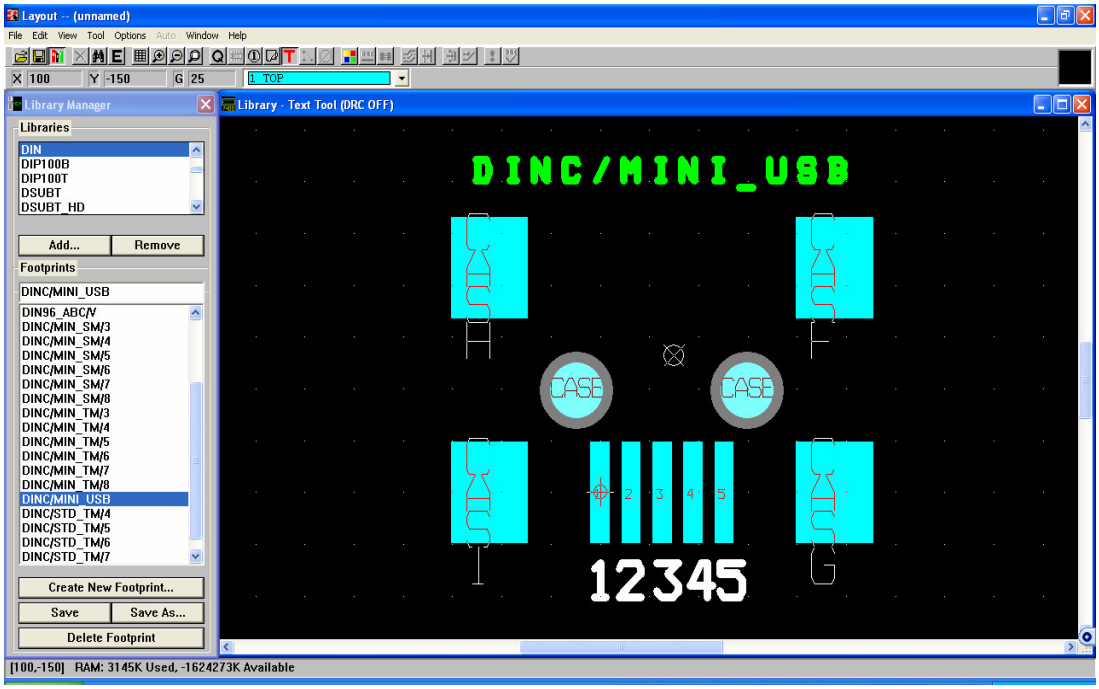


Figure6.8 OrCAD Layout foot print: USB mini B port

Once all the footprints were created and saved in the library files, the schematic design was updated with the footprint information for each component. This can be done by opening the properties window of each component and updating the field “footprints” with the name and path of the footprint created in OrCAD layout. The second step would be to create a netlist file in the schematic capture. This netlist file is used as a resource to create the layout design using the OrCAD tools. The netlist (*.mnl) file is used to export the schematic design to OrCAD layout tool.

CHAPTER 7: CONCLUSION AND FUTURE WORK

The main purpose of this thesis was to design and test a low cost communication board which is capable of handling different kinds of communication protocols to serve as a learning tool for students and researchers. Initial effort went into an extensive research for finding similar communication boards used for educational purposes. However the result of the research was that there were very few or no boards which could serve the purpose of including all types of communication modules into one board and serve as platform for students and researchers to work on. The design and testing of this communication board has been done in order to manufacture a simple, low cost, small in size, easy to handle and versatile microcontroller board which holds various communication modules capable of communicating with another similar board or with a PC or act as a link between two PCs. Students and researchers will find this board very useful to learn basic embedded systems and communication theories by conducting lab exercises and other experiments.

Although a lot of effort and time has gone into the design of the board and then further testing of the hardware, the board is still in a stage where future work needs to be done. Major effort was made in the initial design of the board, including the selection of hardware and other design related components. The effort towards this thesis can be summarized as follows:

- Initial research for communication boards available in the market.

- Research on various communication modules and their working(optical fiber, infrared, USB, serial UART)
- Preparing lab exercises for the students to work on to ensure that the communication modules are helpful as a learning tool for embedded systems students
- Initial research on available hardware for different communication modules.
- Selection of the ideal microcontroller for the board.
- Schematic design for the board.
- Writing test code and driver software for different communication modules.
- Testing of the hardware with different evaluation boards to check the correctness of our design
- Making design changes to the schematic based on the test results
- Creating foot prints of the components for layout design.

The communication board design was completed and further testing was done using each communication module to ensure that the manufactured version of the board will be workable.

The future work in this thesis may include the manufacture of the board and performing direct tests on the communication modules on the board. Data rates and limit to which the data rate can be pushed for normal working of the board can be done. Students taking up embedded systems and advanced embedded systems should be strongly encouraged to take this up as a project to test the working model of the embedded communication board. Sample lab exercises have been provided in the Appendix D of this document. It will serve as a base for students to work on the

different data communication modules and test the data rates using serial UART and I/O pins. Measurement of error rates at different speeds can be carried out.

The communication board has attracted interest in a few of its early demonstrations, like the one at the annual optical communication conference held in the University of North Carolina at Charlotte in November, 2005. Faculty members of different institutions have shown interest in including this board as a part of the course work in embedded systems and communication classes. The board can serve as a lab exercise and a practical learning tool for students learning embedded systems programming and embedded systems communication.

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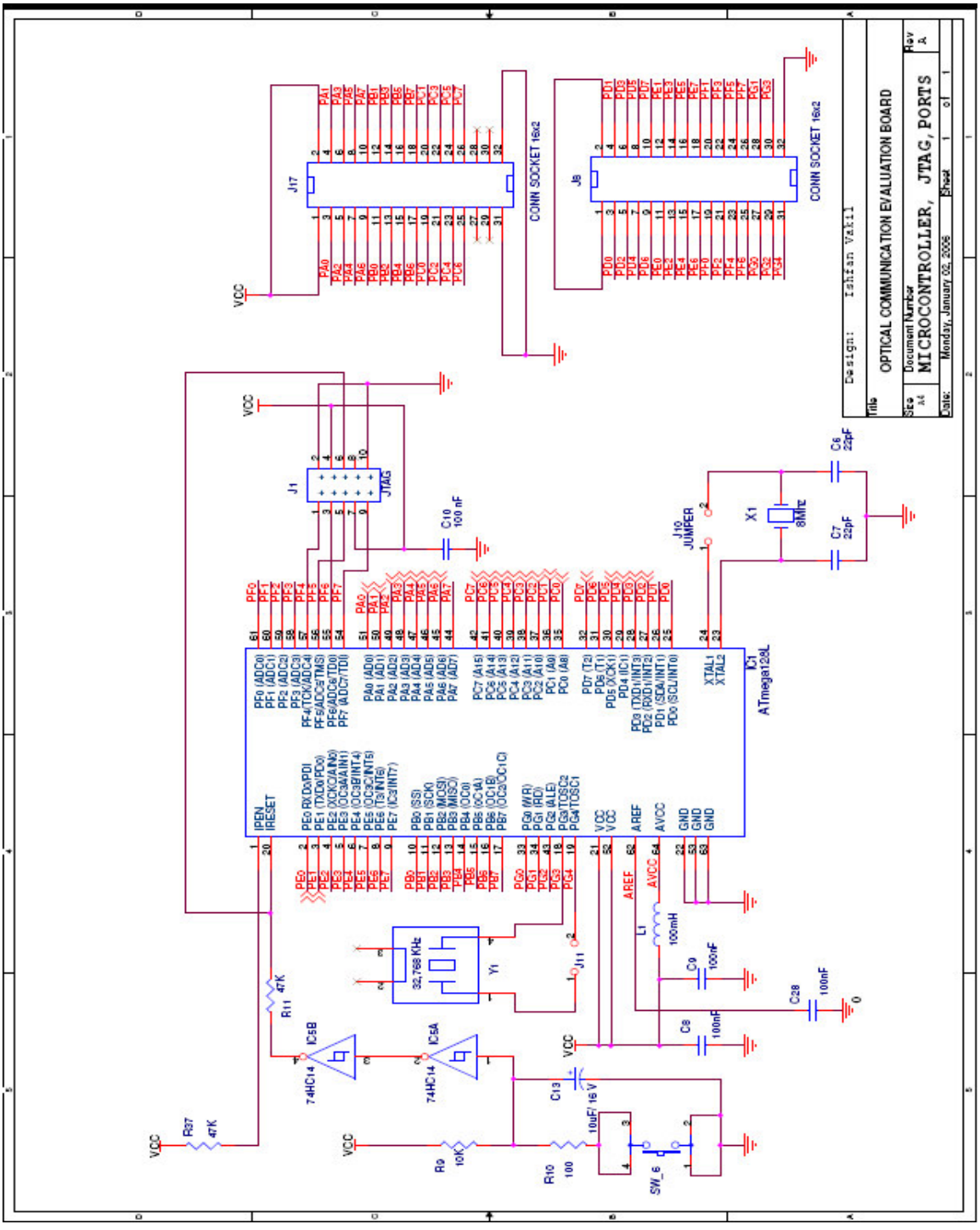
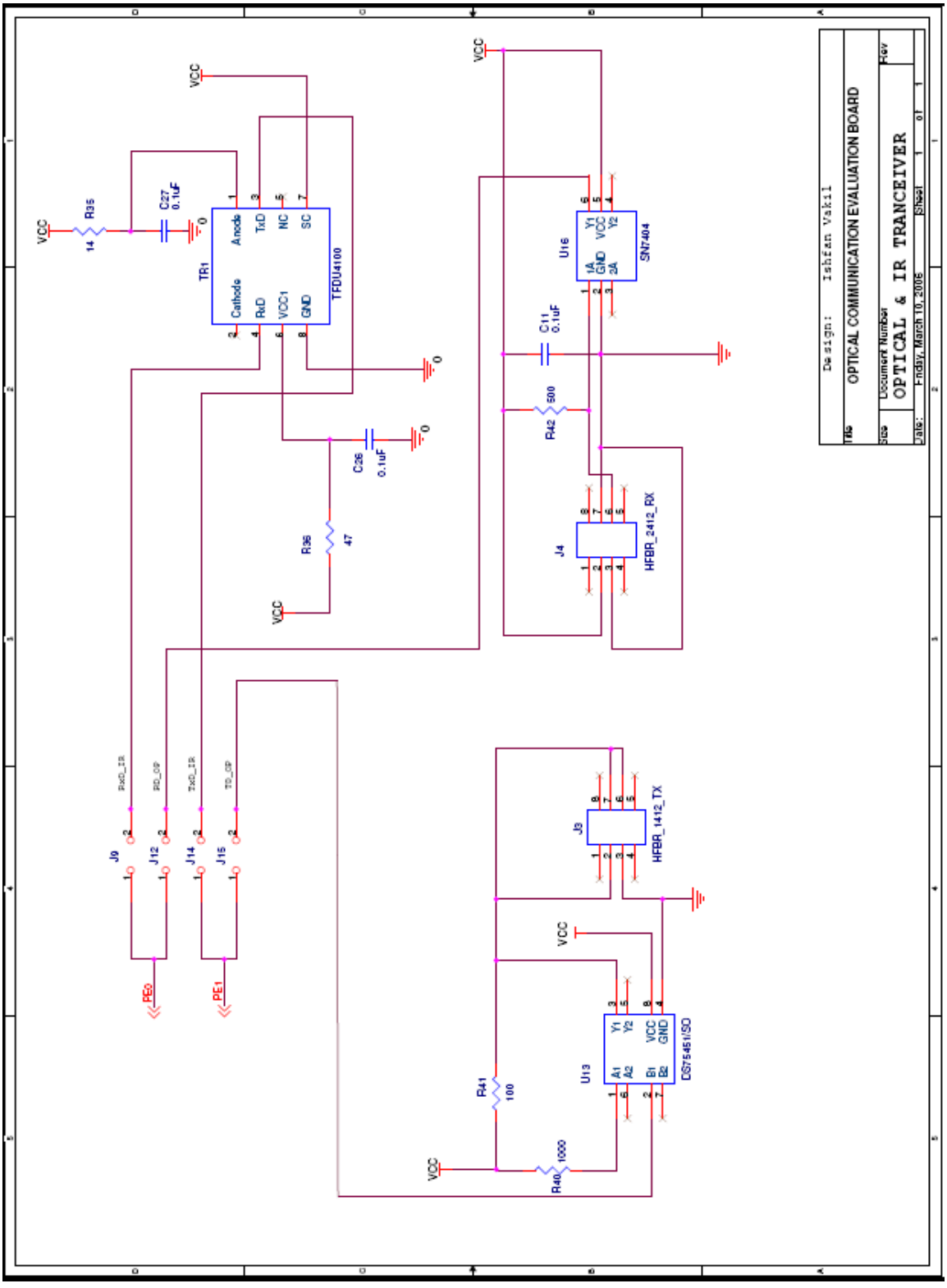
APPENDIX A: SCHEMATIC

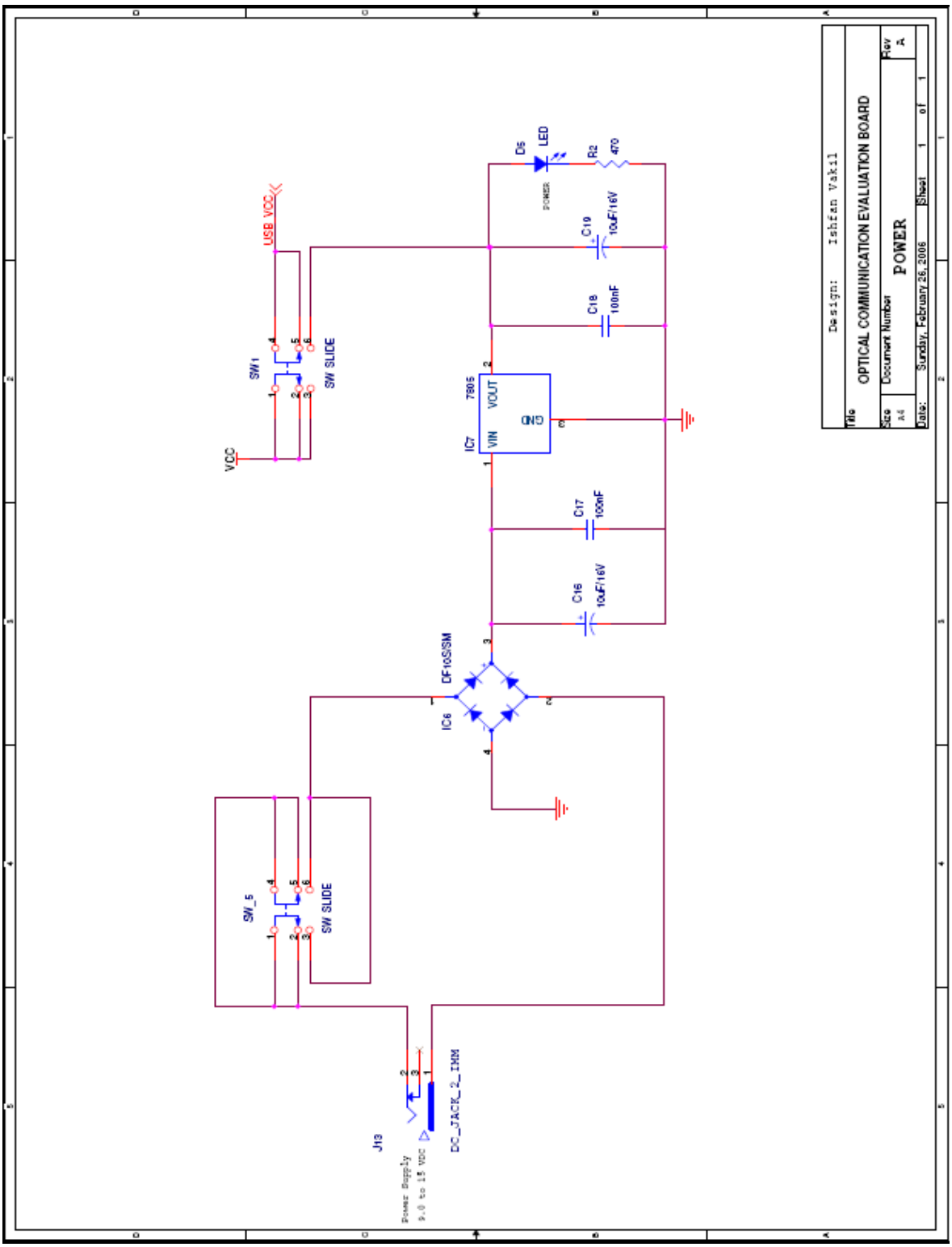
SCHEMATIC: MICROCONTROLLER, JTAG AND I/O PORTS



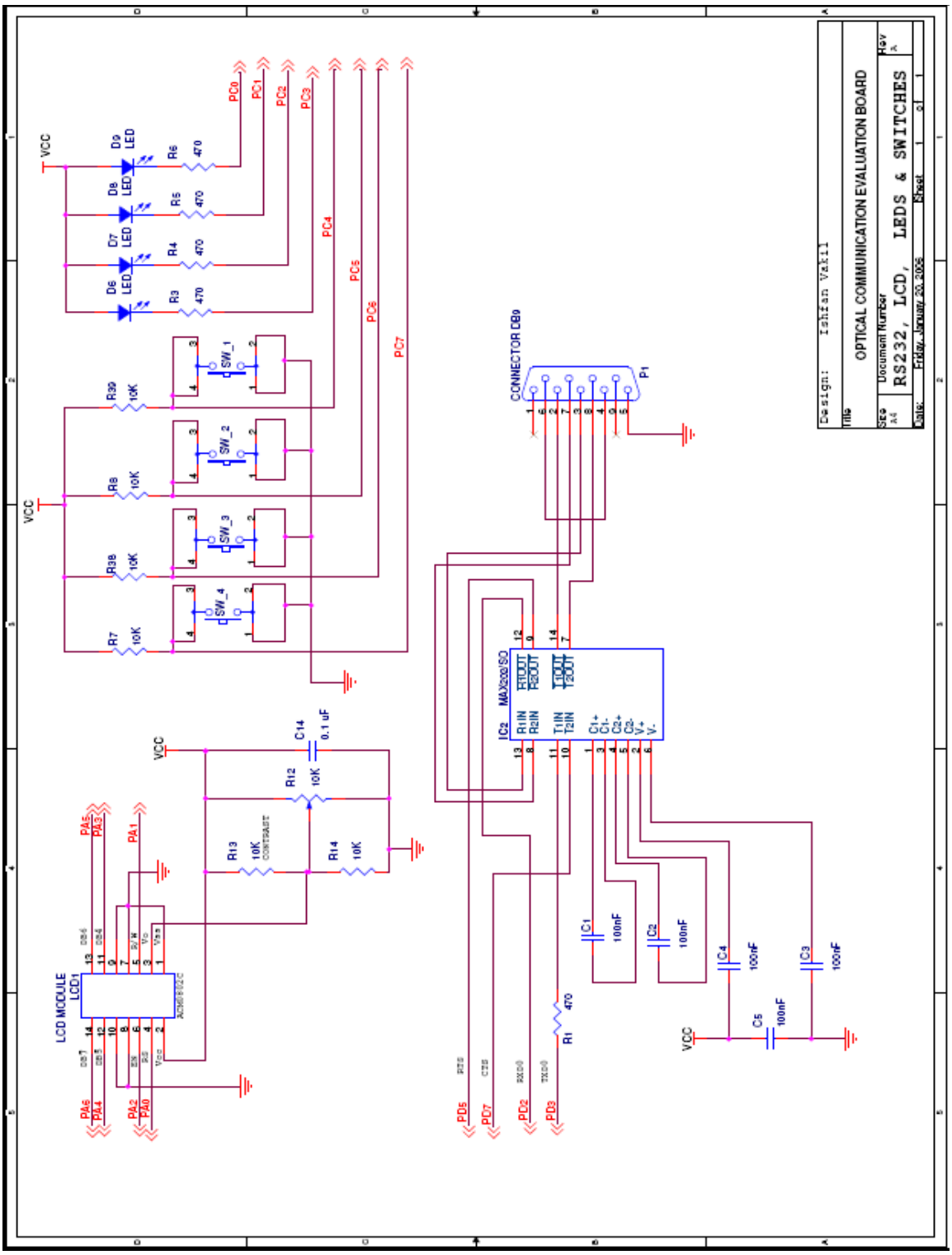
SCHEMATIC: OPTICAL FIBER TRANSMITTER- RECIEVER AND INFRARED TRANSCIEVER



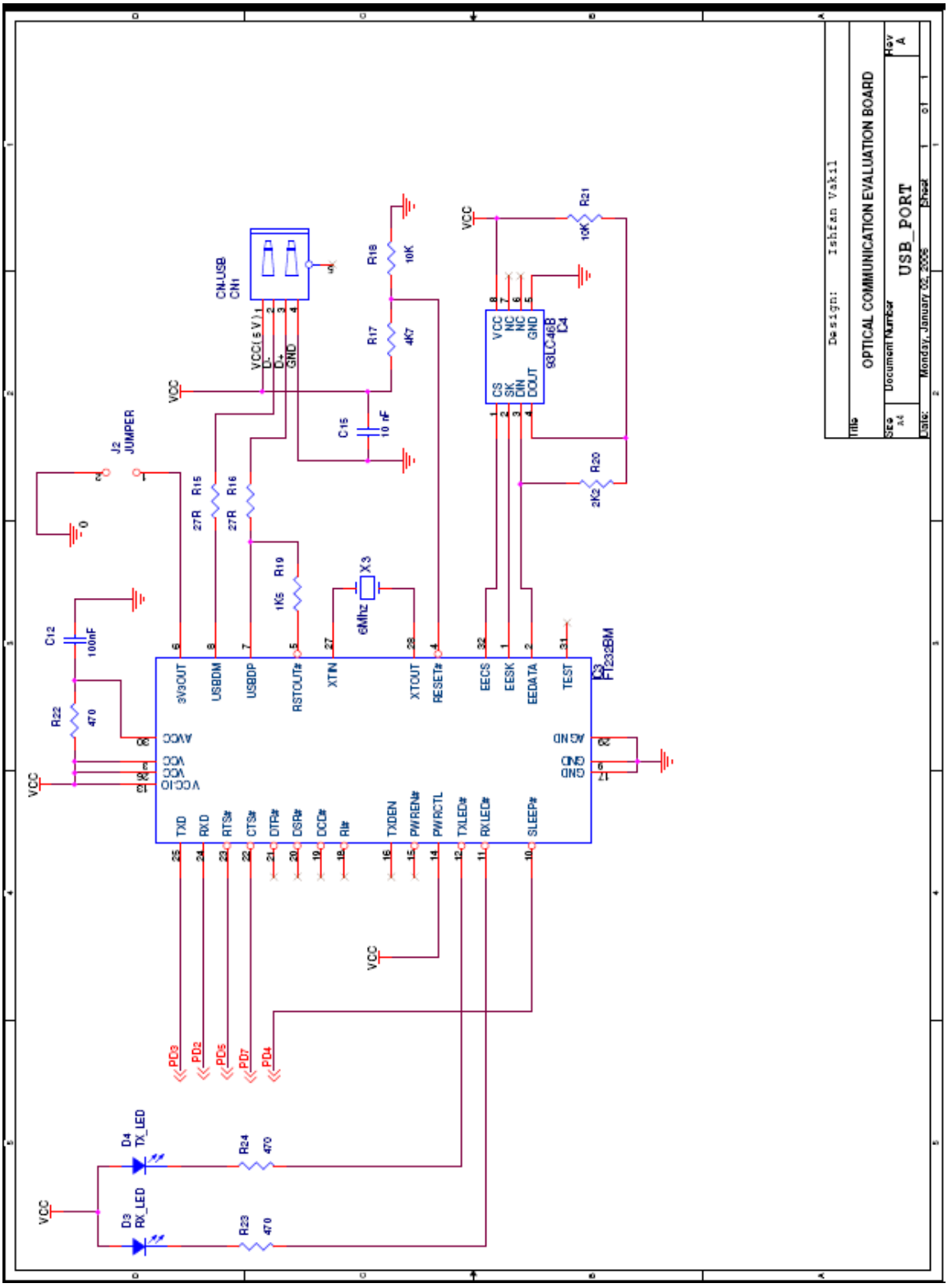
SCHEMATIC: POWER SUPPLY



SCHEMATIC: RS-232 PORT AND LCD



SCHEMATIC: USB CONNECTOR INTERFACE



APPENDIX B: BILL OF MATERIALS (BOM)

Item	Quantity	Reference	Part	PCB footprint
1	1	X1	8Mhz	SM/CRYSTAL_2PIN
2	1	CN1	CN-USB	DINC/MINI_USB
3	11	C1	100nF	SM/C_0603
		C2	100nF	SM/C_0603
		C3	100nF	SM/C_0603
		C4	100nF	SM/C_0603
		C5	100nF	SM/C_0603
		C8	100nF	SM/C_0603
		C9	100nF	SM/C_0603
		C12	100nF	SM/C_0603
		C17	100nF	SM/C_0603
		C18	100nF	SM/C_0603
		C28	100nF	SM/C_0603
4	2	C7	22pF	SM/C_0603
		C6	22pF	SM/C_0603
5	1	C10	100 nF	SM/C_0603
6	3	C11	0.1uF	SM/C_0603
		C26	0.1uF	SM/C_0603
		C27	0.1uF	SM/C_0603
7	1	C13	10uF/ 16 V	SM/C_D55
8	1	C14	0.1 uF	SM/C_0603
9	1	C15	10 nF	SM/C_0603
10	2	C16	10uF/16V	SM/C_D55
		C19	10uF/16V	SM/C_D55
11	1	D3	RX_LED	SM/LED_1206
12	1	D4	TX_LED	SM/LED_1206
13	5	D5	LED	SM/LED_1206
		D6	LED	SM/LED_1206
		D7	LED	SM/LED_1206
		D8	LED	SM/LED_1206
		D9	LED	SM/LED_1206
14	1	IC1	ATmega128L	ATMEGA128L
15	1	IC2	MAX202/SO	MAX202/CSE/SO
16	1	IC3	FT232BM	FT232BM
17	1	IC4	93LC46B	EEPROM_93LC46B
18	1	IC5	74HC14	74HC14
19	1	IC6	DF10S/SM	DF10S

20	1	IC7	7805	7805_D2PAK
21	1	J1	JTAG	BLKCON.100/JTAG
22	7	J2	JUMPER	BLKCON.100/JUMPER
		J9	JUMPER	BLKCON.100/JUMPER
		J10	JUMPER	BLKCON.100/JUMPER
		J11	JUMPER	BLKCON.100/JUMPER
		J12	JUMPER	BLKCON.100/JUMPER
		J14	JUMPER	BLKCON.100/JUMPER
		J15	JUMPER	BLKCON.100/JUMPER
23	1	J3	HFBR_1412_TX	HFBR_X412
24	1	J4	HFBR_2412_RX	HFBR_X412
25	2	J17	CONN SOCKET 16x2	BLKCON.100/CONN_32
		J8	CONN SOCKET 16x2	BLKCON.100/CONN_32
26	1	J13	DC_JACK_2_IMM	DC_JACK
27	1	LCD1	LCD MODULE	BLKCON.100/LCD
28	1	L1	100mH	SM/L_0603
29	1	P1	CONNECTOR DB9	DB9/RS-232
30	9	R1	470	SM/R_0603
		R2	470	SM/R_0603
		R3	470	SM/R_0603
		R4	470	SM/R_0603
		R5	470	SM/R_0603
		R6	470	SM/R_0603
		R22	470	SM/R_0603
		R23	470	SM/R_0603
		R24	470	SM/R_0603
31	9	R7	10K	SM/R_0603
		R8	10K	SM/R_0603
		R9	10K	SM/R_0603
		R13	10K	SM/R_0603
		R14	10K	SM/R_0603
		R18	10K	SM/R_0603
		R21	10K	SM/R_0603
		R38	10K	SM/R_0603
		R39	10K	SM/R_0603
32	2	R10	100	SM/R_0603
		R41	100	SM/R_0603
33	1	R11	47K	SM/R_0603
34	1	R12	10K	BLKCON.100/POTENTIOMETERSM/R_0603
35	2	R15	27R	SM/R_0603
		R16	27R	SM/R_0603

36	1	R17	4K7	SM/R_0603
37	1	R19	1K5	SM/R_0603
38	1	R20	2K2	SM/R_0603
39	1	R35	14	SM/R_0603
40	1	R36	47	SM/R_0603
41	1	R37	47K	SM/R_0603
42	1	R40	1000	SM/R_0603
43	1	R42	500	SM/R_0603
44	5	SW_1	SW PUSHBUTTON-SPST-2/SM	SMD_SW
		SW_2	SW PUSHBUTTON-SPST-2/SM	SMD_SW
		SW_3	SW PUSHBUTTON-SPST-2/SM	SMD_SW
		SW_4	SW PUSHBUTTON-SPST-2/SM	SMD_SW
		SW_6	SW PUSHBUTTON-SPST-2/SM	SMD_SW
45	2	SW_5	SW SLIDE	SLIDE_SW
		SW1	SW SLIDE	SLIDE_SW
46	1	TR1	TFDU4100	TFDU4100
47	1	U13	DS75451/SO	SOG.050/8/DS7545_DRIVER
48	1	U16	SN7404	SOG.050/SN7404_INVT
49	1	X3	6Mhz	SM/CRYSTAL_2PIN
50	1	Y1	32,768 KHz	SM/CRYSTAL_4PIN

APPENDIX C: TEST CODE

LCD.h

```
/*********************************************************/
/*    Purpose:    LCD Driver                             */
/*    Version:    1                                      */
/*    Author:   ISHFAN VAKIL                             */
/*    Date:                                              */
/*    www:                                               */
/*    email:      ivakil@uncc.edu                        */
/*    Software:         AVR studio/ IAR                  */
/*    Hardware:         STK 500/STK 502                  */
/*********************************************************/

#include <ioavr.h>
#include <intrinsics.h>

#define LOW             0
#define HIGH            1
#define CLS             0x01
#define HOME            0x02
#define ENTRY           0x04
#define INCREMENT       0x02
#define DECREMENT       0x00
#define CONTROL         0x08
#define DISPLAY_ON      0x04
#define DISPLAY_OFF     0x00
#define CURSOR_ON       0x02
#define CURSOR_OFF      0x00
#define BLINK           0x01
#define NO_BLINK        0x00
#define SHIFT           0x10
#define SHI_LEFT        0x00
#define SHI_RIGHT       0x04
#define DIS_LEFT        0x08
#define DIS_RIGHT       0x0C
#define FUNCTION_SET    0x20
#define _8BIT           0x10
#define _4BIT           0x00
#define _2LINE          0x08
#define _1LINE          0x00
#define _10DOT          0x04
#define _7DOT           0x00

#define R_W             0x01
#define E               0x04

unsigned char RS;
void itoa(unsigned int value, unsigned char * s);
void wait(unsigned int  duration);
void clrscr(void);
void home(void);
void second_row(void);
void first_row(void);
void lcd_init(unsigned char line, unsigned char dots);
void lcd_out(char c);
void put_lcd(const unsigned char * s);
void put_lcd_xy(unsigned short int x, unsigned short int y, const
unsigned char * s);
```

```
void itoa(unsigned int value, unsigned char * s)
{
      unsigned int i;

      for (i=4;i>0;i--)
      {
            s[i] = (value % 10) + 0x30;
            value /= 10;
      }
}


void wait(unsigned int time)
{
      while (time > 0) time--;
}


void clrscr(void)
{
      RS = LOW;
      lcd_out(CLS);
      wait(1600);
      lcd_out(HOME);
      wait(1600);
      RS = HIGH;
}


void home(void)
{
      RS = LOW;
      lcd_out(HOME);
      wait(1600);
      RS = HIGH;
}

void second_row(void)
{
      RS = LOW;
      lcd_out(0x80 | 0x40);
      wait(1600);
      RS = HIGH;
}

void first_row(void)
{
      RS = LOW;
      lcd_out(0x80 | 0x00);
      wait(1600);
      RS = HIGH;
}

void lcd_init(unsigned char line, unsigned char dots)
{
      wait(15000);

      PORTA = 0x30;
      PORTA = (0x30 | E);
      PORTA = 0x30;
      wait(1000);

      PORTA = 0x30;
      PORTA = (0x30 | E);
```

```
	PORTA = 0x30;
	wait(1000);

	PORTA = 0x30;
	PORTA = (0x30 | E);
	PORTA = 0x30;
	wait(1000);

	PORTA = 0x20;
	PORTA = (0x20 | E);
	PORTA = 0x20;
	wait(1000);

	RS = LOW;

	lcd_out(FUNCTION_SET | _4BIT | line | dots);
	lcd_out(CONTROL | DISPLAY_OFF);
	lcd_out(CONTROL | DISPLAY_ON | CURSOR_OFF | NO_BLINK);
	lcd_out(CLS);
	wait(10000);
	lcd_out(HOME);
	wait(10000);
	lcd_out(ENTRY | INCREMENT);
	RS = HIGH;
}


void lcd_out(char c)
{
	PORTA = ((c & 0xF0) | RS);
	wait(1600);
	PORTA = ((c & 0xF0) | RS | E);
	wait(1600);
	PORTA = ((c & 0xF0) | RS);
	wait(1600);

	PORTA = (((c & 0x0F) << 4) | RS);
	wait(1600);
	PORTA = (((c & 0x0F) << 4) | RS | E);
	wait(1600);
	PORTA = (((c & 0x0F) << 4) | RS);
	wait(1600);
}


void put_lcd(const unsigned char * s)
{
	unsigned short int	i;

	i = 0;

	do
		{
			if (s[i] == '\0') break;
			if (i == 16) second_row();

			if (i == 32)
				{
					first_row();
					i = 0;
				}
			switch (s[i])
			{
				case 0xE4:  lcd_out(0xE1);
```

```
                                        break;

                        case 0xF6:  lcd_out(0xEF);
                                        break;

                        case 0xFC:  lcd_out(0xF5);
                                        break;

                        default:    lcd_out(s[i]);
                                        break;
                }

                i++;
                wait(1600);
        }

    while (s[i] != '\0');
}


void put_lcd_xy(unsigned short int x, unsigned short int y, const
unsigned char * s)
{
    unsigned short int      i,z,help;

    i = 0;

    if (y < 4) z = y;
    else z = 0;

    switch (z)
        {
            case 0:     help = x;
                        break;

            case 1:     help = x + 0x40;
                        break;

            case 2:     help = x + 0x10;
                        break;

            case 3:     help = x + 0x50;
                        break;

            default:
                        break;
        }

    RS = LOW;
    lcd_out(0x80 | help);
    wait(1600);
    RS = HIGH;

    do
        {
            if (s[i] == '\0') break;
            if ((x == 16) && (y == 0))
                {
                    second_row();
                    x = 0;
                    y = 1;
                }
            if ((x == 16) && (y == 3))
                {
```

```
                              first_row();
                              x = 0;
                              y = 0;
                        }

                  switch (s[i])
                  {
                        case 0xE4:  lcd_out(0xE1);
                                    break;

                        case 0xF6:  lcd_out(0xEF);
                        break;

                        case 0xFC:  lcd_out(0xF5);
                                    break;

                        default:    lcd_out(s[i]);
                                    break;
                  }

                  i++;
                  x++;
                  wait(1600);
            }

      while (s[i] != '\0');
}



int main( void )
{
      unsigned int      i;
      unsigned char     str[8];

      i = 0;
      str[5] = 0;

      DDRA = 0xFF;
      DDRB = 0xFF;
      PORTB = 0xAA;

      lcd_init(_2LINE,_7DOT);
      clrscr();
      home();

      //put_lcd_xy(0,0,"*ISHFAN*");
      //put_lcd_xy(0,1,"*VAKIL*");
      lcd_out('I');
      for (;;)
      {
            i++;
            itoa(i,str);
            put_lcd_xy(6,3,&str[1]);
            if (i == 9999) i = 0;
      }
}
```

UART.c

```
/*********************************************************/
/*    Purpose:    UART Driver                            */
/*    Version:    1                                      */
/*    Author:   ISHFAN VAKIL                             */
/*    Date:                                              */
/*    www:                                               */
/*    email:      ivakil@uncc.edu                        */
/*    Software:         AVR studio/ IAR                  */
/*    Hardware:         STK 500/STK 502                  */
/*********************************************************/


#include <ioavr.h>
#include <intrinsics.h>


#define F_CPU           8000000                    //  8 MHz
#define UART_BAUD_RATE  4800                       //  4800 Baud
#define UART_BAUD_SELECT (F_CPU/(UART_BAUD_RATE*16l)-1)

void uart_init(void);
unsigned char USART0_Receive( void );
void USART0_Transmit( unsigned char data );

void uart_init(void)
{
Baudrate festlegen (HIGH-Byte)
SREG_I=0;
UBRR0H = (unsigned char)(UART_BAUD_SELECT>>8);
UBRR0L = (unsigned char)UART_BAUD_SELECT;
UCSR0B= ( 1<<UCSR0B_RXEN0) | ( 1<< UCSR0B_TXEN0);
UCSR0C= (1<<UCSR0C_USBS0) | ( 3<< UCSR0C_UCSZ00);
UCSR0B_TXEN0=1;
UCSR0B_RXEN0=1;
SREG_I=1;
 }

unsigned char USART0_Receive( void )
{
      /* Wait for incomming data */
      while ( !(UCSR0A & (1<<UCSR0A_RXC0)) )
            ;
      /* Return the data */
      return UDR0;
}

void USART0_Transmit( unsigned char data )
{
      /* Wait for empty transmit buffer */
      //while ( !(UCSR0A & (1<<UCSR0A_UDRE0)) )
                  ;
      /* Start transmittion */
      UDR0 = data;
        if( data =='B')
        {
          PORTB= 0x00;
        }
}
```

```
void main(void)
{
        DDRB=0xFF;
        PORTB=0xAA;
       // SREG_I=1;
        UCSR0B_TXEN0=1;
        UCSR0B_RXEN0=1;

        uart_init();
        __enable_interrupt();
            //sei();

        for(;;)                              /* Forever */
      {
         USART0_Transmit('A');
          PORTB=0xAA;
          //UDR0='C';
         // PORTE='C';
      }
}
```

APPENDIX D: SAMPLE LAB EXERCISES

SAMPLE LAB EXERCISE 1:

Learning Objectives: This lab will introduce the students to use UART and interrupts with optical fiber communication on the communications educational board, along with C programming concepts to program the ATmega128L.

Laboratory Assignment: In this lab the student will be program the board to transmit data from one communication board to another using the optical fiber module present on the board. UART will be used to send and receive data. Error counts will be measured at different baud rates.

Steps:

1. Create a new project and name it lab_01.
2. Create the main.c file and include appropriate header files.
3. Program the board to meet the requirements (see requirements).
4. Compile and solve each requirement one at a time.
5. Continue to build and test the code until all the requirements are met.
6. Once all requirements are met, ensure everything is working correctly.
7. Collect the data necessary and write a complete lab report.

Requirements:

1. The code is written in C for the communication board.
2. The code is commented and easy to follow.
3. Use two communication boards to meet the requirements.
4. Connect the optical fiber (provided with the kit) between the optical fiber transmitter of board 1 and optical fiber receiver of board 2.

5. When Switch 1 is pressed on the board 1 start generating characters from ‘a’ to ‘Z’ and continue till Switch 1 is pressed again.
6. Send the characters to the optical fiber transmitter on board 1 by connecting the UART to Optical fiber jumper on the board.
7. Use queues and interrupts to handle the UART serial communication.
8. On board 2 connect the jumper to connect the UART circuit with the optical fiber receiver circuit.
9. Use interrupts on board 2 to detect the incoming characters from board 1.
10. On board 2 confirm that the characters received are correct and calculate the error count.
11. Change the baud rate in both the boards and recompile the program and take error count measurements again.
12. On the LCD display of board 1 display the character send and the baud rate used
13. On the LCD display of board 2 display the character received and the error count.
14. Take measurements for at least 5 different baud rates and provide the results in a tabulated form.

SAMPLE LAB EXERCISE 2:

Learning Objectives: This lab will introduce the students to use I/O pins and interrupts with optical fiber communication on the communications educational board, along with C programming concepts to program the ATmega128L.

Laboratory Assignment: In this lab the student will be program the board to transmit data from one communication board to another using the optical fiber module present on the board. I/O pins will be used to send and receive data. Error counts will be measured at different speeds

Steps:

1. Create a new project and name it lab_02.
2. Create the main.c file and include appropriate header files.
3. Program the board to meet the requirements (see requirements).
4. Compile and solve each requirement one at a time.
5. Continue to build and test the code until all the requirements are met.
6. Once all requirements are met, ensure everything is working correctly.
7. Collect the data necessary and write a complete lab report.

Requirements:

1. The code is written in C for the communication board.
2. The code is commented and easy to follow.
3. Use two communication boards to meet the requirements.
4. Connect the optical fiber (provided with the kit) between the optical fiber transmitter of board 1 and optical fiber receiver of board 2.

5. When switch 1 is pressed on the board 1 start generating characters from ‘a’ to ‘Z’ and continue till switch 1 is pressed again.
6. Program the I/O pin available on the board for serial communication.
7. Program the timers to control the speed of communication.
8. Send the characters to the optical fiber transmitter on board 1 by connecting the I/O pin from the programmed I/O pin connector to optical fiber jumper on the board.
9. Receive the characters from the optical fiber receiver on board 2 by connecting the programmed I/O pin from the I/O pin connector to optical fiber jumper on the board.
10. On board 2 confirm that the characters received are correct and calculate the error count.
11. Change the speed by changing the timer interrupt settings and recompile the program and take error count measurements again.
12. On the LCD display of board 1 display the number of characters sent per second.
13. On the LCD display of board 2 display the number of character received per second and the error count.
14. Take measurements for at least 5 different speeds and provide the results in a tabulated form.
15. Measure the highest rate possible at which the error count is 0.

SAMPLE LAB EXERCISE 3:

Learning Objectives: This lab will introduce the students to use UART and interrupts with infrared communication on the communications educational board, along with C programming concepts to program the ATmega128L.

Laboratory Assignment: In this lab the student will be program the board to transmit data from one communication board to another using the wireless infrared module present on the board. UART will be used to send and receive data. Error counts will be measured at different baud rates and distances between the two boards.

Steps:

1. Create a new project and name it lab_03.
2. Create the main.c file and include appropriate header files.
3. Program the board to meet the requirements (see requirements).
4. Compile and solve each requirement one at a time.
5. Continue to build and test the code until all the requirements are met.
6. Once all requirements are met, ensure everything is working correctly.
7. Collect the data necessary and write a complete lab report.

Requirements:

1. The code is written in C for the communication board.
2. The code is commented and easy to follow.
3. Use two communication boards to meet the requirements.
4. When switch 1 is pressed on the board 1 start generating characters from ‘a’ to ‘Z’ and continue till switch 1 is pressed again.

5. Send the characters to the infrared transceiver on board 1 by connecting the UART to infrared jumper on the board.
6. Use queues and interrupts to handle the UART serial communication.
7. On board 2 connect the jumper to connect the UART circuit with the infrared transceiver circuit.
8. Use interrupts on board 2 to detect the incoming characters from board 1.
9. On board 2 confirm that the characters received are correct and calculate the error count.
10. Change the baud rate in both the boards and recompile the program and take error count measurements again.
11. On the LCD display of board 1 display the baud rate used
12. On the LCD display of board 2 display the character received and the error count.
13. Take measurements for at least 5 different baud rates and provide the results in a tabulated form.
14. For each baud rate, measure the maximum distance between the two boards for error free data communication.

SAMPLE LAB EXERCISE 4:

Learning Objectives: This lab will introduce the students to use I/O pins and interrupts with infrared communication on the communications educational board, along with C programming concepts to program the ATmega128L.

Laboratory Assignment: In this lab the student will be program the board to transmit data from one communication board to another using the infrared module present on the board. I/O pins will be used to send and receive data. Error counts will be measured at different speeds and different distances between the two boards.

Steps:

1. Create a new project and name it lab_04.
2. Create the main.c file and include appropriate header files.
3. Program the board to meet the requirements (see requirements).
4. Compile and solve each requirement one at a time.
5. Continue to build and test the code until all the requirements are met.
6. Once all requirements are met, ensure everything is working correctly.
7. Collect the data necessary and write a complete lab report.

Requirements:

1. The code is written in C for the communication board.
2. The code is commented and easy to follow.
3. Use two communication boards to meet the requirements.
4. When switch 1 is pressed on the board 1 start generating characters from ‘a’ to ‘Z’ and continue till switch 1 is pressed again.
5. Program the I/O pin available on the board for serial communication.

6. Use timers to control the speed of communication.
7. Send the characters to the optical fiber transmitter on board 1 by connecting the I/O pin from the programmed I/O pin connector to infrared jumper on the board.
8. Receive the characters from the infrared transceiver on board 2 by connecting the programmed I/O pin from the I/O pin connector to infrared jumper on the board.
9. On board 2 confirm that the characters received are correct and calculate the error count.
10. Change the speed by changing the timer interrupt settings and recompile the program and take error count measurements again.
11. On the LCD display of board 1 display the number of characters sent per second.
12. On the LCD display of board 2 display the number of character received per second and the error count.
13. Take measurements for at least 5 different speeds and provide the results in a tabulated form.
14. Measure the highest rate possible at which the error count is 0.
15. For each speed, measure the maximum distance between the two boards for error free data communication.