



بسم الله الرحمن الرحيم

College of Engineering & Technology

Electrical and Computer Engineering Department

Graduation Project

**Telemedicine System Based
3G and MIMO WiFi Technology**

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بسم الله الرحمن الرحيم

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كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية والحاسوب

:

**Telemedicine System Based
3G and MIMO WiFi Technology**

:

خليل جواده

بناءً على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة و تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية والحاسوب وذلك البكالوريوس في تخصص هندسة الاتصالات .

توقيع المشرف

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توقيع اللجنة الممتحنة

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توقيع رئيس الدائرة

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Dedication:

**For my parents
and professors ,**

Acknowledgments

We would to extend our special thanks to everyone who has helped us to complete this work.

We would like to express our deepest appreciation and thanks to our supervisor Dr. Murad Abu subaih for his valuable guidance and support, his cooperation and detailed approach along with his encouragement were the major factors to get this work what it is today. It was a great pleasure to work under his supervision through this semester.

Our special thanks go to our parents, brothers, sisters, and friends. Without their support, this project would not have been possible.

Abstract

Telemedicine system facilitates monitoring and offers the homecare service to the patients. thus, it presents an attractive solution to the difficulties of transport in the big cities and hospital streambeds.

The evolution of wireless communication means enable telemedicine system to operate everywhere in the world thus expanding telemedicine benefits, applications, and services, through this project, we try to give a complete description of a proposed wireless telemedicine system, how this system is used in healthcare delivery and what are the technologies used.

The system allows the transmission of vital signals which are the body heart rate and SPO2 signal, also it allow to monitoring the patient case by real time video over wireless networks.

The transmission is performed through 3G network and MIMO WIFI technology applied by two scenarios. The first is 3G network which enable transmission of the acquired from patient's home to the monitoring room at hospital. The second is MIMO WIFI technology is used at hospital to connect the patient's room with monitoring room. Monitoring device is placed on the body of the patient it supplies continuously signals which can be analyzed by dedicated application software.

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List of Abbreviation

Abbreviation	Description
3G	Third Generation
MIMO	Multi Input Multi Output
WiFi	Wireless Fidelity
GSM	Global System For Mobile Communication
ECG	Electrocardiogram
SMS	Short Message Service
QOS	Quality Of Service
IP V6 , V4	Internet Protocol Version 6 Internet Protocol Version 4
SIM	Subscriber Identity Module
SPO2	Saturation Of Peripheral Oxygen
BP	Blood Pressure
HR	Heart Rate
HSDPA	High Speed Downlink Packet Access
RS232	Recommended Standard 232
USB	Universal Serial Bus
TCP/IP	Transmission Control Protocol/ Internet Protocol
WCDMA	Wideband Code Division Multiple Access
GPRS	General Packet Radio Service
EDGE	Enhanced Data For GSM Evolution
PIC	Peripheral Interface Controller
MIPS	Million Instructions Per Second

LAN	Local Area Network
WAN	Wide Area Network
L2TP	Layer 2 Tunnel
PPTP	Point To Point Protocol
PPPOE	Point To Point Protocol Over Ethernet
SPI	Service Provider Interface
USART	Universal Synchronous /Asynchronous Receiver/ Transmitter
IMT	International Mobile Telecommunication
TV	Television
ITU	International Telecommunication Union
UE	User Equipment
IMS	Internet Mail Service
UMTS	Universal Mobile Telecommunication System
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
EVDO	Evolution Data Optimized
SNR	Signal to Noise Ratio
SISO	Single Input Single Output
PC	Personal Computer
LCD	Liquid Crystal Display
TX	Transmitted Data
RX	Received Data
OP AMP	Operational Amplifier

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CHAPTER ONE

INTRODUCTION

- 1.1 Overview
- 1.2 Project Objectives
- 1.3 Project Motivation
- 1.4 Project Idea and Approach
- 1.5 Previous Studies
- 1.6 Time Schedule
- 1.7 Estimated cost
- 1.8 Project Contents

1.1 Overview

Rapid advances in information technology and telecommunications, and more specifically wireless and mobile communications, and their convergence (telematics) are leading to the emergence of a new type of information infrastructure that has the potential of supporting an array of advanced services for healthcare.

In this project , we intend to design a system for human health monitoring, and delivery of vital parameters or signals, and make video conference between patient and doctor. The system is based on third generation network technology (3G) and Multi Input Multi Output Technology (MIMO).

The system is expected to be useful for patients, doctors, and nurses. It will enable remote monitoring as well as consultation.

1.2 Project Objectives

- 1) Remote and live monitoring video of patients.
- 2) Fast, reliable and more accurate transfer of vital parameters by 3G GSM modem and Multi Input Multi Output devices(MIMO).
- 3) Reduction of the financial burden on patients .
- 4) Reduction of the psychological and physical pressure on patients.

1.3 Project Motivation

The motivation of this project is to find a modern mean of patient care to overcome the physical obstacles that was Caused by Israeli occupation which prevents the patient from going to hospitals Sometimes.

Here we suggest a model that uses new technologies for health care which more reliable and provide high speed by using modern wireless technology (MIMO) and 3G GSM network . We can make the patient feels good sure about his health all the time without keeping going to hospitals.

This system will not cost the patient a lot of money because he does not have to visit his or her doctor every time. Doctor can take some of the patient urgent vital parameter by using the planned system. Also, a doctor can advise his patient to contact him through video streaming.

1.4 Project Idea and Approach

The idea of this project is to enhance the speed and quality of remote monitoring and supervision of patients inside homes and hospitals. We try to achieve these goals using modern wireless technology based on (MIMO) WiFi devices and 3G networks.

1.5 Previous Studies

The previous project (Telemedicine System Using GSM and WiFi Networks) uses 2.5 G mobiles and WiFi to transfer body temperature and ECG signal as SMS. But, the data rate of 2.5G is 9.6Kb/s and 3G provides 200Kb/s. The previous project uses cellular phone to transfer data. This leads to limited service that 2.5G provides. Further, The 2.5 G it self provides limited application support compared to 3G.

Related Works:

In [1], a telemedicine system design based on Bluetooth and mobile phone network. This paper introduces a telemedicine system design, which provides several common services based on wireless communication technologies. The system includes the multifunction portable measure equipment design by using embedded system, the reliable communication and customer services design on the Smartphone terminal, powerful database management design in the medical center, the direct interface design on the Browser-Server terminal.

In [2], the authors introduce the issue of a Current trends and future challenges in wireless telemedicine system. This paper discusses the state of the art and the major issues in wireless telemedicine systems such as secure transmission of data, patient monitoring and effective medical video compression.

The paper of [3], discusses enhancement m-Health System by 3G-network. This architecture of a multi-collaborative mobile telemedicine system operating over third-generation (3G) mobile networks is presented. The system architecture is based on advanced signaling protocols that allow multimedia multi-collaborative conferences in IPv4/IPv6 3G scenarios. It is designed to communicate the personnel of an ambulance with medical specialists in a remote hospital through a 3G mobile access, providing appropriate support for real-time transmission of medical data and videoconference, together with other non real-time services. The system has been optimized specifically to operate over 3G mobile networks using the most appropriate codes and quality of service (QoS) mechanisms to improve the services offered.

Reference [4], discusses an Audiovisual Quality Assessment for 3G Networks in Support of E-Healthcare Services, and the (QoS) implications in the application of 3G networks in E-healthcare.

1.6 Time Schedule

The table 1.1 shows the activates and efforts done on the project and the time associated with each one.

Table: 1.1 Time Planning

[illegible]

1.7 Estimated Cost

The components needed to implement the project and their cost are shown in Table 1.2.

Table 1.2: Hardware cost

Equipment	Cost (NIS)
3G GSM Modem*2	1200
Cameras	50
Microcontroller*2	200
TTL to Serial convertor	40
SIM*2 + balance	600
Amplifiers	50
Capacitors	10
Resistance	20
Microphone	30
Total	2200 NIS

1.8 Project Contents

This report is organized as follow:

Chapter One: Introduction

This chapter contains general idea, objectives, motivation, previous studies, and schedule time.

Chapter Two: Theoretical Background

This chapter describes theories and material used in the system.

Chapter Three: System Design

This chapter presents the project design, and general block diagram.

Chapter Four: Hardware Design and Implementation

This chapter describes the equipment or devices used in the system, and their design.

Chapter Five: Software Design Implementation

This chapter describes the software programs used in the system, and their implementation.

Chapter Six: Result and performance

CHAPTER TWO

THEORITICAL BACKGROUND

2.1 Medical Parameters

2.1.1 Series Pulse Oximeter (SPO2) Parameter

2.1.2 Heart Rate (HR)

2.2 Components

2.2.1 3rd Generation GSM Modem

2.2.2 Arduino Microcontroller

2.2.3 Multi Input Multi Output (MIMO)WiFi Router

2.2.4 Heart Rate and SPO2 Sensor

2.3 3rd Generation Mobiles

2.3.1 3rd Generation GSM Overview

2.3.4 Multi Input Multi Output(MIMO) WiFi System

2.1 Medical Parameter

This section explains the vital parameters that will be considered in the system.

2.1.1 Series Pulse Oximeter (SPO2) Parameter

The M Series Pulse Oximeter (**SPO2**) continuously and non-invasively measures the oxygen saturation of arteriolar hemoglobin at a peripheral measurement site, (i.e. foot, toe or finger) in figure 2.1. It is used for monitoring patients who are at risk of developing hypoxemia. SpO2 monitoring gives information about both the cardiac and respiratory systems, and provides details of oxygen transportation in the body. It is widely used because it is non-invasive, continuous, easily applied and painless.[7]

The oximetry sensor contains two light emitting diodes (LEDs) that transmit red and infrared light through the body's extremities. The transmitted light is then received by a photo detector.

Oxygen-saturated blood absorbs light differently than unsaturated blood. Thus the amount of red and infrared light absorbed by blood flowing through a suitable peripheral area of the body, typically the finger in adults and the foot in neonates, can be used to calculate the ratio of oxygenated hemoglobin to total hemoglobin in arterial blood. The monitor displays this ratio as percent SpO2. Normal values typically range from 95% to 100% at sea level.

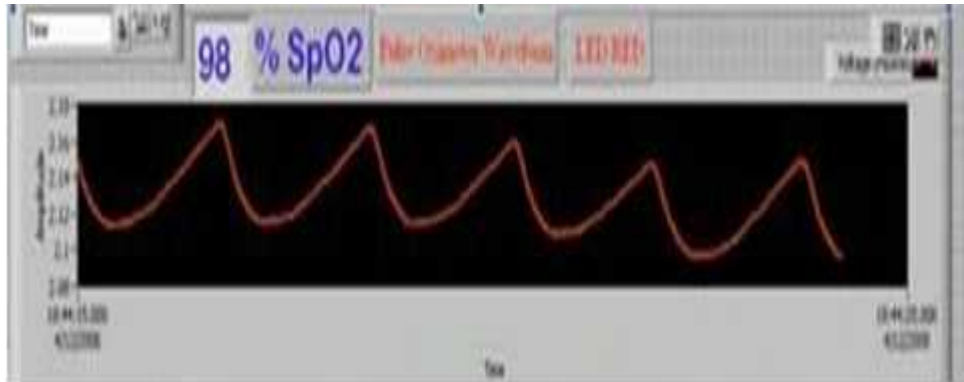


Figure 2.1: Series Pulse Oximeter (SPO2) Parameter Signal

$$\%SpO_2 = \frac{HbO_2}{Hb+HbO_2} * 100\% \quad (2.1)$$

Where: *HbO2* and *Hb* denote oxyhaemoglobin and deoxyhaemoglobin, respectively.

The designed pulse oximeter using finger-type probe is depicted, the light emitter with red (with wavelength of 600-750nm) and infrared (with wavelength 850-1000nm) LEDs and the TCS-230 photo detector are opposite of each other with the measuring site in-between as shown in Figure 2.2.[7]

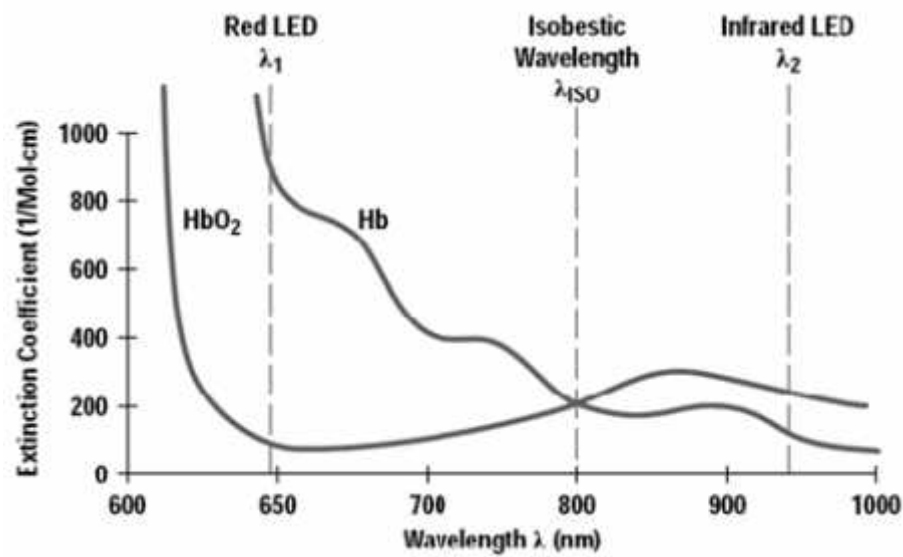


Figure 2.2: Explains How designed Pulse Oximeter

2.1.2 Heart Rate (HR) Parameter

Is the number of heartbeats per unit of time, typically expressed as *beats per minute*(bpm). Heart rate can vary as the body's need to absorb oxygen and excrete carbon dioxide changes, such as during exercise or sleep.

The measurement of heart rate is used by medical professionals to assist in the diagnosis and tracking of medical conditions. It is also used by individuals, such as athletes, who are interested in monitoring their heart rate to gain maximum efficiency from their training. The *R wave to R wave interval* (*RR interval*) is the inverse of the heart rate.

Heart rate is measured by finding the pulse of the body. This pulse rate can be measured at any point on the body where the artery's pulsation is transmitted to the surface by pressuring it with the index and middle fingers; often it is compressed against an underlying structure like bone. The thumb should not be used for measuring another person's heart rate, as its strong pulse may interfere with correct perception of the target pulse.

2.2 Components

This section describes the most important or major electronic devices that will be used throughout this system, for monitoring, processing and delivery of vital parameters.

2.2.1 3rd Generation GSM Modem

This is the 3G modem that will be used in Figure 2.3. It supports or can handle the (HSDPA) standard, and can support high speed or data rate. Also it contains a (RS232+USB) interface. This modem has the following features:

- 1) RS232+USB interface
- 2) Based on Simcom module SIM5216E
- 3) With TCP/IP stack
- 4) WCDMA/HSDPA 900/2100MHZ
- 5) GSM/GPRS/EDGE:850/900/1800MHZ
- 6) GPRS class 12
- 7) EDGE class 12



Figure 2.3: 3rd Generation GSM Modem

2.2.2 Microcontroller (Arduino)

The Arduino microcontroller in figure 2.4 is an easy to use yet powerful single board computer that has gained considerable traction in the hobby and professional market. The Arduino is open-source, which means hardware is reasonably priced and development software is free. This guide is for students in ME 2011, or students anywhere who are confronting the Arduino for the first time.

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the ATmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform.

The main advantages of Arduino microcontrollers:

- 1) Inexpensive - Arduino boards are relatively inexpensive compared to other microcontroller platforms.
- 2) Simple, clear programming environment - The Arduino programming environment is easy-to-use for beginners, yet flexible enough for advanced users.
- 3) Open source and extensible software- The Arduino software and is published as open source tools, available for extension by experienced programmers.
- 4) Open source and extensible hardware - The Arduino is based on Atmel's ATMEGA8 and ATMEGA168 microcontrollers.



Fig 2.4: Arduino microcontroller ship

2.2.3 Multi Input Multi Output (MIMO)Wi-Fi Router

Cisco Linksys E3000

A Wireless-N router with simultaneous 2.4 and 5 GHz bands designed to increase bandwidth. Optimized for smoother and faster HD(High Data rate) video streaming, file transfers, and wireless gaming. It contains three internal antenna, and it has four port, for Ethernet network and USB interface. Built-in AV media server streams entertainment content. The USB port provides connectivity to storage devices for file sharing at home or over the Internet.

The router comes with 4 LAN ports and one WAN port on the back. All are Gigabit-capable, meaning they support throughput up to 1,000Mbps on our 2.4GHz frequency tests, the router scores, as expected, weren't as high as those of the 5GHz frequency. It scored 43.5Mbps on the close-range throughput test and 33.6Mbps on the long-range test. On the mixed-mode test, where the router was set to work with both N and legacy G wireless clients, it scored 44.4Mbps.

The Linksys E3000 offers very good range, up to 280 feet in the 2.4GHz band and about 250 feet with its 5GHz band. Both are long among high-end true dual-band routers.

In general Table 2.1 contains other specifications of MIMO linksysE3000 shown in Figure 2.5:

Table 2.1: General Features of MIMO linksysE3000 Router

Data Link Protocol	Ethernet, Gigabit Ethernet, IEEE 802.11b, IEEE 802.11n, IEEE 802.11a, IEEE 802.11g, Fast Ethernet
Data Transfer Rate	300 Mbps
Network / Transport Protocol	L2TP , PPTP , PPPOE
Encryption Algorithm	WPA2, WPA2-Enterprise, WPA-Enterprise, WPA
Antennas	3 Internal



Figure 2.5: MIMO linksysE3000 Router

2.2.4 Heart Rate and SPO2 Sensor

Heart rate measurement indicates the soundness of the human cardiovascular system. To measure the heart rate by sensing the change in blood volume in a finger artery while the heart is pumping the blood. It consists of an infrared LED that transmits an IR signal through the fingertip of the subject, a part of which is reflected by the blood cells. The reflected signal is detected by a photo diode sensor. The changing blood volume with heartbeat results in a train of pulses at the output of the photo diode.

The sensor in figure 2.6 unit consists of an infrared light-emitting-diode (IR LED) and a photodiode, placed side by side as shown in figure 2.5. The IR diode transmits an infrared light into the fingertip (placed over the sensor unit), and the photodiode senses the portion of the light that is reflected back. The intensity of reflected light depends upon the blood volume inside the fingertip. So, each heart beat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With a proper signal conditioning, this little change in the amplitude of the reflected light can be converted into a pulse.

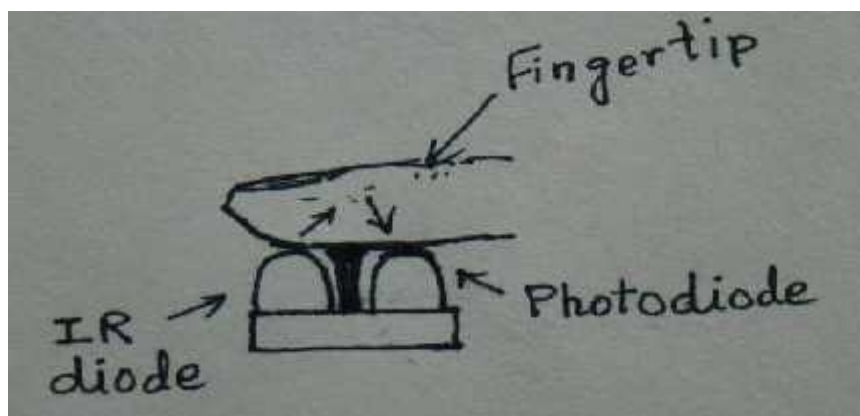


Figure 2.6: Fingertip placement over the sensor unit

2.3 3rd Generation Mobiles

3G refers to the third generation of mobile telephony (cellular) technology. The third generation, as the name suggests, follows two earlier generations.

3.3.1 3rd Generation GSM Overview .[8]

3G or 3rd generation mobile telecommunications is a generation of standards for mobile phones and mobile telecommunication services fulfilling the **International Mobile Telecommunications-2000 (IMT-2000)** specifications by the International Telecommunication Union.

Application services include wide-area wireless voice telephone, mobile Internet access, video calls and mobile TV, all in a mobile environment. To meet the IMT-2000 standards, a system is required to provide peak data rates of at least 200 Kbit/s, with the following features:

Data rates

ITU has not provided a clear definition of the data rate users can expect from 3G equipment or providers. Thus users sold 3G service may not be able to point to a standard and say that the rates it specifies are not being met. While stating in commentary that "it is expected that IMT-2000 will provide higher transmission rates: a minimum data rate of 2 Mbit/s for stationary or walking users, and 384 kbit/s in a moving vehicle, the ITU does not actually clearly specify minimum or average rates or what modes of the interfaces qualify as 3G, so various rates are sold as 3G intended to meet customers expectations of broadband data.

Security

3G networks offer greater security than their 2G predecessors. By allowing the UE (User Equipment) to authenticate the network it is attaching to, the user can be sure the network is the intended one and not an impersonator.

In addition to the 3G network infrastructure security, end-to-end security is offered when application frameworks such as IMS are accessed, although this is not strictly a 3G property.

Standards comply with the IMT2000/3G

The following common standards comply with the IMT2000/3G standard:

1) Enhanced Data Rates for GSM Evolution (**EDGE**) a revision by the 3GPP organization to the older 2G GSM based transmission methods, utilizing the same switching nodes, base station sites and frequencies as GPRS(General Packet Radio Service), but new base station and cell phone RF circuits. It is based on the three times as efficient 8PSK modulation scheme as supplement to the original GMSK modulation scheme. EDGE is still used extensively due to its ease of upgrade from existing 2G GSM infrastructure and cell-phones.[9]

- EDGE combined with the GPRS 2.5G technology is called EGPRS(Enhancement GPRS) , and allows peak data rates in the order of 200 Kbit/s, just as the original Universal Mobile Telecommunications System Wide Code Division Multiple Access

(UMTSWCDMA) versions, and thus formally fulfills the IMT2000 requirements on 3G systems. However, in practice EDGE is seldom marketed as a 3G system, but a 2.9G system. EDGE shows slightly better system spectral efficiency than the original UMTS and CDMA2000 systems, but it is difficult to reach much higher peak data rates due to the limited GSM spectral bandwidth of 200 kHz, and it is thus a dead end.

- EDGE was also a mode in the IS-135 TDMA(Time Division Multiple Access) system, today ceased.

2) The Universal Mobile Telecommunications System (**UMTS**), created and revised by the 3rd Generation Partnership Project (**3GPP**). The family is a full revision from GSM in terms of encoding methods and hardware, although some GSM sites can be retrofitted to broadcast in the UMTS/W-CDMA format.

- Wideband Code Division Multiple Access(**W-CDMA**)is the most common deployment, commonly operated on the 2100 MHz band. A few others use the 900 and 1850 MHz bands.
- High Speed Packet Access(**HSPA**)is a revision and upgrade to W-CDMA UMTS, used by AT&T Wireless, Telstra and Telecom NZ, typically broadcasting on the 850 MHz band. HSPA requires updates to the HSPA+ a revision and upgrade of HSPA, can provide peak data rates up to 56 Mbit/s in the downlink in theory (28 Mbit/s in existing services) and 22 Mbit/s in the uplink. It utilizes multiple base stations to potentially double the channels available utilizing MIMO principles.[9]

3) The Code Division Multiple Access 2000 (**CDMA2000**) system, or IS-2000, including CDMA2000 1x and CDMA2000 High Rate Packet Data (or EVDO), standardized by 3GPP2 (differing from the 3GPP), evolving from the original IS-95 CDMA system, is used especially in North America, China, India, Japan, South Korea, Southeast Asia, Europe and Africa.[9]

2.3.3 Multi Input Multi Output(MIMO) WiFi System.[10]

Multiple-input multiple-output (**MIMO**) in Figure 2.7. Can extend the capabilities of the 3G and 4G systems to provide customers with increased data throughput for mobile high-speed data applications.

MIMO systems use multiple antennas at both the transmitter and receiver to increase the capacity of the wireless channel. This leads higher spectral efficiency (more bits per second per hertz of bandwidth).

With **MIMO**, it may be possible to provide in excess of 1 Mbps for 2.5G wireless **TDMA** **EDGE** and as high as 20 Mbps for 4G systems.

With **MIMO**, different signals are transmitted out of each antenna simultaneously in the same bandwidth and then separated at the receiver.

MIMO can support multiple independent channels in the same bandwidth, provided the multipath environment is rich enough.

This means that high capacities are theoretically possible, unless there is a direct line-of-sight between the transmitter and receiver.

If the number of transmitting antennas is N , and the number of receiving antennas is M , this leads to the Shannon limit on channel capacity C is:

$$C = \log_2(1 + N * M * SNR_0)$$

Where, SNR_0 is the average signal-to-noise ratio at the receiver in single input single output system (SISO), and B is the bandwidth of the system.

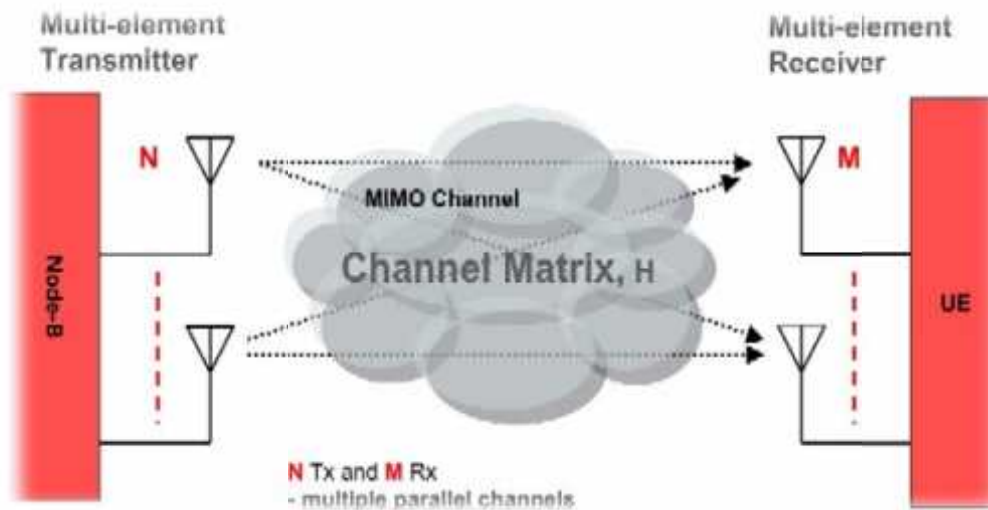


Figure 2.7: Multi Input Multi Output (MIMO) WiFi System

CHAPTER THREE

SYSTEM DESIGN

- 3.1 Introduction
- 3.2 General System Block Diagram
- 3.3 System Scenarios
- 3.4 Monitoring Sensor Connection
 - 3.4.1 General Connection
 - 3.4.2 Heart Rate and SPO2Sensor
- 3.5 Arduino Microcontroller
- 3.6 MIMO Device
 - 3.6.1 CISCO Link Sys E3000 MIMO Device
 - 3.6.2 Access Point
- 3.7 3rd Generation GSM Modem

3.1 Introduction

This chapter discusses the system concept and the scenarios which are MIMO WiFi and 3rd Generation GSM Network. It also describes the subsidiary block diagrams of each part.

Additionally, features and detailed schematic diagrams for each component, will be shown.

3.2 General System Block Diagram

The figure 3.1 describe general block diagram of the system to transfer vital parameter in first and second scenario.

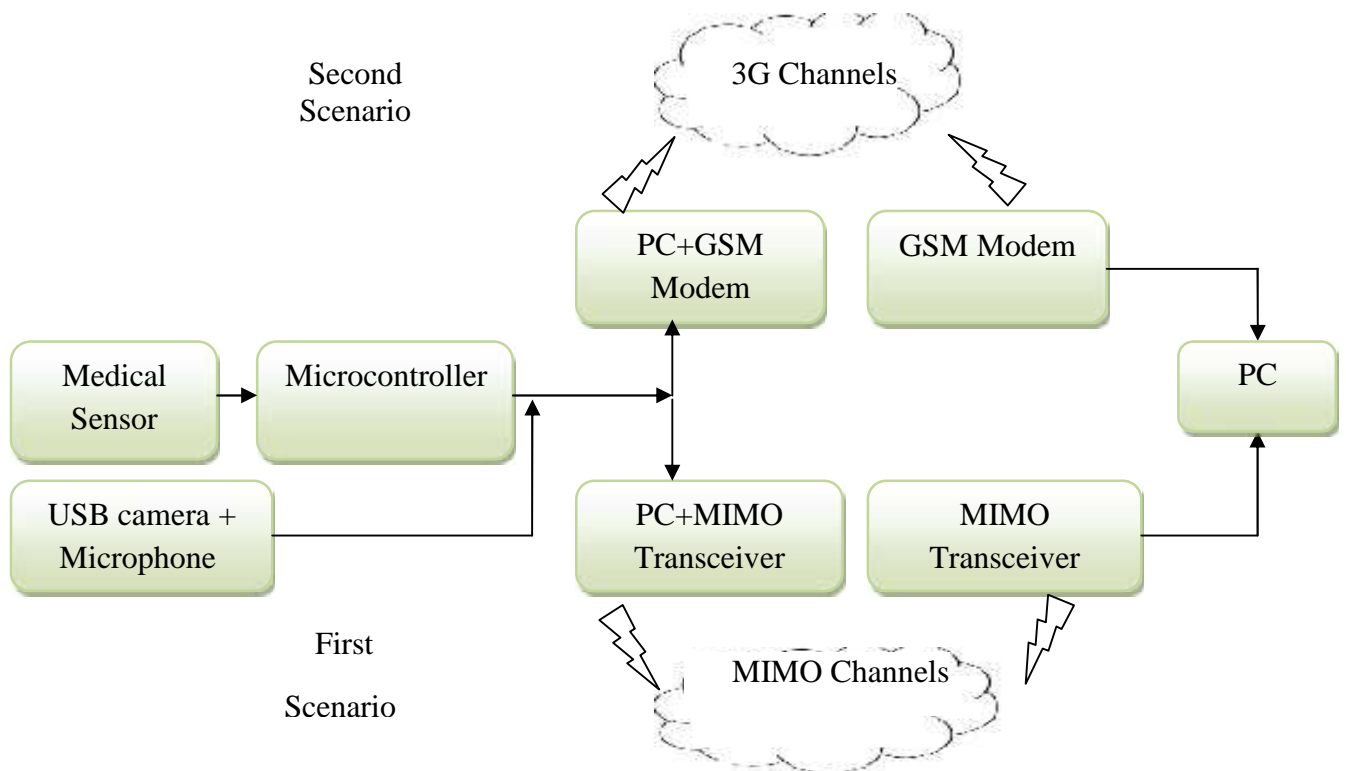


Figure 3.1: General System Block Diagram

3.3 System Scenarios

The communication part of the system involves two Scenarios. The **first** scenario based on the MIMO WiFi as shown in Figure 3.1. the first step is measuring vital signal by using specific circuit that will be designed then introduced vital signal to arduino microcontroller to process it, and the arduino microcontroller send the processing vital signal to serial interface RS232 of the laptop to send it through WiFi network, these previous steps in the patient side inside hospital. In the monitoring room the measurements of the patient to display at the laptop.

The **second** scenario, It is based on 3G network. In this scenario the patient in the home as shown in Figure 3.1, after measurement the vital signal, and processing it in the arduino microcontroller, then arduino send vital signal to 3G GSM modem to transfer it to the second 3G GSM modem in the monitoring room in hospital. In monitoring room the 3G GSM modem connected to laptop to display the result.

In both scenarios of the system, monitoring is constantly performed by reading signals every 10 minutes.

As shown in figure 3.1. The USB camera connect with the laptop in each of scenario, in the first scenario the camera connecting to laptop via USB port and we using matlab program to process the video signal and transmission to laptop in monitoring room through WiFi. In second scenario the 3G GSM modem connected with laptop in the patient side and we using matlab program to process the video signal and transmission through 3G network. In the other 3G GSM modem connecting to laptop in monitoring side. it will showing this programmed in matlab in chapter five.

The whole system Scenarios can be described by two flowcharts in figure 3.2, and figure 3.3.

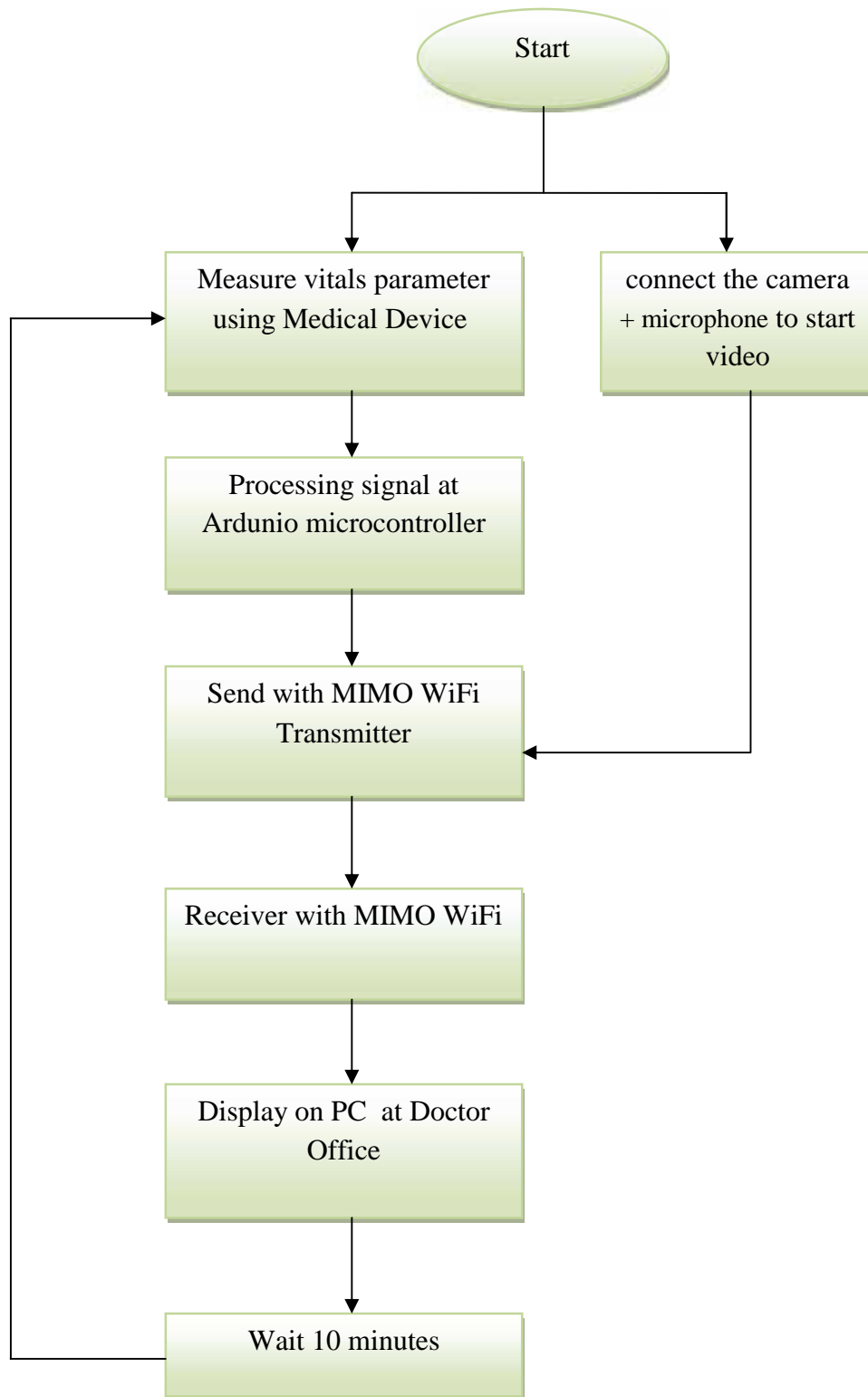


Figure 3.2: Flowchart of the First Scenario in Hospital Monitoring

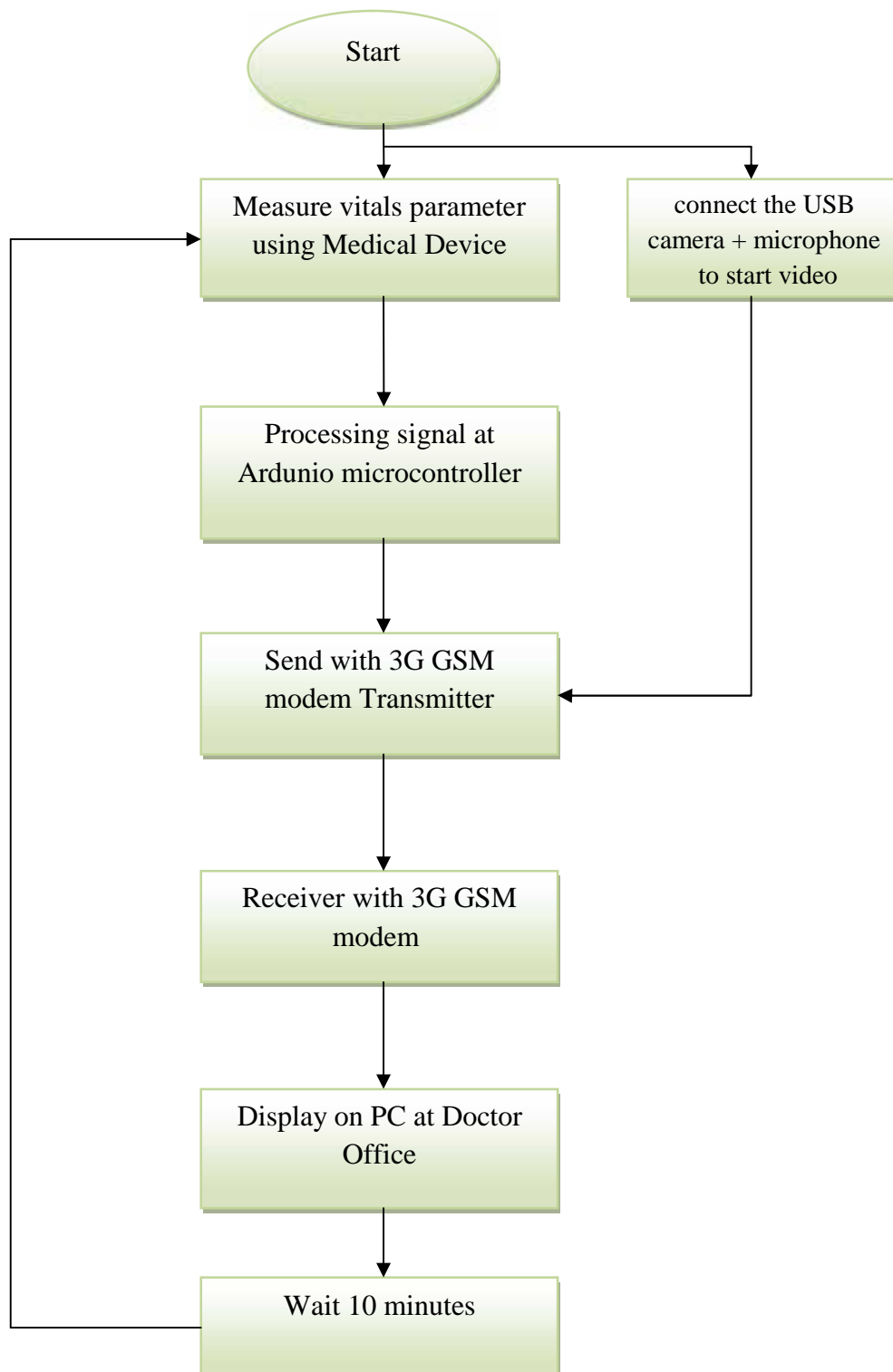


Figure 3.3: Flowchart of the Second Scenario in Home Monitoring

3.4 Monitoring Sensor Connection

3.4.1 General Connection

As shown in figure 3.4. The sensor measure HR and SPO2 parameter, but the magnitude of which is too small to be detected directly by a microcontroller. Therefore, a two-stage high gain, active low pass filter is designed using two Operational Amplifiers (OpAmps) to filter and amplify the signal to appropriate voltage level so that the result can be detected by a Arduino microcontroller.

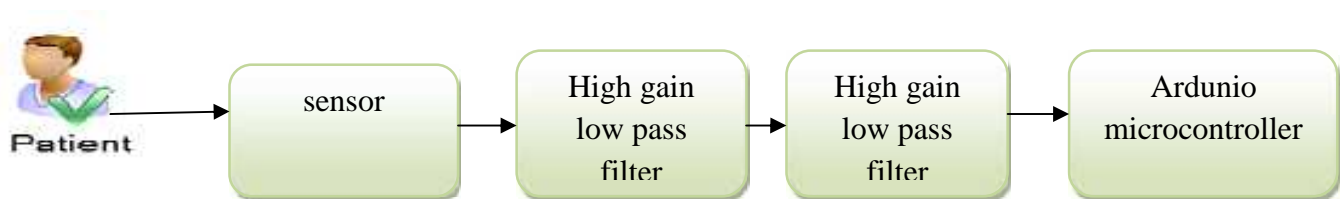


Figure3.4: Block Diagram of sensor Connection

3.4.2 Heart Rate and SPO2 Sensor

The signal conditioning circuit consists of two identical active low pass filters with a cut-off frequency of about 2.5 Hz. This means the maximum measurable heart rate is about 150 bpm. The operational amplifier IC used in this circuit is MCP602, a dual OpAmp chip from Microchip. It operates at a single power supply and provides rail-to-rail output swing. The filtering is necessary to block any higher frequency noises present in the signal. The gain of each filter stage is set to 101, giving the total amplification of about 10000. A 1 uF capacitor at the input of each stage is required to block the dc component in the signal. The equations for calculating gain and cut-off frequency of the active low pass filter are shown in the circuit diagram. The two stage amplifier/filter provides sufficient gain to boost the weak signal coming from the photo sensor unit and convert it into a pulse. An LED connected at the output blinks every time a heart beat is detected. The output from the signal conditioner goes to the A0 analog input of Arduino microcontroller.

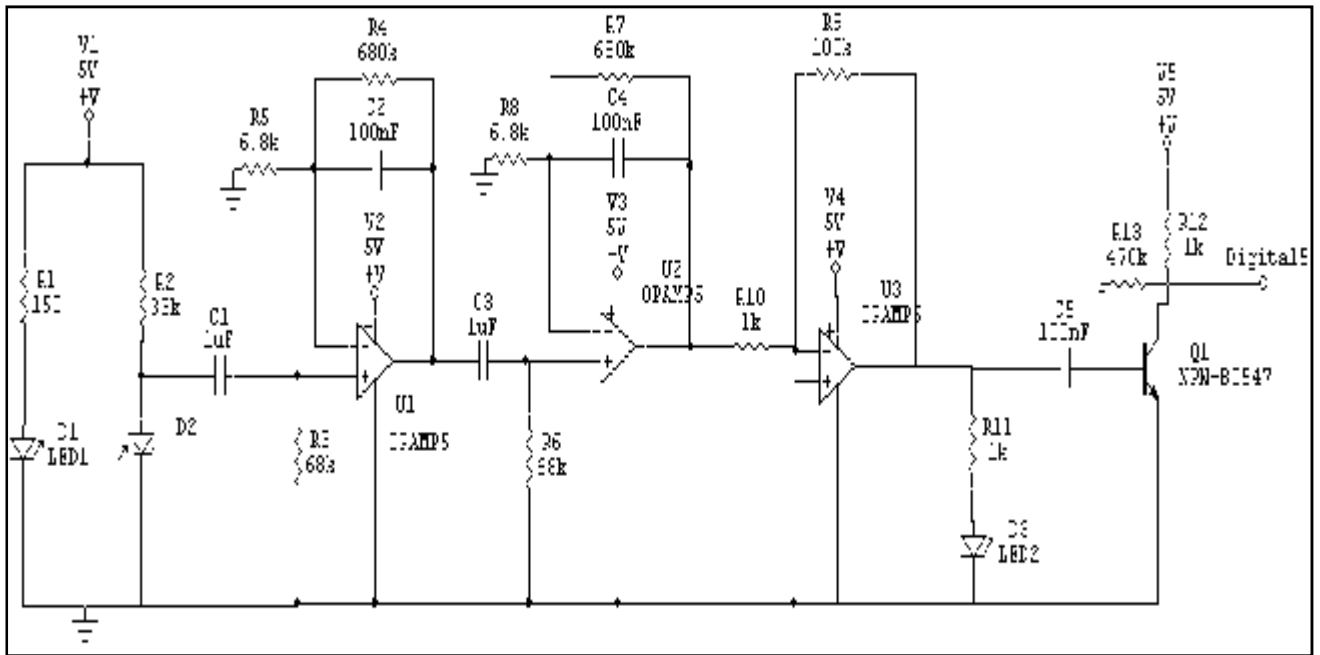


Fig3.5: Sensor circuit

3.5 Arduino Microcontroller

This section describes the microcontroller used in the system. The microcontroller type used in this system is arduino 328. Ardunio receive (vital signal) from the circuit that designed and transfer it to the laptop via RS232 connection in the first scenario , In the second scenario after the ardunio microcontroller receive(vital signal) the ardunio send it to 3G GSM modem by using ardunio program that include AT commands to 3G GSM modem to transfer it.

We have used two microcontrollers: first jointed with Wi-Fi transceiver in the first scenario, and the second connected to 3G GSM modem in the second scenario, as shown in Figure 3. 5.

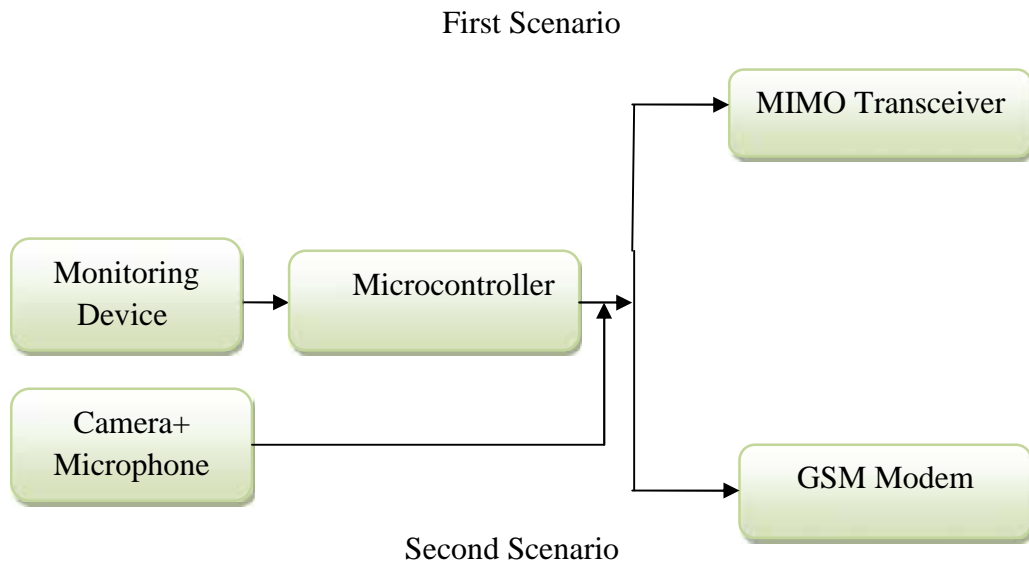


Figure3.6: Block Diagram of Microcontroller in MIMO WiFi and GSM Scenarios

3.6 MIMO Device

3.6.1 CISCO Link Sys E3000 MIMO Device

This section discusses how the MIMO transceiver device works in the system, and the way to connect this device with other devices. In this system the MIMO transceiver is operating at 2.4 GHz frequency, and it used 802.11n to transmit and receive data which provide 300Mbps, and this device contain with 3 antennas for transmitter and 3 antennas for receiver.

The MIMO transceiver connects with microcontroller in serial, and it also takes the data from the microcontroller after processing it to transmit by 802.11n standard to the receiver throughout MIMO WiFi Access point, as shown in figure 3.6.

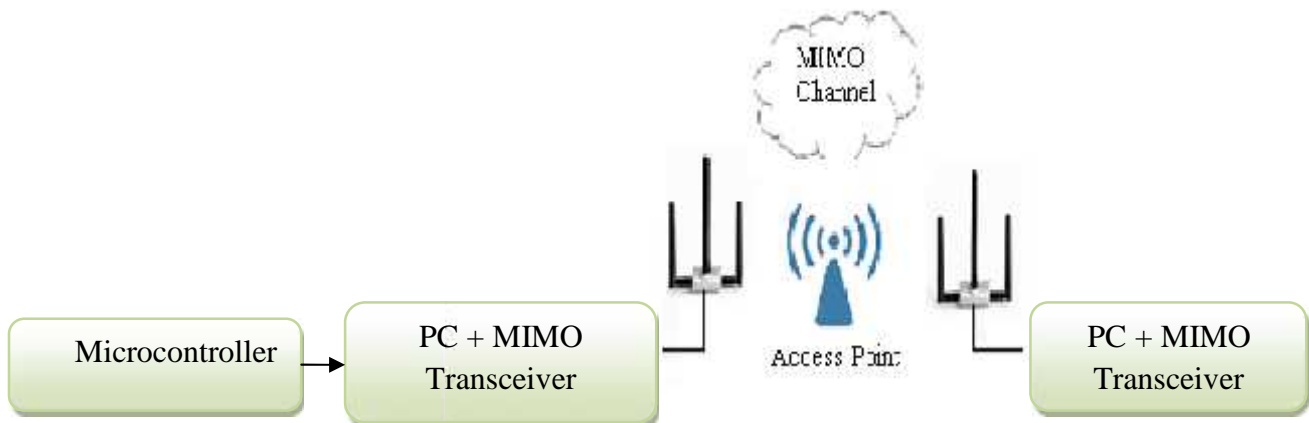


Figure3.7: Block Diagram of MIMO WiFi Devices Connection

The chosen MIMO Device is CISCO Link Sys E3000. It is a MIMO access point device as shown in figure 3.7. It will be used in system. This device can operate with 802.11 a\b\g\n standards, and it provides data rate up to 300Mbps. Also, it can be connected with LAN and wireless station and vice versa, and it can operate at different network protocols like L2TP, PPTP, PPPOE.**[14]**

The Linksys E3000 offers very good range, up to 280 feet in the 2.4GHz band and about 250 feet with its 5GHz band. Both are long among high-end true dual-band routers.

This access point has a good interface to deal with other networks. So it has four interfacing ports for Ethernet network, one port for USB interfacing, also it contain one port for internet connection.



Figure3.8: CISCO Linksys E3000 Device

3.6.2 Access Point

The access point is an important component in this system, specially on MIMO scenario. It lies between MIMO transmitter and MIMO receiver, so that the data in this scenario must go through to this device. The main function of the access point in MIMO system is receive to data from MIMO transmitter and broadcast it to other receiving labtop, operating in the 802.11n mode.

3.7 3rd Generation GSM Modem

As we shown previously in the second scenario, we used a programmable 3rd G GSM modem by using (AT commands) set, based on Simcom module SIM5216E with TCP/IP stack, to make the system active. In this scenario, the modem is located after the microcontroller by using a RS232 interfaces as shown in figure 3.10.[11]



Figure 3.9 : Block Diagram of GSM Modem Connection

As shown in above block diagram, the arduino microcontroller after processing the vital signal , arduino sent vital signal and the AT commands through RS232 to the 3G GSM modem. The AT commands that the arduino send it to 3G GSM modem that written in C language in the arduino program to operate the 3G GSM modem to send vital signal through SMS from the patient in the home to the second 3G GSM modem in the monitoring room in the hospital. In the monitoring room the second 3G GSM modem connected it to PC via RS232 to display the measuring vital signal of the patient.

CHAPTER FOUR

HARDWARE DESIGN IMPLEMENTATION

- 4.1 Introduction
- 4.2 Interfacing Arduino Microcontroller
- 4.3. Sensor Interfacing
- 4.4 PC Interfacing
- 4.5 3G GSM Modem Interfacing
- 4.6 Video Connection In The System
- 4.7 Hardware Connections of MIMO Wi-Fi and 3G GSM Scenarios

4.1 Introduction

After viewing the general system design in the previous chapter, in this chapter we will introduce the specific details of the connection and interfacing for several components in each scenario.

This chapter presents hardware details by pointing to each pin and showing how it is combined and connected with other pins in each device.

4.2 Interfacing Arduino Microcontroller

In this project, two Arduino microcontrollers have been used. One is jointed with PC in the MIMO Wi-Fi scenario. The other one is connected to 3G GSM modem in the second scenario.

Arduino microcontroller is a central unit in this project, it receives the medical signal from the sensor circuit, processes them and sending the results to the transceivers.

The sensor circuit have been connected to Arduino via digital and analog pins on the Arduino board which has 14 digital input/output pins and 6 analog input pins.

The following figure shows a description of the Arduino microcontroller pins.

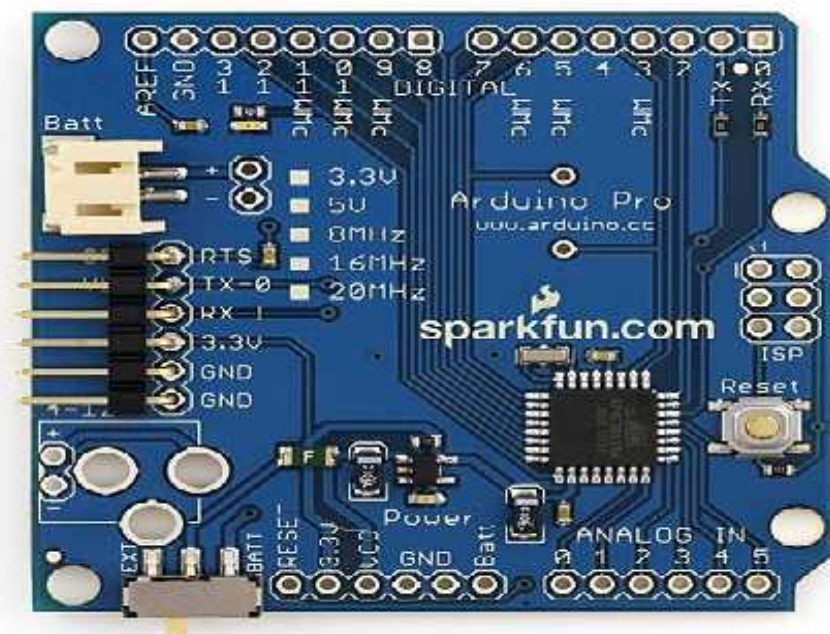


Figure 4.1: Arduino Chip Pins

Description of the Arduino Pins:

Power Pins:

The Arduino Pro can be powered via the USB header, with a battery, or with an external power supply. The battery power jack is a JST header. A power jack for an external supply can be soldered to the board.

The power pins are as follows:

- 1) **VIN**. The voltage supplied to the board from a battery or the DC power jack (according to the position of the switch). You can supply voltage through this pin, or, if supplying voltage via a battery or DC power supply, access it through this pin.
- 2) **VCC**. The regulated power supply on the board. This comes from the battery or DC power supply via the regulator, or from the USB-to-TTL Serial convertor.
- 3) **GND**. Ground pin.

Input and Output Pins:

Each of the 14 digital pins on the Pro can be used as an input or output. They operate at 3.3 volts:

- 1) **Serial**: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data.
- 2) External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value.
- 3) **PWM**: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output.
- 4) **SPI**: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication.
- 5) **LED**: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Pro. has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to VCC, Additionally, some pins have specialized functionality:

- 6) **I2C**: analog input pins A4 (SDA) and A5 (SCL). Support I2C (TWI) communication.

There are a couple of other pins on the board:

- 7) **AREF**. Reference voltage for the analog inputs.
- 8) Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

The open-source Arduino environment makes it easy to write code and upload it to the i/o board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java and based on Processing, avr-gcc, and other open source software.

As shown in Figure 4.2, a battery has been used to power the Arduino, so we have turned the switch on the Arduino board to the “Battery” position. Then, a 5V battery has been connected to (Vin) and (GND) pins, but there is an internal regulator on the Arduino board to regulate the input power to 5V, because the Arduino operates at 5V.

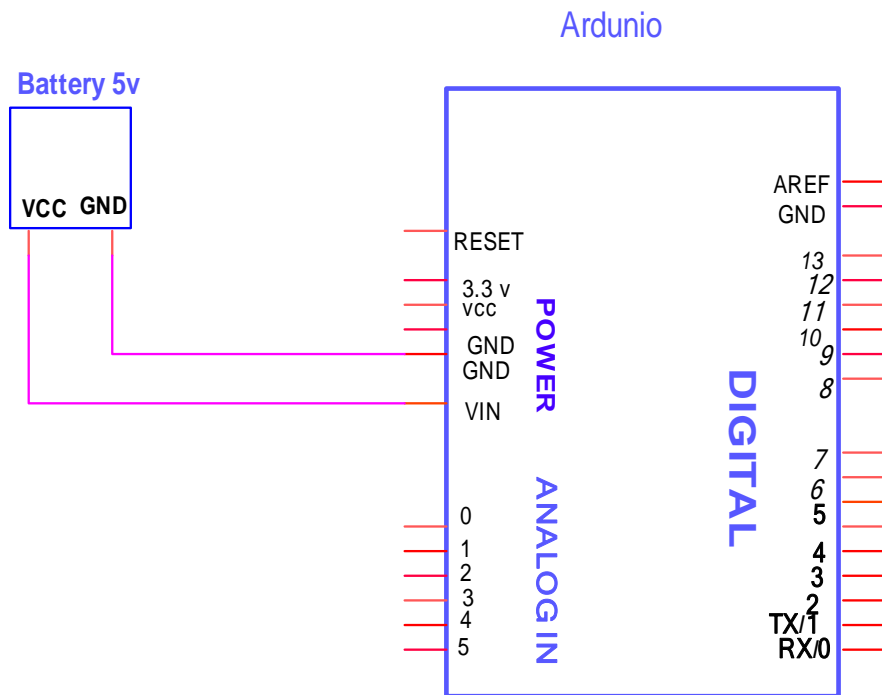


Figure 4.2: Interfacing Arduino Microcontroller with a Battery

4.3 Sensor Interfacing

In this project, a sensor measure heart rate(HR) and series pulse oximeter(SPO2) from the finger of the patient. As shown in previous chapter the design of heart rate and series pulse oximeter sensor need positive 5 v power supply. The output of the sensor inserting to pin 5 of arduino.

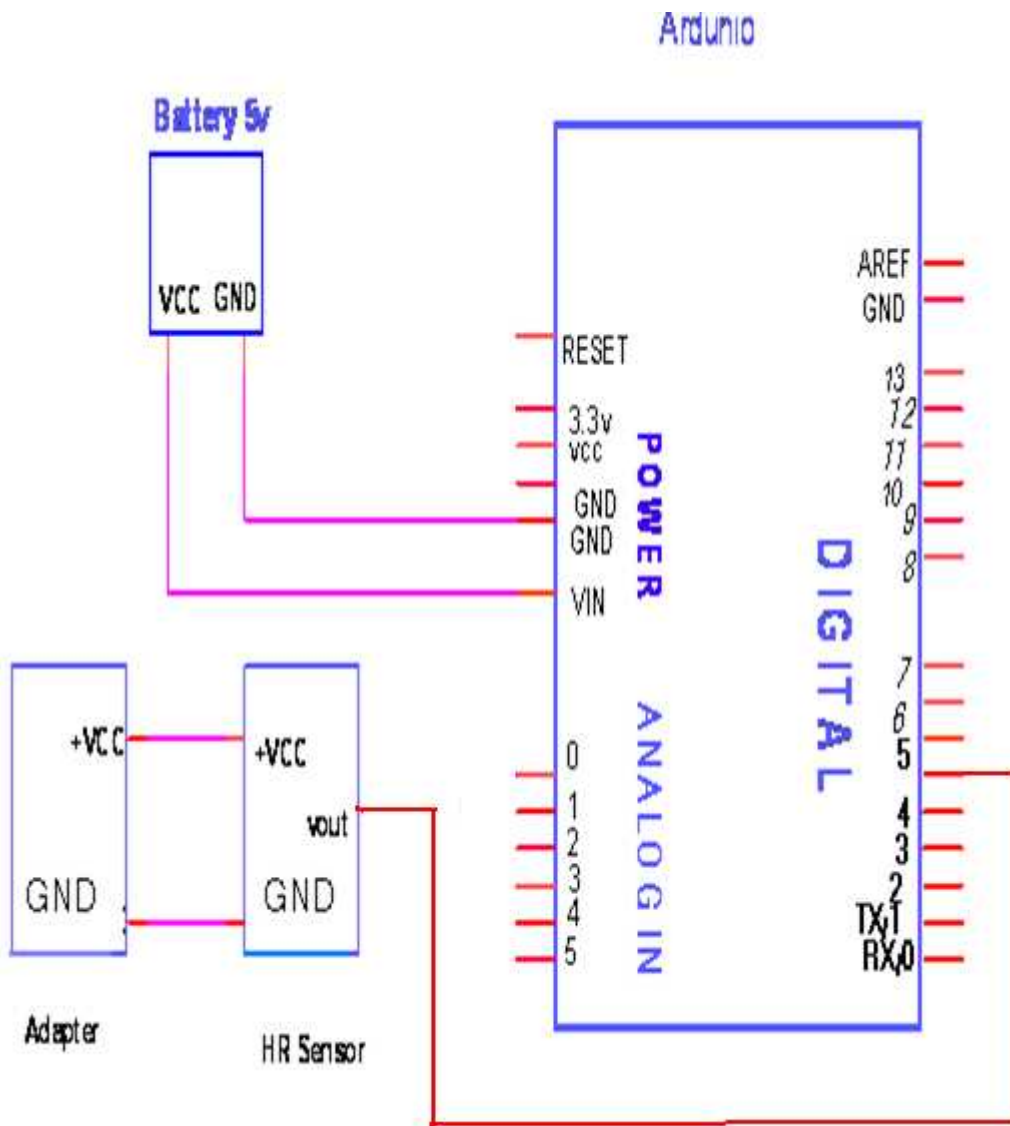


Figure4.3: interfacing sensor to Arduino

4.4 PC Interfacing

Figure 4.4 shows the connection between Arduino microcontroller and PC in the first scenario.

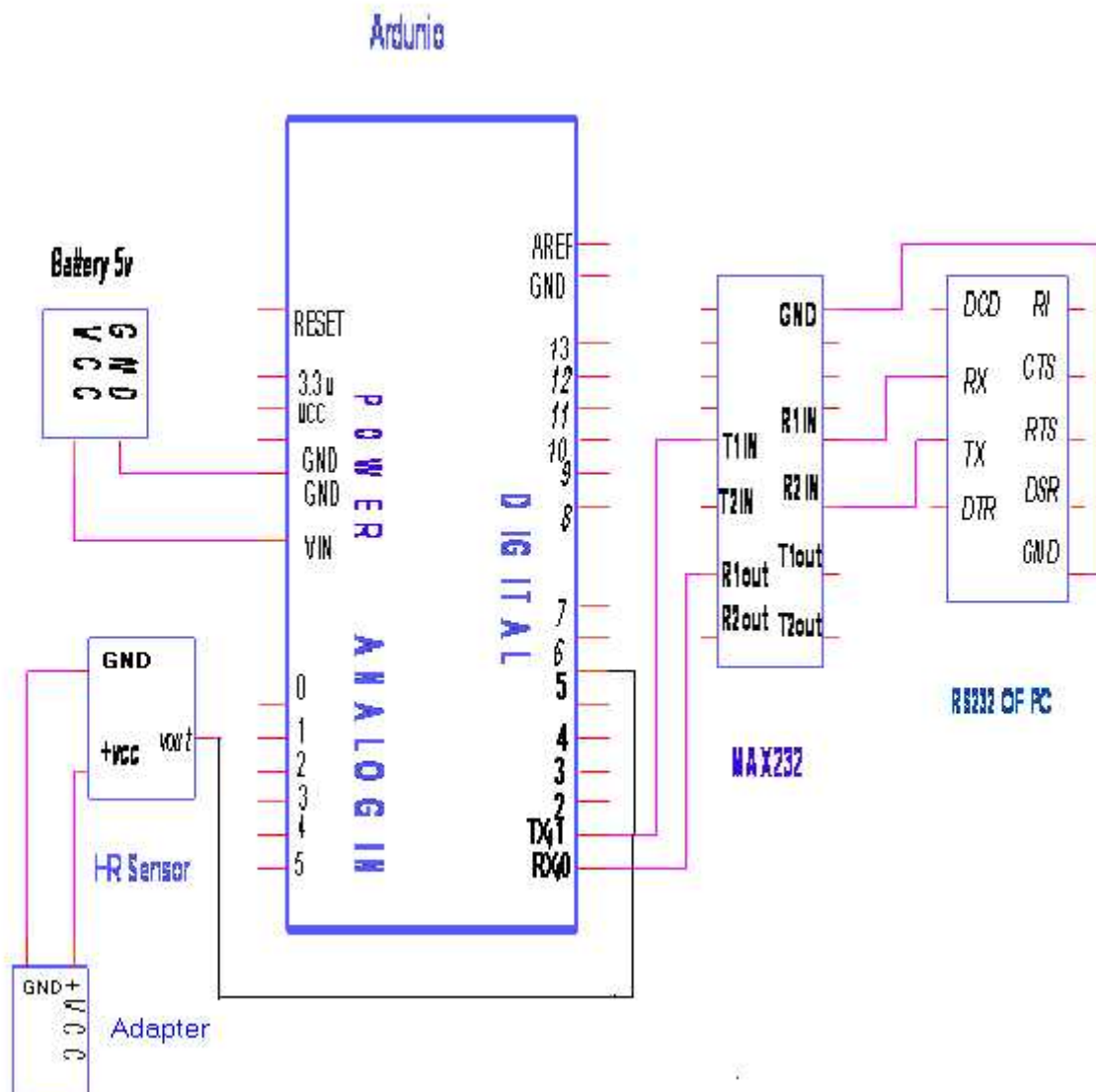


Figure 4.4: Interfacing PC with Arduino

4.5 3G GSM Modem Interfacing

Figure 4.5 shows the connection between Arduino microcontroller and 3G GSM modem in the second scenario.

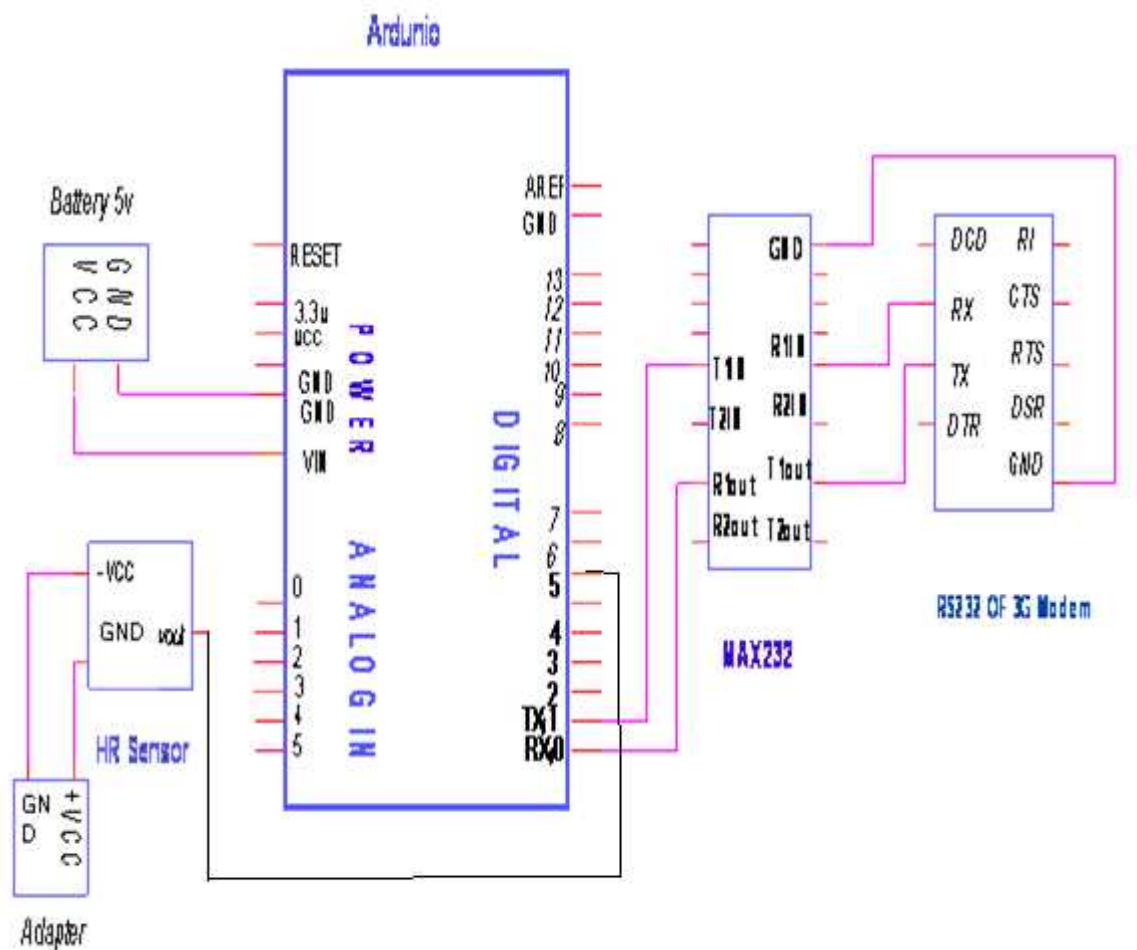


Figure 4.5: Interfacing 3G GSM modem with Arduino

4.6 Video Connection In The System

Figure 4.6 shows the connection of USB camera and microphone in the two scenarios in the system .

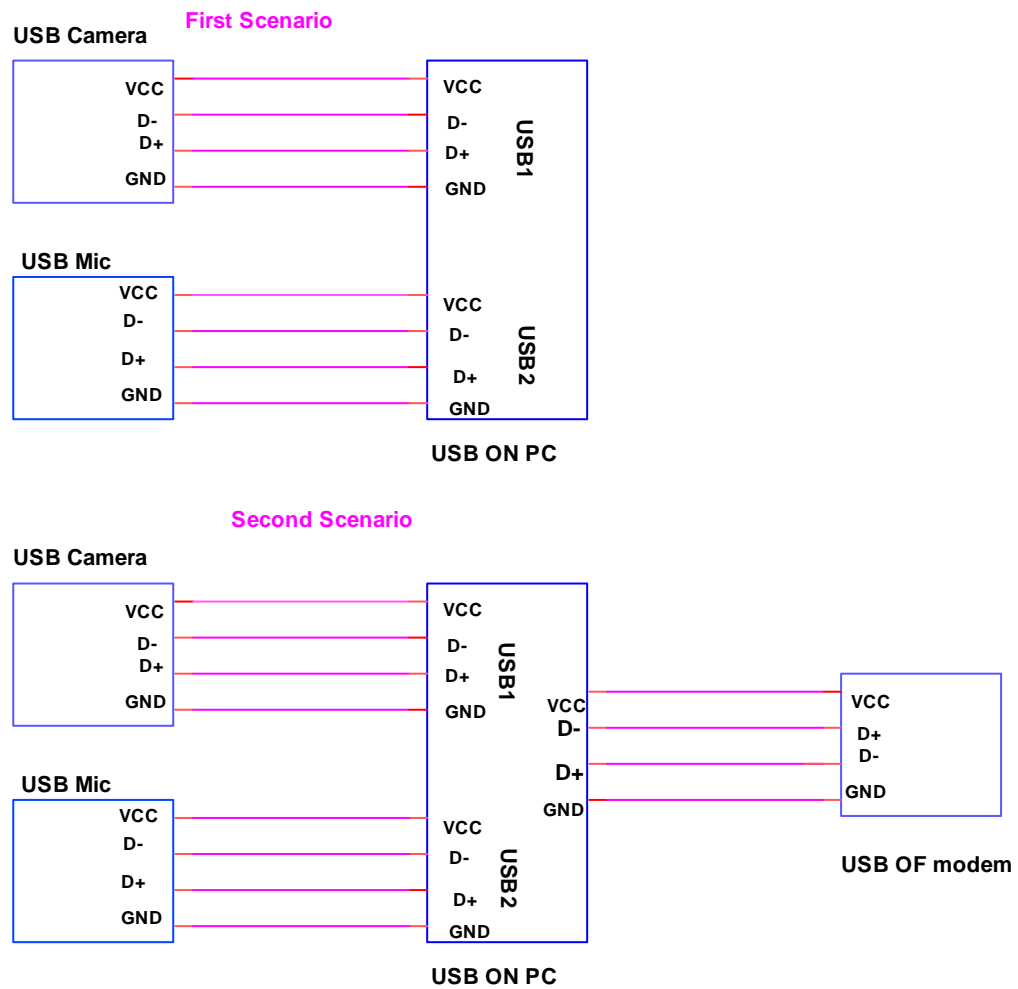


Figure 4.6: USB camera and microphone connection in the system

4.7 Hardware Connections of MIMO Wi-Fi and 3G GSM Scenarios

Figure 4.7 describe the whole connection in the First and Second scenarios of the project.

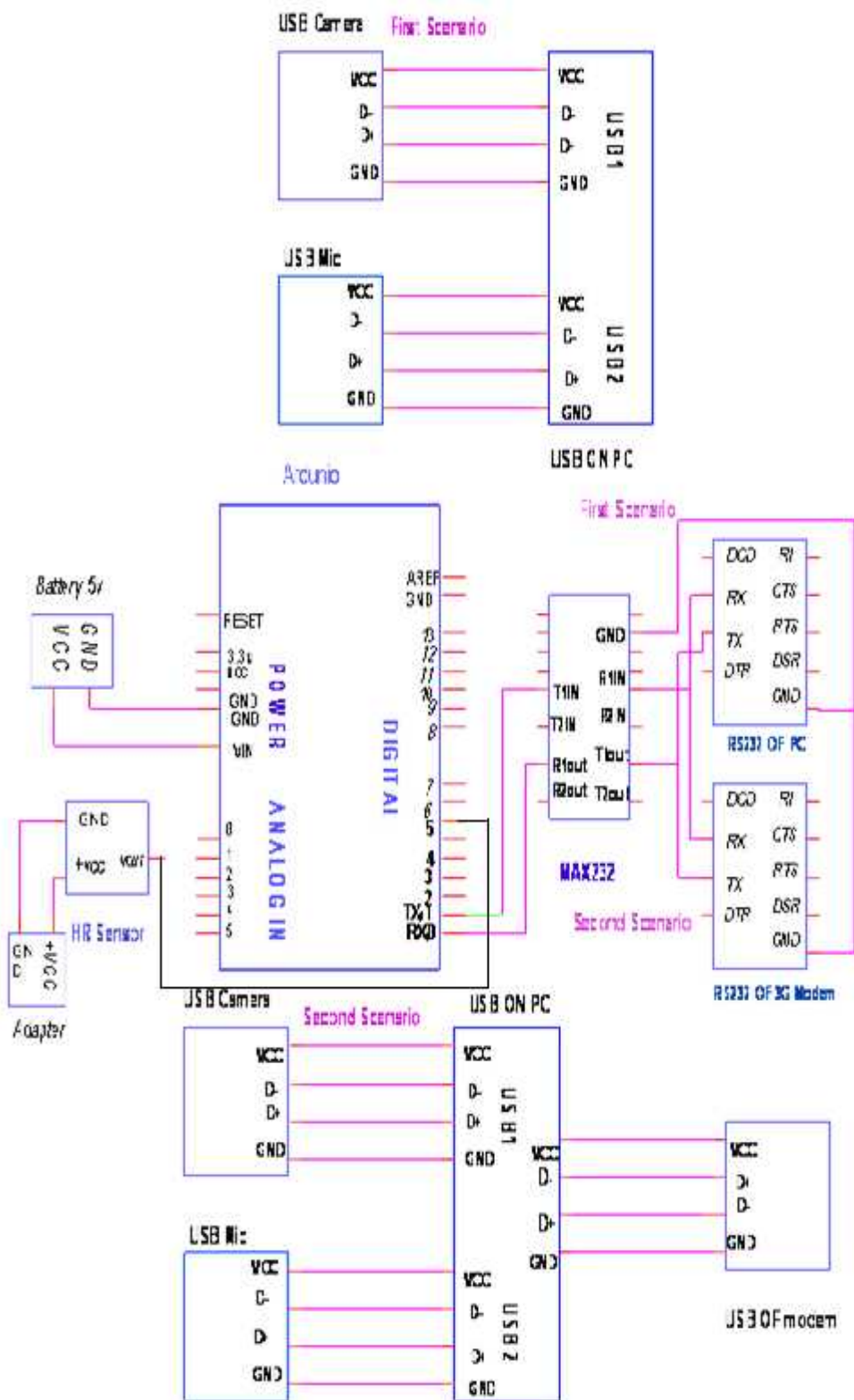


Figure 4.7: Whole Connections of two scenarios

CHAPTER FIVE

SOFTWARE DESIGN IMPLEMENTATION

5.1 Introduction

5.2 Arduino Programming

5.3 labview Programming

5.4 Sensors Programming

5.5 Programming PC with Labview

5.5.1 Transmitting data by labview software

5.5.2 Receiving Data by LabVIEW Software

5.6 Programming 3G GSM modem with SIMCOM_SIM5216

5.7 Transferring video

5.1 Introduction

Software is an important part in any technological system. Operating and controlling any component in this project requires software handling.

This chapter explains the required software with detailed steps and procedures of programming every used component in this project.

It should be noted that most of the designed system has been programmed using the Arduino and Labview software which has controlled the microcontrollers and the transceivers.

5.2 Arduino Programming

When we connect the Arduino microcontroller to PC or LabTop, then follow these four steps to get successfully connection between Arduino and PC or LabTop.

On Windows they **Found New Hardware Wizard** will now open up as Windows will have detected that you have connected a new piece of hardware to your PC as show in fig.5.1. Tell it NOT to connect to Windows update (Select **No, not at this time**) and then click **Next**.



Fig5.1: Hardware Wizard

Uncheck “**Search removable media**”. Check “**Include this location in the search**” and then click the **Browse** button. Browse to the location of the USB drivers and then click **Next** as show in Fig.5.2.

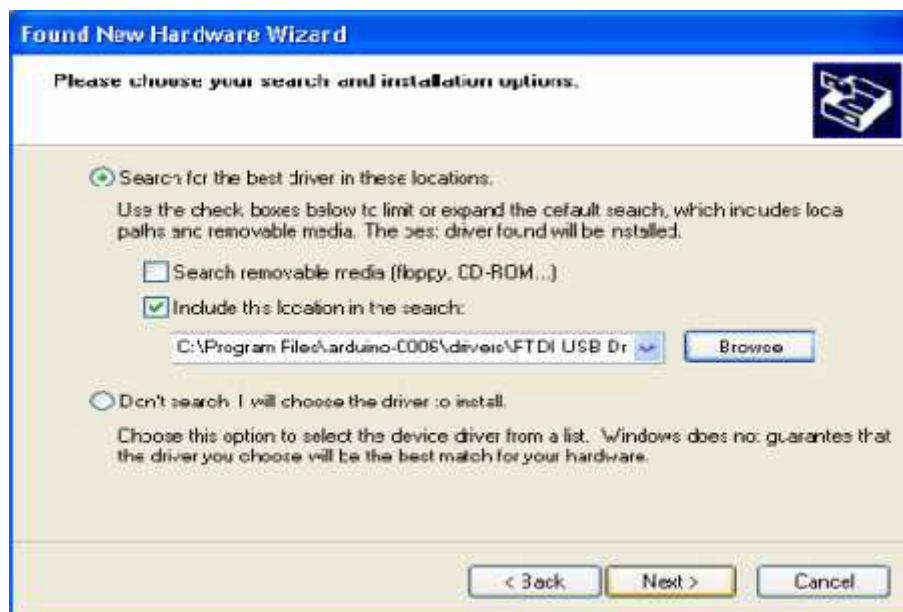


Fig5.2: Hardware Location Wizard

On the next page select “**Install from a list or specific location (Advanced)**” and click **Next** as show in Fig.5.3.



Fig5.3: Hardware install from list location

The wizard will now search for a suitable driver and then tell you that a “USB Serial Converter” has been found and that the hardware wizard is now complete. Click Finish.



Fig5.4: Finishing installing

Arduino software is the IDE processor, but can send the Arduino program (or “sketch”) to the micro controller in the same board. The Arduino IDE is a cross-platform application written in Java, and is derived from the IDE for the Processing programming language and the Wiring project. It is designed to introduce programming to artists and other newcomers unfamiliar with software development. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation, and is also capable of compiling and uploading programs to the board. As the Arduino system is open source, anyone can purchase a blank micro controller and put the boot loader on it, or even write their own boot loader.

The Arduino IDE comes with a C/C++ library called "Wiring" (from the project of the same name), which makes many common input/output operations much easier. Arduino programs are written in C/C++, although users only need define two functions to make a runnable program:

Setup () – a function run once at the start of a program that can initialize settings.

Loop () – a function called repeatedly until the board powers off.

Currently, there are 22 IDE versions of software Arduino program, in this project version 21 has been used. Figure 5.5 shows the interface of Arduino program.



Figure 5.5: Arduino Program Interface

Arduino Programming Steps:

1) First Step: Selecting Arduino Board

Selecting the entry in the Tools >> Board >> menu that corresponds to the chosen Arduino. We choose the Arduino pro (5V, 16 MHz) / ATmega 328, as shown in Figure 5.6.

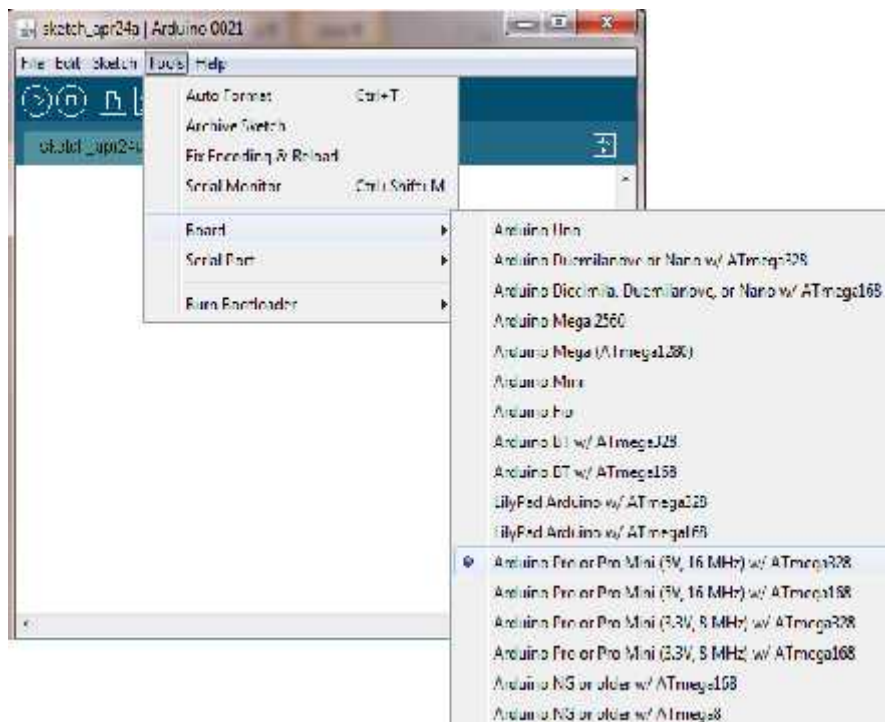


Figure 5.6: Select Arduino Board

2) Second Step: Selecting the Serial Port

The board communicates with the computer via a USB interface, but with a serial protocol. All this means is that we must select the correct serial port number.

Selecting the serial device of the Arduino board is from Tools >> Serial Port menu. As shown in Figure 5.7, COM8 serial port is selected in this project.

To find out, Arduino board can be disconnected and the menu should be re-opened; the entry that disappears should be the Arduino board. Reconnect the board and select that serial port.

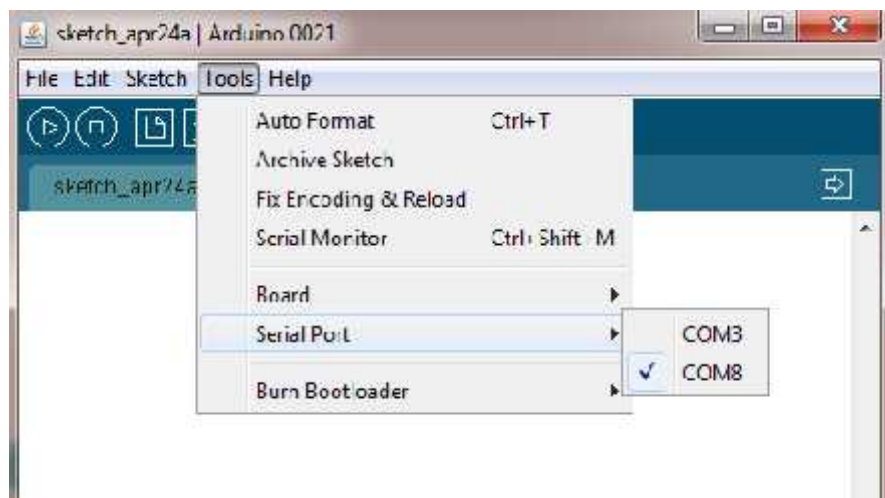


Figure 5.7: Selecting Serial Port

3) Third Step: Saving the Program

After writing the code, saving is done by selecting File >> Save, show in Figure 5.8.

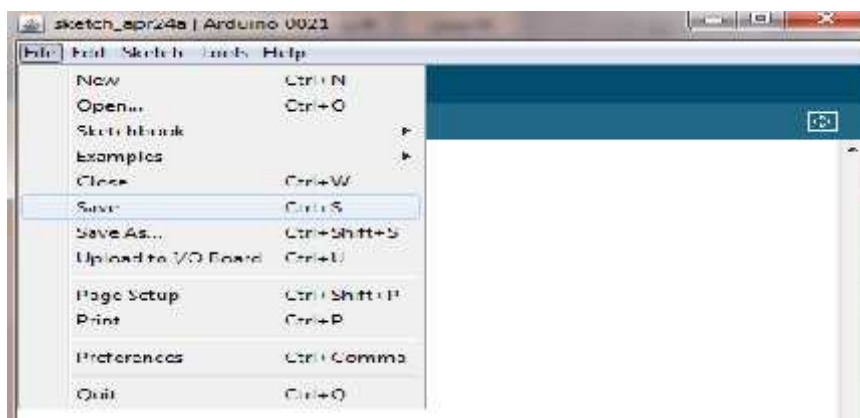


Figure 5.8: Saving the Program

4) Forth Step: Compiling the Program

Compiling can be selected from Sketch >> Verify/Compile, as shown in Fig 5.9.

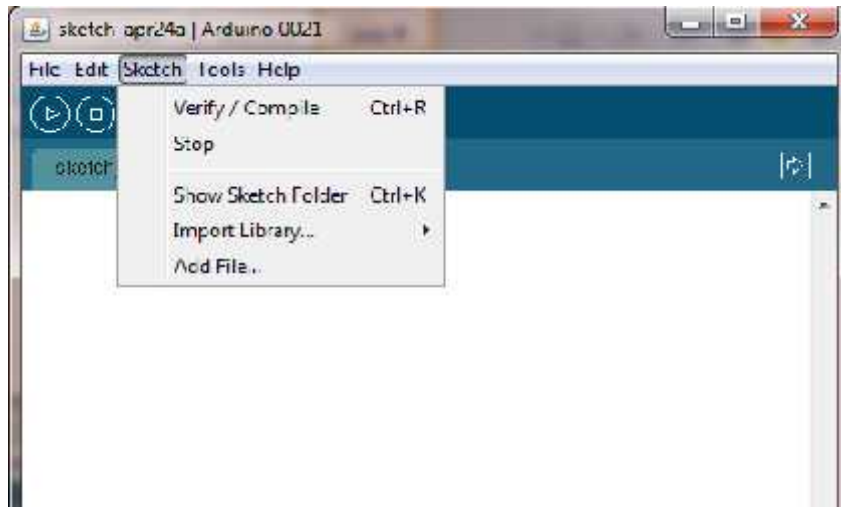


Figure 5.9: Compiling the Program

5) Fifth Step: Uploading the Program

Uploading is done by selecting File >> Upload to I/O Board, as shown in Figure 5.10. After waiting a few seconds; we can see the RX and TX leds on the board flashing. If the upload is successful, the message "Done uploading." will appear in the status bar.

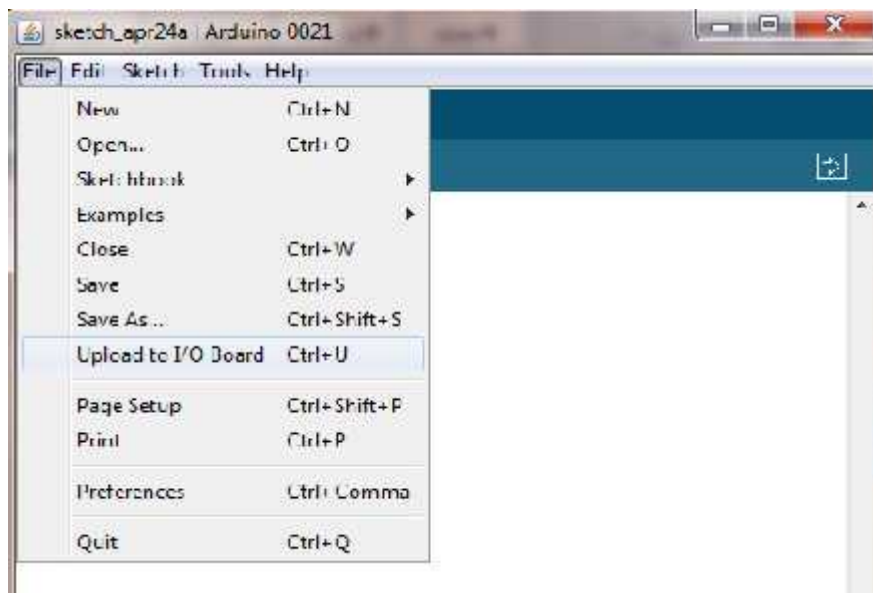


Figure 5.10: Uploading the Program

6) Sixth Step: Displaying Result on Serial Monitor

Serial Monitor displays serial data being sent from the Arduino board (USB or serial board). It is also used to send data to the board.

Result on the Serial Monitor is displayed by selecting Tools >> Serial Monitor, as shown in Figure 5.11.

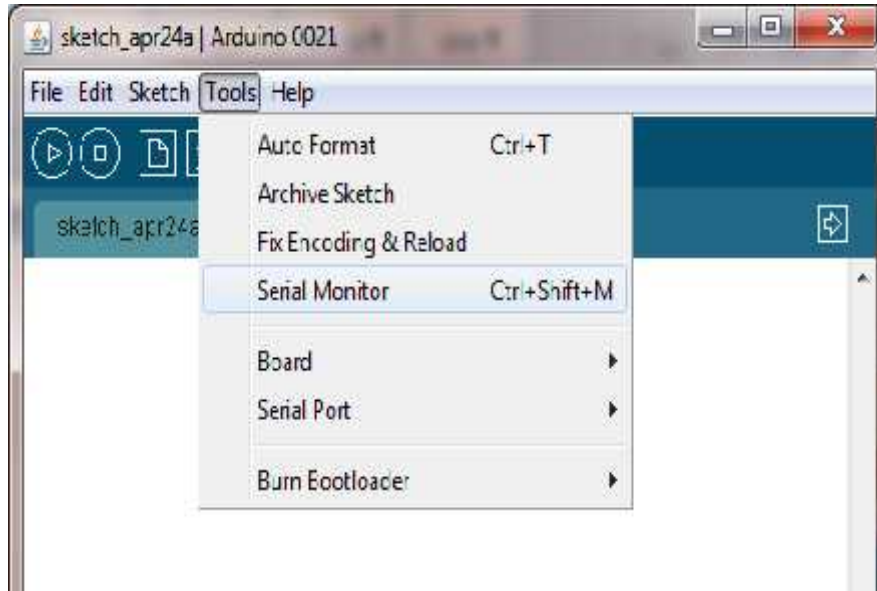


Figure 5.11: Displaying Serial Monitor

Figure 5.12 shows the serial monitor on which the results are displayed to make sure that the code works properly:

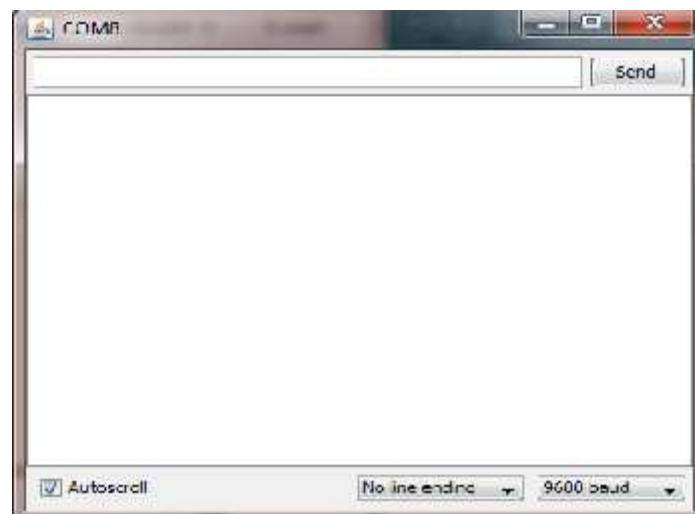


Figure 5.12: Serial Monitor

5.3 Labview programming

Labview is a graphical programming tool that is used to interface with hardware equipment. The graphical Labview program replaces traditional code, which reduces development time by using the pre-made modules, called Virtual Instruments (VIs).

Labview can acquire data and control devices via IEEE-488 (GPIB), RS-232/422 and modular (VXI or CAMAC) instruments as well as plug-in I/O boards.

Labview has serial VIs that communicate to the serial port on a PC. These serial VIs can be used to communicate with a 2-wire device

using a DS3900 that accepts data and commands from the serial port and converts the information to 2-wire protocol.

Currently, there are many versions of software Labview program, in this project version 7.1 has been used. Figure 5.13 shows the Interface of Labview software.



Figure 5.13: Interface of Lab View Software

After pressing the “New..” button, another screen will pop up with several various window panes. select the “Blank VI” option .

You will have two screens available. One is the ‘front panel’ and the second is called ‘block diagram’. Front Panel will always have the ‘controls’ and ‘indicators’ required by the program to show the input and output parameters. ‘Block diagram’ will have the detailed graphical representation of the actual program.

Front Panel: This is the user interface (display) for your Lab VIEW programs show in Fig5.14.

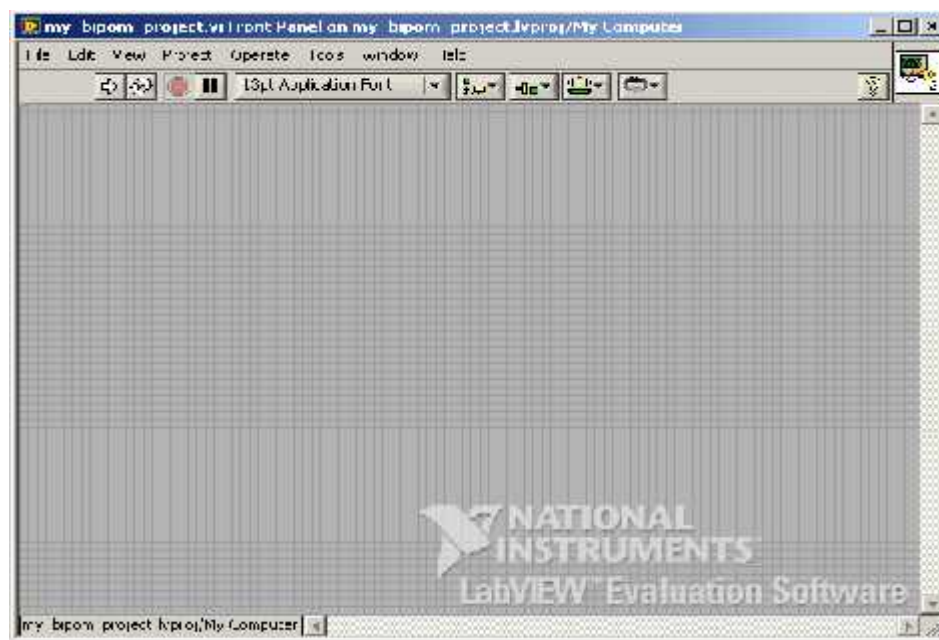


Figure 5.14: Front Panel

Block Diagram: This is the actual program that consists of blocks as show in Fig 5.15.

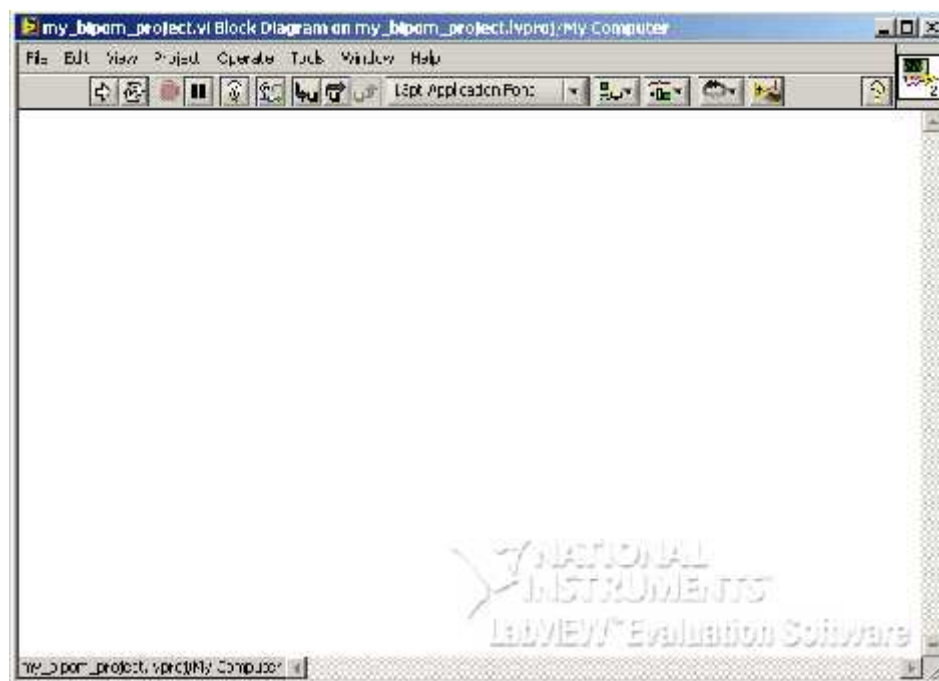


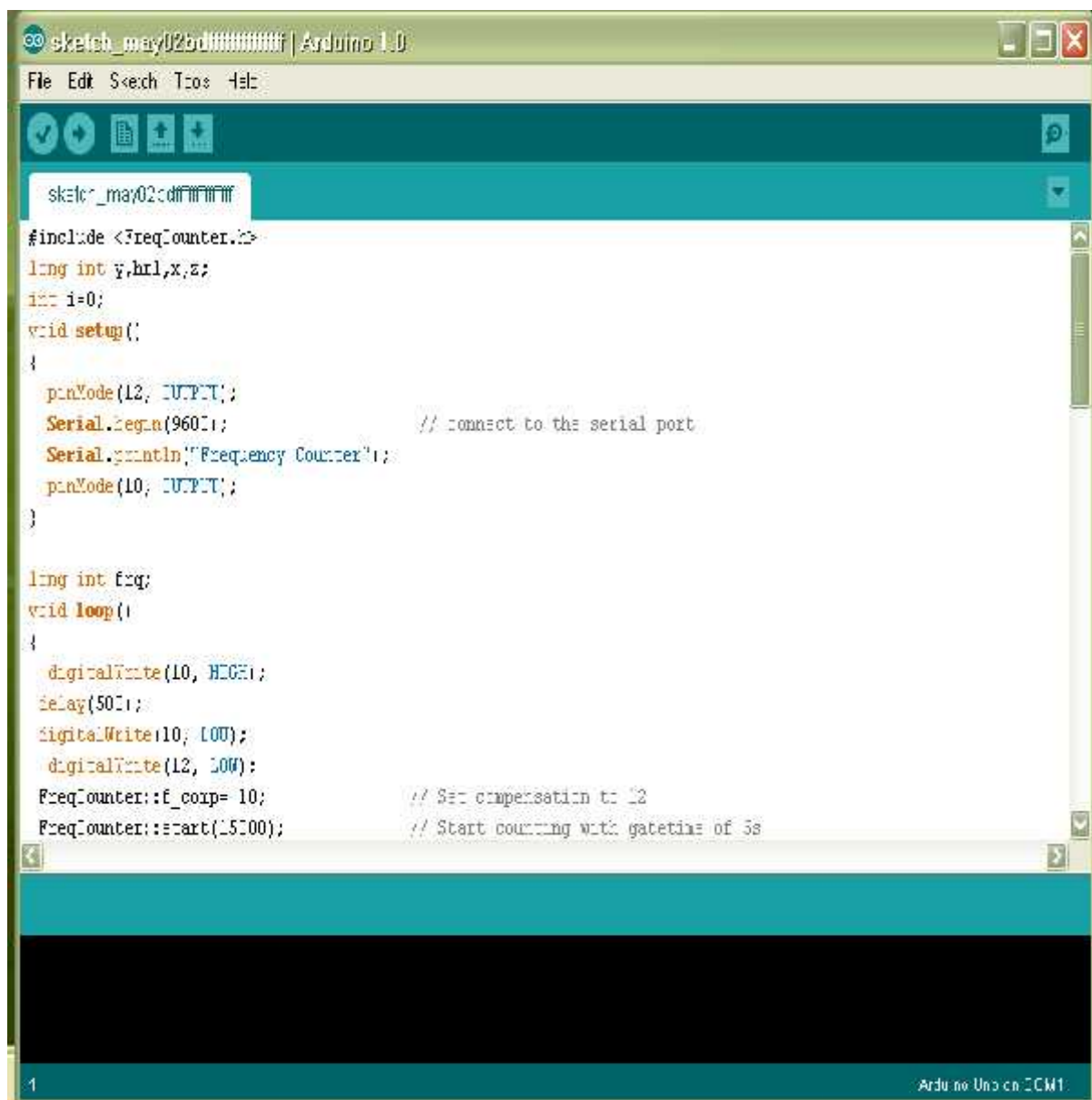
Figure 5.15: Block Diagram

5.4 Sensors Programming

After getting the analog signal from heart rate sensor, it has been processed and analyzed by sending it to Arduino microcontroller through analog pin5. analog Read()command has been used to read the obtained signal from the Arduino microcontroller.

Heart rate is obtained by calculating the number of squared wave in the signal in one minutes . To measure the heart rate, we built a frequency counter that measure the pulses in the signal. And SPO2 from Heart rate.

The Figure 5.16 is the Code of Calculating the Heart Rate and SPO2 parameters.

The image is a screenshot of the Arduino IDE interface. The title bar at the top reads "sketch_may02:00000000000000000000 | Arduino 1.0". Below the title bar is a menu bar with "File", "Edit", "Sketch", "Tools", and "Help". Under the "Sketch" menu, there are icons for saving, opening, and other sketch-related functions. The main text area contains the following C++ code:

```
#include <FreqCounter.h>
long int y,hrl,x,z;
int i=0;
void setup()
{
  pinMode(12, OUTPUT);
  Serial.begin(9600);          // connect to the serial port
  Serial.println("Frequency Counter");
  pinMode(10, OUTPUT);
}

long int freq;
void loop()
{
  digitalWrite(10, HIGH);
  delay(500);
  digitalWrite(10, LOW);
  digitalWrite(12, LOW);
  FreqCounter::f_corr= 10;      // Set compensation to 12
  FreqCounter::start(15000);    // Start counting with gate time of 3s
```

The bottom status bar shows "1" on the left and "Arduino Uno on ICW1" on the right.

Figure 5.16: Code of Calculating the Heart Rate

5.5 Programming PC with Labview

The labview program that be using in the MIMO WiFi scenario in the transmitter and in the receiver. First we write labview program to reading data from arduino microcontroller from a patient side and display the result on the interface of labview (front panel) on PC. This program showing in figure 5.17.

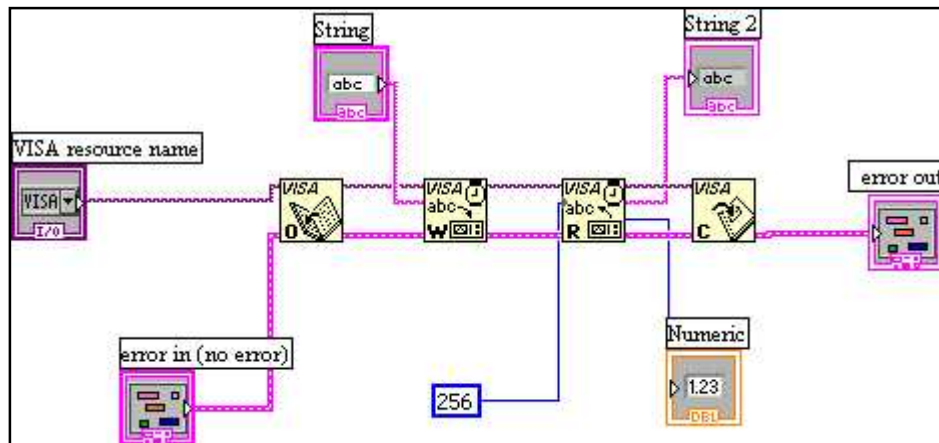


Figure 5.17: Reading data from Arduino

VISA Open: Opens a session to the device specified by **VISA resource name** and returns a session identifier that can be used to call any other operations of that device.

VISA Read: Reads the specified number of bytes from the device or interface specified by VISA resource name and returns the data in read buffer. Whether the data is read synchronously or asynchronously is platform-dependent. Right-click the node and select Do I/O Synchronously from the shortcut menu to read data synchronously. The operation returns only when the transfer terminate.

VISA Write: Writes the data from write buffer to the device or interface specified by VISA resource name. Whether the data is transferred synchronously or asynchronously is platform-dependent. Right-click the node and select Do I/O Synchronously from the shortcut menu to write data synchronously. The operation returns only when the transfer terminates.

VISA Close: Closes a device session or event object specified by **VISA resource name**. For each VISA session that you open, you should close the session when you are finished with it.

Figure 5.18 shows the front panel of previous program , it read from com3 and display the result on Read box .

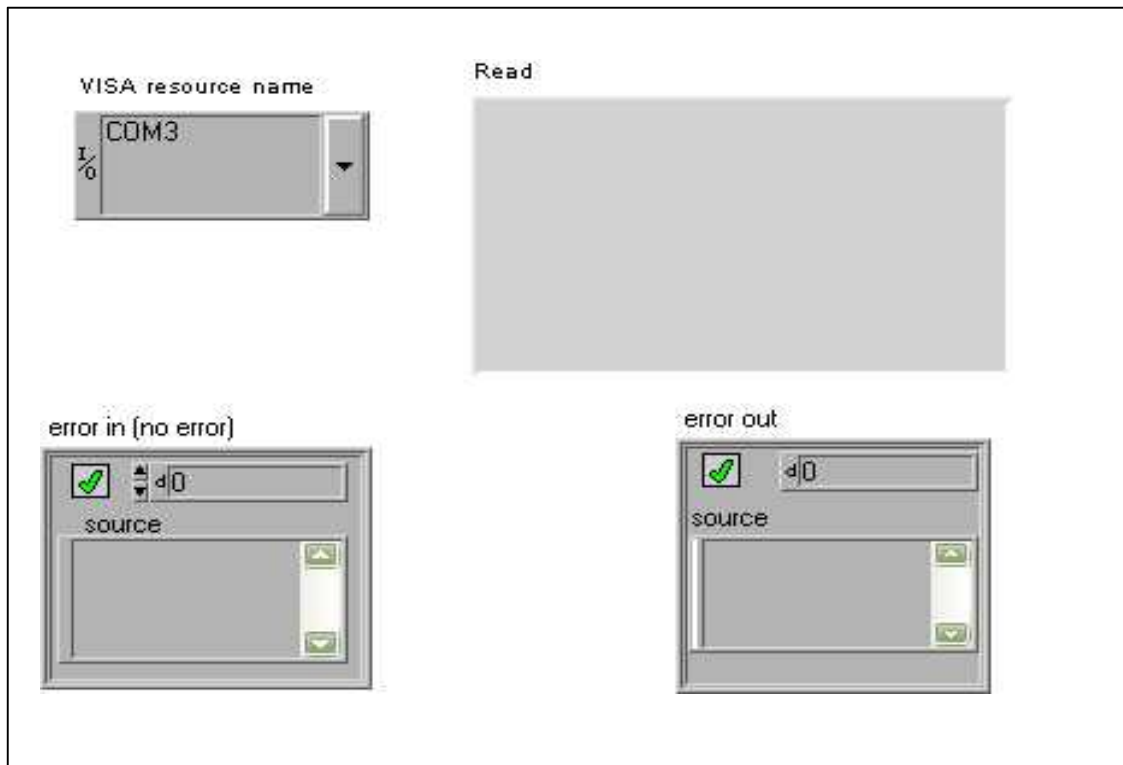


Figure 5.18: Front Panel of LABVIEW program

5.5.1 Transmitting data by labview software

TCP/IP is a way of sending and receiving data reliably over a network. TCP/IP functions are built into LabView, and give the instrumentation and control engineer a way of transmitting information across the network reliably.

TCP/IP is an Internet Protocol (IP). The TCP part of the name refers to Transmission Control Protocol. When you send something over the net it is subdivided into packets, and each packet could take a different route from one computer to the other over the net. Those packets could arrive at different times and be out of order. Some might not make it at all, and when that happens, TCP will request a re-send to be sure that it has all of the packets. Then, TCP reassembles the packets. The nice thing is that you don't have to worry about all of those things. TCP makes it all happen reliably.

After showing in the previous program (reading data from arduino microcontroller), then we using another program in labview to sending the data that read from arduino. The reading from Arduino is repetition in a each 10 minutes and the sending operation it repeated each 10 minutes. The transmitter is called Server.

The following block diagram in Fig.5.19 show how the server send data.

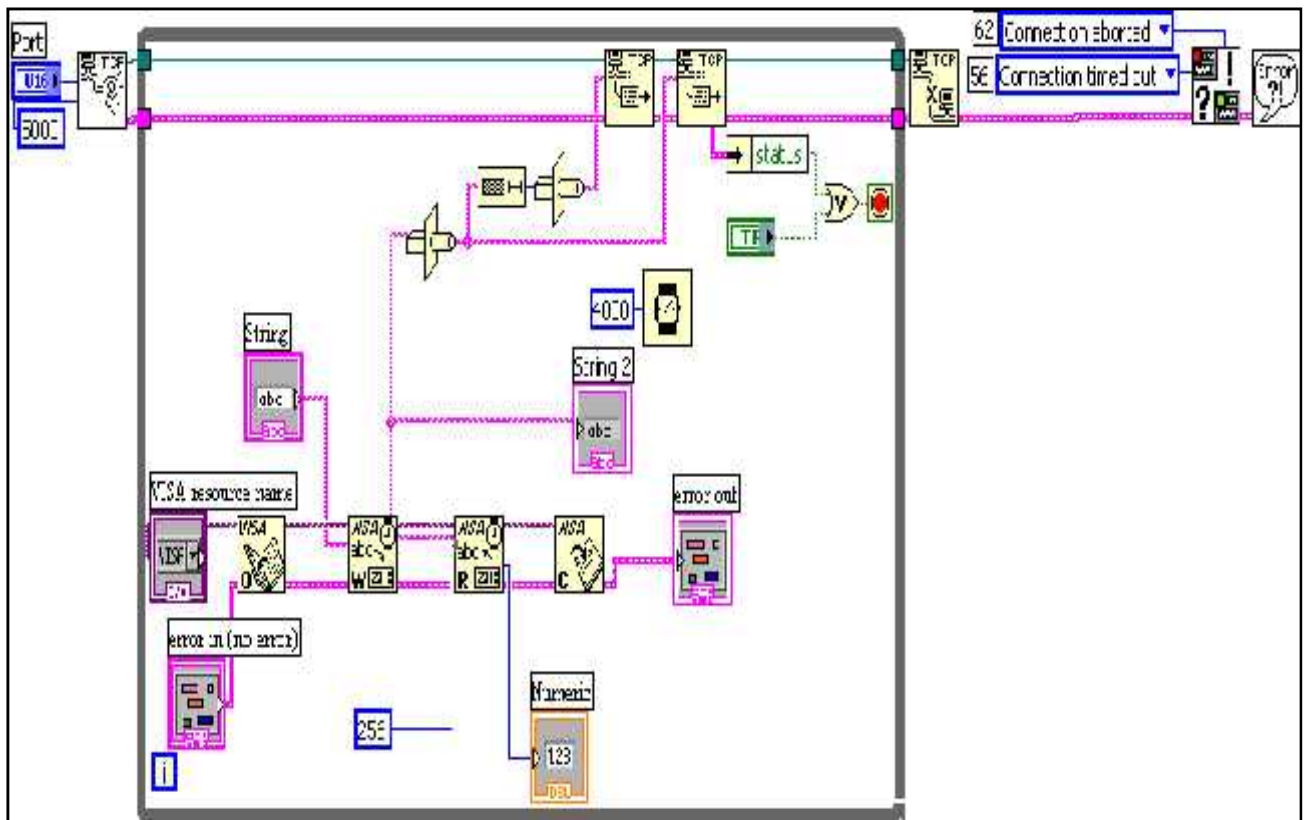


Figure 5.19: Block diagram of the server

We need several blocks for a server to transmitting data on the PC: TCP Listen, TCP Write, TCP close connection, Type Cast, and Wait Until Next ms Multiple, as shown in Figure 5.13.

TCP Listen: Creates a listener and waits for an accepted TCP network connection at the specified **port**.

TCP Write: Writes data to a TCP network connection.

TCP Close Connection: Closes a TCP network connection.

Type Cast: Casts **x** to the data type, **type**, by flattening it and unflattening it using the new data type. The connector pane displays the default data types for this polymorphic function.

Wait Until Next ms Multiple: Waits until the value of the millisecond timer becomes a multiple of the specified **millisecond multiple**. Use this function to synchronize activities. You can call this function in a loop to control the loop execution rate. However, it is possible that the first loop period might be short. This function makes asynchronous system calls, but the nodes themselves function synchronously. Therefore, it does not complete execution until the specified time has elapsed.

5.5.2 Receiving Data by LabVIEW Software

With TCP/IP connections, a computer can function either as the client or the server. The following block diagram in Fig5.20 represents a client application that initiates a connection to a remote server with TCP Open Connection.

The following block diagram shows how to received and display the result in the interface of labview on PC and in C_infile.

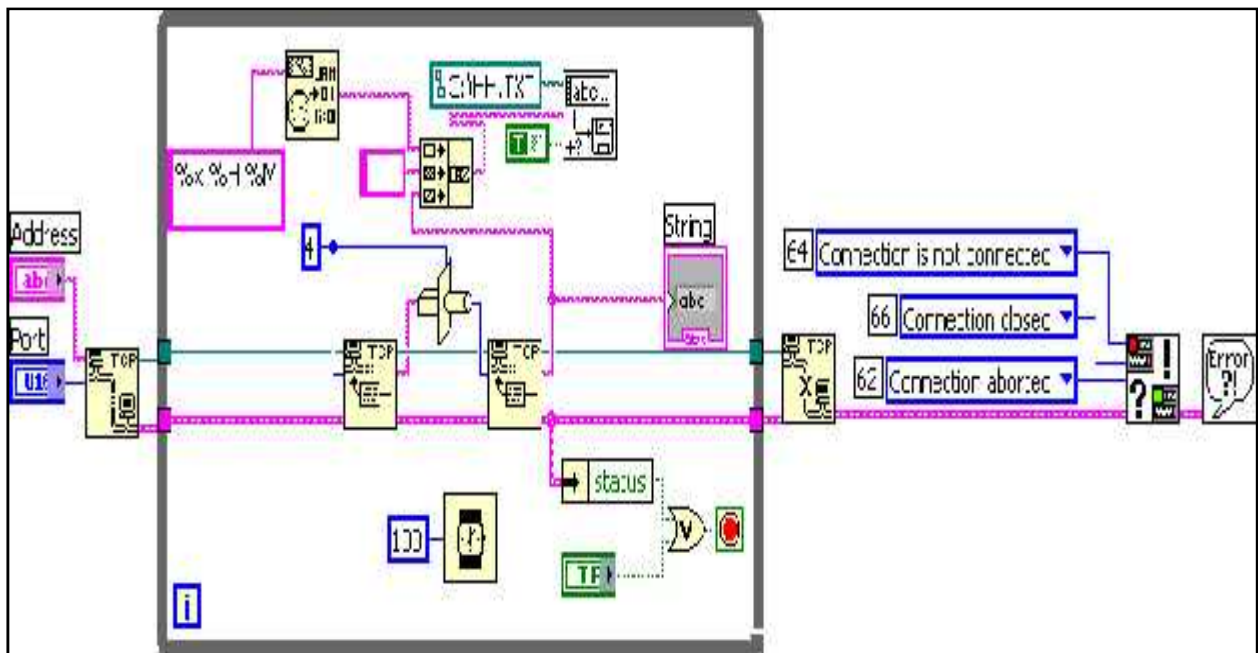


Figure 5.20: Block Diagram of Client

We need several blocks for a client to display a recovered data on the PC: TCP open connection, TCP read, TCP close connection, Fract/Exp String To Number, and Wait Until Next ms Multiple, as shown in Figure 5.14.

TCP Open Connection: Opens a TCP network connection with the **address** and **port**.

TCP Read: Reads a number of bytes from a TCP network connection, returning the results in **data out**.

Fract/Exp String To Number: Interprets the characters 0 through 9, plus, minus, e, E, and the decimal point (usually period) in **string** starting at **offset** as a floating-point number in engineering notation, exponential, or fractional format and returns it in **number**. The connector pane displays the default data types for this polymorphic function.

5.6 Programming 3G GSM modem with SIMCOM_SIM5215

The Arduino has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provide UART TTL serial communication, which is available on digital pins 0 (RX) and 1 (TX). The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board via a USB connection.

Steps for Programming 3G GSM modem

Serial communication has been used for communication between the Arduino board and the cellular shield. The Arduino hardware has built-in support for serial communication on pins 0 and 1 (which also goes to the computer via the USB connection). The native serial support happens via a piece of hardware (built into the chip) called a UART.

A universal asynchronous receiver / transmitter, is a type of "asynchronous receiver/transmitter", a piece of computer hardware that translates data between parallel and serial forms.

The NewSoftSerial library has been developed to allow serial communication on other digital pins of the Arduino, using software to replicate the functionality.

First we added the NewSoftSerial library to the Arduino program, by selecteing sketch >> import library >> NewSoftSerial, as shown in Figure 5.21.

NewSoftSerial library used to send serial commands to the cellular module from any digital pin on Arduino.

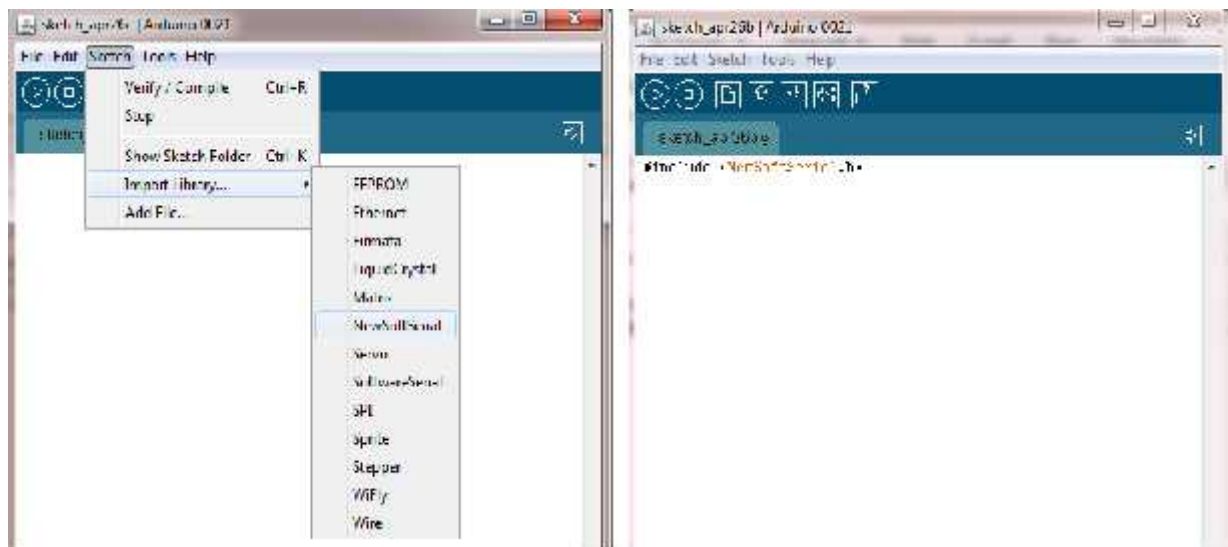


Fig5.21: Adding New Soft Serial Library

We can control the 3G GSM modem with SIMCOM_SIM5215 by AT commands. The AT commands are instructions used to control a modem. AT is the abbreviation of ATtention.

Every command line starts with "AT" or "at". That's why modem commands are called AT commands. In this project we are interested in sending text messages from Arduino to a mobile through the 3G GSM modem.

The AT commands for sending text messages are:

First, we need to tell the module that our SMS will be in ASCII text:

AT+CMGF = 1

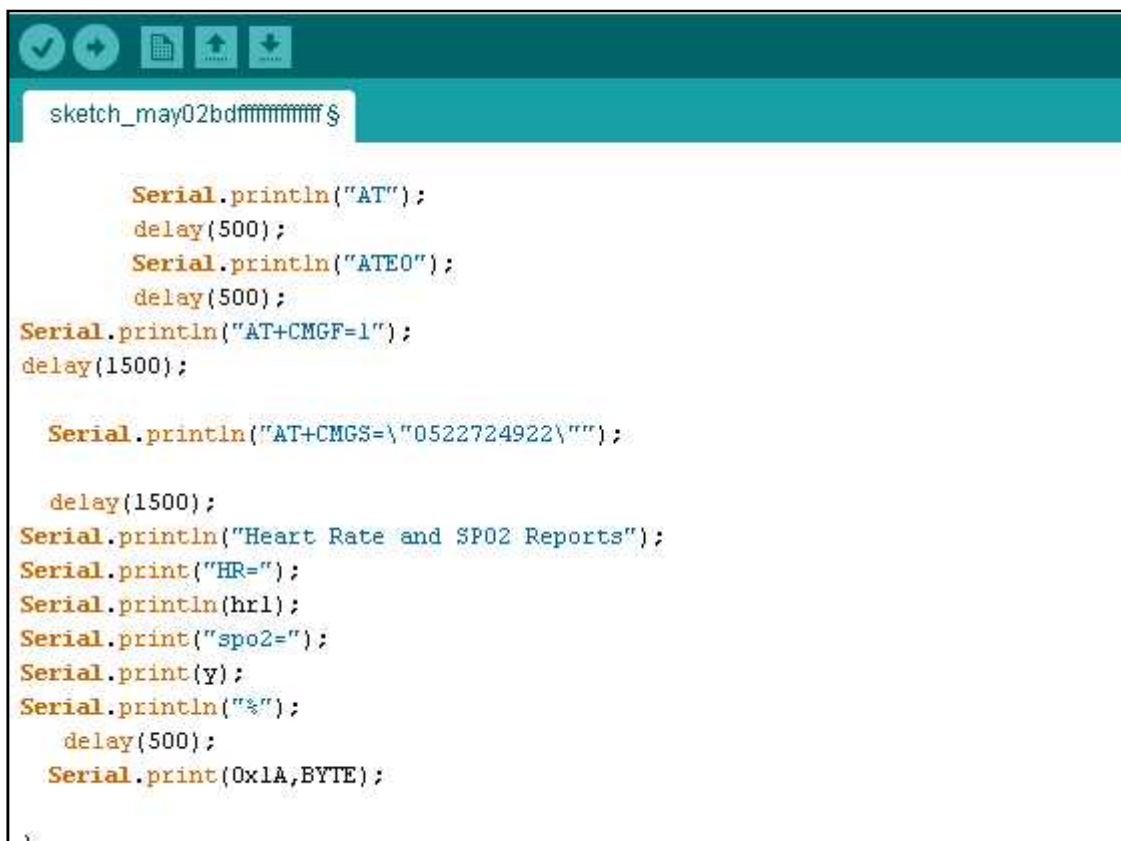
Then giving the mobile phone number to send the message to:

AT+CMGS = "number of the mobile"

Finally to end SMS:

Ctrl-Z expressed in the ASCII code.

Figure 5.18 shows a code to check sending parameters by 3G GSM modem that contains the heart rate and SPO2 of the patient :

The image shows a screenshot of an Arduino IDE code editor. The title bar at the top is teal and contains several icons: a checkmark, a circular arrow, a grid, and two arrows pointing up and down. Below the title bar, the file name 'sketch_may02bdm' is visible in a text box. The main area of the editor is white and contains C++ code for sending an SMS. The code uses the Serial library for communication and includes several delay functions to manage timing. The code is as follows:

```
Serial.println("AT");
delay(500);
Serial.println("ATE0");
delay(500);
Serial.println("AT+CMGF=1");
delay(1500);

Serial.println("AT+CMGS=\"0522724922\"");

delay(1500);
Serial.println("Heart Rate and SPO2 Reports");
Serial.print("HR=");
Serial.println(hr1);
Serial.print("spo2=");
Serial.print(y);
Serial.println("%");
delay(500);
Serial.print(0x1A,BYTE);
```

Fig5.22: SMS code

5.7 Transferring video

We use the matlab program in both scenarios to transfer video. In MIMO Wi-Fi scenario we transfer video from the patient side inside the hospital to the monitoring room, in GSM scenario we transfer video patient side outside hospital to the monitoring room. This need a two computers one in the transmitter operate as a server , and the second in the receiver operate as client. Figure 5.23 shows the matlab program that transferring the video (sound and image) from patient side in both scenarios to the monitoring room.

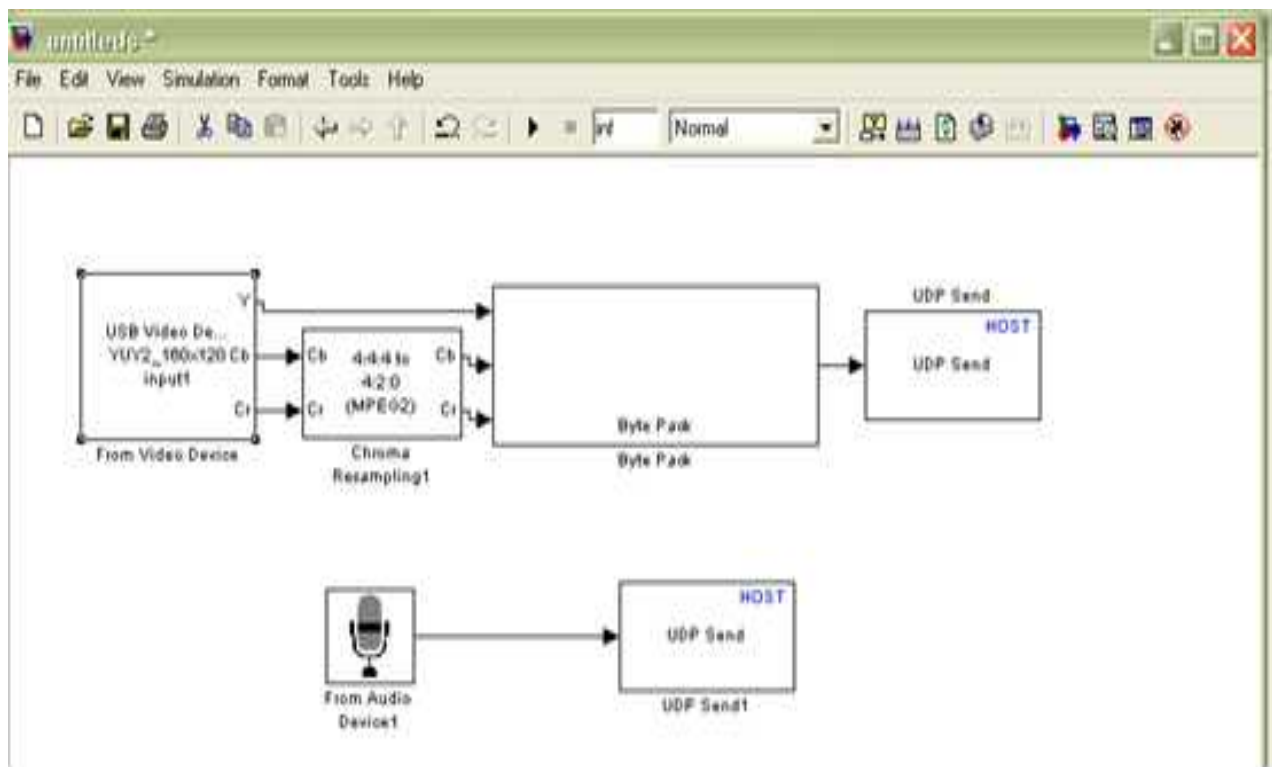


Figure 5.23: Matlab program that transmitting the video

We need several blocks for a server to transmitting video on the PC: UDP send, Byte pack, Chroma Resampling, from video device, from audio device as shown in Figure 5.23.

UDP send: The UDP Send block transmits an input vector as a UDP message over an IP network port.

Byte pack : Using the input port, the block converts data of one or more data types into a single uint8 vector for output. With the options available, you specify the input data types and the alignment of the data in the output vector. Because UDP messages are in uint8 data format, use this block before a UDP Send block to format the data for transmission using the UDP protocol.

Chroma Resampling : The Chroma Resampling block down samples or up samples chrominance components of pixels to reduce the bandwidth required for transmission or storage of a signal.

From video device : The From Video Device block lets you acquire image and video data streams from image acquisition devices, such as cameras and frame grabbers, in order to bring the image data into a Simulink model. The block also lets you configure and preview the acquisition directly from Simulink.

The From Video Device block opens, initializes, configures, and controls an acquisition device. The opening, initializing, and configuring occur once, at the start of the model's execution. During the model's run time, the block buffers image data, delivering one image frame for each simulation time step.

From audio device : The From Audio Device block reads audio data from an audio device in real time. This block has the following limitations:

- Not supported for use with the Simulink Model block.
- Not currently supported on Solaris™ platforms.

Use the **Device** parameter to specify the device from which to acquire audio. This parameter is automatically populated based on the audio devices installed on your system. If you plug or unplug an audio device from your system, type `clear mex` at the MATLAB command prompt to update this list.

Figure 5.24 shows the matlab program, which receives the video in both scenarios , and display it on computer in the monitoring room.

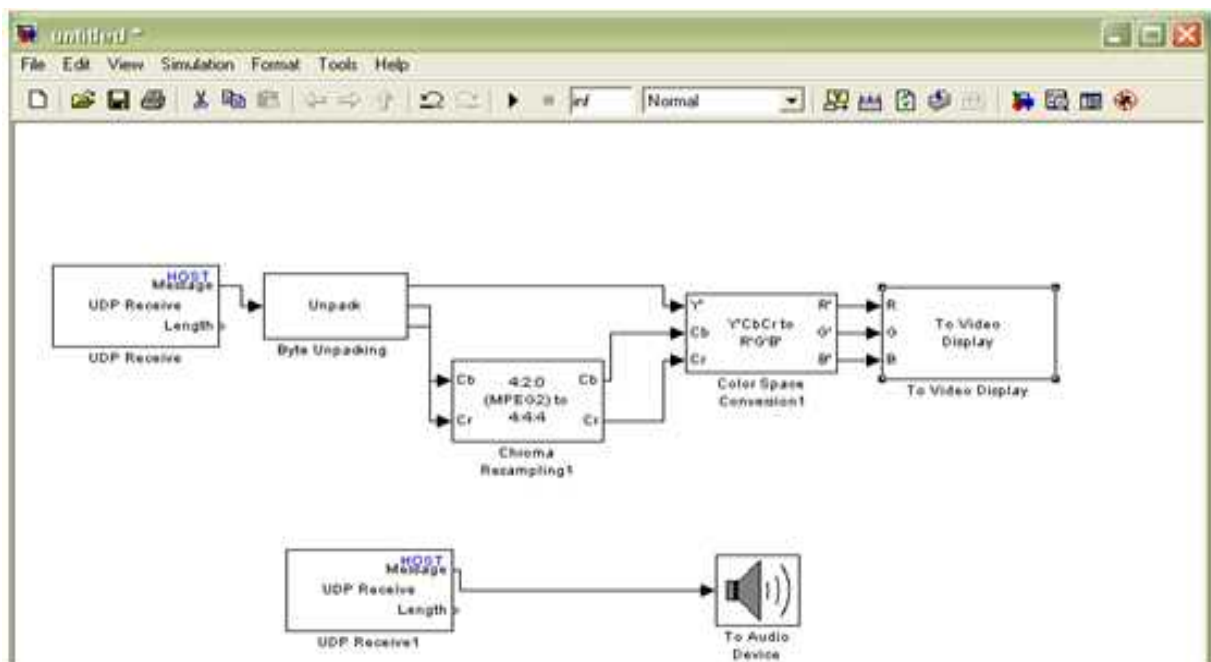


Figure 5.24: Matlab program that receives the video

We need several blocks for a client to display the receiving video on the PC: UDP receive , Byte unpacking, Chroma Resampling, color space conversion , to video display, to audio device as shown in Figure 5.17.

UDP receive: The UDP Receive block receives UDP packets from an IP network port and saves them to its buffer. With each sample, the block output, emits the contents of a single UDP packet as a data vector.

Byte unpacking: This block is the exact analog of the Pack block. It can receive a vector of one of the following types: double, int8, uint8, int16, uint16, int32, uint32, and Boolean.

Chroma Resampling: The Chroma Resampling block down samples or up samples chrominance components of pixels to reduce the bandwidth required for transmission or storage of a signal.

Color space conversion: The Color Space Conversion block converts color information between color spaces. Use the **Conversion** parameter to specify the color spaces you are converting between. Your choices are R'G'B' to Y'CbCr, Y'CbCr to R'G'B', R'G'B' to intensity, R'G'B' to HSV, HSV to R'G'B', sR'G'B' to XYZ, XYZ to sR'G'B', sR'G'B' to L*a*b*, and L*a*b* to sR'G'B'.

To video display: The To Video Display block sends video data to your computer screen.

To audio device : The To Audio Device block sends audio data to your computer's audio device. This block has the following limitations:

- Not supported for use with the Simulink Model block.
- Not currently supported on Solaris platforms.

Use the **Device** parameter to specify the device to which you want to send the audio data. This parameter is automatically populated based on the audio devices installed on your system. If you plug or unplug an audio device from your system, type clear mex at the MATLAB command prompt to update the list.

CHAPTER SIX

RESULTS AND PERFORMANCE

6.1 Introduction.

6.2 Testing and Results.

6.2.1 Sensors Testing.

6.2.2 MIMO Wi-Fi Testing.

6.2.3 3G GSM Testing.

6.3 Performance Evaluation.

6.3.1 Delay.

6.3.2 Data Rate.

6.3.3 Coverage.

6.1 Introduction

The final stage to complete the project is to test the system to get results and measure the performance of our system.

This chapter shows all measurements needed to evaluate the performance of this system such as delay, data rate, range and security.

6.2 Testing and Results

Checking and testing of the sensors, microcontrollers and transceivers are individually illustrated in this section in addition to the testing results.

6.2.1 Sensors Testing

Heart rate sensor circuit has been tested as following:

The HR circuit, shown in Figure 6.1, was implemented and tested, then the circuit was connected to the oscilloscope device to obtain the HR signal which is shown in

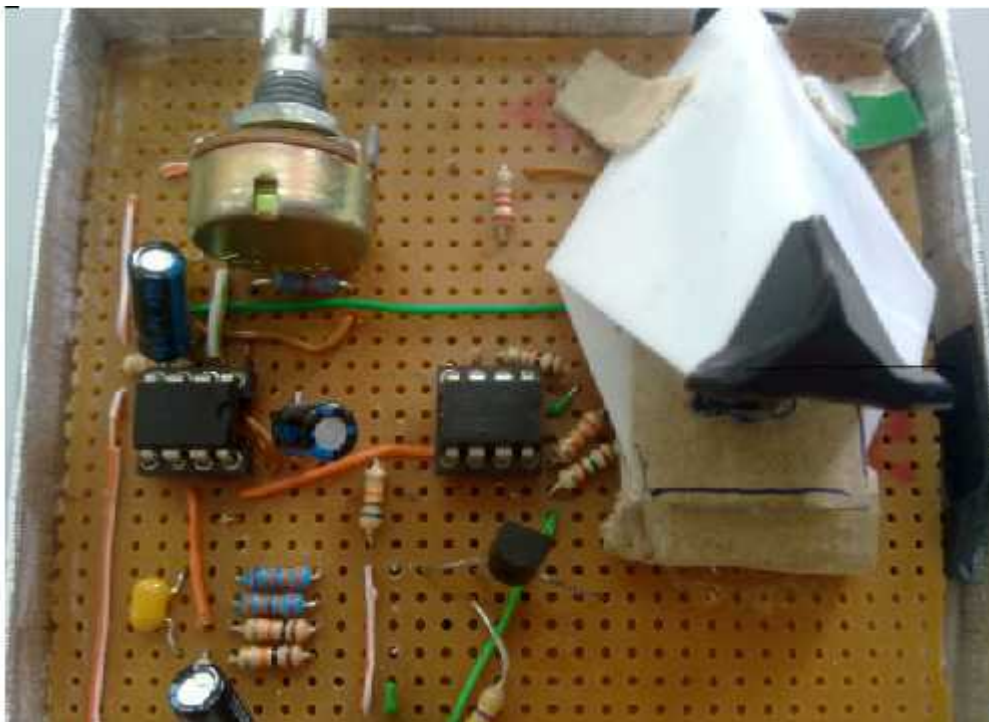


Figure 6.1: Heart rate Circuit

Figure 6.2 shows the signal when the Heart rate circuit was connected to the “simulator” device that simulates the human heart.

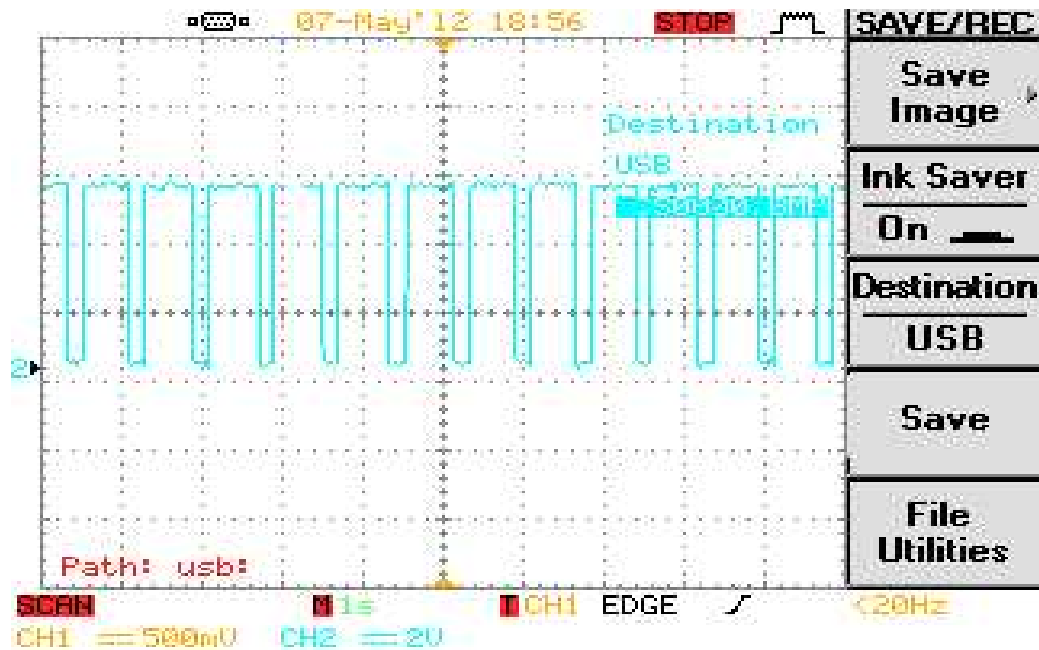


Figure 6.2: Heart rate Signal

After that the HR circuit was connected to the Arduino microcontroller through an analog pin. See Figure 6. 3.

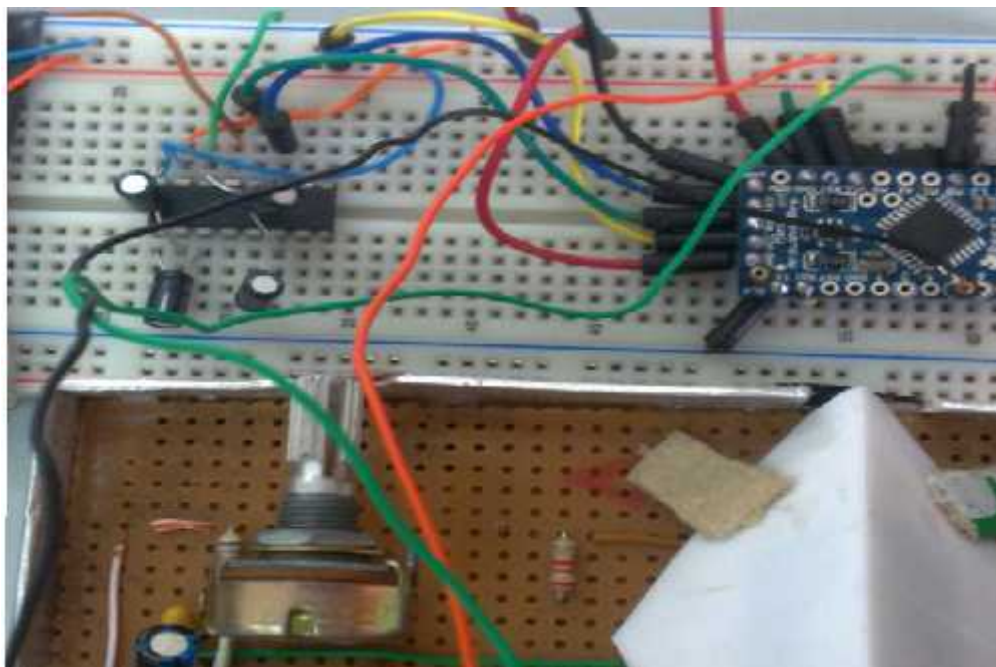


Figure 6.3: Connection between Heart rate Circuit and Arduino

After processing and programming the HR signal to obtain the heart rate, a test was performed and the results were 76, 86 and 70 beats per minutes. Figure 6.4 shows an example of the results.



Figure 6.4: Heart Rate and SPO2 Report

6.2.2 MIMO Wi-Fi Testing

After testing the TCP connection by the LabVIEW program, the data was sent from PC to the PC. This data contain the heart rate and SPO2 of the patient. Figure 6.5 shows an example which contain only the heart rate and SPO2 result.

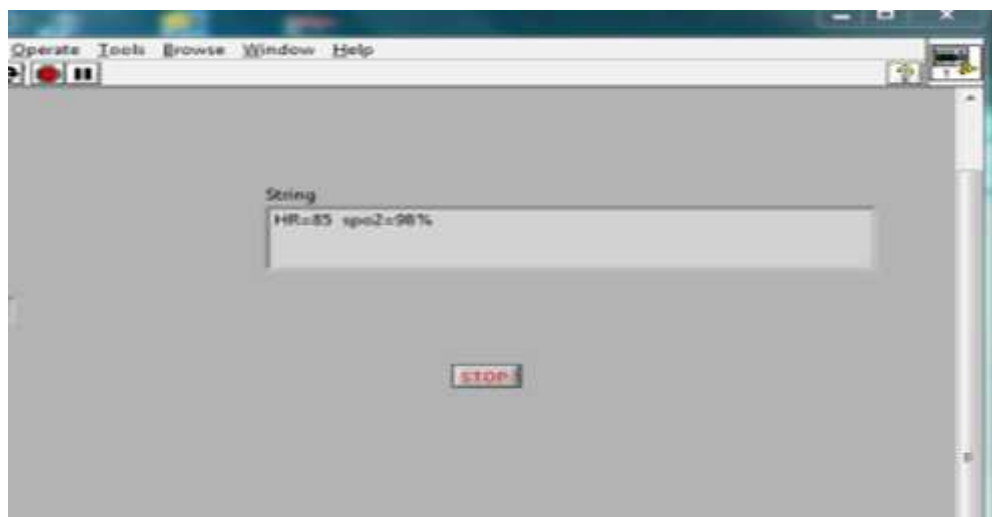


Figure 6.5: Received heart rate and SPO2 in MIMO WiFi scenario

6.2.3 3G GSM Testing

The connection between the 3G GSM modem and the Arduino was successfully achieved. After that we applied a test to initialize the 3G GSM modem. The initialization of 3G GSM modem took a little time about 25 seconds.

After initializing the 3G GSM modem, the modem has registered in the cellular network. As a result the modem is partially ready to communicate and locate the network. See Figure 6.6.

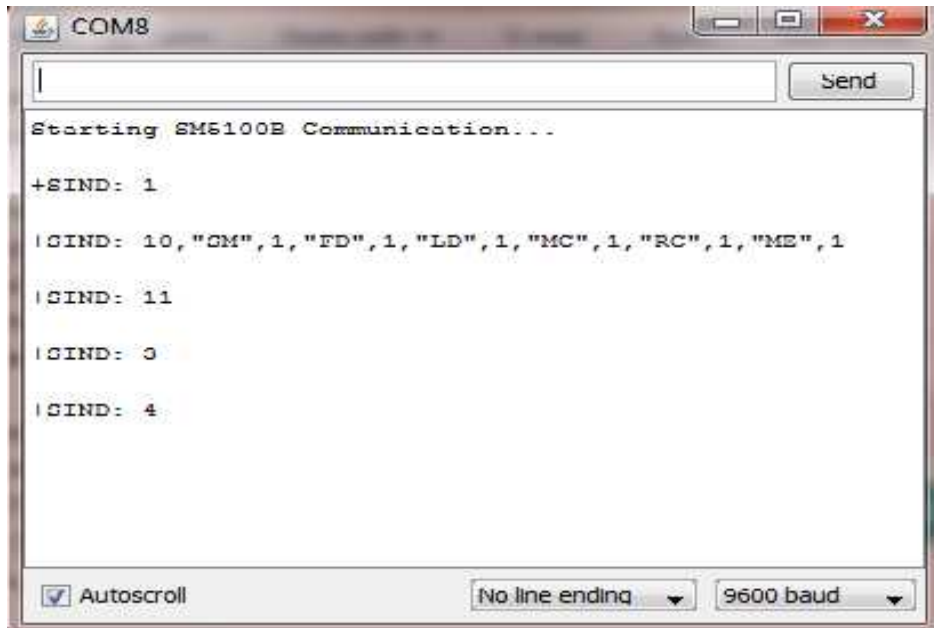


Figure 6.6: Result of Initializing 3G GSM modem

Finally, all the units have completely been connected to configure the whole system; that is the 3G GSM modem has been connected to the Arduino microcontroller which is joined with sensor circuit.

After processing and programming the heart rate signal to obtain the heart rate, and SPO2 . Figure 6.7 shows the received heart rate and SPO2 in 3G GSM scenario.

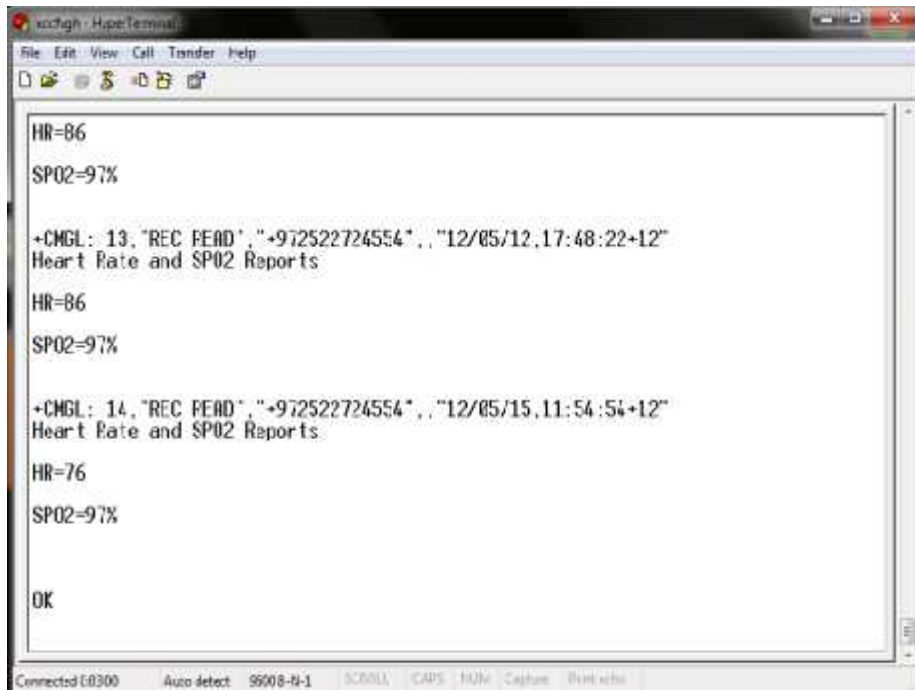


Figure 6.7: Received heart rate and SPO2 in 3G GSM scenario

6.3 Performance Evaluation

To evaluate the performance in this project, we have to measure the Delay, Data Rate and Range. These measurements should be applied to both GSM and Wi-Fi scenarios.

6.3.1 Delay

The delay is a significant factor in this project as the nature of the sent data requires fast transmission.

The delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

The delay is made of four components: propagation time, transmission time, queuing time and processing delay.

- 1) Propagation Time: measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

$$\text{Propagation Time} = \frac{\text{Distance}}{\text{Propagation speed}}$$

- 2) Transmission Time: the time required for transmission of a message depends on the size of the message and the bandwidth of the channel.

$$\text{Transmission Time} = \frac{\text{Message size}}{\text{Bandwidth}}$$

- 3) Queuing Time: the time needed for each intermediate or end device to hold the message before it can be processed. The queuing time is not a fixed factor; it changes with the load imposed on the network. When there is heavy traffic on the network, the queuing time increases.
- 4) Processing Time: the time it takes routers to process the packet header. Processing delay is a key component in network delay.

The delay in GSM scenario from the moment of sending the message from the module to completely arrive at the mobile is **9 sec**. If the size of the message increases, the delay increases. The reported result is an average of multiple experiments.

But in Wi-Fi scenario, we have conducted three experiments to obtain the delay. This delay was measured by using Ping. The ping is a computer network administration utility used to test the reachability of a host on an Internet Protocol (IP) network and to measure the round-trip time for messages sent from the originating host to a destination computer.

The first experiment was when we placed the transmitter and the access point and the receiver “personal computer” in the same floor, the average delay in this case was **0.6 msec** which was obtained from 15 readings.

The second one when we placed access point and the transmitter in the same floor and placed the receiver “personal computer” in another floor, in this case the delay was **1.1msec** gotten from 15 readings.

The third one when we placed the transmitter in the first floor and the access point in the second floor and placed the receiver “personal computer” in the third floor, in this case the delay was **9 msec** obtained from 15 readings.

6.3.2 Data Rate

In this project, Cisco Linksys E300 supports 802.11g standard. It operates at a maximum physical layer bit rate of 300 Mbit/s or about 115Mbps average throughput. This is much more comparator to 3G GSM which provides 144 Kbit/s data rate and **80 Kbit/s** throughput.

6.3.3 Coverage

A Wi-Fi signal provides coverage typically up to **250 feet** from an AP depending on factors such as walls.

A GSM signal provides far more widespread coverage of **several miles** or more from a cell site.

The previous measurements and results compared to previous project are summarized in the following table:

Table 6.1: Summarized Results

	GSM	3G GSM	Wi-Fi	MIMO Wi-Fi
Delay	8 sec	9 sec	6.7 msec	9 msec
Data Rate	9.6 Kbps	144 Kbps	54 Mbps	300 Mbps
Range	Several Miles	Several Miles	200 feet	250 feet

APPENDIX A

Code of GPRS Connection.

Code of Frequency Counter.

Code of SMS Testing.

Code of SMS that contain Heart Rate and Spo2 Reports.

Code of MIMO WiFi that contain Heart Rate and Spo2 Reports.

Code of GPRS Connection.

at

OK

at+creg?

+CREG: 0,1

OK

at&k0

OK

at+cgdcont=1,"IP","internet"

OK

AT#USERID=""

OK

at#userid=""

OK

AT+CGQREQ=1,0,0,3,0,0

OK

at#gprs=0

OK

at#gprs=1

+IP: 31.154.156.54

OK

at

OK

at#sktd=0,80,"www.google.co.il"

CONNECT

At Transmitter:

at

at+cgdcont=1,IP,static,0.0.0.0

at#sgact=1,1

at#sd=1,0,1080,10.16.2.8

At Receiver:

at

at+cgdcont=1,IP,static,0.0.0.0

at#sgact=1,1

at#frwl=1,255.255.0.0,0.0.0.0

at#sl=1,1,1080

at#sa=1

at#sh=1

Code of Frequency Counter.

```
#include <FreqCounter.h>

void setup()

{
    Serial.begin(9600);          // connect to the serial port
    Serial.println("Frequency Counter");
}

long int frq;

void loop() {
    FreqCounter::f_comp= 10;      // Set compensation to 12
    FreqCounter::start(15000);    // Start counting with gatetime of 100ms
    while (FreqCounter::f_ready == 0)    // wait until counter ready
    frq=FreqCounter::f_freq;        // read result
    Serial.println(frq);           // print result
    delay(20);
}
```

Code of SMS Testing.

```
int timesToSend = 1;    // Numbers of SMS to send

int count = 0;

void setup()
{
    Serial.begin(9600);

    delay(3000);

    Serial.println("AT");

    delay(500);

    Serial.println("ATE0");

    delay(500);
}

void loop(){
    Serial.println("AT+CMGF=1");

    delay(1500);

    Serial.println("AT+CMGS=\"0522724922\"");    // send the SMS the
number

    delay(1500);

    Serial.print("Hello...");    // the SMS body

    delay(500);

    Serial.print(0x1A,BYTE);    // end of message command 1A (hex)

    delay(50000);

}
```

Code of SMS that contain Heart Rate and Spo2 Reports.

```
#include <SoftwareSerial.h>

#include <FreqCounter.h>

long int y,hr1,x;

long int frq;

void setup()

{

    Serial.begin(115200); // connect to the serial port


    pinMode(12, OUTPUT);

}

void loop()

{

    digitalWrite(12, HIGH);

    delay(5000);

    FreqCounter::f_comp= 10;          // Set compensation to 12

    FreqCounter::start(15000);        // Start counting with gatetime of 5s

    while (FreqCounter::f_ready == 0);

    x=FreqCounter::f_freq;

    hr1=(x*4);

    if (hr1<120)

    {

        if (hr1>120)

            y=hr1-18;

        else

            if (hr1>100)
```

```
y=hr1-8;

else

if (hr1>96)

y=hr1+1;

else

if (hr1>91)

y=hr1+3;

else

if (hr1>86)

y=hr1+8;

else

if (hr1>81)

y=hr1+13;

else

if (hr1>76)

y=hr1+17;

else

if (hr1>71)

y=hr1+23;

else

if (hr1>60)

y=hr1+28;


Serial.println("AT");

delay(500);

Serial.println("ATE0");

delay(500);
```

```
Serial.println("AT+CMGF=1");

delay(1500);

Serial.println("AT+CMGS=\"0522724922\"");

delay(1500);

Serial.println("Heart Rate and SPO2 Reports");

Serial.print("HR=");

Serial.println(hr1);

Serial.print("spo2=");

Serial.print(y);

Serial.println("%");           // the SMS body

delay(500);

Serial.print(0x1A,BYTE);

}

}

digitalWrite(12, LOW);

delay(3600000);

}
```

Code of MIMO WiFi that contain Heart Rate and Spo2 Reports.

```
#include <SoftwareSerial.h>

#include <FreqCounter.h>

long int y,hr1,x;

long int frq;

void setup()

{

    Serial.begin(115200); // connect to the serial port


    pinMode(12, OUTPUT);

}

void loop()

{

    digitalWrite(12, HIGH);

    delay(5000);

    FreqCounter::f_comp= 10;          // Set compensation to 12

    FreqCounter::start(15000);        // Start counting with gatetime of 5s

    while (FreqCounter::f_ready == 0);

    x=FreqCounter::f_freq;

    hr1=(x*4);

    if (hr1<120)

    {

        if (hr1>120)

            y=hr1-18;

        else

            if (hr1>100)
```

```
y=hr1-8;

else

if (hr1>96)

y=hr1+1;

else

if (hr1>91)

y=hr1+3;

else

if (hr1>86)

y=hr1+8;

else

if (hr1>81)

y=hr1+13;

else

if (hr1>76)

y=hr1+17;

else

if (hr1>71)

y=hr1+23;

else

if (hr1>60)

y=hr1+28;
```

```
Serial.println("Heart Rate and SPO2 Reports");
```

```
Serial.print("HR=");
```

```
Serial.println(hr1);
```

```
Serial.print("spo2=");
```



```
Serial.print(y);  
Serial.println("%");  
}  
}  
digitalWrite(12, LOW);  
delay(30000);  
}
```

APPENDIX B

DATA SHEET

For

Arduino Microcontroller (ATmega328P)

3G HSDPA Modem

Cisco Linksys E3000

LM 358N

MAX 232

3G GSM Modem (AT Commands)

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14. <http://www.AURDUINO.CC> , Arduino Microcontroller.
15. <http://www.analog.com>, Amplifier LM358N.
16. <http://www.mathworks.com> ,Matlab
17. <http://www.MATLABCENTER.COM>.

Features

- High Performance, Low Power Atmel® AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
 - 131 Powerful Instructions – Most Single Clock Cycle Execution
 - 32 x 8 General Purpose Working Registers
 - Fully Static Operation
 - Up to 20 MIPS Throughput at 20MHz
 - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
 - 4/8/16/32KBytes of In-System Self-Programmable Flash program memory
 - 256/512/512/1KBytes EEPROM
 - 512/1K/1K/2KBytes Internal SRAM
 - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
 - Data retention: 20 years at 85°C/100 years at 25°C⁽¹⁾
 - Optional Boot Code Section with Independent Lock Bits
 - In-System Programming by On-chip Boot Program
 - True Read-While-Write Operation
 - Programming Lock for Software Security
- Atmel® QTouch® library support
 - Capacitive touch buttons, sliders and wheels
 - QTouch and QMatrix® acquisition
 - Up to 64 sense channels
- Peripheral Features
 - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
 - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
 - Real Time Counter with Separate Oscillator
 - Six PWM Channels
 - 8-channel 10-bit ADC in TQFP and QFN/MLF package
 - Temperature Measurement
 - 6-channel 10-bit ADC in PDIP Package
 - Temperature Measurement
 - Programmable Serial USART
 - Master/Slave SPI Serial Interface
 - Byte-oriented 2-wire Serial Interface (Philips I²C compatible)
 - Programmable Watchdog Timer with Separate On-chip Oscillator
 - On-chip Analog Comparator
 - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
 - Power-on Reset and Programmable Brown-out Detection
 - Internal Calibrated Oscillator
 - External and Internal Interrupt Sources
 - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
 - 23 Programmable I/O Lines
 - 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
 - 1.8 - 5.5V
- Temperature Range:
 - -40°C to 85°C
- Speed Grade:
 - 0 - 4MHz@1.8 - 5.5V, 0 - 10MHz@2.7 - 5.5V, 0 - 20MHz @ 4.5 - 5.5V
- Power Consumption at 1MHz, 1.8V, 25°C
 - Active Mode: 0.2mA
 - Power-down Mode: 0.1µA
 - Power-save Mode: 0.75µA (Including 32kHz RTC)



8-bit Atmel Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash

ATmega48A
ATmega48PA
ATmega88A
ATmega88PA
ATmega168A
ATmega168PA
ATmega328
ATmega328P

Summary

Rev. 8271DS-AVR-05/11



1. Pin Configurations

Figure 1-1. Pinout ATmega48A/PA/88A/PA/168A/PA/328/P

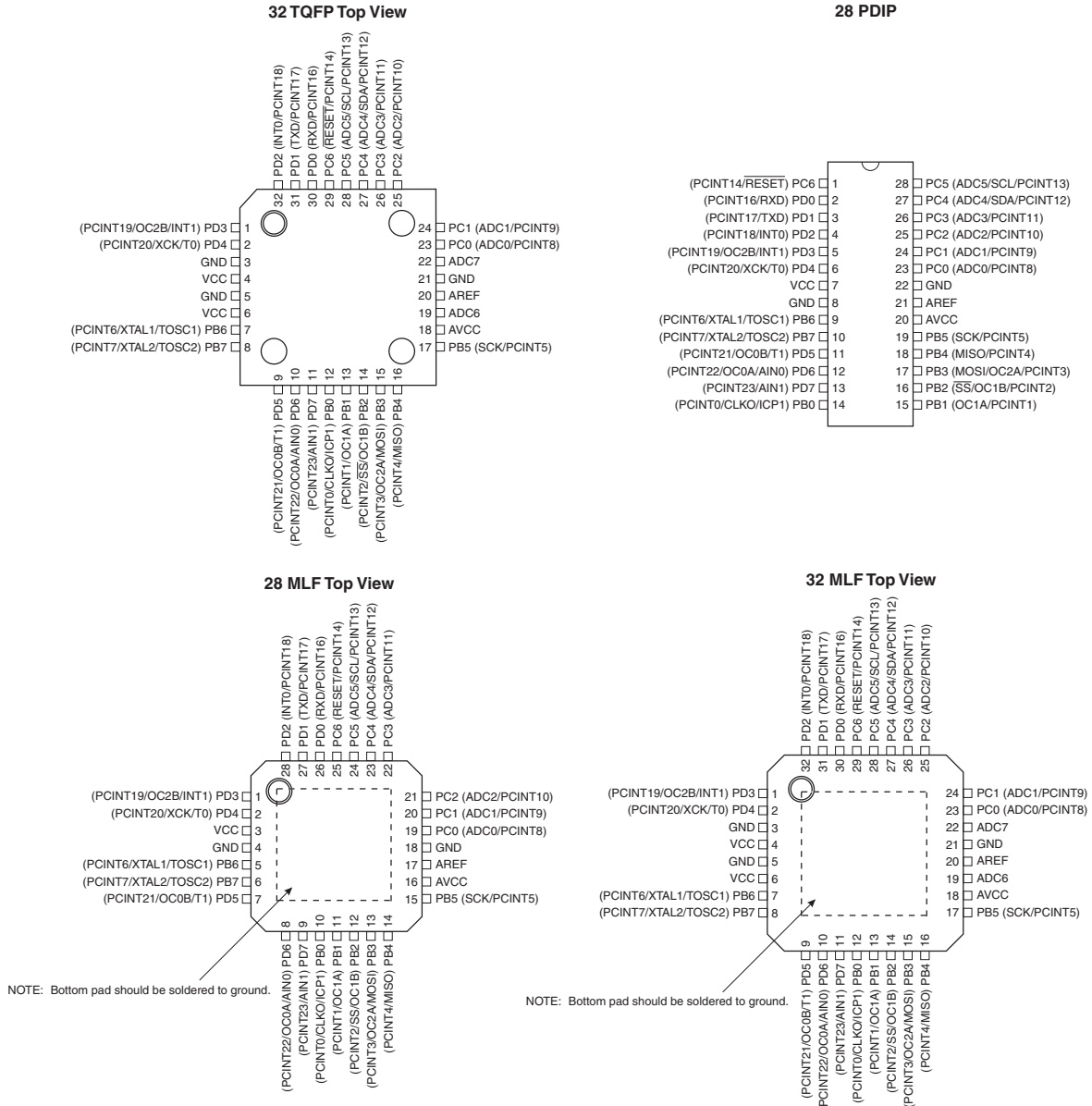


Table 1-1. 32UFBGA - Pinout ATmega48A/48PA/88A/88PA/168A/168PA

	1	2	3	4	5	6
A	PD2	PD1	PC6	PC4	PC2	PC1
B	PD3	PD4	PD0	PC5	PC3	PC0
C	GND	GND			ADC7	GND
D	VDD	VDD			AREF	ADC6
E	PB6	PD6	PB0	PB2	AVDD	PB5
F	PB7	PD5	PD7	PB1	PB3	PB4

1.1 Pin Descriptions

1.1.1 VCC

Digital supply voltage.

1.1.2 GND

Ground.

1.1.3 Port B (PB7:0) XTAL1/XTAL2/TOSC1/TOSC2

Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Depending on the clock selection fuse settings, PB6 can be used as input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

Depending on the clock selection fuse settings, PB7 can be used as output from the inverting Oscillator amplifier.

If the Internal Calibrated RC Oscillator is used as chip clock source, PB7...6 is used as TOSC2...1 input for the Asynchronous Timer/Counter2 if the AS2 bit in ASSR is set.

The various special features of Port B are elaborated in ["Alternate Functions of Port B" on page 84](#) and ["System Clock and Clock Options" on page 27](#).

1.1.4 Port C (PC5:0)

Port C is a 7-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The PC5...0 output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running.

1.1.5 PC6/ $\overline{\text{RESET}}$

If the RSTDISBL Fuse is programmed, PC6 is used as an I/O pin. Note that the electrical characteristics of PC6 differ from those of the other pins of Port C.

If the RSTDISBL Fuse is unprogrammed, PC6 is used as a Reset input. A low level on this pin for longer than the minimum pulse length will generate a Reset, even if the clock is not running. The minimum pulse length is given in [Table 29-12 on page 324](#). Shorter pulses are not guaranteed to generate a Reset.

The various special features of Port C are elaborated in ["Alternate Functions of Port C" on page 87](#).

1.1.6 Port D (PD7:0)

Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.

The various special features of Port D are elaborated in ["Alternate Functions of Port D" on page 90](#).

1.1.7 **AV_{CC}**

AV_{CC} is the supply voltage pin for the A/D Converter, PC3:0, and ADC7:6. It should be externally connected to V_{CC}, even if the ADC is not used. If the ADC is used, it should be connected to V_{CC} through a low-pass filter. Note that PC6...4 use digital supply voltage, V_{CC}.

1.1.8 **AREF**

AREF is the analog reference pin for the A/D Converter.

1.1.9 **ADC7:6 (TQFP and QFN/MLF Package Only)**

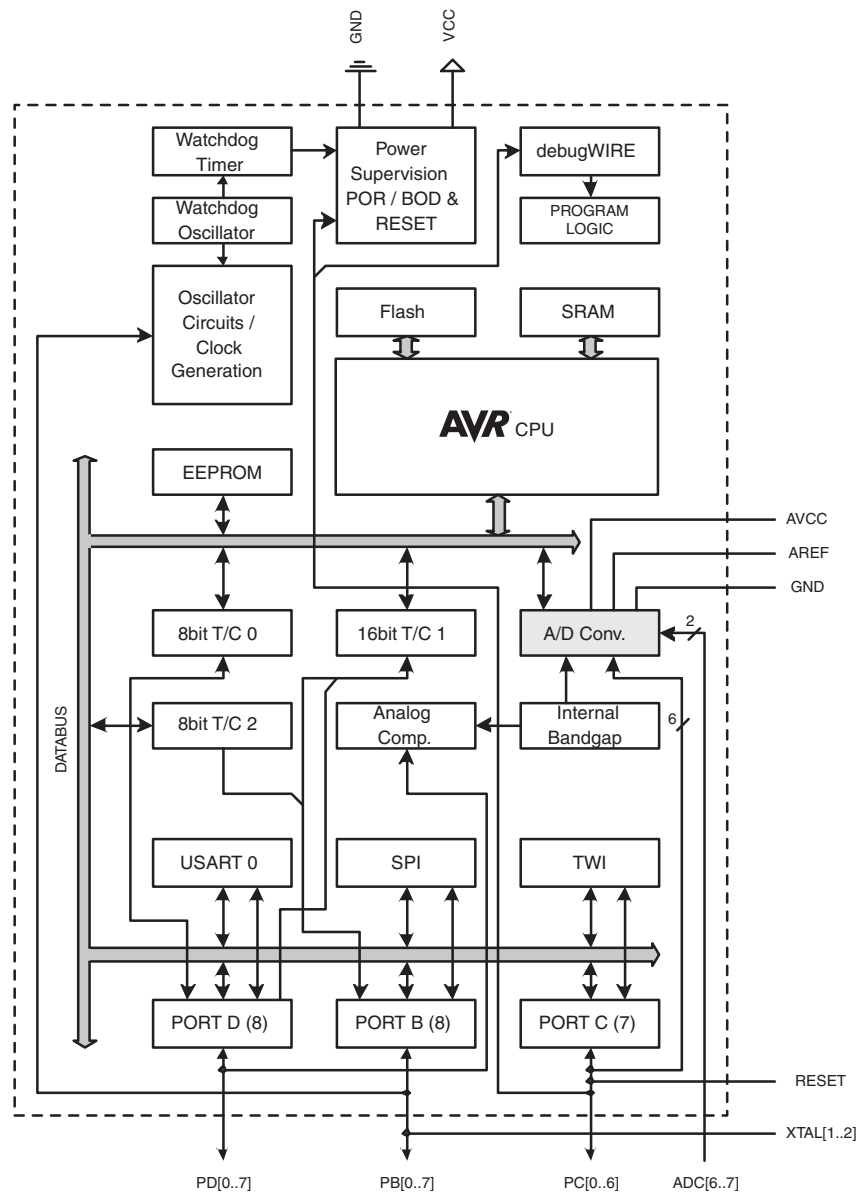
In the TQFP and QFN/MLF package, ADC7:6 serve as analog inputs to the A/D converter. These pins are powered from the analog supply and serve as 10-bit ADC channels.

2. Overview

The ATmega48A/PA/88A/PA/168A/PA/328/P 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 ATmega48A/PA/88A/PA/168A/PA/328/P achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

2.1 Block Diagram

Figure 2-1. Block Diagram



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 ATmega48A/PA/88A/PA/168A/PA/328/P provides the following features: 4K/8Kbytes of In-System Programmable Flash with Read-While-Write capabilities, 256/512/512/1Kbytes EEPROM, 512/1K/1K/2Kbytes SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte-oriented 2-wire Serial Interface, an SPI serial port, a 6-channel 10-bit ADC (8 channels in TQFP and QFN/MLF packages), a programmable Watchdog Timer with internal Oscillator, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, USART, 2-wire Serial Interface, 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.

Atmel® offers the QTouch® library for embedding capacitive touch buttons, sliders and wheels functionality into AVR® microcontrollers. The patented charge-transfer signal acquisition offers robust sensing and includes fully debounced reporting of touch keys and includes Adjacent Key Suppression® (AKS™) technology for unambiguous detection of key events. The easy-to-use QTouch Suite toolchain allows you to explore, develop and debug your own touch applications.

The device is manufactured using Atmel's high density non-volatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed In-System through an SPI serial interface, by a conventional non-volatile 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 operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega48A/PA/88A/PA/168A/PA/328/P is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications.

The ATmega48A/PA/88A/PA/168A/PA/328/P 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.

2.2 Comparison Between Processors

The ATmega48A/PA/88A/PA/168A/PA/328/P differ only in memory sizes, boot loader support, and interrupt vector sizes. [Table 2-1](#) summarizes the different memory and interrupt vector sizes for the devices.

Table 2-1. Memory Size Summary

Device	Flash	EEPROM	RAM	Interrupt Vector Size
ATmega48A	4KBytes	256Bytes	512Bytes	1 instruction word/vector
ATmega48PA	4KBytes	256Bytes	512Bytes	1 instruction word/vector
ATmega88A	8KBytes	512Bytes	1KBytes	1 instruction word/vector

Table 2-1. Memory Size Summary (Continued)

Device	Flash	EEPROM	RAM	Interrupt Vector Size
ATmega88PA	8KBytes	512Bytes	1KBytes	1 instruction word/vector
ATmega168A	16KBytes	512Bytes	1KBytes	2 instruction words/vector
ATmega168PA	16KBytes	512Bytes	1KBytes	2 instruction words/vector
ATmega328	32KBytes	1KBytes	2KBytes	2 instruction words/vector
ATmega328P	32KBytes	1KBytes	2KBytes	2 instruction words/vector

ATmega48A/PA/88A/PA/168A/PA/328/P support a real Read-While-Write Self-Programming mechanism. There is a separate Boot Loader Section, and the SPM instruction can only execute from there. In ATmega 48A/48PA there is no Read-While-Write support and no separate Boot Loader Section. The SPM instruction can execute from the entire Flash.

3. Resources

A comprehensive set of development tools, application notes and datasheets are available for download on <http://www.atmel.com/avr>.

4. Data Retention

Reliability Qualification results show that the projected data retention failure rate is much less than 1 PPM over 20 years at 85°C or 100 years at 25°C.

5. About Code Examples

This documentation contains simple code examples that briefly show how to use various parts of the device. These code examples assume that the part specific header file is included before compilation. Be aware that not all C compiler vendors include bit definitions in the header files and interrupt handling in C is compiler dependent. Please confirm with the C compiler documentation for more details.

For I/O Registers located in extended I/O map, “IN”, “OUT”, “SBIS”, “SBIC”, “CBI”, and “SBI” instructions must be replaced with instructions that allow access to extended I/O. Typically “LDS” and “STS” combined with “SBRS”, “SBRC”, “SBR”, and “CBR”.

6. Capacitive Touch Sensing

The Atmel® QTouch® Library provides a simple to use solution to realize touch sensitive interfaces on most Atmel AVR® microcontrollers. The QTouch Library includes support for the Atmel QTouch and Atmel QMatrix® acquisition methods.

Touch sensing can be added to any application by linking the appropriate Atmel QTouch Library for the AVR Microcontroller. This is done by using a simple set of APIs to define the touch channels and sensors, and then calling the touch sensing API's to retrieve the channel information and determine the touch sensor states.

The QTouch Library is FREE and downloadable from the Atmel website at the following location: www.atmel.com/qtouchlibrary. For implementation details and other information, refer to the [Atmel QTouch Library User Guide](#) - also available for download from Atmel website.

7. Register Summary

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
(0xFF)	Reserved	–	–	–	–	–	–	–	–	
(0xFE)	Reserved	–	–	–	–	–	–	–	–	
(0xFD)	Reserved	–	–	–	–	–	–	–	–	
(0xFC)	Reserved	–	–	–	–	–	–	–	–	
(0xFB)	Reserved	–	–	–	–	–	–	–	–	
(0xFA)	Reserved	–	–	–	–	–	–	–	–	
(0xF9)	Reserved	–	–	–	–	–	–	–	–	
(0xF8)	Reserved	–	–	–	–	–	–	–	–	
(0xF7)	Reserved	–	–	–	–	–	–	–	–	
(0xF6)	Reserved	–	–	–	–	–	–	–	–	
(0xF5)	Reserved	–	–	–	–	–	–	–	–	
(0xF4)	Reserved	–	–	–	–	–	–	–	–	
(0xF3)	Reserved	–	–	–	–	–	–	–	–	
(0xF2)	Reserved	–	–	–	–	–	–	–	–	
(0xF1)	Reserved	–	–	–	–	–	–	–	–	
(0xF0)	Reserved	–	–	–	–	–	–	–	–	
(0xEF)	Reserved	–	–	–	–	–	–	–	–	
(0xEE)	Reserved	–	–	–	–	–	–	–	–	
(0xED)	Reserved	–	–	–	–	–	–	–	–	
(0xEC)	Reserved	–	–	–	–	–	–	–	–	
(0xEB)	Reserved	–	–	–	–	–	–	–	–	
(0xEA)	Reserved	–	–	–	–	–	–	–	–	
(0xE9)	Reserved	–	–	–	–	–	–	–	–	
(0xE8)	Reserved	–	–	–	–	–	–	–	–	
(0xE7)	Reserved	–	–	–	–	–	–	–	–	
(0xE6)	Reserved	–	–	–	–	–	–	–	–	
(0xE5)	Reserved	–	–	–	–	–	–	–	–	
(0xE4)	Reserved	–	–	–	–	–	–	–	–	
(0xE3)	Reserved	–	–	–	–	–	–	–	–	
(0xE2)	Reserved	–	–	–	–	–	–	–	–	
(0xE1)	Reserved	–	–	–	–	–	–	–	–	
(0xE0)	Reserved	–	–	–	–	–	–	–	–	
(0xDF)	Reserved	–	–	–	–	–	–	–	–	
(0xDE)	Reserved	–	–	–	–	–	–	–	–	
(0xDD)	Reserved	–	–	–	–	–	–	–	–	
(0xDC)	Reserved	–	–	–	–	–	–	–	–	
(0xDB)	Reserved	–	–	–	–	–	–	–	–	
(0xDA)	Reserved	–	–	–	–	–	–	–	–	
(0xD9)	Reserved	–	–	–	–	–	–	–	–	
(0xD8)	Reserved	–	–	–	–	–	–	–	–	
(0xD7)	Reserved	–	–	–	–	–	–	–	–	
(0xD6)	Reserved	–	–	–	–	–	–	–	–	
(0xD5)	Reserved	–	–	–	–	–	–	–	–	
(0xD4)	Reserved	–	–	–	–	–	–	–	–	
(0xD3)	Reserved	–	–	–	–	–	–	–	–	
(0xD2)	Reserved	–	–	–	–	–	–	–	–	
(0xD1)	Reserved	–	–	–	–	–	–	–	–	
(0xD0)	Reserved	–	–	–	–	–	–	–	–	
(0xCF)	Reserved	–	–	–	–	–	–	–	–	
(0xCE)	Reserved	–	–	–	–	–	–	–	–	
(0xCD)	Reserved	–	–	–	–	–	–	–	–	
(0xCC)	Reserved	–	–	–	–	–	–	–	–	
(0xCB)	Reserved	–	–	–	–	–	–	–	–	
(0xCA)	Reserved	–	–	–	–	–	–	–	–	
(0xC9)	Reserved	–	–	–	–	–	–	–	–	
(0xC8)	Reserved	–	–	–	–	–	–	–	–	
(0xC7)	Reserved	–	–	–	–	–	–	–	–	
(0xC6)	UDR0	USART I/O Data Register								201
(0xC5)	UBRR0H					USART Baud Rate Register High				205
(0xC4)	UBRR0L	USART Baud Rate Register Low								205
(0xC3)	Reserved	–	–	–	–	–	–	–	–	
(0xC2)	UCSR0C	UMSEL01	UMSEL00	UPM01	UPM00	USBS0	UCSZ01 / UDORD0	UCSZ00 / UCPHA0	UCPOL0	203/214
(0xC1)	UCSR0B	RXCIE0	TXCIE0	UDRIE0	RXEN0	TXEN0	UCSZ02	RXB80	TXB80	202
(0xC0)	UCSR0A	RXC0	TXC0	UDRE0	FE0	DOR0	UPE0	U2X0	MPCM0	201

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
(0xBF)	Reserved	–	–	–	–	–	–	–	–	
(0xBE)	Reserved	–	–	–	–	–	–	–	–	
(0xBD)	TWAMR	TWAM6	TWAM5	TWAM4	TWAM3	TWAM2	TWAM1	TWAM0	–	246
(0xBC)	TWCR	TWINT	TWEA	TWSTA	TWSTO	TWWC	TWEN	–	TWIE	243
(0xBB)	TWDR	2-wire Serial Interface Data Register								245
(0xBA)	TWAR	TWA6	TWA5	TWA4	TWA3	TWA2	TWA1	TWA0	TWGCE	246
(0xB9)	TWSR	TWS7	TWS6	TWS5	TWS4	TWS3	–	TWPS1	TWPS0	245
(0xB8)	TWBR	2-wire Serial Interface Bit Rate Register								243
(0xB7)	Reserved	–	–	–	–	–	–	–	–	
(0xB6)	ASSR	–	EXCLK	AS2	TCN2UB	OCR2AUB	OCR2BUB	TCR2AUB	TCR2BUB	166
(0xB5)	Reserved	–	–	–	–	–	–	–	–	
(0xB4)	OCR2B	Timer/Counter2 Output Compare Register B								164
(0xB3)	OCR2A	Timer/Counter2 Output Compare Register A								164
(0xB2)	TCNT2	Timer/Counter2 (8-bit)								164
(0xB1)	TCCR2B	FOC2A	FOC2B	–	–	WGM22	CS22	CS21	CS20	163
(0xB0)	TCCR2A	COM2A1	COM2A0	COM2B1	COM2B0	–	–	WGM21	WGM20	160
(0xAF)	Reserved	–	–	–	–	–	–	–	–	
(0xAE)	Reserved	–	–	–	–	–	–	–	–	
(0xAD)	Reserved	–	–	–	–	–	–	–	–	
(0xAC)	Reserved	–	–	–	–	–	–	–	–	
(0xAB)	Reserved	–	–	–	–	–	–	–	–	
(0xAA)	Reserved	–	–	–	–	–	–	–	–	
(0xA9)	Reserved	–	–	–	–	–	–	–	–	
(0xA8)	Reserved	–	–	–	–	–	–	–	–	
(0xA7)	Reserved	–	–	–	–	–	–	–	–	
(0xA6)	Reserved	–	–	–	–	–	–	–	–	
(0xA5)	Reserved	–	–	–	–	–	–	–	–	
(0xA4)	Reserved	–	–	–	–	–	–	–	–	
(0xA3)	Reserved	–	–	–	–	–	–	–	–	
(0xA2)	Reserved	–	–	–	–	–	–	–	–	
(0xA1)	Reserved	–	–	–	–	–	–	–	–	
(0xA0)	Reserved	–	–	–	–	–	–	–	–	
(0x9F)	Reserved	–	–	–	–	–	–	–	–	
(0x9E)	Reserved	–	–	–	–	–	–	–	–	
(0x9D)	Reserved	–	–	–	–	–	–	–	–	
(0x9C)	Reserved	–	–	–	–	–	–	–	–	
(0x9B)	Reserved	–	–	–	–	–	–	–	–	
(0x9A)	Reserved	–	–	–	–	–	–	–	–	
(0x99)	Reserved	–	–	–	–	–	–	–	–	
(0x98)	Reserved	–	–	–	–	–	–	–	–	
(0x97)	Reserved	–	–	–	–	–	–	–	–	
(0x96)	Reserved	–	–	–	–	–	–	–	–	
(0x95)	Reserved	–	–	–	–	–	–	–	–	
(0x94)	Reserved	–	–	–	–	–	–	–	–	
(0x93)	Reserved	–	–	–	–	–	–	–	–	
(0x92)	Reserved	–	–	–	–	–	–	–	–	
(0x91)	Reserved	–	–	–	–	–	–	–	–	
(0x90)	Reserved	–	–	–	–	–	–	–	–	
(0x8F)	Reserved	–	–	–	–	–	–	–	–	
(0x8E)	Reserved	–	–	–	–	–	–	–	–	
(0x8D)	Reserved	–	–	–	–	–	–	–	–	
(0x8C)	Reserved	–	–	–	–	–	–	–	–	
(0x8B)	OCR1BH	Timer/Counter1 - Output Compare Register B High Byte								140
(0x8A)	OCR1BL	Timer/Counter1 - Output Compare Register B Low Byte								140
(0x89)	OCR1AH	Timer/Counter1 - Output Compare Register A High Byte								140
(0x88)	OCR1AL	Timer/Counter1 - Output Compare Register A Low Byte								140
(0x87)	ICR1H	Timer/Counter1 - Input Capture Register High Byte								140
(0x86)	ICR1L	Timer/Counter1 - Input Capture Register Low Byte								140
(0x85)	TCNT1H	Timer/Counter1 - Counter Register High Byte								140
(0x84)	TCNT1L	Timer/Counter1 - Counter Register Low Byte								140
(0x83)	Reserved	–	–	–	–	–	–	–	–	
(0x82)	TCCR1C	FOC1A	FOC1B	–	–	–	–	–	–	139
(0x81)	TCCR1B	ICNC1	ICES1	–	WGM13	WGM12	CS12	CS11	CS10	138
(0x80)	TCCR1A	COM1A1	COM1A0	COM1B1	COM1B0	–	–	WGM11	WGM10	136
(0x7F)	DIDR1	–	–	–	–	–	–	AIN1D	AIN0D	251
(0x7E)	DIDR0	–	–	ADC5D	ADC4D	ADC3D	ADC2D	ADC1D	ADC0D	268

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
(0x7D)	Reserved	–	–	–	–	–	–	–	–	
(0x7C)	ADMUX	REFS1	REFS0	ADLAR	–	MUX3	MUX2	MUX1	MUX0	264
(0x7B)	ADCSRB	–	ACME	–	–	–	ADTS2	ADTS1	ADTS0	267
(0x7A)	ADCSRA	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0	265
(0x79)	ADCH	ADC Data Register High byte								267
(0x78)	ADCL	ADC Data Register Low byte								267
(0x77)	Reserved	–	–	–	–	–	–	–	–	
(0x76)	Reserved	–	–	–	–	–	–	–	–	
(0x75)	Reserved	–	–	–	–	–	–	–	–	
(0x74)	Reserved	–	–	–	–	–	–	–	–	
(0x73)	Reserved	–	–	–	–	–	–	–	–	
(0x72)	Reserved	–	–	–	–	–	–	–	–	
(0x71)	Reserved	–	–	–	–	–	–	–	–	
(0x70)	TIMSK2	–	–	–	–	–	OCIE2B	OCIE2A	TOIE2	165
(0x6F)	TIMSK1	–	–	ICIE1	–	–	OCIE1B	OCIE1A	TOIE1	141
(0x6E)	TIMSK0	–	–	–	–	–	OCIE0B	OCIE0A	TOIE0	113
(0x6D)	PCMSK2	PCINT23	PCINT22	PCINT21	PCINT20	PCINT19	PCINT18	PCINT17	PCINT16	76
(0x6C)	PCMSK1	–	PCINT14	PCINT13	PCINT12	PCINT11	PCINT10	PCINT9	PCINT8	76
(0x6B)	PCMSK0	PCINT7	PCINT6	PCINT5	PCINT4	PCINT3	PCINT2	PCINT1	PCINT0	76
(0x6A)	Reserved	–	–	–	–	–	–	–	–	
(0x69)	EICRA	–	–	–	–	ISC11	ISC10	ISC01	ISC00	73
(0x68)	PCICR	–	–	–	–	–	PCIE2	PCIE1	PCIE0	
(0x67)	Reserved	–	–	–	–	–	–	–	–	
(0x66)	OSCCAL	Oscillator Calibration Register								38
(0x65)	Reserved	–	–	–	–	–	–	–	–	
(0x64)	PRR	PRTWI	PRTIM2	PRTIM0	–	PRTIM1	PRSPI	PRUSART0	PRADC	43
(0x63)	Reserved	–	–	–	–	–	–	–	–	
(0x62)	Reserved	–	–	–	–	–	–	–	–	
(0x61)	CLKPR	CLKPCE	–	–	–	CLKPS3	CLKPS2	CLKPS1	CLKPS0	38
(0x60)	WDTCR	WDIF	WDIE	WDP3	WDCE	WDE	WDP2	WDP1	WDP0	56
0x3F (0x5F)	SREG	I	T	H	S	V	N	Z	C	10
0x3E (0x5E)	SPH	–	–	–	–	–	(SP10) ⁵	SP9	SP8	13
0x3D (0x5D)	SPL	SP7	SP6	SP5	SP4	SP3	SP2	SP1	SP0	13
0x3C (0x5C)	Reserved	–	–	–	–	–	–	–	–	
0x3B (0x5B)	Reserved	–	–	–	–	–	–	–	–	
0x3A (0x5A)	Reserved	–	–	–	–	–	–	–	–	
0x39 (0x59)	Reserved	–	–	–	–	–	–	–	–	
0x38 (0x58)	Reserved	–	–	–	–	–	–	–	–	
0x37 (0x57)	SPMCSR	SPMIE	(RWWSB) ⁵	–	(RWWSRE) ⁵	BLBSET	PGWRT	PGERS	SELFPRGEN	295
0x36 (0x56)	Reserved	–	–	–	–	–	–	–	–	
0x35 (0x55)	MCUCR	–	BODS ⁽⁶⁾	BODSE ⁽⁶⁾	PUD	–	–	IVSEL	IVCE	46/70/94
0x34 (0x54)	MCUSR	–	–	–	–	WDRF	BORF	EXTRF	PORF	56
0x33 (0x53)	SMCR	–	–	–	–	SM2	SM1	SM0	SE	41
0x32 (0x52)	Reserved	–	–	–	–	–	–	–	–	
0x31 (0x51)	Reserved	–	–	–	–	–	–	–	–	
0x30 (0x50)	ACSR	ACD	ACBG	ACO	ACI	ACIE	ACIC	ACIS1	ACIS0	249
0x2F (0x4F)	Reserved	–	–	–	–	–	–	–	–	
0x2E (0x4E)	SPDR	SPI Data Register								177
0x2D (0x4D)	SPSR	SPIF	WCOL	–	–	–	–	–	SPI2X	176
0x2C (0x4C)	SPCR	SPIE	SPE	DORD	MSTR	CPOL	CPHA	SPR1	SPR0	175
0x2B (0x4B)	GPOR2	General Purpose I/O Register 2								26
0x2A (0x4A)	GPOR1	General Purpose I/O Register 1								26
0x29 (0x49)	Reserved	–	–	–	–	–	–	–	–	
0x28 (0x48)	OCR0B	Timer/Counter0 Output Compare Register B								
0x27 (0x47)	OCR0A	Timer/Counter0 Output Compare Register A								
0x26 (0x46)	TCNT0	Timer/Counter0 (8-bit)								
0x25 (0x45)	TCCR0B	FOC0A	FOC0B	–	–	WGM02	CS02	CS01	CS00	
0x24 (0x44)	TCCR0A	COM0A1	COM0A0	COM0B1	COM0B0	–	–	WGM01	WGM00	
0x23 (0x43)	GTCCR	TSM	–	–	–	–	–	PSRAS1	PSRSYN0	145/167
0x22 (0x42)	EEARH	(EEPROM Address Register High Byte) ⁵								22
0x21 (0x41)	EEARL	EEPROM Address Register Low Byte								22
0x20 (0x40)	EEDR	EEPROM Data Register								22
0x1F (0x3F)	EEDCR	–	–	EEP1	EEP0	EERIE	EEMPE	EEPE	EERE	22
0x1E (0x3E)	GPOR0	General Purpose I/O Register 0								26
0x1D (0x3D)	EIMSK	–	–	–	–	–	–	INT1	INT0	74
0x1C (0x3C)	EIFR	–	–	–	–	–	–	INTF1	INTF0	74

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Page
0x1B (0x3B)	PCIFR	—	—	—	—	—	PCIF2	PCIF1	PCIF0	
0x1A (0x3A)	Reserved	—	—	—	—	—	—	—	—	
0x19 (0x39)	Reserved	—	—	—	—	—	—	—	—	
0x18 (0x38)	Reserved	—	—	—	—	—	—	—	—	
0x17 (0x37)	TIFR2	—	—	—	—	—	OCF2B	OCF2A	TOV2	165
0x16 (0x36)	TIFR1	—	—	ICF1	—	—	OCF1B	OCF1A	TOV1	141
0x15 (0x35)	TIFR0	—	—	—	—	—	OCF0B	OCF0A	TOV0	
0x14 (0x34)	Reserved	—	—	—	—	—	—	—	—	
0x13 (0x33)	Reserved	—	—	—	—	—	—	—	—	
0x12 (0x32)	Reserved	—	—	—	—	—	—	—	—	
0x11 (0x31)	Reserved	—	—	—	—	—	—	—	—	
0x10 (0x30)	Reserved	—	—	—	—	—	—	—	—	
0x0F (0x2F)	Reserved	—	—	—	—	—	—	—	—	
0x0E (0x2E)	Reserved	—	—	—	—	—	—	—	—	
0x0D (0x2D)	Reserved	—	—	—	—	—	—	—	—	
0x0C (0x2C)	Reserved	—	—	—	—	—	—	—	—	
0x0B (0x2B)	PORTD	PORTD7	PORTD6	PORTD5	PORTD4	PORTD3	PORTD2	PORTD1	PORTD0	95
0x0A (0x2A)	DDRD	DDD7	DDD6	DDD5	DDD4	DDD3	DDD2	DDD1	DDD0	95
0x09 (0x29)	PIND	PIND7	PIND6	PIND5	PIND4	PIND3	PIND2	PIND1	PIND0	95
0x08 (0x28)	PORTC	—	PORTC6	PORTC5	PORTC4	PORTC3	PORTC2	PORTC1	PORTC0	94
0x07 (0x27)	DDRC	—	DDC6	DDC5	DDC4	DDC3	DDC2	DDC1	DDC0	94
0x06 (0x26)	PINC	—	PINC6	PINC5	PINC4	PINC3	PINC2	PINC1	PINC0	94
0x05 (0x25)	PORTB	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0	94
0x04 (0x24)	DDRB	DDB7	DDB6	DDB5	DDB4	DDB3	DDB2	DDB1	DDB0	94
0x03 (0x23)	PINB	PINB7	PINB6	PINB5	PINB4	PINB3	PINB2	PINB1	PINB0	94
0x02 (0x22)	Reserved	—	—	—	—	—	—	—	—	
0x01 (0x21)	Reserved	—	—	—	—	—	—	—	—	
0x00 (0x20)	Reserved	—	—	—	—	—	—	—	—	

- Note:
- For compatibility with future devices, reserved bits should be written to zero if accessed. Reserved I/O memory addresses should never be written.
 - I/O Registers within the address range 0x00 - 0x1F are directly bit-accessible using the SBI and CBI instructions. In these registers, the value of single bits can be checked by using the SBIS and SBIC instructions.
 - Some of the Status Flags are cleared by writing a logical one to them. Note that, unlike most other AVRs, the CBI and SBI instructions will only operate on the specified bit, and can therefore be used on registers containing such Status Flags. The CBI and SBI instructions work with registers 0x00 to 0x1F only.
 - When using the I/O specific commands IN and OUT, the I/O addresses 0x00 - 0x3F must be used. When addressing I/O Registers as data space using LD and ST instructions, 0x20 must be added to these addresses. The ATmega48A/PA/88A/PA/168A/PA/328/P is a complex microcontroller with more peripheral units than can be supported within the 64 location reserved in Opcode for the IN and OUT instructions. For the Extended I/O space from 0x60 - 0xFF in SRAM, only the ST/STS/STD and LD/LDS/LDD instructions can be used.
 - Only valid for ATmega88A/88PA/168A/168PA/328/328P.
 - BODS and BODSE only available for picoPower devices ATmega48PA/88PA/168PA/328P

8. Instruction Set Summary

Mnemonics	Operands	Description	Operation	Flags	#Clocks
ARITHMETIC AND LOGIC INSTRUCTIONS					
ADD	Rd, Rr	Add two Registers	$Rd \leftarrow Rd + Rr$	Z,C,N,V,H	1
ADC	Rd, Rr	Add with Carry two Registers	$Rd \leftarrow Rd + Rr + C$	Z,C,N,V,H	1
ADIW	RdI,K	Add Immediate to Word	$Rdh:Rdl \leftarrow Rdh:Rdl + K$	Z,C,N,V,S	2
SUB	Rd, Rr	Subtract two Registers	$Rd \leftarrow Rd - Rr$	Z,C,N,V,H	1
SUBI	Rd, K	Subtract Constant from Register	$Rd \leftarrow Rd - K$	Z,C,N,V,H	1
SBC	Rd, Rr	Subtract with Carry two Registers	$Rd \leftarrow Rd - Rr - C$	Z,C,N,V,H	1
SBCI	Rd, K	Subtract with Carry Constant from Reg.	$Rd \leftarrow Rd - K - C$	Z,C,N,V,H	1
SBIW	RdI,K	Subtract Immediate from Word	$Rdh:Rdl \leftarrow Rdh:Rdl - K$	Z,C,N,V,S	2
AND	Rd, Rr	Logical AND Registers	$Rd \leftarrow Rd \bullet Rr$	Z,N,V	1
ANDI	Rd, K	Logical AND Register and Constant	$Rd \leftarrow Rd \bullet K$	Z,N,V	1
OR	Rd, Rr	Logical OR Registers	$Rd \leftarrow Rd \vee Rr$	Z,N,V	1
ORI	Rd, K	Logical OR Register and Constant	$Rd \leftarrow Rd \vee K$	Z,N,V	1
EOR	Rd, Rr	Exclusive OR Registers	$Rd \leftarrow Rd \oplus Rr$	Z,N,V	1
COM	Rd	One's Complement	$Rd \leftarrow 0xFF - Rd$	Z,C,N,V	1
NEG	Rd	Two's Complement	$Rd \leftarrow 0x00 - Rd$	Z,C,N,V,H	1
SBR	Rd,K	Set Bit(s) in Register	$Rd \leftarrow Rd \vee K$	Z,N,V	1
CBR	Rd,K	Clear Bit(s) in Register	$Rd \leftarrow Rd \bullet (0xFF - K)$	Z,N,V	1
INC	Rd	Increment	$Rd \leftarrow Rd + 1$	Z,N,V	1
DEC	Rd	Decrement	$Rd \leftarrow Rd - 1$	Z,N,V	1
TST	Rd	Test for Zero or Minus	$Rd \leftarrow Rd \bullet Rd$	Z,N,V	1
CLR	Rd	Clear Register	$Rd \leftarrow Rd \oplus Rd$	Z,N,V	1
SER	Rd	Set Register	$Rd \leftarrow 0xFF$	None	1
MUL	Rd, Rr	Multiply Unsigned	$R1:R0 \leftarrow Rd \times Rr$	Z,C	2
MULS	Rd, Rr	Multiply Signed	$R1:R0 \leftarrow Rd \times Rr$	Z,C	2
MULSU	Rd, Rr	Multiply Signed with Unsigned	$R1:R0 \leftarrow Rd \times Rr$	Z,C	2
FMUL	Rd, Rr	Fractional Multiply Unsigned	$R1:R0 \leftarrow (Rd \times Rr) \ll 1$	Z,C	2
FMULS	Rd, Rr	Fractional Multiply Signed	$R1:R0 \leftarrow (Rd \times Rr) \ll 1$	Z,C	2
FMULSU	Rd, Rr	Fractional Multiply Signed with Unsigned	$R1:R0 \leftarrow (Rd \times Rr) \ll 1$	Z,C	2
BRANCH INSTRUCTIONS					
RJMP	k	Relative Jump	$PC \leftarrow PC + k + 1$	None	2
JMP		Indirect Jump to (Z)	$PC \leftarrow Z$	None	2
JMP ⁽¹⁾	k	Direct Jump	$PC \leftarrow k$	None	3
RCALL	k	Relative Subroutine Call	$PC \leftarrow PC + k + 1$	None	3
ICALL		Indirect Call to (Z)	$PC \leftarrow Z$	None	3
CALL ⁽¹⁾	k	Direct Subroutine Call	$PC \leftarrow k$	None	4
RET		Subroutine Return	$PC \leftarrow STACK$	None	4
RETI		Interrupt Return	$PC \leftarrow STACK$	I	4
CPSE	Rd,Rr	Compare, Skip if Equal	if $(Rd = Rr)$ $PC \leftarrow PC + 2$ or 3	None	1/2/3
CP	Rd,Rr	Compare	$Rd - Rr$	Z, N, V, C, H	1
CPC	Rd,Rr	Compare with Carry	$Rd - Rr - C$	Z, N, V, C, H	1
CPI	Rd,K	Compare Register with Immediate	$Rd - K$	Z, N, V, C, H	1
SBRC	Rr, b	Skip if Bit in Register Cleared	if $(Rr(b)=0)$ $PC \leftarrow PC + 2$ or 3	None	1/2/3
SBRSC	Rr, b	Skip if Bit in Register is Set	if $(Rr(b)=1)$ $PC \leftarrow PC + 2$ or 3	None	1/2/3
SBIS	P, b	Skip if Bit in I/O Register Cleared	if $(P(b)=0)$ $PC \leftarrow PC + 2$ or 3	None	1/2/3
SBIS	P, b	Skip if Bit in I/O Register is Set	if $(P(b)=1)$ $PC \leftarrow PC + 2$ or 3	None	1/2/3
BRBS	s, k	Branch if Status Flag Set	if $(SREG(s) = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRBC	s, k	Branch if Status Flag Cleared	if $(SREG(s) = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BREQ	k	Branch if Equal	if $(Z = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRNE	k	Branch if Not Equal	if $(Z = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRCS	k	Branch if Carry Set	if $(C = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRCC	k	Branch if Carry Cleared	if $(C = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRSH	k	Branch if Same or Higher	if $(C = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRLO	k	Branch if Lower	if $(C = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRMI	k	Branch if Minus	if $(N = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRPL	k	Branch if Plus	if $(N = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRGE	k	Branch if Greater or Equal, Signed	if $(N \oplus V = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRLT	k	Branch if Less Than Zero, Signed	if $(N \oplus V = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRHS	k	Branch if Half Carry Flag Set	if $(H = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRHC	k	Branch if Half Carry Flag Cleared	if $(H = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRTS	k	Branch if T Flag Set	if $(T = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRTC	k	Branch if T Flag Cleared	if $(T = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRVS	k	Branch if Overflow Flag is Set	if $(V = 1)$ then $PC \leftarrow PC + k + 1$	None	1/2
BRVC	k	Branch if Overflow Flag is Cleared	if $(V = 0)$ then $PC \leftarrow PC + k + 1$	None	1/2

Mnemonics	Operands	Description	Operation	Flags	#Clocks
BRIE	k	Branch if Interrupt Enabled	if (I = 1) then PC ← PC + k + 1	None	1/2
BRID	k	Branch if Interrupt Disabled	if (I = 0) then PC ← PC + k + 1	None	1/2
BIT AND BIT-TEST INSTRUCTIONS					
SBI	P,b	Set Bit in I/O Register	I/O(P,b) ← 1	None	2
CBI	P,b	Clear Bit in I/O Register	I/O(P,b) ← 0	None	2
LSL	Rd	Logical Shift Left	Rd(n+1) ← Rd(n), Rd(0) ← 0	Z,C,N,V	1
LSR	Rd	Logical Shift Right	Rd(n) ← Rd(n+1), Rd(7) ← 0	Z,C,N,V	1
ROL	Rd	Rotate Left Through Carry	Rd(0) ← C, Rd(n+1) ← Rd(n), C ← Rd(7)	Z,C,N,V	1
ROR	Rd	Rotate Right Through Carry	Rd(7) ← C, Rd(n) ← Rd(n+1), C ← Rd(0)	Z,C,N,V	1
ASR	Rd	Arithmetic Shift Right	Rd(n) ← Rd(n+1), n=0...6	Z,C,N,V	1
SWAP	Rd	Swap Nibbles	Rd(3...0) ← Rd(7...4), Rd(7...4) ← Rd(3...0)	None	1
BSET	s	Flag Set	SREG(s) ← 1	SREG(s)	1
BCLR	s	Flag Clear	SREG(s) ← 0	SREG(s)	1
BST	Rr, b	Bit Store from Register to T	T ← Rr(b)	T	1
BLD	Rd, b	Bit load from T to Register	Rd(b) ← T	None	1
SEC		Set Carry	C ← 1	C	1
CLC		Clear Carry	C ← 0	C	1
SEN		Set Negative Flag	N ← 1	N	1
CLN		Clear Negative Flag	N ← 0	N	1
SEZ		Set Zero Flag	Z ← 1	Z	1
CLZ		Clear Zero Flag	Z ← 0	Z	1
SEI		Global Interrupt Enable	I ← 1	I	1
CLI		Global Interrupt Disable	I ← 0	I	1
SES		Set Signed Test Flag	S ← 1	S	1
CLS		Clear Signed Test Flag	S ← 0	S	1
SEV		Set Twos Complement Overflow.	V ← 1	V	1
CLV		Clear Twos Complement Overflow	V ← 0	V	1
SET		Set T in SREG	T ← 1	T	1
CLT		Clear T in SREG	T ← 0	T	1
SEH		Set Half Carry Flag in SREG	H ← 1	H	1
CLH		Clear Half Carry Flag in SREG	H ← 0	H	1
DATA TRANSFER INSTRUCTIONS					
MOV	Rd, Rr	Move Between Registers	Rd ← Rr	None	1
MOVW	Rd, Rr	Copy Register Word	Rd+1:Rd ← Rr+1:Rr	None	1
LDI	Rd, K	Load Immediate	Rd ← K	None	1
LD	Rd, X	Load Indirect	Rd ← (X)	None	2
LD	Rd, X+	Load Indirect and Post-Inc.	Rd ← (X), X ← X + 1	None	2
LD	Rd, -X	Load Indirect and Pre-Dec.	X ← X - 1, Rd ← (X)	None	2
LD	Rd, Y	Load Indirect	Rd ← (Y)	None	2
LD	Rd, Y+	Load Indirect and Post-Inc.	Rd ← (Y), Y ← Y + 1	None	2
LD	Rd, -Y	Load Indirect and Pre-Dec.	Y ← Y - 1, Rd ← (Y)	None	2
LDD	Rd,Y+q	Load Indirect with Displacement	Rd ← (Y + q)	None	2
LD	Rd, Z	Load Indirect	Rd ← (Z)	None	2
LD	Rd, Z+	Load Indirect and Post-Inc.	Rd ← (Z), Z ← Z+1	None	2
LD	Rd, -Z	Load Indirect and Pre-Dec.	Z ← Z - 1, Rd ← (Z)	None	2
LDD	Rd, Z+q	Load Indirect with Displacement	Rd ← (Z + q)	None	2
LDS	Rd, k	Load Direct from SRAM	Rd ← (k)	None	2
ST	X, Rr	Store Indirect	(X) ← Rr	None	2
ST	X+, Rr	Store Indirect and Post-Inc.	(X) ← Rr, X ← X + 1	None	2
ST	-X, Rr	Store Indirect and Pre-Dec.	X ← X - 1, (X) ← Rr	None	2
ST	Y, Rr	Store Indirect	(Y) ← Rr	None	2
ST	Y+, Rr	Store Indirect and Post-Inc.	(Y) ← Rr, Y ← Y + 1	None	2
ST	-Y, Rr	Store Indirect and Pre-Dec.	Y ← Y - 1, (Y) ← Rr	None	2
STD	Y+q,Rr	Store Indirect with Displacement	(Y + q) ← Rr	None	2
ST	Z, Rr	Store Indirect	(Z) ← Rr	None	2
ST	Z+, Rr	Store Indirect and Post-Inc.	(Z) ← Rr, Z ← Z + 1	None	2
ST	-Z, Rr	Store Indirect and Pre-Dec.	Z ← Z - 1, (Z) ← Rr	None	2
STD	Z+q,Rr	Store Indirect with Displacement	(Z + q) ← Rr	None	2
STS	k, Rr	Store Direct to SRAM	(k) ← Rr	None	2
LPM		Load Program Memory	R0 ← (Z)	None	3
LPM	Rd, Z	Load Program Memory	Rd ← (Z)	None	3
LPM	Rd, Z+	Load Program Memory and Post-Inc	Rd ← (Z), Z ← Z+1	None	3
SPM		Store Program Memory	(Z) ← R1:R0	None	-
IN	Rd, P	In Port	Rd ← P	None	1
OUT	P, Rr	Out Port	P ← Rr	None	1
PUSH	Rr	Push Register on Stack	STACK ← Rr	None	2

Mnemonics	Operands	Description	Operation	Flags	#Clocks
POP	Rd	Pop Register from Stack	Rd ← STACK	None	2
MCU CONTROL INSTRUCTIONS					
NOP		No Operation		None	1
SLEEP		Sleep	(see specific descr. for Sleep function)	None	1
WDR		Watchdog Reset	(see specific descr. for WDR/timer)	None	1
BREAK		Break	For On-chip Debug Only	None	N/A

Note: 1. These instructions are only available in ATmega168PA and ATmega328P.

9. Ordering Information

9.1 ATmega48A

Speed (MHz)	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20 ⁽³⁾	1.8 - 5.5	ATmega48A-AU ATmega48A-AUR ⁽⁵⁾ ATmega48A-CCU ATmega48A-CCUR ⁽⁵⁾ ATmega48A-MMH ⁽⁴⁾ ATmega48A-MMHR ⁽⁴⁾⁽⁵⁾ ATmega48A-MU ATmega48A-MUR ⁽⁵⁾ ATmega48A-PU	32A 32A 32CC1 32CC1 28M1 28M1 32M1-A 32M1-A 28P3	Industrial (-40°C to 85°C)

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See ["Speed Grades" on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0 mm) Plastic Quad Flat Package (TQFP)
32CC1	32-ball, 4 x 4 x 0.6 mm package, ball pitch 0.5 mm, Ultra Thin, Fine-Pitch Ball Grid Array (UFBGA)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45 mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50 mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)

9.2 ATmega48PA

Speed (MHz) ⁽³⁾	Power Supply	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20	1.8 - 5.5	ATmega48PA-AU	32A	Industrial (-40°C to 85°C)
		ATmega48PA-AUR ⁽⁵⁾	32A	
		ATmega48PA-CCU	32CC1	
		ATmega48PA-CCUR ⁽⁵⁾	32CC1	
		ATmega48PA-MMH ⁽⁴⁾	28M1	
		ATmega48PA-MMHR ⁽⁴⁾⁽⁵⁾	28M1	
		ATmega48PA-MU	32M1-A	
		ATmega48PA-MUR ⁽⁵⁾	32M1-A	
		ATmega48PA-PU	28P3	
		ATmega48PA-AN	32A	Industrial (-40°C to 105°C)
		ATmega48PA-ANR ⁽⁴⁾	32A	
		ATmega48PA-MMN	28M1	
		ATmega48PA-MMNR ⁽⁴⁾	28M1	
		ATmega48PA-MN	32M1-A	
		ATmega48PA-MNR ⁽⁴⁾	32M1-A	
		ATmega48PA-PN	28P3	

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See ["Speed Grades" on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
32CC1	32-ball, 4 x 4 x 0.6mm package, ball pitch 0.5mm, Ultra Thin, Fine-Pitch Ball Grid Array (UFBGA)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)



9.3 ATmega88A

Speed (MHz)	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20 ⁽³⁾	1.8 - 5.5	ATmega88A-AU ATmega88A-AUR ⁽⁵⁾ ATmega88A-CCU ATmega88A-CCUR ⁽⁵⁾ ATmega88A-MMH ⁽⁴⁾ ATmega88A-MMHR ⁽⁴⁾⁽⁵⁾ ATmega88A-MU ATmega88A-MUR ⁽⁵⁾ ATmega88A-PU	32A 32A 32CC1 32CC1 28M1 28M1 32M1-A 32M1-A 28P3	Industrial (-40°C to 85°C)

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See ["Speed Grades" on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
32CC1	32-ball, 4 x 4 x 0.6mm package, ball pitch 0.5mm, Ultra Thin, Fine-Pitch Ball Grid Array (UFBGA)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)

9.4 ATmega88PA

Speed (MHz) ⁽³⁾	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20	1.8 - 5.5	ATmega88PA-AU	32A	Industrial (-40°C to 85°C)
		ATmega88PA-AUR ⁽⁵⁾	32A	
		ATmega88PA-CCU	32CC1	
		ATmega88PA-CCUR ⁽⁵⁾	32CC1	
		ATmega88PA-MMH ⁽⁴⁾	28M1	
		ATmega88PA-MMHR ⁽⁴⁾⁽⁵⁾	28M1	
		ATmega88PA-MU	32M1-A	
		ATmega88PA-MUR ⁽⁵⁾	32M1-A	
		ATmega88PA-PU	28P3	
		ATmega88PA-AN	32A	Industrial (-40°C to 105°C)
		ATmega88PA-ANR ⁽⁵⁾	32A	
		ATmega88PA-MMN	28M1	
		ATmega88PA-MMNR ⁽⁵⁾	28M1	
		ATmega88PA-MN	32M1-A	
		ATmega88PA-MNR ⁽⁵⁾	32M1-A	
		ATmega88PA-PN	28P3	

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See ["Speed Grades" on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
32CC1	32-ball, 4 x 4 x 0.6mm package, ball pitch 0.5 mm, Ultra Thin, Fine-Pitch Ball Grill Array (UFBGA)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45 mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50 mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)



9.5 ATmega168A

Speed (MHz) ⁽³⁾	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20	1.8 - 5.5	ATmega168A-AU ATmega168A-AUR ⁽⁵⁾ ATmega168A-CCU ATmega168A-CCUR ⁽⁵⁾ ATmega168A-MMH ⁽⁴⁾ ATmega168A-MMHR ⁽⁴⁾⁽⁵⁾ ATmega168A-MU ATmega168A-MUR ⁽⁵⁾ ATmega168A-PU	32A 32A 32CC1 32CC1 28M1 28M1 32M1-A 32M1-A 28P3	Industrial (-40°C to 85°C)

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See ["Speed Grades" on page 322](#)
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
32CC1	32-ball, 4 x 4 x 0.6 mm package, ball pitch 0.5mm, Ultra Thin, Fine-Pitch Ball Grill Array (UFBGA)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)



9.6 ATmega168PA

Speed (MHz) ⁽³⁾	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20	1.8 - 5.5	ATmega168PA-AU ATmega168PA-AUR ⁽⁵⁾ ATmega168PA-CCU ATmega168PA-CCUR ⁽⁵⁾ ATmega168PA-MMH ⁽⁴⁾ ATmega168PA-MMHR ⁽⁴⁾⁽⁵⁾ ATmega168PA-MU ATmega168PA-MUR ⁽⁵⁾ ATmega168PA-PU	32A 32A 32CC1 32CC1 28M1 28M1 32M1-A 32M1-A 28P3	Industrial (-40°C to 85°C)
20	1.8 - 5.5	ATmega168PA-AN ATmega168PA-ANR ⁽⁵⁾ ATmega168PA-MN ATmega168PA-MNR ⁽⁵⁾ ATmega168PA-PN	32A 32A 32M1-A 32M1-A 28P3	Industrial (-40°C to 105°C)

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See ["Speed Grades" on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
32CC1	32-ball, 4 x 4 x 0.6mm package, ball pitch 0.5mm, Ultra Thin, Fine-Pitch Ball Grid Array (UFBGA)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)

9.7 ATmega328

Speed (MHz)	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20 ⁽³⁾	1.8 - 5.5	ATmega328-AU ATmega328-AUR ⁽⁵⁾ ATmega328-MMH ⁽⁴⁾ ATmega328-MMHR ⁽⁴⁾⁽⁵⁾ ATmega328-MU ATmega328-MUR ⁽⁵⁾ ATmega328-PU	32A 32A 28M1 28M1 32M1-A 32M1-A 28P3	Industrial (-40°C to 85°C)

- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See [Figure 29-1 on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)

9.8 ATmega328P

Speed (MHz) ⁽³⁾	Power Supply (V)	Ordering Code ⁽²⁾	Package ⁽¹⁾	Operational Range
20	1.8 - 5.5	ATmega328P-AU	32A	Industrial (-40°C to 85°C)
		ATmega328P-AUR ⁽⁵⁾	32A	
		ATmega328P-MMH ⁽⁴⁾	28M1	
		ATmega328P-MMHR ⁽⁴⁾⁽⁵⁾	28M1	
		ATmega328P-MU	32M1-A	
		ATmega328P-MUR ⁽⁵⁾	32M1-A	
		ATmega328P-PU	28P3	
		ATmega328P-AN	32A	Industrial (-40°C to 105°C)
		ATmega328P-ANR ⁽⁵⁾	32A	
		ATmega328P-MN	32M1-A	
		ATmega328P-MNR ⁽⁵⁾	32M1-A	
		ATmega328P-PN	28P3	

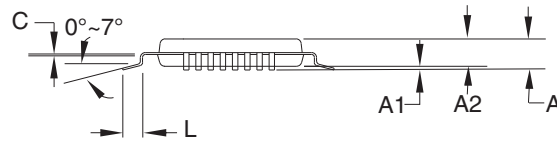
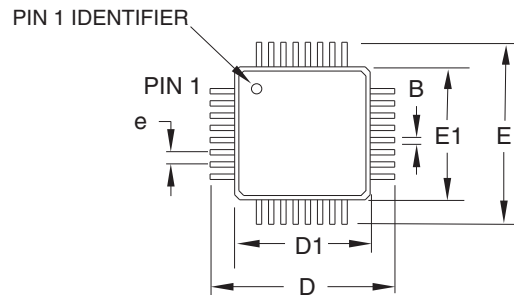
- Note:
1. This device can also be supplied in wafer form. Please contact your local Atmel sales office for detailed ordering information and minimum quantities.
 2. Pb-free packaging complies to the European Directive for Restriction of Hazardous Substances (RoHS directive). Also Halide free and fully Green.
 3. See [Figure 29-1 on page 322](#).
 4. NiPdAu Lead Finish.
 5. Tape & Reel.

Package Type	
32A	32-lead, Thin (1.0mm) Plastic Quad Flat Package (TQFP)
28M1	28-pad, 4 x 4 x 1.0 body, Lead Pitch 0.45mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)
28P3	28-lead, 0.300" Wide, Plastic Dual Inline Package (PDIP)
32M1-A	32-pad, 5 x 5 x 1.0 body, Lead Pitch 0.50mm Quad Flat No-Lead/Micro Lead Frame Package (QFN/MLF)



10. Packaging Information

10.1 32A



COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	—	—	1.20	
A1	0.05	—	0.15	
A2	0.95	1.00	1.05	
D	8.75	9.00	9.25	
D1	6.90	7.00	7.10	Note 2
E	8.75	9.00	9.25	
E1	6.90	7.00	7.10	Note 2
B	0.30	—	0.45	
C	0.09	—	0.20	
L	0.45	—	0.75	
e	0.80 TYP			

Notes:

1. This package conforms to JEDEC reference MS-026, Variation ABA.
2. Dimensions D1 and E1 do not include mold protrusion. Allowable protrusion is 0.25 mm per side. Dimensions D1 and E1 are maximum plastic body size dimensions including mold mismatch.
3. Lead coplanarity is 0.10 mm maximum.

2010-10-20



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San Jose, CA 95131

TITLE

32A, 32-lead, 7 x 7 mm Body Size, 1.0 mm Body Thickness,
0.8 mm Lead Pitch, Thin Profile Plastic Quad Flat Package (TQFP)

DRAWING NO.

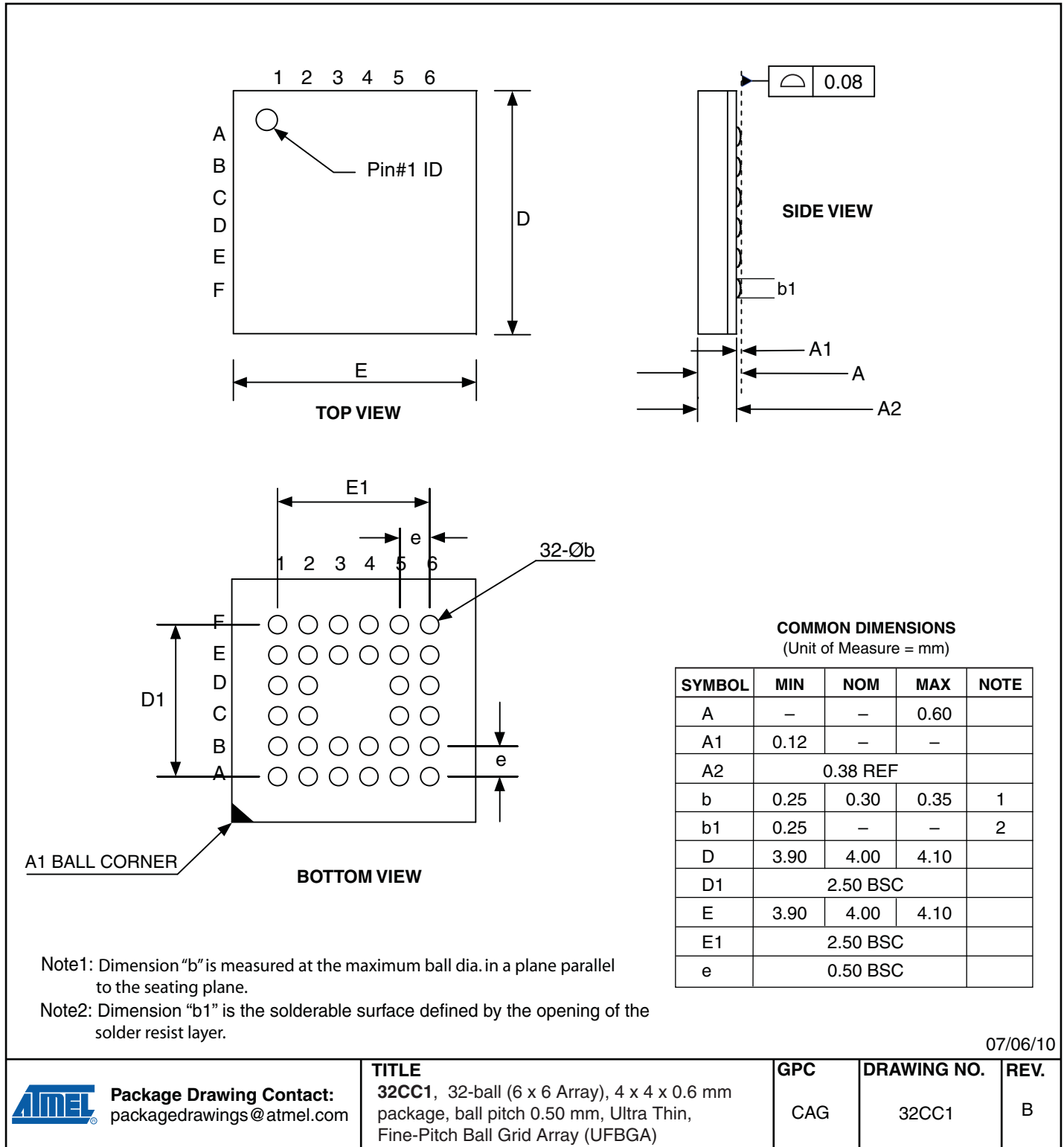
32A

REV.

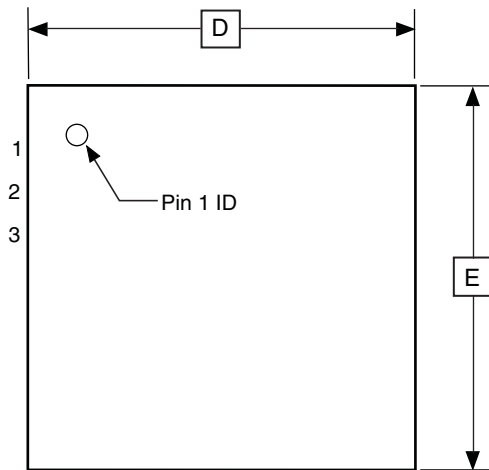
C



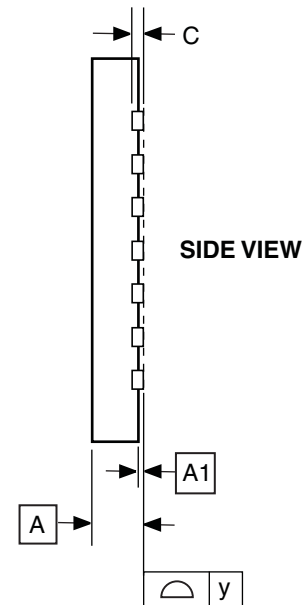
10.2 32CC1



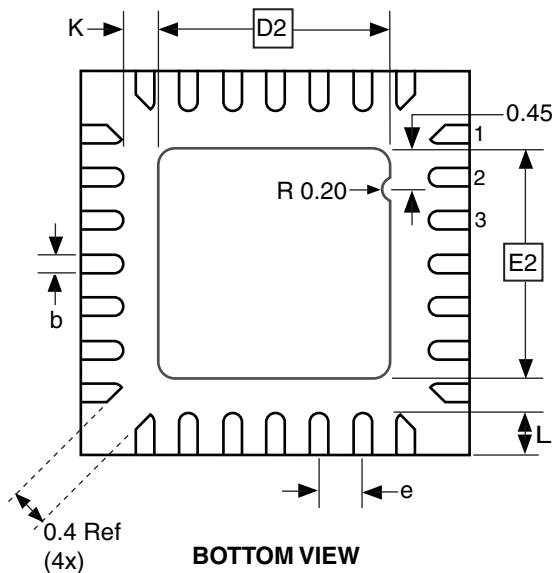
10.3 28M1



TOP VIEW



SIDE VIEW



BOTTOM VIEW

Note: The terminal #1 ID is a Laser-marked Feature.

COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	0.80	0.90	1.00	
A1	0.00	0.02	0.05	
b	0.17	0.22	0.27	
C	0.20 REF			
D	3.95	4.00	4.05	
D2	2.35	2.40	2.45	
E	3.95	4.00	4.05	
E2	2.35	2.40	2.45	
e	0.45			
L	0.35	0.40	0.45	
y	0.00	—	0.08	
K	0.20	—	—	

10/24/08



Package Drawing Contact:
packagedrawings@atmel.com

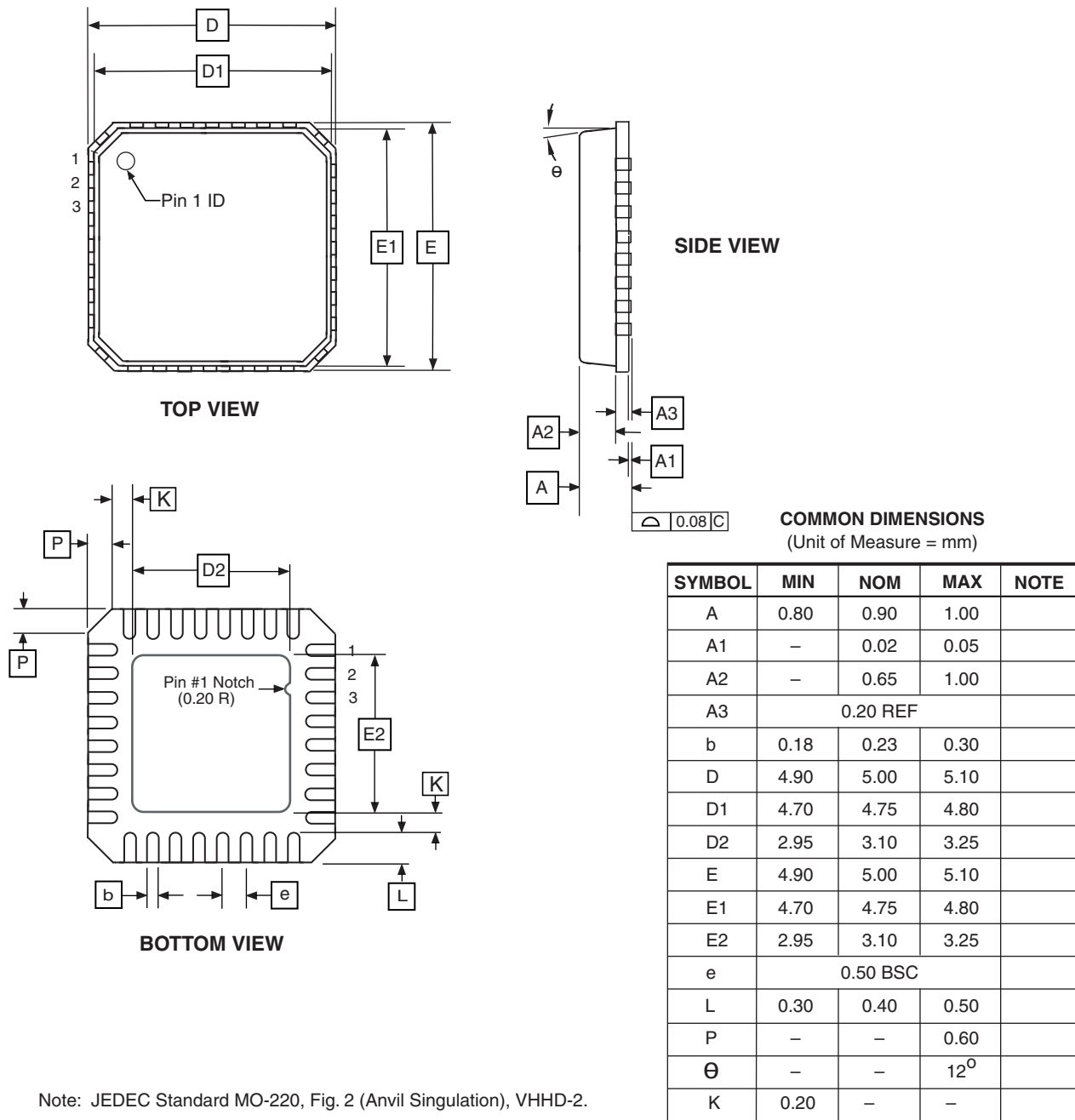
TITLE
28M1, 28-pad, 4 x 4 x 1.0 mm Body, Lead Pitch 0.45 mm,
2.4 x 2.4 mm Exposed Pad, Thermally Enhanced
Plastic Very Thin Quad Flat No Lead Package (VQFN)

GPC
ZBV

DRAWING NO.
28M1

REV.
B

10.4 32M1-A



5/25/06



2325 Orchard Parkway
San Jose, CA 95131

TITLE

32M1-A, 32-pad, 5 x 5 x 1.0 mm Body, Lead Pitch 0.50 mm,
3.10 mm Exposed Pad, Micro Lead Frame Package (MLF)

DRAWING NO.

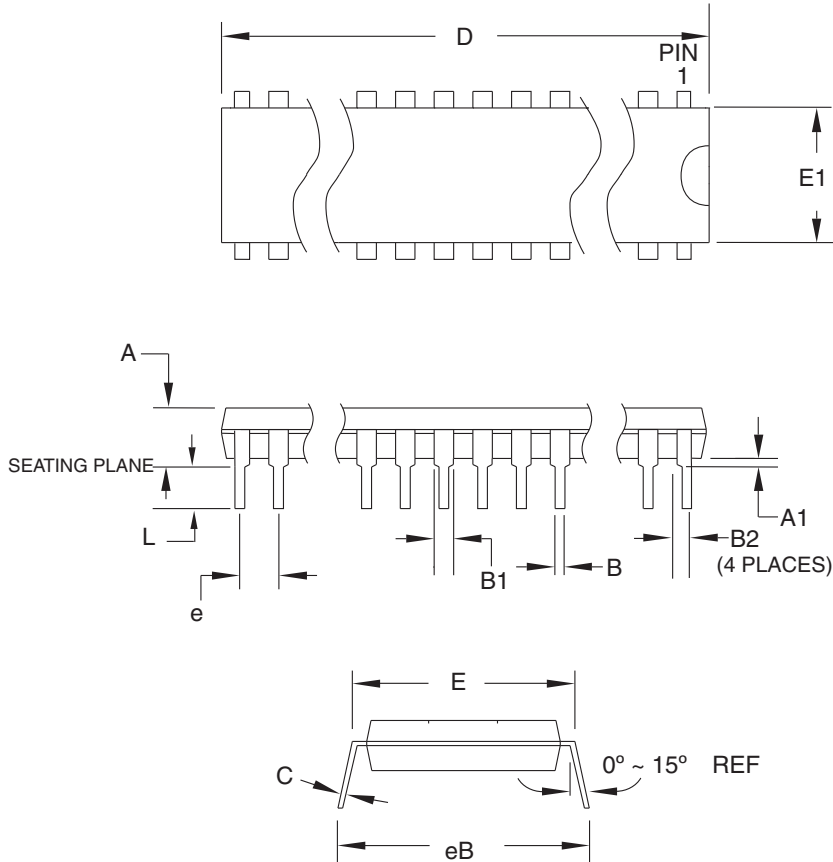
32M1-A

REV.

E



10.5 28P3



COMMON DIMENSIONS
(Unit of Measure = mm)

SYMBOL	MIN	NOM	MAX	NOTE
A	—	—	4.5724	
A1	0.508	—	—	
D	34.544	—	34.798	Note 1
E	7.620	—	8.255	
E1	7.112	—	7.493	Note 1
B	0.381	—	0.533	
B1	1.143	—	1.397	
B2	0.762	—	1.143	
L	3.175	—	3.429	
C	0.203	—	0.356	
eB	—	—	10.160	
e	2.540 TYP			

Note: 1. Dimensions D and E1 do not include mold Flash or Protrusion.
Mold Flash or Protrusion shall not exceed 0.25 mm (0.010").

09/28/01



2325 Orchard Parkway
San Jose, CA 95131

TITLE

28P3, 28-lead (0.300"/7.62 mm Wide) Plastic Dual
Inline Package (PDIP)

DRAWING NO.

28P3

REV.

B



11. Errata

11.1 Errata ATmega48A

The revision letter in this section refers to the revision of the ATmega48A device.

11.1.1 Rev. D

- **Analog MUX can be turned off when setting ACME bit**

1. **Analog MUX can be turned off when setting ACME bit**

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.2 Errata ATmega48PA

The revision letter in this section refers to the revision of the ATmega48PA device.

11.2.1 Rev. D

- **Analog MUX can be turned off when setting ACME bit**

1. **Analog MUX can be turned off when setting ACME bit**

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.3 Errata ATmega88A

The revision letter in this section refers to the revision of the ATmega88A device.

11.3.1 Rev. F

- **Analog MUX can be turned off when setting ACME bit**

1. **Analog MUX can be turned off when setting ACME bit**

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.4 Errata ATmega88PA

The revision letter in this section refers to the revision of the ATmega88PA device.

11.4.1 Rev. F

- **Analog MUX can be turned off when setting ACME bit**

1. **Analog MUX can be turned off when setting ACME bit**

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.5 Errata ATmega168A

The revision letter in this section refers to the revision of the ATmega168A device.

11.5.1 Rev. E

- **Analog MUX can be turned off when setting ACME bit**

1. **Analog MUX can be turned off when setting ACME bit**

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.6 Errata ATmega168PA

The revision letter in this section refers to the revision of the ATmega168PA device.

11.6.1 Rev E

- **Analog MUX can be turned off when setting ACME bit**

1. **Analog MUX can be turned off when setting ACME bit**

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.7 Errata ATmega328

The revision letter in this section refers to the revision of the ATmega328 device.

11.7.1 Rev D

- **Analog MUX can be turned off when setting ACME bit**

1. Analog MUX can be turned off when setting ACME bit

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.7.2 Rev C

Not sampled.

11.7.3 Rev B

- **Analog MUX can be turned off when setting ACME bit**
- **Unstable 32kHz Oscillator**

1. Analog MUX can be turned off when setting ACME bit

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

2. Unstable 32kHz Oscillator

The 32kHz oscillator does not work as system clock. The 32kHz oscillator used as asynchronous timer is inaccurate.

Problem Fix/ Workaround

None.

11.7.4 Rev A

- **Analog MUX can be turned off when setting ACME bit**
- **Unstable 32kHz Oscillator**

1. Analog MUX can be turned off when setting ACME bit

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

2. Unstable 32kHz Oscillator

The 32kHz oscillator does not work as system clock. The 32kHz oscillator used as asynchronous timer is inaccurate.

Problem Fix/ Workaround

None.

11.8 Errata ATmega328P

The revision letter in this section refers to the revision of the ATmega328P device.

11.8.1 Rev D

- **Analog MUX can be turned off when setting ACME bit**

1. Analog MUX can be turned off when setting ACME bit

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

11.8.2 Rev C

Not sampled.

11.8.3 Rev B

- **Analog MUX can be turned off when setting ACME bit**
- **Unstable 32kHz Oscillator**

1. Analog MUX can be turned off when setting ACME bit

If the ACME (Analog Comparator Multiplexer Enabled) bit in ADCSRB is set while MUX3 in ADMUX is '1' (ADMUX[3:0]=1xxx), all MUX'es are turned off until the ACME bit is cleared.

Problem Fix/Workaround

Clear the MUX3 bit before setting the ACME bit.

2. Unstable 32kHz Oscillator

The 32kHz oscillator does not work as system clock. The 32kHz oscillator used as asynchronous timer is inaccurate.

Problem Fix/ Workaround

None.

11.8.4 Rev A

- **Unstable 32kHz Oscillator**

1. Unstable 32kHz Oscillator

The 32kHz oscillator does not work as system clock. The 32kHz oscillator used as asynchronous timer is inaccurate.

Problem Fix/ Workaround

None.

12. Datasheet Revision History

Please note that the referring page numbers in this section are referred to this document. The referring revision in this section are referring to the document revision.

12.1 Rev. 8271D – 05/11

1. Added Atmel QTouch Sensing Capability Feature
2. Updated ["Register Description" on page 94](#) with PINxn as R/W.
3. Added a footnote to the PINxn, [page 94](#).
4. Updated
5. Updated ["Ordering Information", "ATmega328" on page 546](#). Added "ATmega328-MMH" and "ATmega328-MMHR".
6. Updated ["Ordering Information", "ATmega328P" on page 547](#). Added "ATmega328P-MMH" and "ATmega328P-MMHR".
7. Added ["Ordering Information"](#) for ATmega48PA/88PA/168PA/328P @ 105°C
8. Updated ["Errata ATmega328" on page 555](#) and ["Errata ATmega328P" on page 556](#)
98. Updated the datasheet according to the Atmel new brand style guide.

12.2 Rev. 8271C – 08/10

1. Added 32UFBGA Pinout, [Table 1-1 on page 2](#).
2. Updated the ["SRAM Data Memory", Figure 8-3 on page 19](#).
3. Updated ["Ordering Information" on page 540](#) with CCU and CCUR code related to ["32CC1" Package drawing](#).
4. ["32CC1" Package drawing](#) added on ["Packaging Information" on page 548](#).

12.3 Rev. 8271B – 04/10

1. Updated [Table 9-8](#) with correct value for timer oscillator at xtal2/tos2
2. Corrected use of SBIS instructions in assembly code examples.
3. Corrected BOD and BODSE bits to R/W in [Section 10.11.2 on page 46](#), [Section 12.5 on page 70](#) and [Section 14.4 on page 94](#)
4. Figures for bandgap characterization added, [Figure 30-34 on page 350](#), [Figure 30-81 on page 375](#), [Figure 30-128 on page 400](#), [Figure 30-175 on page 425](#), [Figure 30-222 on page 450](#), [Figure 30-269 on page 475](#), [Figure 30-316 on page 500](#) and [Figure 30-363 on page 525](#).
5. Updated ["Packaging Information" on page 548](#) by replacing 28M1 with a correct corresponding package.

12.4 Rev. 8271A – 12/09

1. New datasheet 8271 with merged information for ATmega48PA, ATmega88PA, ATmega168PA and ATmega48A, ATmega88A and ATmega168A. Also included information on ATmega328 and ATmega328P
2. Changes done:
 - New devices added: ATmega48A/ATmega88A/ATmega168A and ATmega328
 - Updated Feature Description
 - Updated [Table 2-1 on page 6](#)
 - Added note for BOD Disable on [page 41](#).
 - Added note on BOD and BODSE in "MCUCR – MCU Control Register" on [page 94](#) and "Register Description" on [page 295](#)
 - Added limitation information for the application "Boot Loader Support – Read-While-Write Self-Programming" on [page 280](#)
 - Added limitation information for "Program And Data Memory Lock Bits" on [page 297](#)
 - Added specified DC characteristics
 - Added typical characteristics
 - Removed exception information in "Address Match Unit" on [page 224](#).

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Datasheet

Linksys E3000 | High Performance Wireless-N Router



Simultaneous Dual-Band (2.4 and 5 GHz)
Gigabit Ethernet (10/100/1000) Ports

From the worldwide leader in wireless networking

Features

- Give visitors simple and password-protected Internet access
- WPA, WPA2, and other enhanced security features
- Stream your stored multimedia to devices around your home
- Up to 300 Mbps wireless speeds*
- Gigabit Ethernet 10/100/1000 Mbps wired speed
- Extended wireless coverage for larger homes
- 5 GHz band avoids interference from 2.4 GHz wireless networks
- Connect and share USB storage throughout your home and over the Internet. Includes built-in UPnP AV media server
- Optimized for streaming HD video
- Optimized for wireless gaming

Specifications

Model Name	Linksys E3000
Description	High Performance Wireless-N Router
Model Number	E3000
Number of Antennas	6 Total, 3 Internal Antennas per Each 2.4 GHz and 5 GHz Radio Band
Detachable (Yes/No)	No
Modulation	802.11b: CCK, QPSK, BPSK 802.11g: OFDM 802.11a: OFDM 802.11n: BPSK, QPSK, 16-QAM, 64-QAM
Receive Sensitivity	2.4 GHz 11 Mbps: -87 dBm @ Typical 54 Mbps: -77 dBm @ Typical MCS15 (20MHz): -71 dBm @ Typical MCS15 (40MHz): -68 dBm @ Typical 5 GHz 54 Mbps: -74 dBm @ Typical MCS15 (20 MHz): -68 dBm @ Typical MCS15 (40 MHz): -65 dBm @ Typical
Antenna Gain in dBi	2.4 GHz: RIFA 1 and RIFA 2 and RIFA 3 <= 4 dBi (Typical) 5 GHz: RIFA 1 and RIFA 2 and RIFA 3 <= 3.5 dBi (Typical)
UPnP	Supported
Security Features	WEP, WPA, WPA2
Security Key Bits	Up to 128-Bit Encryption

Environmental

Dimensions	8.86" x 1.38" x 7.09" (225 x 35 x 180 mm)
Weight	15.94 oz (452 g)
Power	12V, 2A
Certification	FCC, IC, CE, Wi-Fi A/B/G/N
Operating Temperature	32 to 104°F (0 to 40°C)
Storage Temperature	-4 to 140°F (-20 to 60°C)
Operating Humidity	10 to 80% Noncondensing
Storage Humidity	5 to 90% Noncondensing

Minimum System Requirements

- **Internet Browser:** Internet Explorer 6, Safari 3, or Firefox 2 for Optional Browser-Based Configuration
- **PC:** Wireless Network-Enabled PC with CD or DVD Drive, Running Windows XP SP3, Windows Vista SP1, or Windows 7
- **Mac:** Wireless Network-Enabled Mac with CD or DVD Drive, Running OS X Tiger 10.4.11, Leopard 10.5.8, or Snow Leopard 10.6.1

Package Contents

- Linksys E3000 High Performance Wireless-N Router
- CD-ROM with Cisco Connect Software
- Ethernet Network Cable
- Power Adapter

*The maximum performance for wireless is derived from IEEE Standard 802.11 specifications. Actual performance can vary, including lower wireless network capacity, data throughput rate, range and coverage. Performance depends on many factors, conditions and variables, including distance from the access point, volume of network traffic, building materials and construction, operating system used, mix of wireless products used, interference and other adverse conditions.

Specifications are subject to change without notice.

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LM158/LM258/LM358/LM2904

Low Power Dual Operational Amplifiers

General Description

The LM158 series consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional $\pm 15V$ power supplies.

The LM358 is also available in a chip sized package (8-Bump micro SMD) using National's micro SMD package technology.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

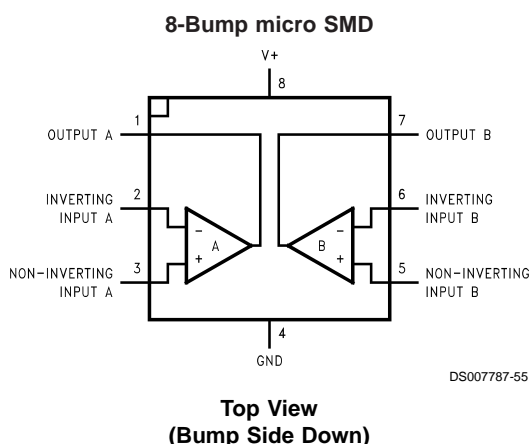
Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation
- Pin-out same as LM1558/LM1458 dual op amp

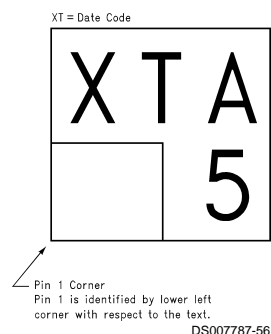
Features

- Available in 8-Bump micro SMD chip sized package, (See AN-1112)
- Internally frequency compensated for unity gain
- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz (temperature compensated)
- Wide power supply range:
 - Single supply: 3V to 32V
 - or dual supplies: $\pm 1.5V$ to $\pm 16V$
- Very low supply current drain (500 μA) — essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing: 0V to $V^+ - 1.5V$

Connection Diagrams



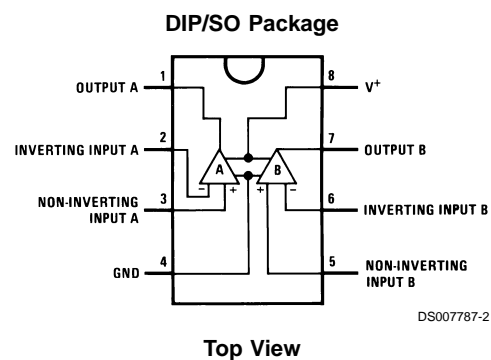
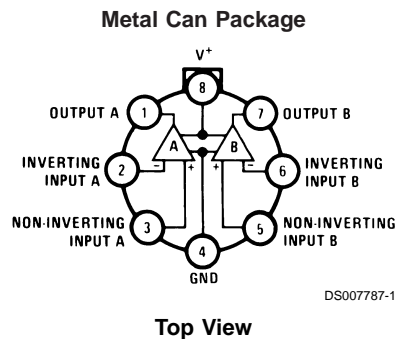
micro SMD Marking Orientation



Bumps are numbered counter-clockwise.

Top View

Connection Diagrams (Continued)



Ordering Information

Package	Temperature Range				NSC Drawing
	-55°C to 125°C	-25°C to 85°C	0°C to 70°C	-40°C to 85°C	
SO-8			LM358AM LM358M	LM2904M	M08A
8-Pin Molded DIP			LM358AN LM358N	LM2904N	N08E
8-Pin Ceramic DIP	LM158AJ/883(Note 1) LM158J/883(Note 1) LM158J LM158AJLQML(Note 2) LM158AJQMLV(Note 2)				J08A
TO-5, 8-Pin Metal Can	LM158AH/883(Note 1) LM158H/883(Note 1) LM158AH LM158H LM158AHLQML(Note 2) LM158AHLQMLV(Note 2)	LM258H	LM358H		H08C
8-Bump micro SMD			LM358BP LM358BPX		BPA08AAA

Note 1: LM158 is available per SMD #5962-8771001

LM158A is available per SMD #5962-8771002

Note 2: See STD Mil DWG 5962L87710 for Radiation Tolerant Devices

Absolute Maximum Ratings (Note 11)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

	LM158/LM258/LM358 LM158A/LM258A/LM358A	LM2904
Supply Voltage, V^+	32V	26V
Differential Input Voltage	32V	26V
Input Voltage	-0.3V to +32V	-0.3V to +26V
Power Dissipation (Note 3)		
Molded DIP	830 mW	830 mW
Metal Can	550 mW	
Small Outline Package (M)	530 mW	530 mW
micro SMD	435mW	
Output Short-Circuit to GND (One Amplifier) (Note 4) $V^+ \leq 15V$ and $T_A = 25^\circ C$	Continuous 50 mA	Continuous 50 mA
Operating Temperature Range		
LM358	0°C to +70°C	-40°C to +85°C
LM258	-25°C to +85°C	
LM158	-55°C to +125°C	
Storage Temperature Range	-65°C to +150°C	-65°C to +150°C
Lead Temperature, DIP (Soldering, 10 seconds)	260°C	260°C
Lead Temperature, Metal Can (Soldering, 10 seconds)	300°C	300°C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260°C	260°C
Small Outline Package		
Vapor Phase (60 seconds)	215°C	215°C
Infrared (15 seconds)	220°C	220°C
See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.		
ESD Tolerance (Note 12)	250V	250V

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 7), $T_A = 25^\circ C$	1	2		2	3		2	5		mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^\circ C$, $V_{CM} = 0V$, (Note 8)	20	50		45	100		45	150		nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$	2	10		5	30		3	30		nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 9) (LM2904, $V^+ = 26V$), $T_A = 25^\circ C$	0	$V^+ - 1.5$		0	$V^+ - 1.5$		0	$V^+ - 1.5$		V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps $V^+ = 30V$ (LM2904 $V^+ = 26V$) $V^+ = 5V$	1 0.5	2 1.2		1 0.5	2 1.2		1 0.5	2 1.2		mA mA

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 7), $T_A = 25^\circ C$		2	7		2	7	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^\circ C$, $V_{CM} = 0V$, (Note 8)		45	250		45	250	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$		5	50		5	50	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 9) (LM2904, $V^+ = 26V$), $T_A = 25^\circ C$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps $V^+ = 30V$ (LM2904 $V^+ = 26V$) $V^+ = 5V$		1 0.5	2 1.2		1 0.5	2 1.2	mA mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 6), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25^\circ C$, $R_L \geq 2 k\Omega$, (For $V_O = 1V$ to $11V$)	50	100		25	100		50	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25^\circ C$, $V_{CM} = 0V$ to $V^+ - 1.5V$	70	85		65	85		70	85		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to $30V$ (LM2904, $V^+ = 5V$ to $26V$), $T_A = 25^\circ C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling		$f = 1 kHz$ to $20 kHz$, $T_A = 25^\circ C$ (Input Referred), (Note 10)	-120			-120			-120			dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ C$	20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25^\circ C$, $V_O = 2V$	10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25^\circ C$, $V_O = 200 mV$, $V^+ = 15V$	12	50		12	50		12	50		μA
Short Circuit to Ground		$T_A = 25^\circ C$, (Note 4), $V^+ = 15V$	40	60		40	60		40	60		mA
Input Offset Voltage		(Note 7)	4			5			7			mV
Input Offset Voltage Drift		$R_S = 0\Omega$	7	15		7	20		7			$\mu V/^\circ C$
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$	30			75			100			nA
Input Offset Current Drift		$R_S = 0\Omega$	10	200		10	300		10			$pA/^\circ C$
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$	40	100		40	200		40	300		nA
Input Common-Mode Voltage Range		$V^+ = 30V$, (Note 9) (LM2904, $V^+ = 26V$)	0	$V^+ - 2$		0	$V^+ - 2$		0	$V^+ - 2$		V

Electrical Characteristics (Continued) $V^+ = +5.0V$, (Note 6), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = +15V$ ($V_O = 1V$ to $11V$) $R_L \geq 2\text{ k}\Omega$	25			15			25			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$)	$R_L = 2\text{ k}\Omega$ 26			26			26			V
			$R_L = 10\text{ k}\Omega$ 27 28			27 28			27 28			V
	V_{OL}	$V^+ = 5V$, $R_L = 10\text{ k}\Omega$	5 20			5 20			5 20			mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$	10 20			10 20			10 20			mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$	10 15			5 8			5 8			mA

Electrical Characteristics $V^+ = +5.0V$, (Note 6), unless otherwise stated

Parameter		Conditions	LM358			LM2904			Units
			Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25^\circ\text{C}$, $R_L \geq 2\text{ k}\Omega$, (For $V_O = 1V$ to $11V$)	25 100			25 100			V/mV
Common-Mode Rejection Ratio		$T_A = 25^\circ\text{C}$, $V_{CM} = 0V$ to $V^+ - 1.5V$	65 85			50 70			dB
Power Supply Rejection Ratio		$V^+ = 5V$ to $30V$ (LM2904, $V^+ = 5V$ to $26V$), $T_A = 25^\circ\text{C}$	65 100			50 100			dB
Amplifier-to-Amplifier Coupling		$f = 1\text{ kHz}$ to 20 kHz , $T_A = 25^\circ\text{C}$ (Input Referred), (Note 10)	-120			-120			dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ\text{C}$	20 40			20 40			mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25^\circ\text{C}$, $V_O = 2V$	10 20			10 20			mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25^\circ\text{C}$, $V_O = 200\text{ mV}$, $V^+ = 15V$	12 50			12 50			μA
Short Circuit to Ground		$T_A = 25^\circ\text{C}$, (Note 4), $V^+ = 15V$	40 60			40 60			mA
Input Offset Voltage		(Note 7)	9			10			mV
Input Offset Voltage Drift		$R_S = 0\Omega$	7			7			$\mu\text{V}/^\circ\text{C}$
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$	150			45 200			nA
Input Offset Current Drift		$R_S = 0\Omega$	10			10			$\text{pA}/^\circ\text{C}$
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$	40 500			40 500			nA
Input Common-Mode Voltage Range		$V^+ = 30V$, (Note 9) (LM2904, $V^+ = 26V$)	0 $V^+ - 2$			0 $V^+ - 2$			V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 6), unless otherwise stated

Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$V^+ = +15V$ ($V_O = 1V$ to $11V$) $R_L \geq 2\text{ k}\Omega$	15			15			V/mV
Output Voltage Swing	V_{OH}	26			22			V
	V_{OL}	5			5			mV
Output Current	Source	10			10			mA
	Sink	5			5			mA

Note 3: For operating at high temperatures, the LM358/LM358A, LM2904 must be derated based on a $+125^\circ\text{C}$ maximum junction temperature and a thermal resistance of 120°C/W for MDIP, 182°C/W for Metal Can, 189°C/W for Small Outline package, and 230°C/W for micro SMD, which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM258/LM258A and LM158/LM158A can be derated based on a $+150^\circ\text{C}$ maximum junction temperature. The dissipation is the total of both amplifiers — use external resistors, where possible, to allow the amplifier to saturate or to reduce the power which is dissipated in the integrated circuit.

Note 4: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+ . At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Note 5: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V^+ voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than $-0.3V$ (at 25°C).

Note 6: These specifications are limited to $-55^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$ for the LM158/LM158A. With the LM258/LM258A, all temperature specifications are limited to $-25^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$, the LM358/LM358A temperature specifications are limited to $0^\circ\text{C} \leq T_A \leq +70^\circ\text{C}$, and the LM2904 specifications are limited to $-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$.

Note 7: $V_O \cong 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to $V^+ - 1.5V$) at 25°C . For LM2904, V^+ from 5V to 26V.

Note 8: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

Note 9: The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25°C). The upper end of the common-mode voltage range is $V^+ - 1.5V$ (at 25°C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+ .

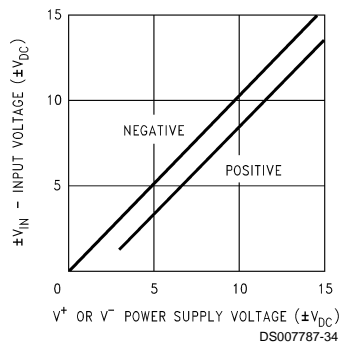
Note 10: Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

Note 11: Refer to RETS158AX for LM158A military specifications and to RETS158X for LM158 military specifications.

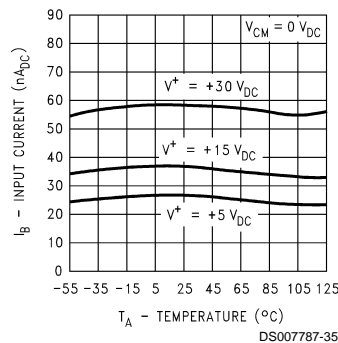
Note 12: Human body model, 1.5 k Ω in series with 100 pF.

Typical Performance Characteristics

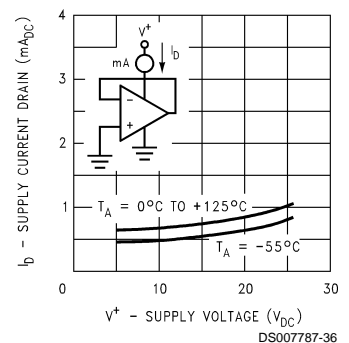
Input Voltage Range



Input Current

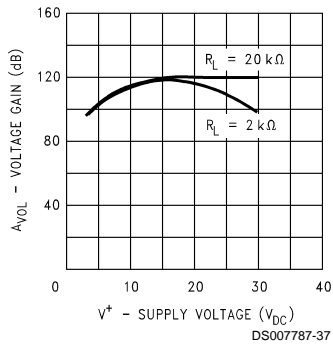


Supply Current

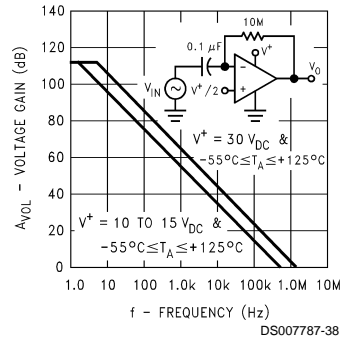


Typical Performance Characteristics (Continued)

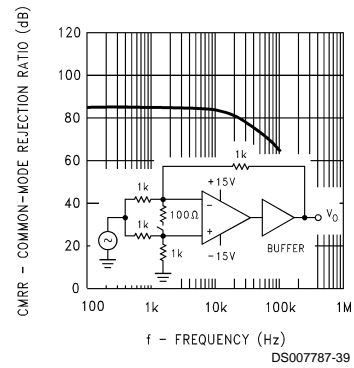
Voltage Gain



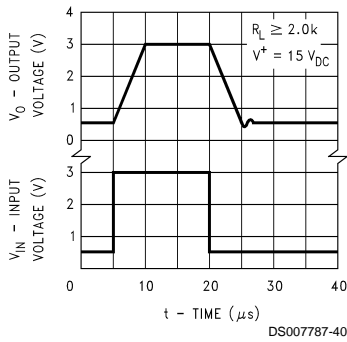
Open Loop Frequency Response



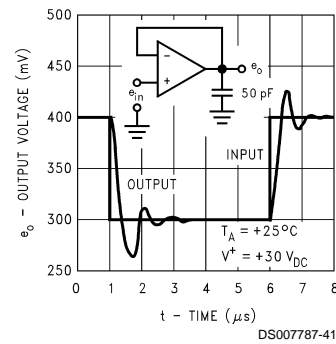
Common-Mode Rejection Ratio



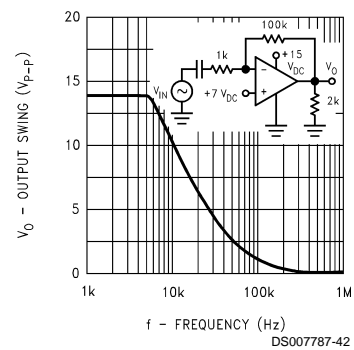
Voltage Follower Pulse Response



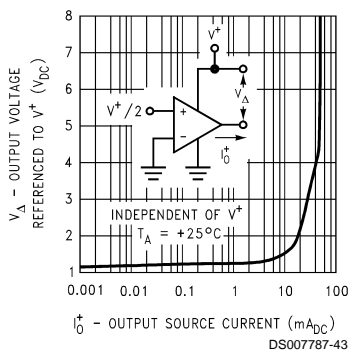
Voltage Follower Pulse Response (Small Signal)



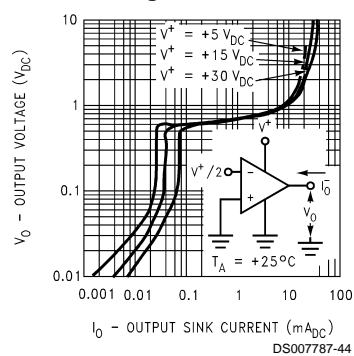
Large Signal Frequency Response



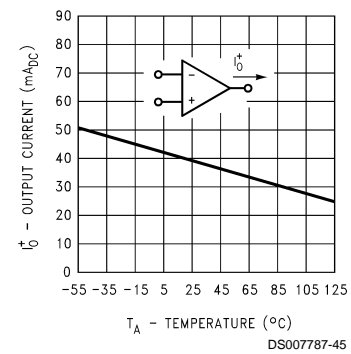
Output Characteristics Current Sourcing



Output Characteristics Current Sinking

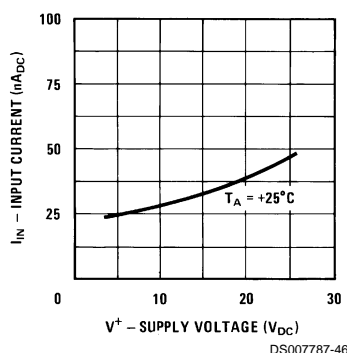


Current Limiting

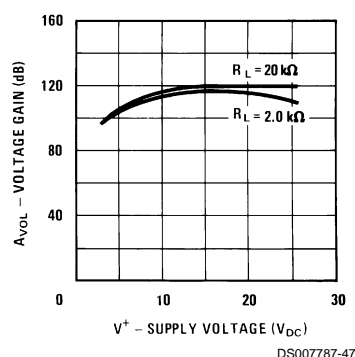


Typical Performance Characteristics (Continued)

Input Current (LM2902 only)



Voltage Gain (LM2902 only)



Application Hints

The LM158 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC} . These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At $25^\circ C$ amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC} .

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than $-0.3 V_{DC}$ (at $25^\circ C$). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply current drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion. Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

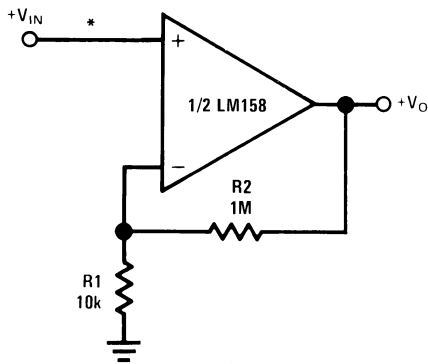
The bias network of the LM158 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of 3 V_{DC} to 30 V_{DC} .

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at $25^\circ C$ provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

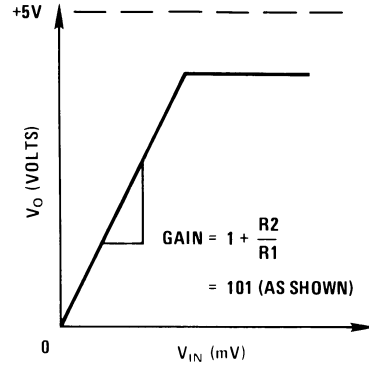
The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$

Non-Inverting DC Gain (0V Output)



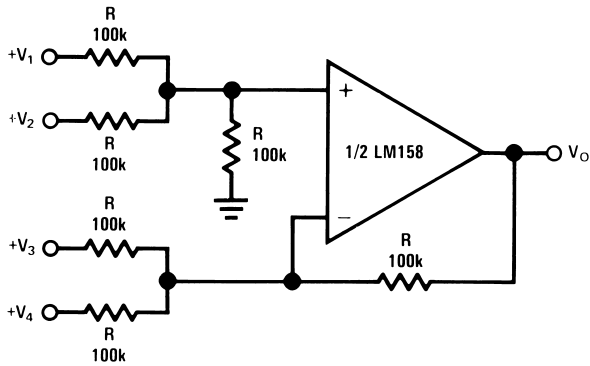
DS007787-6



DS007787-7

*R not needed due to temperature independent I_{IN}

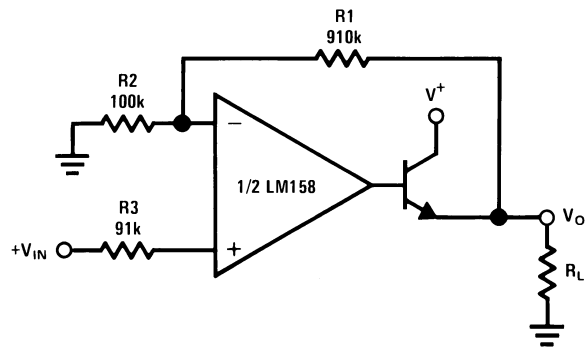
DC Summing Amplifier ($V_{\text{IN'S}} \geq 0 \text{ V}_{\text{DC}}$ and $V_{\text{O}} \geq 0 \text{ V}_{\text{DC}}$)



DS007787-8

Where: $V_{\text{O}} = V_1 + V_2 + V_3 + V_4$
 $(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_{\text{O}} > 0 \text{ V}_{\text{DC}}$

Power Amplifier

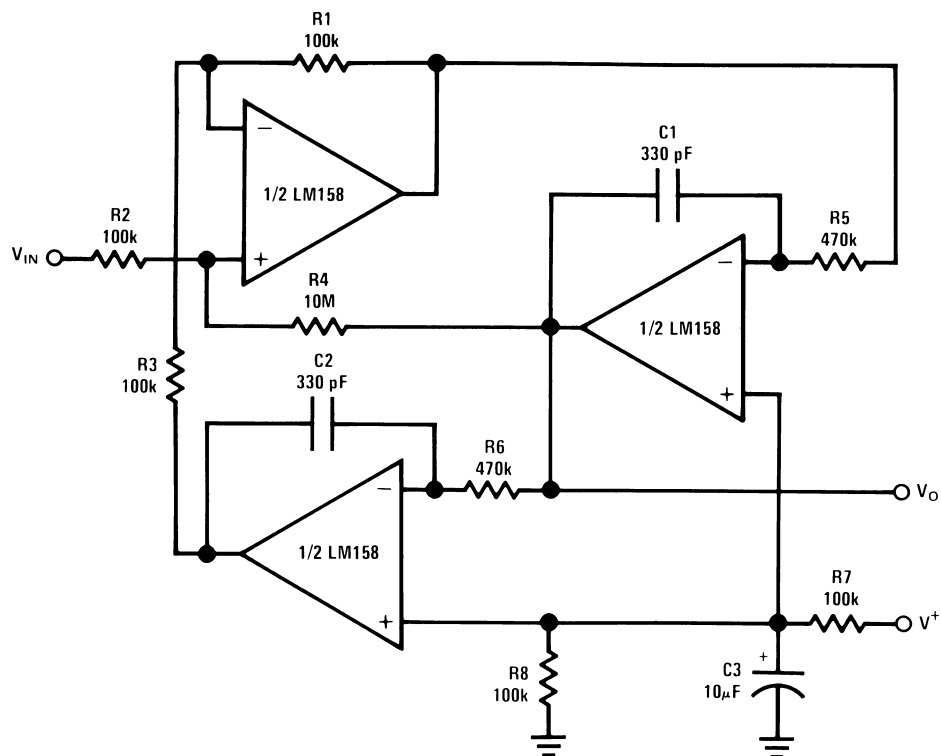


DS007787-9

$V_{\text{O}} = 0 \text{ V}_{\text{DC}}$ for $V_{\text{IN}} = 0 \text{ V}_{\text{DC}}$
 $A_V = 10$

Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$ (Continued)

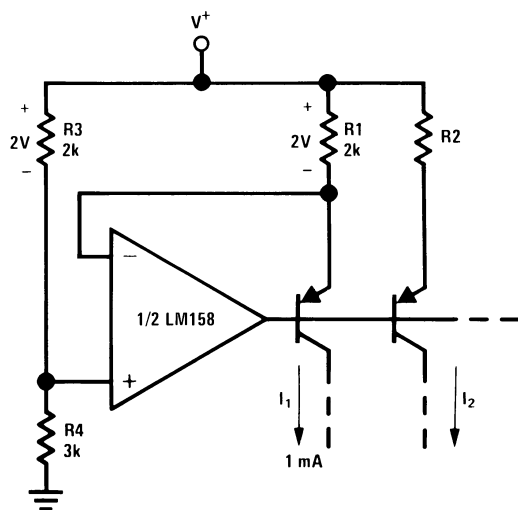
“BI-QUAD” RC Active Bandpass Filter



DS007787-10

$f_o = 1 \text{ kHz}$
 $Q = 50$
 $A_v = 100 \text{ (40 dB)}$

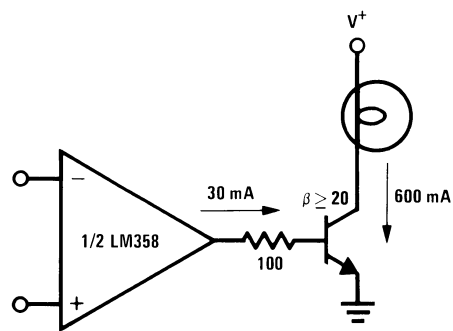
Fixed Current Sources



DS007787-11

$$I_2 = \left(\frac{R_1}{R_2} \right) I_1$$

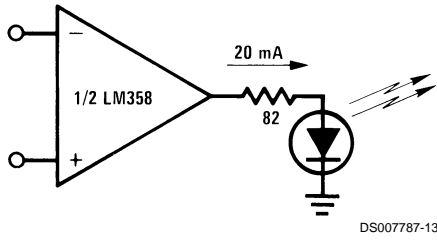
Lamp Driver



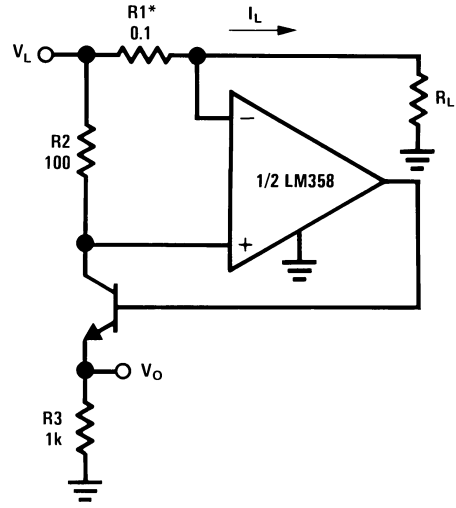
DS007787-12

Typical Single-Supply Applications $(V^+ = 5.0 V_{DC})$ (Continued)

LED Driver



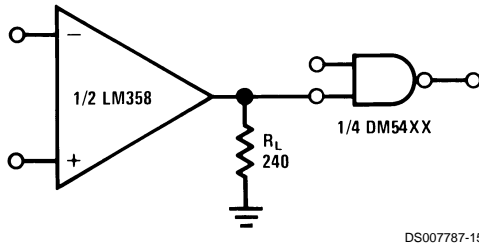
Current Monitor



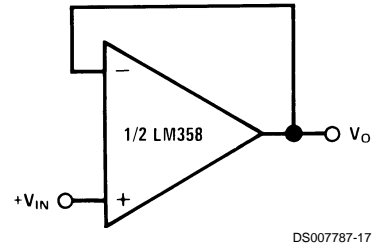
$$V_O = \frac{1V(I_L)}{1A}$$

*(Increase R1 for I_L small)
 $V_L \leq V^+ - 2V$

Driving TTL

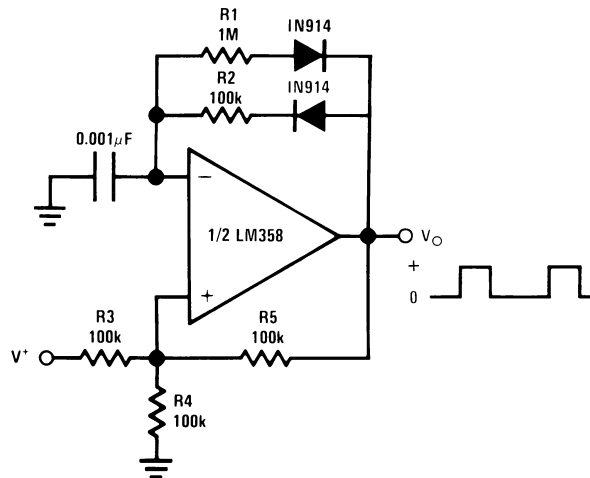


Voltage Follower



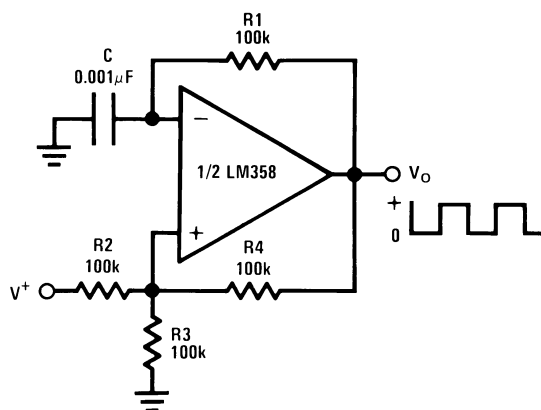
$$V_O = V_{IN}$$

Pulse Generator



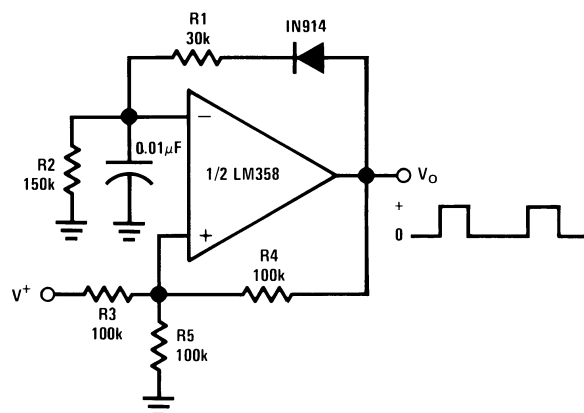
Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$ (Continued)

Squarewave Oscillator



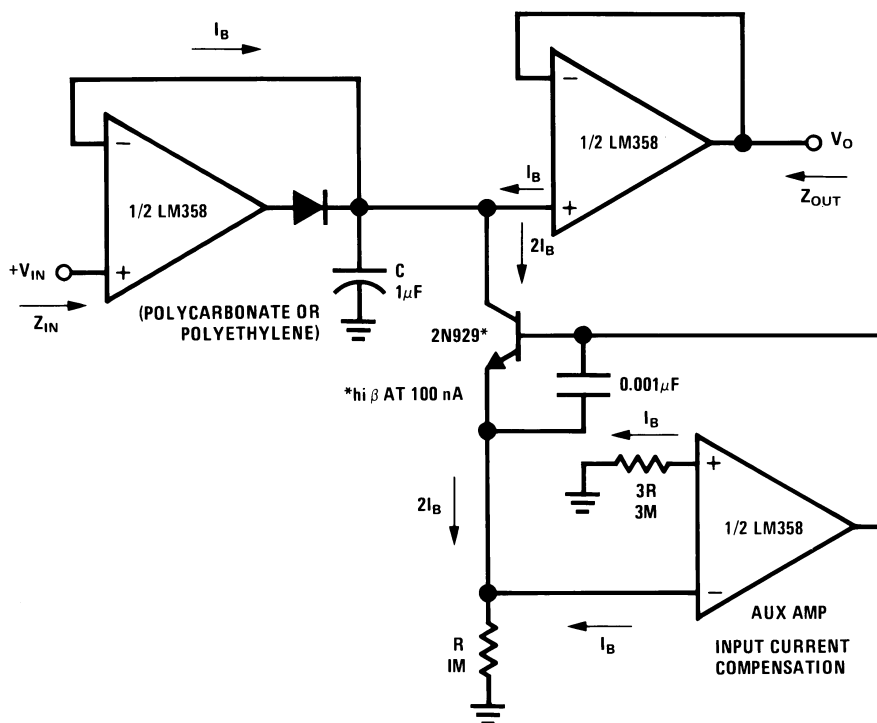
DS007787-18

Pulse Generator



DS007787-19

Low Drift Peak Detector

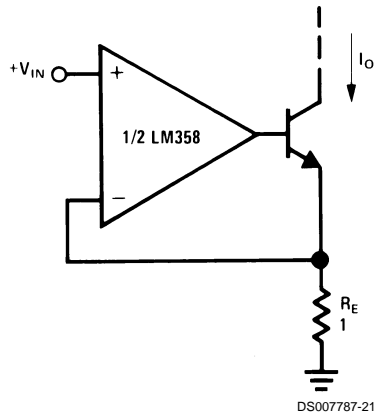


DS007787-20

HIGH Z_{IN}
LOW Z_{OUT}

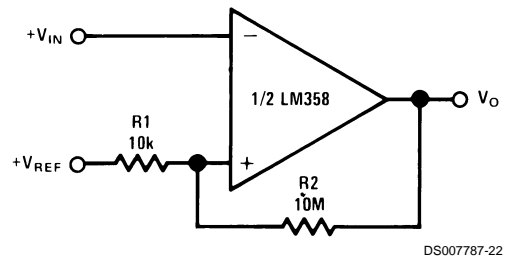
Typical Single-Supply Applications ($V^+ = 5.0 V_{DC}$) (Continued)

High Compliance Current Sink

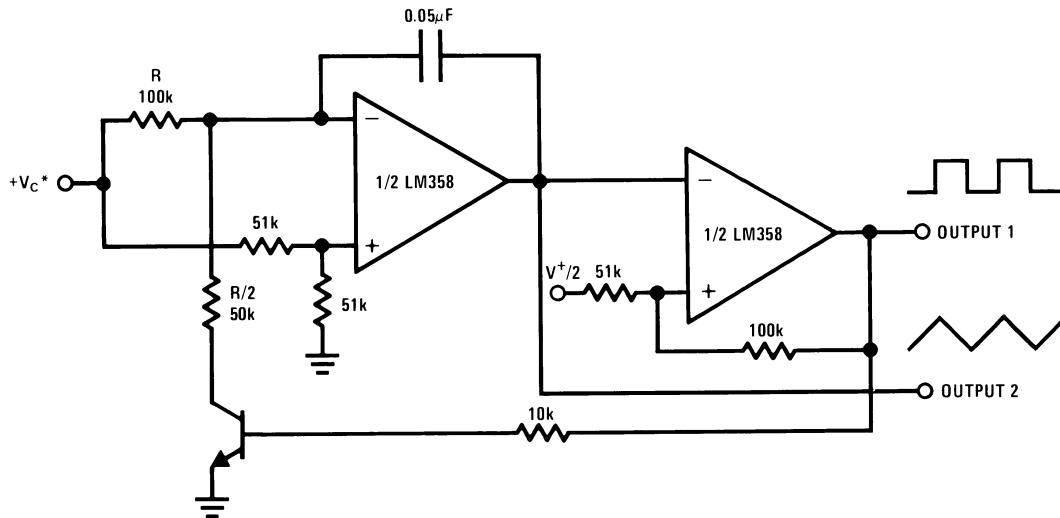


$I_O = 1 \text{ amp/volt } V_{IN}$
(Increase R_E for I_O small)

Comparator with Hysteresis



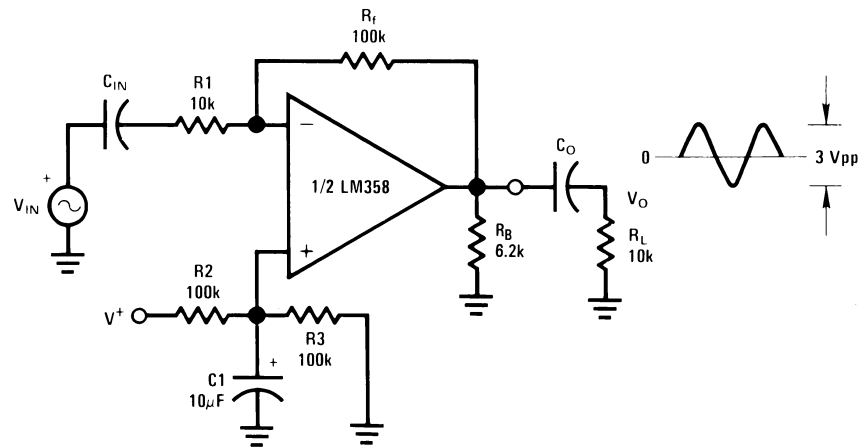
Voltage Controlled Oscillator (VCO)



*WIDE CONTROL VOLTAGE RANGE: $0 V_{DC} \leq V_C \leq 2 (V^+ - 1.5V_{DC})$

Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$ (Continued)

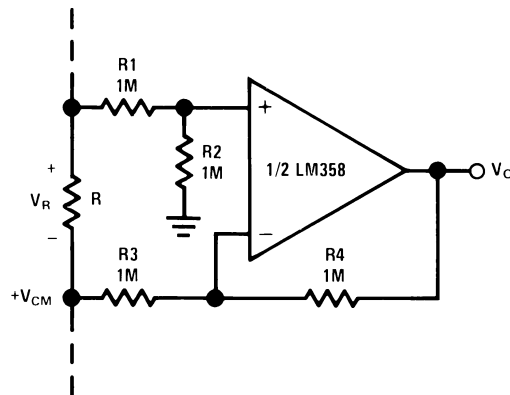
AC Coupled Inverting Amplifier



DS007787-24

$$A_V = \frac{R_f}{R_1} \quad (\text{As shown, } A_V = 10)$$

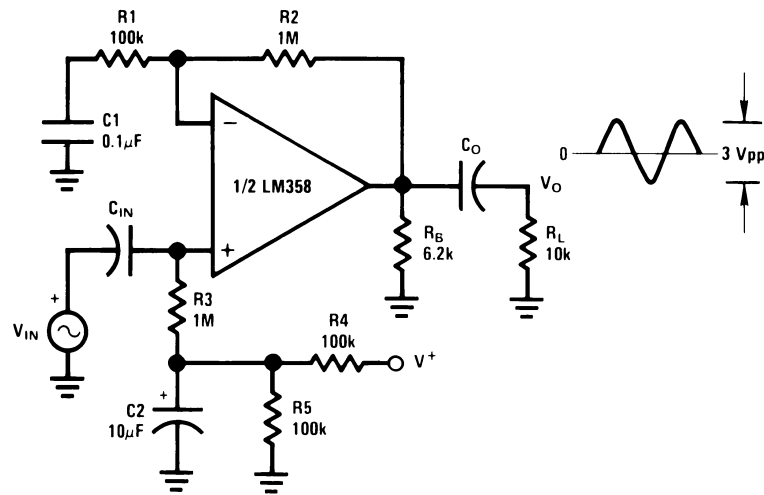
Ground Referencing a Differential Input Signal



DS007787-25

Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$ (Continued)

AC Coupled Non-Inverting Amplifier

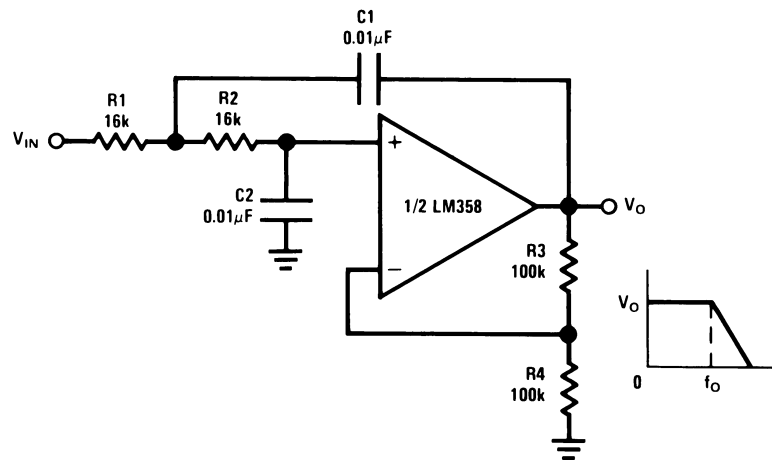


DS007787-26

$$A_V = 1 + \frac{R_2}{R_1}$$

 $A_V = 11 \text{ (As Shown)}$

DC Coupled Low-Pass RC Active Filter

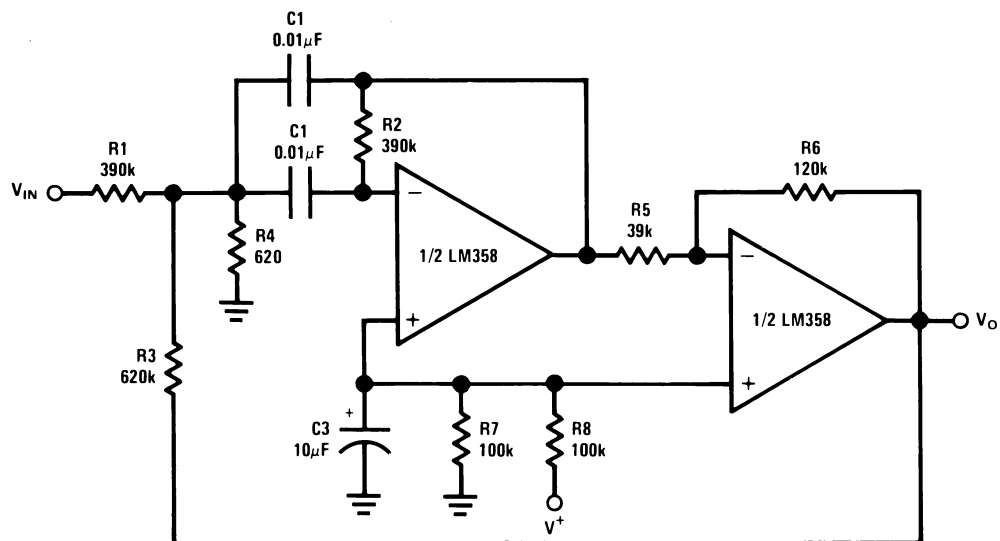


DS007787-27

 $f_o = 1 \text{ kHz}$
 $Q = 1$
 $A_V = 2$

Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$ (Continued)

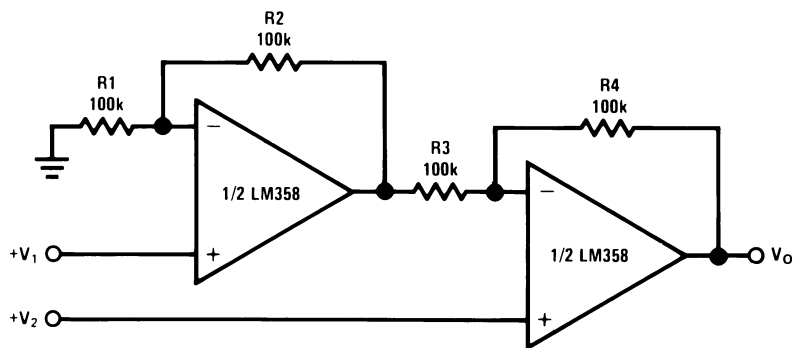
Bandpass Active Filter



DS007787-28

$f_o = 1 \text{ kHz}$
 $Q = 25$

High Input Z, DC Differential Amplifier



DS007787-29

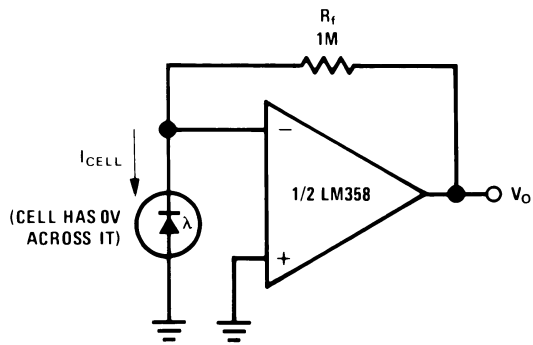
For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$$V_O = 1 + \frac{R4}{R3} (V_2 - V_1)$$

As Shown: $V_O = 2 (V_2 - V_1)$

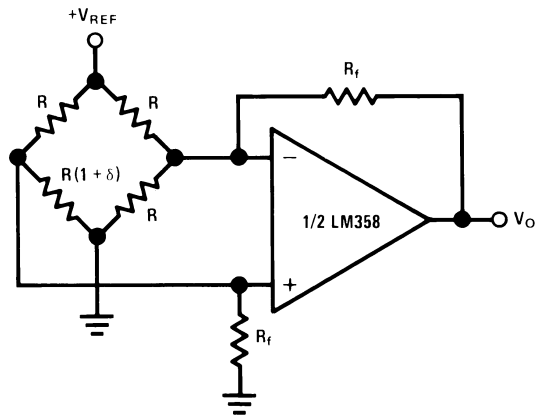
Typical Single-Supply Applications $(V^+ = 5.0 \text{ V}_{\text{DC}})$ (Continued)

Photo Voltaic-Cell Amplifier



DS007787-30

Bridge Current Amplifier

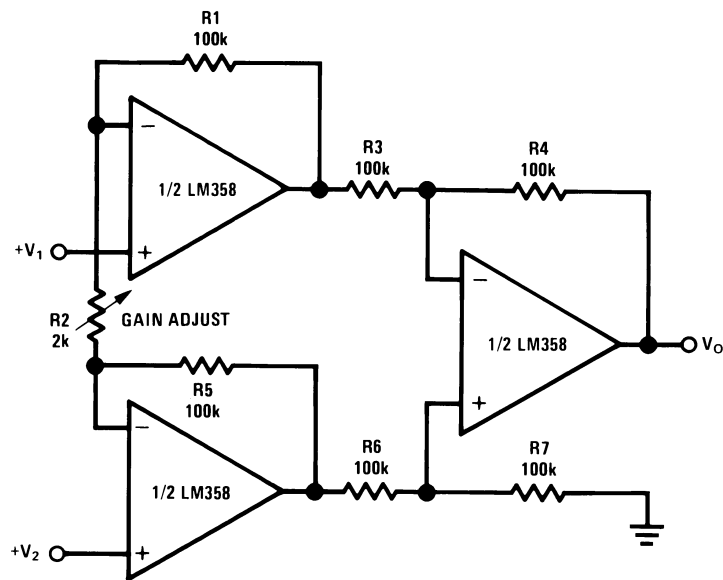


DS007787-33

For $\delta \ll 1$ and $R_f \gg R$

$$V_O \approx V_{\text{REF}} \left(\frac{\delta}{2} \right) \frac{R_f}{R}$$

High Input Z Adjustable-Gain DC Instrumentation Amplifier



DS007787-31

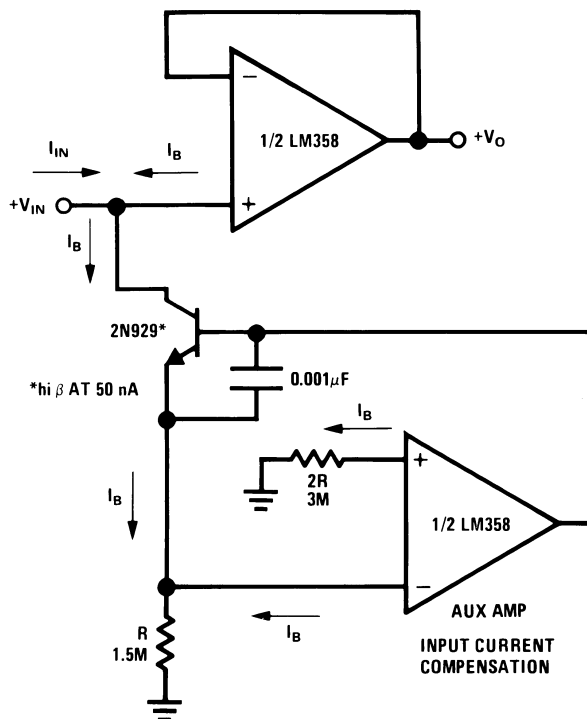
If $R_1 = R_5$ & $R_3 = R_4 = R_6 = R_7$ (CMRR depends on match)

$$V_O = 1 + \frac{2R_1}{R_2} (V_2 - V_1)$$

As shown $V_O = 101 (V_2 - V_1)$

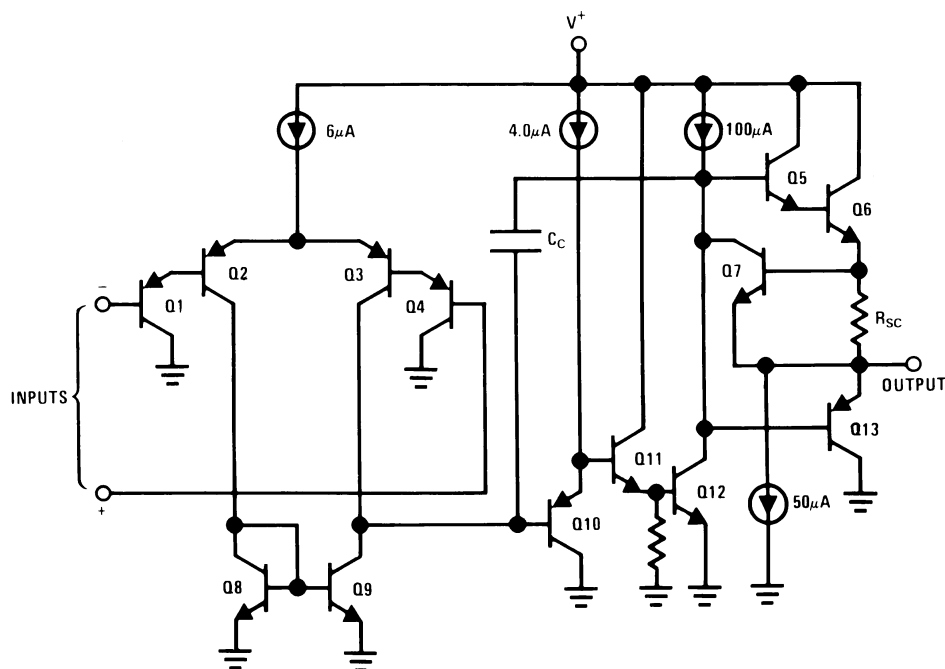
Typical Single-Supply Applications ($V^+ = 5.0\text{ V}_{\text{DC}}$) (Continued)

Using Symmetrical Amplifiers to Reduce Input Current (General Concept)

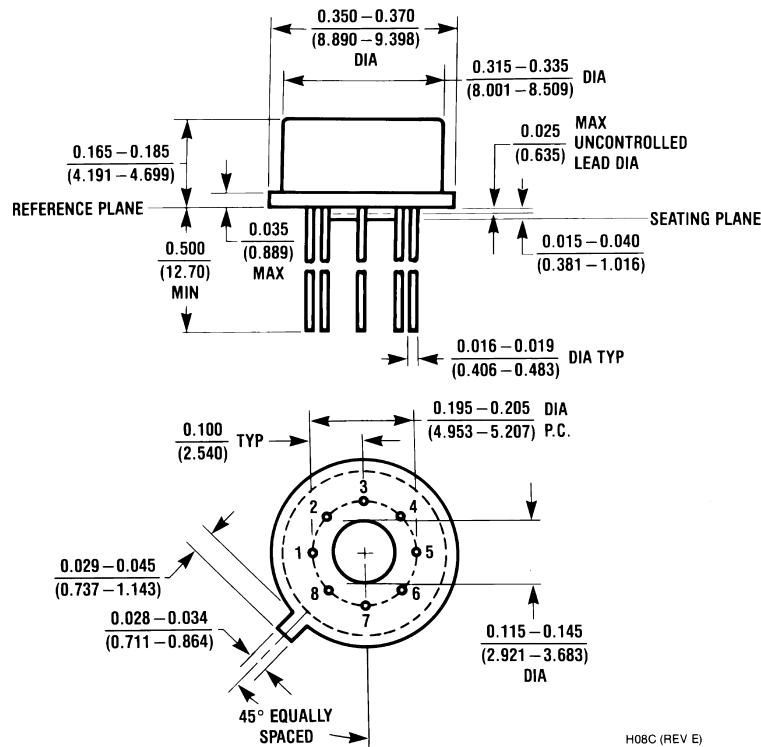


DS007787-32

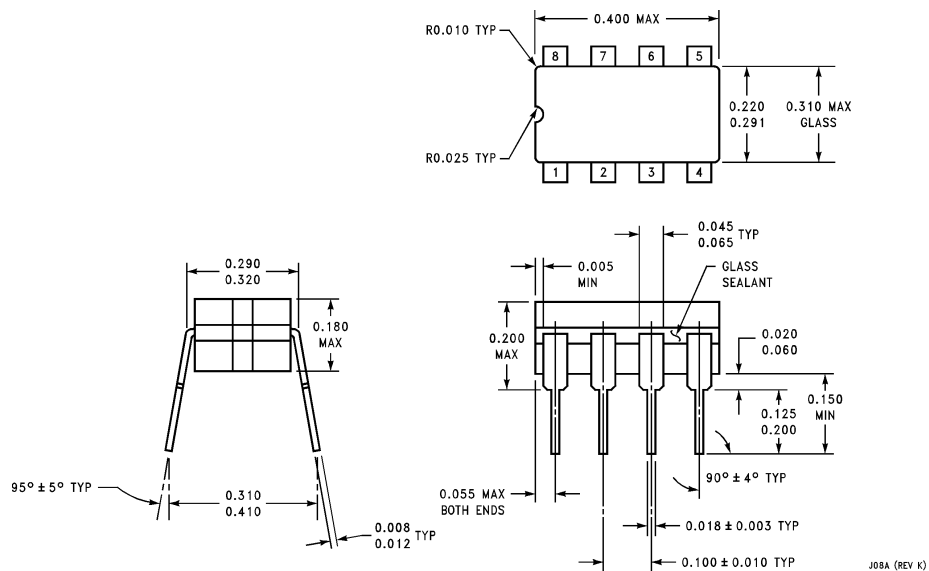
Schematic Diagram (Each Amplifier)



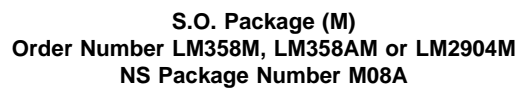
DS007787-3

Physical Dimensions inches (millimeters) unless otherwise noted

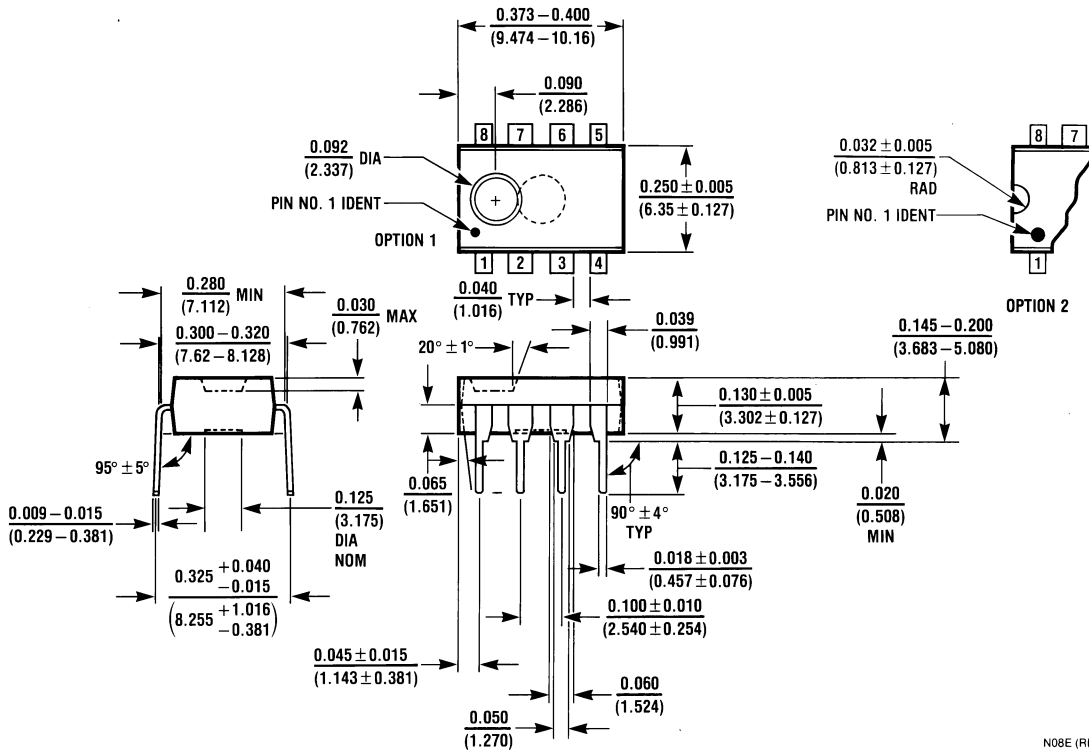
Metal Can Package (H)
Order Number LM158AH, LM158AH/883, LM158H,
LM158H/883, LM258H or LM358H
NS Package Number H08C



Cerdip Package (J)
Order Number LM158J, LM158J/883, LM158AJ or LM158AJ/883
NS Package Number J08A



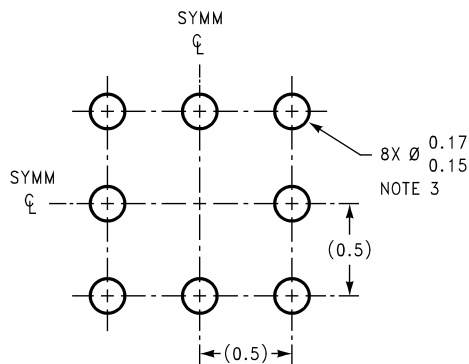
Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



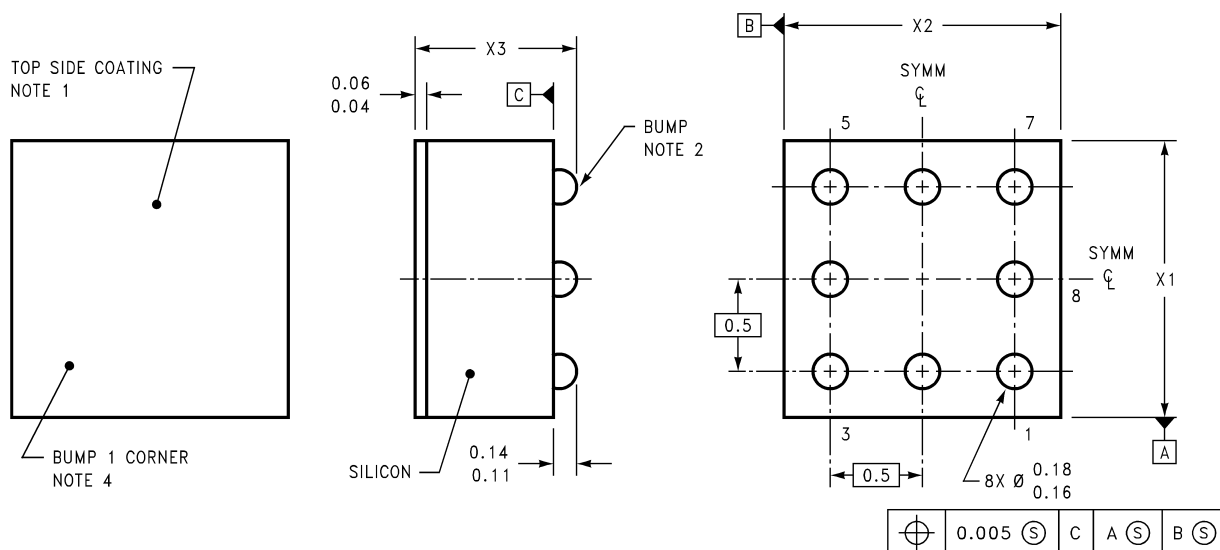
N08E (REV F)

Molded Dip Package (N)
Order Number LM358AN, LM358N or LM2904N
NS Package Number N08E

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



LAND PATTERN RECOMMENDATION



DIMENSIONS ARE IN MILLIMETERS

BPA08XXX (REV A)

NOTES: UNLESS OTHERWISE SPECIFIED

1. EPOXY COATING
2. 63Sn/37Pb EUTECTIC BUMP
3. RECOMMEND NON-SOLDER MASK DEFINED LANDING PAD.
4. PIN 1 IS ESTABLISHED BY LOWER LEFT CORNER WITH RESPECT TO TEXT ORIENTATION REMAINING PINS ARE NUMBERED COUNTERCLOCKWISE.
5. XXX IN DRAWING NUMBER REPRESENTS PACKAGE SIZE VARIATION WHERE X_1 IS PACKAGE WIDTH, X_2 IS PACKAGE LENGTH AND X_3 IS PACKAGE HEIGHT.
6. REFERENCE JEDEC REGISTRATION MO-211, VARIATION BC.

8-Bump micro SMD
NS Package Number BPA08AAA
 $X_1 = 1.285$ $X_2 = 1.285$ $X_3 = 0.700$

Notes

LIFE SUPPORT POLICY

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



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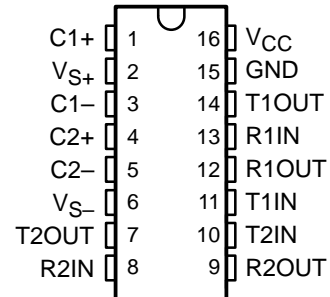
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507

MAX232, MAX232I DUAL EIA-232 DRIVERS/RECEIVERS

SLLS0471 – FEBRUARY 1989 – REVISED OCTOBER 2002

- Meet or Exceed TIA/EIA-232-F and ITU Recommendation V.28
- Operate With Single 5-V Power Supply
- Operate Up to 120 kbit/s
- Two Drivers and Two Receivers
- ± 30 -V Input Levels
- Low Supply Current . . . 8 mA Typical
- Designed to be Interchangeable With Maxim MAX232
- ESD Protection Exceeds JESD 22 – 2000-V Human-Body Model (A114-A)
- Applications
 - TIA/EIA-232-F
 - Battery-Powered Systems
 - Terminals
 - Modems
 - Computers

MAX232 . . . D, DW, N, OR NS PACKAGE
MAX232I . . . D, DW, OR N PACKAGE
(TOP VIEW)



description/ordering information

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply EIA-232 voltage levels from a single 5-V supply. Each receiver converts EIA-232 inputs to 5-V TTL/CMOS levels. These receivers have a typical threshold of 1.3 V and a typical hysteresis of 0.5 V, and can accept ± 30 -V inputs. Each driver converts TTL/CMOS input levels into EIA-232 levels. The driver, receiver, and voltage-generator functions are available as cells in the Texas Instruments LinASIC™ library.

ORDERING INFORMATION

T _A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP (N)	Tube	MAX232N	MAX232N
	SOIC (D)	Tube	MAX232D	MAX232
		Tape and reel	MAX232DR	
	SOIC (DW)	Tube	MAX232DW	MAX232
		Tape and reel	MAX232DWR	
–40°C to 85°C	SOP (NS)	Tape and reel	MAX232NSR	MAX232
	PDIP (N)	Tube	MAX232IN	MAX232IN
	SOIC (D)	Tube	MAX232ID	MAX232I
		Tape and reel	MAX232IDR	
	SOIC (DW)	Tube	MAX232IDW	MAX232I
		Tape and reel	MAX232IDWR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.



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MAX232, MAX232I
DUAL EIA-232 DRIVERS/RECEIVERS

SLLS047I – FEBRUARY 1989 – REVISED OCTOBER 2002

Function Tables

EACH DRIVER

INPUT TIN	OUTPUT TOUT
L	H
H	L

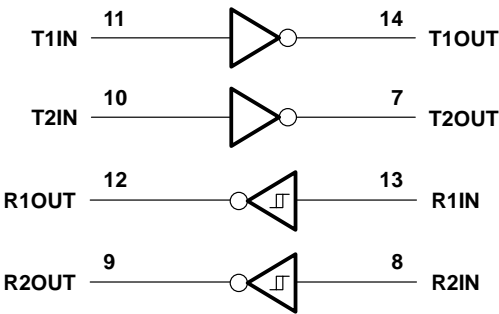
H = high level, L = low level

EACH RECEIVER

INPUT RIN	OUTPUT ROUT
L	H
H	L

H = high level, L = low level

logic diagram (positive logic)



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Input supply voltage range, V_{CC} (see Note 1)	–0.3 V to 6 V
Positive output supply voltage range, V_{S+}	$V_{CC} - 0.3$ V to 15 V
Negative output supply voltage range, V_{S-}	–0.3 V to –15 V
Input voltage range, V_I : Driver	–0.3 V to $V_{CC} + 0.3$ V
Receiver	± 30 V
Output voltage range, V_O : T1OUT, T2OUT	$V_{S-} - 0.3$ V to $V_{S+} + 0.3$ V
R1OUT, R2OUT	–0.3 V to $V_{CC} + 0.3$ V
Short-circuit duration: T1OUT, T2OUT	Unlimited
Package thermal impedance, θ_{JA} (see Note 2): D package	73°C/W
DW package	57°C/W
N package	67°C/W
NS package	64°C/W
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	260°C
Storage temperature range, T_{stg}	–65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to network ground terminal.

2. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

		MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage	4.5	5	5.5	V
V_{IH}	High-level input voltage (T1IN, T2IN)	2			V
V_{IL}	Low-level input voltage (T1IN, T2IN)			0.8	V
R1IN, R2IN	Receiver input voltage			± 30	V
T_A	Operating free-air temperature	MAX232	0	70	°C
		MAX232I	–40	85	

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted) (see Note 3 and Figure 4)

PARAMETER	TEST CONDITIONS	MIN	TYP‡	MAX	UNIT
I_{CC} Supply current	$V_{CC} = 5.5$ V, All outputs open, $T_A = 25^\circ\text{C}$		8	10	mA

‡ All typical values are at $V_{CC} = 5$ V and $T_A = 25^\circ\text{C}$.

NOTE 3: Test conditions are C1–C4 = 1 μF at $V_{CC} = 5$ V ± 0.5 V.

MAX232, MAX232I

DUAL EIA-232 DRIVERS/RECEIVERS

SLLS047I – FEBRUARY 1989 – REVISED OCTOBER 2002

DRIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

PARAMETER		TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V _{OH}	High-level output voltage	T1OUT, T2OUT R _L = 3 kΩ to GND	5	7		V
V _{OL}	Low-level output voltage‡	T1OUT, T2OUT R _L = 3 kΩ to GND		–7	–5	V
r _o	Output resistance	T1OUT, T2OUT V _{S+} = V _{S–} = 0, V _O = ±2 V	300			Ω
I _{OS} §	Short-circuit output current	T1OUT, T2OUT V _{CC} = 5.5 V, V _O = 0		±10		mA
I _{IS}	Short-circuit input current	T1IN, T2IN V _I = 0			200	μA

† All typical values are at V_{CC} = 5 V, T_A = 25°C.

‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.

§ Not more than one output should be shorted at a time.

NOTE 3: Test conditions are C1–C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 3)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SR	Driver slew rate	R _L = 3 kΩ to 7 kΩ, See Figure 2			30	V/μs
SR(t)	Driver transition region slew rate	See Figure 3		3		V/μs
	Data rate	One TOUT switching		120		kbit/s

NOTE 3: Test conditions are C1–C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

RECEIVER SECTION

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature range (see Note 3)

PARAMETER		TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V _{OH}	High-level output voltage	R1OUT, R2OUT I _{OH} = –1 mA	3.5			V
V _{OL}	Low-level output voltage‡	R1OUT, R2OUT I _{OL} = 3.2 mA			0.4	V
V _{IT+}	Receiver positive-going input threshold voltage	R1IN, R2IN V _{CC} = 5 V, T _A = 25°C		1.7	2.4	V
V _{IT–}	Receiver negative-going input threshold voltage	R1IN, R2IN V _{CC} = 5 V, T _A = 25°C	0.8	1.2		V
V _{hys}	Input hysteresis voltage	R1IN, R2IN V _{CC} = 5 V	0.2	0.5	1	V
r _i	Receiver input resistance	R1IN, R2IN V _{CC} = 5, T _A = 25°C	3	5	7	kΩ

† All typical values are at V_{CC} = 5 V, T_A = 25°C.

‡ The algebraic convention, in which the least positive (most negative) value is designated minimum, is used in this data sheet for logic voltage levels only.

NOTE 3: Test conditions are C1–C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

switching characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 3 and Figure 1)

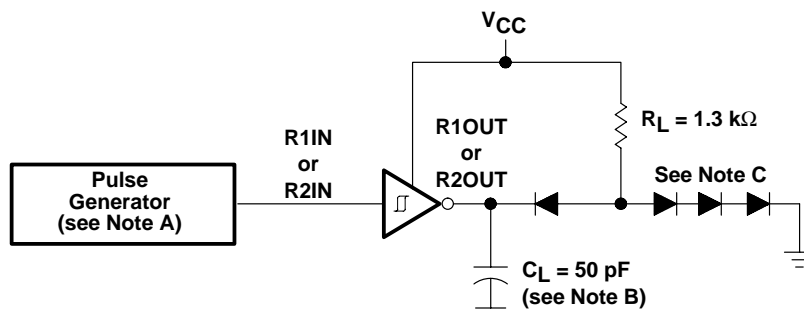
PARAMETER		TYP	UNIT
t _{PLH(R)}	Receiver propagation delay time, low- to high-level output	500	ns
t _{PHL(R)}	Receiver propagation delay time, high- to low-level output	500	ns

NOTE 3: Test conditions are C1–C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

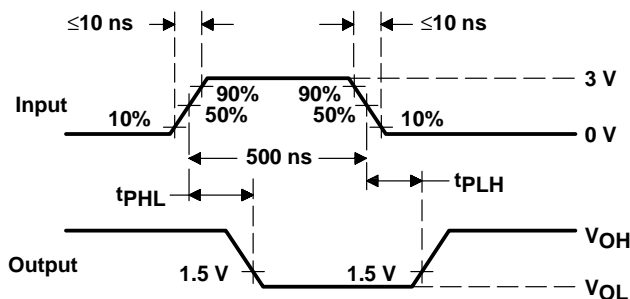


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PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT



WAVEFORMS

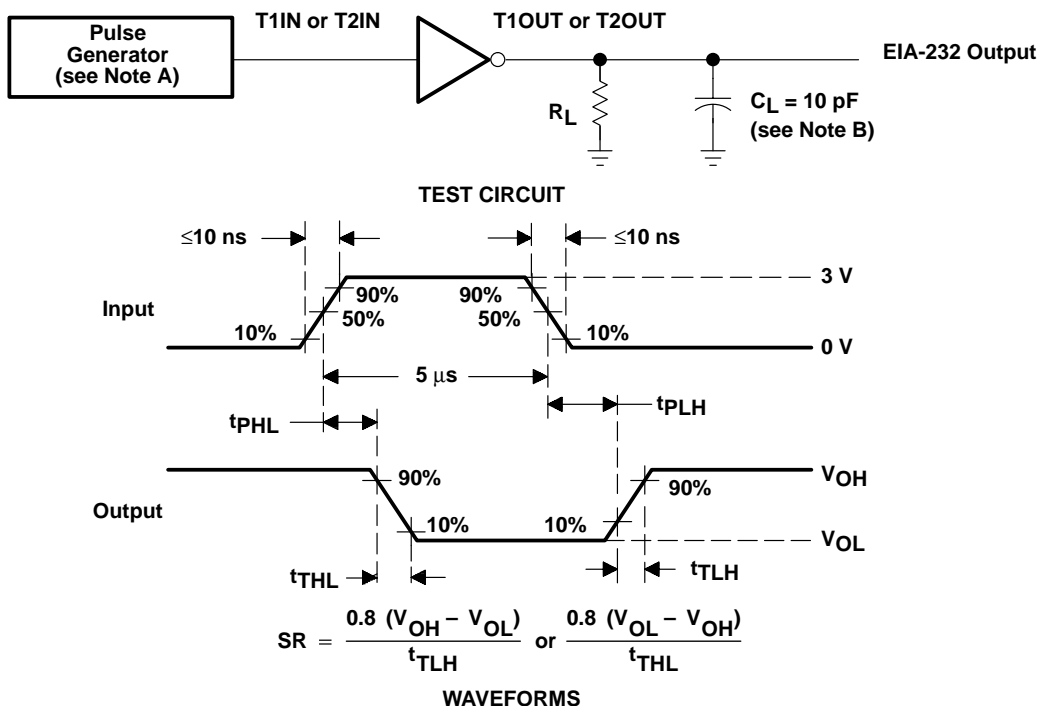
- NOTES: A. The pulse generator has the following characteristics: $Z_O = 50 \Omega$, duty cycle $\leq 50\%$.
B. C_L includes probe and jig capacitance.
C. All diodes are 1N3064 or equivalent.

Figure 1. Receiver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements

MAX232, MAX232I DUAL EIA-232 DRIVERS/RECEIVERS

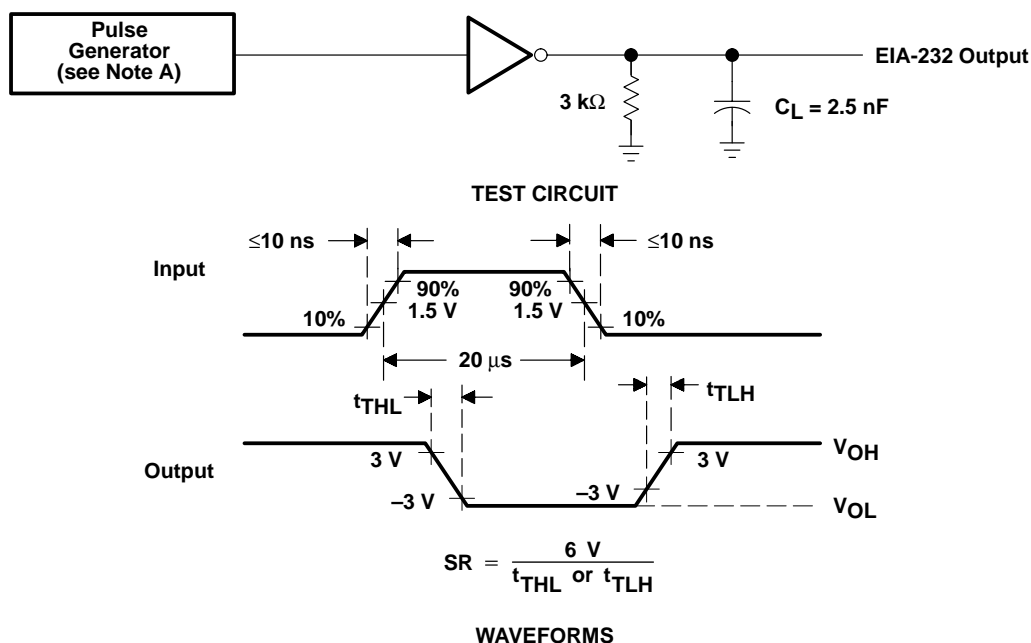
SLLS047I – FEBRUARY 1989 – REVISED OCTOBER 2002

PARAMETER MEASUREMENT INFORMATION



NOTES: A. The pulse generator has the following characteristics: $Z_O = 50 \Omega$, duty cycle $\leq 50\%$.
B. C_L includes probe and jig capacitance.

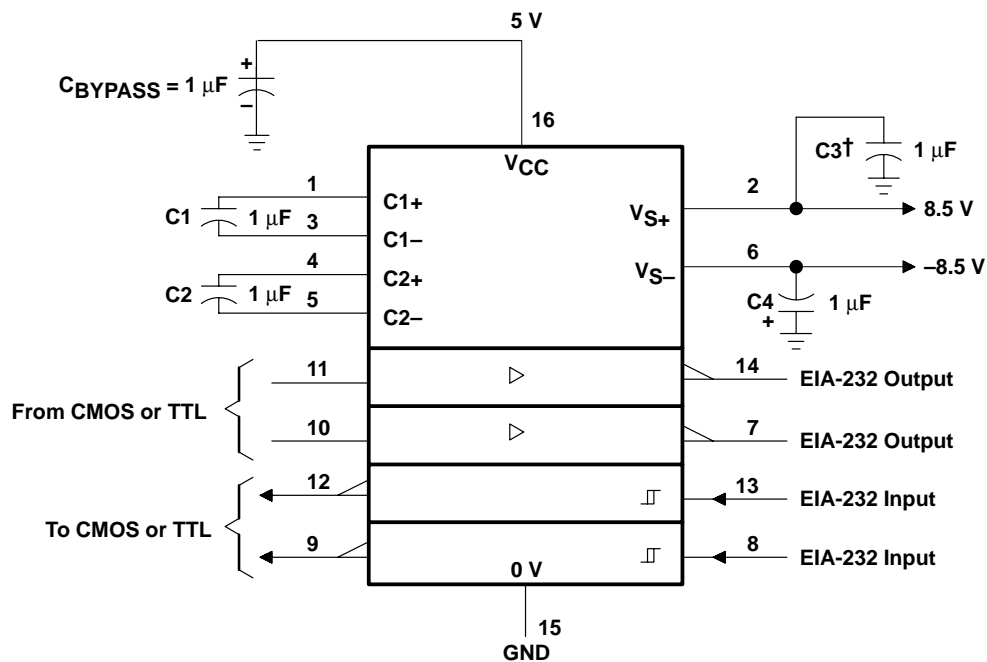
Figure 2. Driver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements (5- μs Input)



NOTE A: The pulse generator has the following characteristics: $Z_O = 50 \Omega$, duty cycle $\leq 50\%$.

Figure 3. Test Circuit and Waveforms for t_{THL} and t_{TLH} Measurements (20- μs Input)

APPLICATION INFORMATION



† C3 can be connected to VCC or GND.

Figure 4. Typical Operating Circuit

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UMTS/HSDPA 3GPP release 5

RS232+USB 3G/HSDPA MODEM

GSM 3GPP release 99

LED for signal

Product description

SIM application toolkit

General features

3V SIM card slot

Industrial design

Internet, data and SMS service

Aluminum casing

Output Power

RS232+USB interface

Class 4(2W @ 850/ 900MHz GSM)

Class 1(1W @ 1800MHz GSM)

Based on Simcom module SIM5216E

Class 3 (0.25W @ 900/2100MHZ)

With TCP/IP stack

Input voltage 7.5V-30V DC

WCDMA/HSDPA 900/2100MHZ

Input current 1A-2A

GSM/GPRS/EDGE:850/900/1800MHZ

Standby current: 56mA

GPRS class 12

Working current: 100-140mA

Working temperature: -30 to +80 degrees

EDGE class 12

Storage temperature:-40 to +85 degrees

Size 85*54*25mm

Weight 100g

Accessories: AC/DC adaptor, DB9 RS232
cable, USB cable, antenna, 2 mounting plates,
CD

Spec for Data:

HSDPA: Max. 3.6 mbps (DL)

WCDMA: Max. 384 Kbps (DL), Max.384Kbps
(UL)

EDGE: Max. 236. 8 Kbps (DL),Max118 Kbps
(UL)

GPRS: Max. 85.6 Kbps (DL), Max.42.8 Kbps
(UL)

CSD: 2.4/4.8/9.6/ 14.4kbps,

Non-transparent mode

GPRS coding scheme: CS 1-4

EDGE coding scheme: MCS 1-9

PAP,PPP, PBCCH USSD

UMTS R99

Spec for SMS

MO, MT,CB

SMS Cell broadcast

Text and PDU mode