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SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT –I- INTRODUCTION TO EMBEDDED SYSTEM
SECA1603

I INTRODUCTION TO EMBEDDED SYSTEM

Embedded system- characteristics of embedded system- categories of embedded system- requirements of embedded systems- challenges and design issues of embedded system- trends in embedded system- system integration- hardware and software partition- applications of embedded system- control system and industrial automation-biomedical- data communication system-network information appliances- IVR systems- GPS systems

Introduction to Embedded system

An embedded system is one kind of a computer system mainly designed to perform several tasks like to access, process, store and also control the data in various electronics- based systems. Embedded systems are a combination of hardware and software where software is usually known as firmware that is embedded into the hardware. One of its most important characteristics of these systems is, it gives the o/p within the time limits. Embedded systems support to make the work more perfect and convenient. So, we frequently use embedded systems in simple and complex devices too. The applications of embedded systems mainly involve in our real life for several devices like microwave, calculators, TV remote control, home security and neighborhood traffic control systems

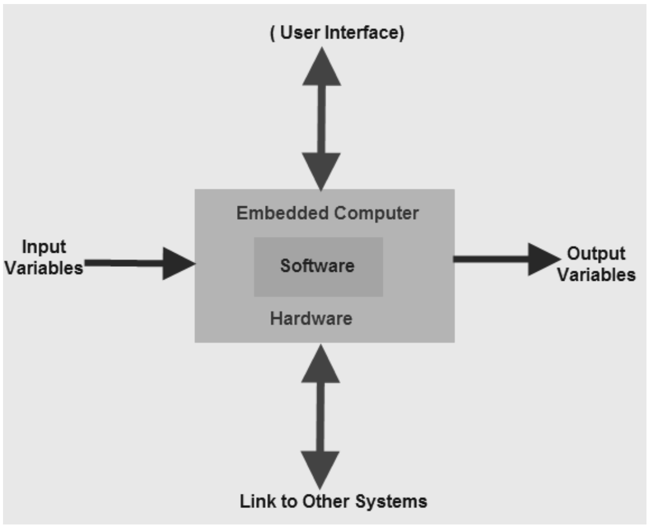

Fig:1.1:Block Diagram of Embedded system

The embedded system basics are the combination of embedded system hardware and embedded system software.

Embedded System Hardware

An embedded system uses a hardware platform to perform the operation. Hardware of the embedded system is assembled with a microprocessor/microcontroller. It has the elements such as input/output interfaces, memory, user interface and the display unit. Generally, an embedded system comprises of the following

- Power Supply
- Memory
- Processor
- Timers
- Output/Output circuits
- Serial communication ports
    - SASC (System application specific circuits)

Embedded System Software

The software of an embedded system is written to execute a particular function. It is normally written in a high-level setup and then compiled down to offer code that can be stuck within a non-volatile memory in the hardware. An embedded system software is intended to keep in view of the following three limits

- Convenience of system memory
- Convenience of processor's speed
- When the embedded system runs constantly, there is a necessity to limit power dissipation for actions like run, stop and wake up.

Embedded System Characteristics

- Generally, an embedded system executes a particular operation and does the similar continually. For instance: A pager is constantly functioning as a pager.
- All the computing systems have limitations on design metrics, but those can be especially tight. Design metric is a measure of an execution features like size, power, cost and also performance.
- It must perform fast enough and consume less power to increase battery life.
- Several embedded systems should constantly react to changes in the system and also calculate particular results in real time without any delay. For instance, a car cruise controller; it continuously displays and responds to speed & brake sensors. It must calculate acceleration/de-accelerations frequently in a limited time; a delayed computation can consequence in letdown to control the car.
- It must be based on a microcontroller or microprocessor based.
- It must require a memory, as its software generally inserts in ROM. It does not require any secondary memories in the PC.
- It must need connected peripherals to attach input & output devices.
- An Embedded system is inbuilt with hardware and software where the hardware is used for security and performance and Software is used for more flexibility and features**.**

Embedded System Applications

The applications of an embedded system basics include smart cards, computer networking, satellites, telecommunications, digital consumer electronics, missiles, etc.

Categories of Embedded System

Embedded systems are classified into four categories based on their performance and functional requirements:

- Standalone embedded systems
- Real time embedded systems
- Networked embedded systems
- Mobile embedded systems

Embedded Systems are classified into three types based on the performance of the microcontroller such as

- Small scale embedded systems
- Medium scale embedded systems
  - Sophisticated embedded systems **Stand Alone Embedded Systems**

Standalone embedded systems do not require a host system like a computer, it works by itself. It takes the input from the input ports either analog or digital and processes, calculates and converts the data and gives the resulting data through the connected device- Which either controls, drives or displays the connected devices. Examples for the stand alone embedded systems are mp3 players, digital cameras, video game consoles, microwave ovens and temperature measurement systems.

Real Time Embedded Systems

A real time embedded system is defined as, a system which gives a required o/p in a particular time. These types of embedded systems follow the time deadlines for completion of a task. Real time embedded systems are classified into two types such as soft and hard real time systems. Further this Real-Time Embedded System is divided into two type's i.e.

Soft Real Time Embedded Systems

In these types of embedded systems time/deadline is not so strictly followed. If deadline of the task is passed (means the system didn't give result in the defined time) still result or output is accepted.

Hard Real-Time Embedded Systems –

In these types of embedded systems time/deadline of task is strictly followed. Task must be completed in between time frame (defined time interval) otherwise result/output may not be accepted.

Examples

- Traffic control system
- Military usage in defense sector
- Medical usage in health sector

Networked Embedded Systems

These types of embedded systems are related to a network to access the resources. The connected network can be LAN, WAN or the internet. The connection can be any wired or wireless. This type of embedded system is the fastest growing area in embedded system applications. The embedded web server is a type of system wherein all embedded devices are connected to a web server and accessed and controlled by a web browser. Example for the LAN networked embedded system is a home security system wherein all sensors are connected and run on the protocol TCP/IP

Mobile Embedded Systems

Mobile embedded systems are used in portable embedded devices like cell phones, mobiles, digital cameras, mp3 players and personal digital assistants, etc. The basic limitation of these devices is the other resources and limitation of memory.

Small Scale Embedded Systems

These types of embedded systems are designed with a single 8 or 16-bit microcontroller that may even be activated by a battery. For developing embedded software for small scale embedded systems, the main programming tools are an editor, assembler, cross assembler and integrated development environment (IDE).

Medium Scale Embedded Systems

These types of embedded systems design with a single or 16 or 32 bit microcontroller, RISCs or DSPs. These types of embedded systems have both hardware and software complexities. For developing embedded software for medium scale embedded systems, the main programming tools are C, C++, JAVA, Visual C++, RTOS, debugger, source code engineering tool, simulator and IDE.

Sophisticated Embedded Systems

These types of embedded systems have enormous hardware and software complexities, that may need ASIPs, IPs, PLAs, scalable or configurable processors. They are used for cutting-edge applications that need hardware and software Co-design and components which have to assemble in the final system.

Requirements of Embedded system

Reliability
Cost-effectiveness
Low power consumption Efficient use of processing power Efficient use of memory
Appropriate execution time

Reliability

Embedded system have to work without the need for resetting or rebooting. This call for a very reliable hardware and software. For example : if an embedded system comes to a halt because of hardware error, the system must reset itself without the need for human intervention. However the embedded software developers must make the reliability of the hardware as well as that of the software.

Cost-effectiveness

If an embedded system is designed for a very special purpose such as for deep space or for nuclear power plant station cost may not be an issue. However if the embedded system is designed for a mass market purpose like CD players, toys and mobile devices cost is a major concern. Application Specific Integrated Circuit (ASIC) is used by the designers to reduce the hardware components and hence the cost also reduces.

Low power consumption

Most of the embedded systems are powered by battery, rather than a main supply. In such case the power consumption should be minimized to avoid draining the Batteries. For example : by reducing the number of hardware component the power consumption can be reduced. As well as by designing the processor to revert to low power or sleep mode when there is no operation to perform

Efficient use of processing power

A wide variety of processors with varying processing powers are available to embedded systems. Developers must keep processing power, memory and cost in mind while choosing the right processor. The processing power requirement is specified in ,Million Instruction Per Second (MIPS). With the availability of so many processor, choosing a processor has become a tough task nowadays

Efficient use of memory

Most of the embedded systems do not have secondary storage such as hard disk. The memory chip available on the embedded systems are only Read Only memory and Random Access memory. As most of the embedded systems do not have secondary storage, “flash memory” is used to store the program. Nowadays micro-controller and Digital signal processors also comes with onboard memory. Such processors are used for small embedded system as the cost generally is low and the execution generally is fast

Appropriate execution time

In real time embedded systems, certain task must be performed within a specified period of time. Normally desktop pc cannot achieve real time performance. Therefore, special operating system known as real time operating systems run on these embedded systems. In hard real time embedded system deadlines has to be strictly met but whereas in soft real time embedded system the task may not be performed in a timely manner. The software developer needs to ascertain whether the embedded system is a hard real time or soft one and has to perform the performance analysis accordingly

Challenges and issues in embedded system

Co-design
Embedding an operating system
Code optimization
Efficient input or output
Testing and debugging

Co-design

An embedded system consists of hardware and software, deciding which function of the system should be implemented in hardware and software is of a major consideration. For example in hardware implementation the task execution is faster compared with the other one. On the downside a chip cost money, consumes valuable power and occupies space. A software implementation is better if these are the major concern. This issue of choosing between hardware and software implementation is known as a co-design issue

Embedding an operating system

It is possible to write embedded software without any operating system embedded into the system. Developers can implement services such as memory management, input/output management and so on. Writing your own routines necessary for a particular application results in compact and efficient coding. Embedded operating system provide the necessary Application Programming Interfaces (API).

Code optimization

Developers need not worry much about the code optimization, because the processor is highly powerful, plenty of memory is generally available. Memory and Execution time are the important constraints in embedded system. Sometimes to achieve the required response time the programmer has to write certain portion of coding in assembly language. Of course, with the availability of sophisticated development tools, this is less of an issue in recent years.

Efficient input or output

In most of the embedded system, the input interfaces have limited functionality. Writing embedded software is a different ball game compared with writing a user interface with a full-fledged keyboard, a mouse and a large display. Many systems available in process control take electrical signal as input and produce electrical signal as output, since they don't use I/O devices. Developing, testing and debugging such systems is much more challenging than doing the same with the desktop systems.

Testing and debugging

Software for an embedded system cannot be tested on the target hardware during the development phase because debugging will be extremely difficult. Testing and debugging the software on the host system by actual simulation of field conditions is very challenging. Nowadays, the job is made a bits simpler with the availability of "profilers" that tell you clearly which line of code are executed and which lines are not executed. Using the output of such profilers we can locate the untested lines of code and ensure that they are also executed by providing the necessary test input data. It is these challenges that made embedded software development a "black art" in earlier days. This is no longer the case, however the developments in embedded software are changing the scenario completely.

Recent trends in embedded system

Processors
Memory
Operating Systems
Programming Languages
Development Tools

Processors

In an effort to cater to different applications, several semiconductor electronics vendors have released many processors. We can find 8-bit, 16-bit, and 32 bit processors with different processing powers and memory addressing capabilities. Many sophisticated DSP are available to cater to numerous application needs including audio and video coding and image processing. The processor boards around which the embedded systems can be built come with the necessary RAM and ROM as well as peripherals such as a serial port, USB port and Ethernet connectivity.

Memory

Both RAM and ROM memory devices are becoming increasingly cheaper paving the way for devices that can store large numbers of programs and their data. Secondary devices such as Hard disk are also being integrated into embedded systems such as mobile communication and computing devices . Devices that do not have secondary storage use flash memory and the capacity of flash memory chips is also rising very rapidly making it possible to incorporate heavy OS

Operating Systems

As most everyone knows Microsoft currently holds the lion share of the market in operating systems that run desktop computers. Many operating systems which are available nower days are categorized as embedded operating systems, real time operating systems and mobile operating system. These operating system occupies much less memory. This reduces the development time and the effort considerably

Programming Languages

The era of writing the embedded software in assembly languages is now almost history. High level languages are extensively used for embedded software development. Object oriented programming languages are also extensively used. Another important development is the use of JAVA. Because of JAVA platform independence it has become very popular for embedded software development

Development Tools

Many advances in development tools are accelerating embedded software development. These development tools include Cross compiler, Debbugers and Emulators. Using these tools developers can write programs on host machines, test the software thoroughly and port to the target hardware. The cycle time for the development has been reduced considerably in recent years because of these development tools. Many of them are available free of cost from major software vendors

Control System and Industrial Automation

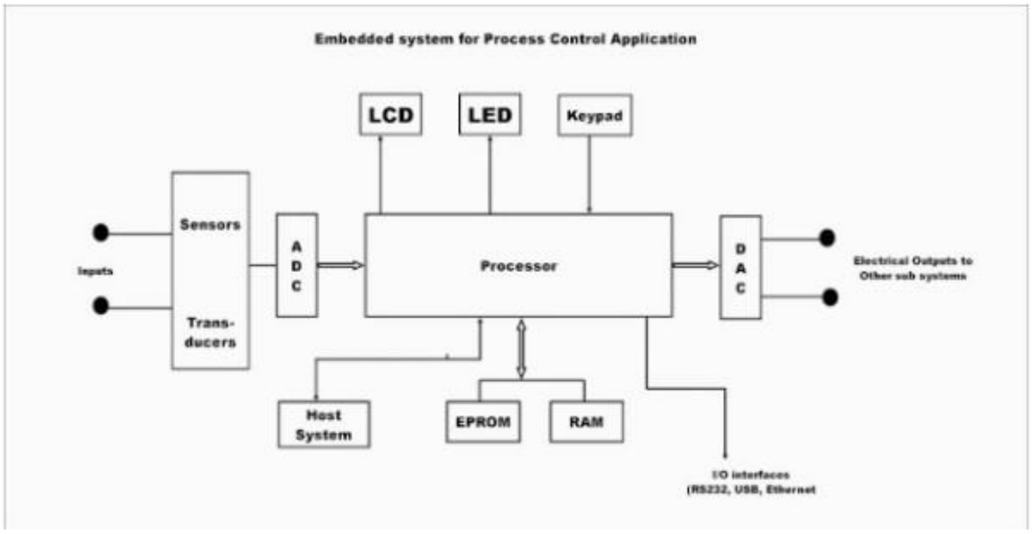
Embedded system for Process Control Application
LCD
LED
Keypad
Sensors
Trans-ducers
Inputs
A D C
Processor
D A C
Electrical Outputs to Other sub systems
Host System
EPROM
RAM
I/O interfaces (RS232, USB, Ethernet

Fig:1.2:Block Diagram of control system and industrial automation

The embedded system takes electrical signals as input. Generally sensors or transducers are used to convert the physical entity into an electrical signal. The processor can process only digital signals, the ADC(Analog to Digital Convertor) converts the analog signals to its equivalent digital signals, which is an electrical representation of a bit stream of 0s and 1s. RAM is used to store the volatile data. A DAC(Digital to Analog Convertor) is used to convert the output digital signal to analog format. The processor board also includes input/output interface, such as serial interface , USB port and an Ethernet port for connectivity to the external systems. For the user interaction LCD and LED and a keypad are provided. These modules may or may not be required depending on the application. Depending on the application the designer chooses the necessary modules and carries out the design. While designing the reliability, performance and the cost need to be kept in the mind. Some of the typical process control applications in nuclear plants and telemetry and tele command units in satellite communication systems. Some of the embedded systems have to operate in very hostile environments

Biomedical systems

Much of the progress made in the health care industry is due to the development in the electronic industry Hospitals are full of embedded systems, including X-ray control units, EEG and ECG units and equipments used for diagnostic testing such as endoscopy and so on. These systems use PC add on cards which take the ECG signals and process them and the PC monitor is used for the display. Even the PC secondary storage is used to store the ECG records. Biometric systems for finger print and face recognition are gaining wide
use in the agencies concerned with the securities

The input fingerprint must be processed and compared with the available database using pattern recognition algorithm, which requires intensive processing. The biometric systems use a Digital Signal Processor(DSP) for signal processing such as filtering and edge enhancement of the image. And a general purpose processor for implementing the pattern matching algorithms

Data communication system

Internet has acted as the catalyst for the embedded system. Modem that connects two computers is an embedded system. Dialup modems normally used to access the internet are embedded systems with a DSP inside. Using the DSP and the associated software the modem establishes the connection using the standard protocols. As the digital signal is modulated a lot of signal processing is involved therefore, DSP is used.

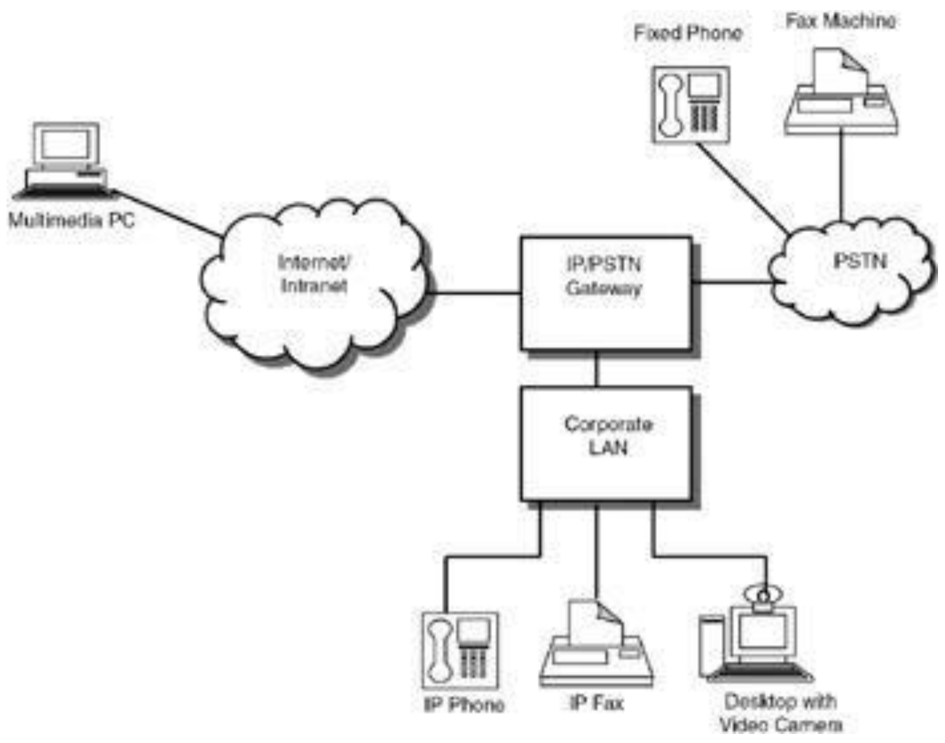

Fig:1.3:Multimedia Communication over IP Network

“Convergence” is the mantra nowadays. For years we used different networks for different services. Telephone network (PSTN) for making voice call and sending fax messages. Internet for data rate services such as email, file transfer and web services. WAN act as the backbone network supporting the data, voice and video communication services

Telecommunication

Telecommunication infrastructure element includes networking components such as Telephone switches, Loop carriers, terminal adapters, ATM switches, frame relays and so on. Mobile communication components includes base station, Mobile switching centers and so on. Satellite communication equipment includes earth station controller, onboard processing elements, telemetry and so on

Audio codec

Normally when voice is transmitted over the telephone network the voice is coded at the rate of 64kbps using a technique known as PCM. In radio system speech is compressed to save the bandwidth. At the transmitting side the audio signal are compressed to achieve data rates and at the receiving end the audio signal is expanded to retrieve the original Signal. These codecs use DSP extensively and gets embedded into cell phones and equipment of mobile and fixed communication systems. MP3 player is a good example, where are the signals are encoded and transmitted from a music kiosk to be played on the MP3 device

Automatic speech generation system

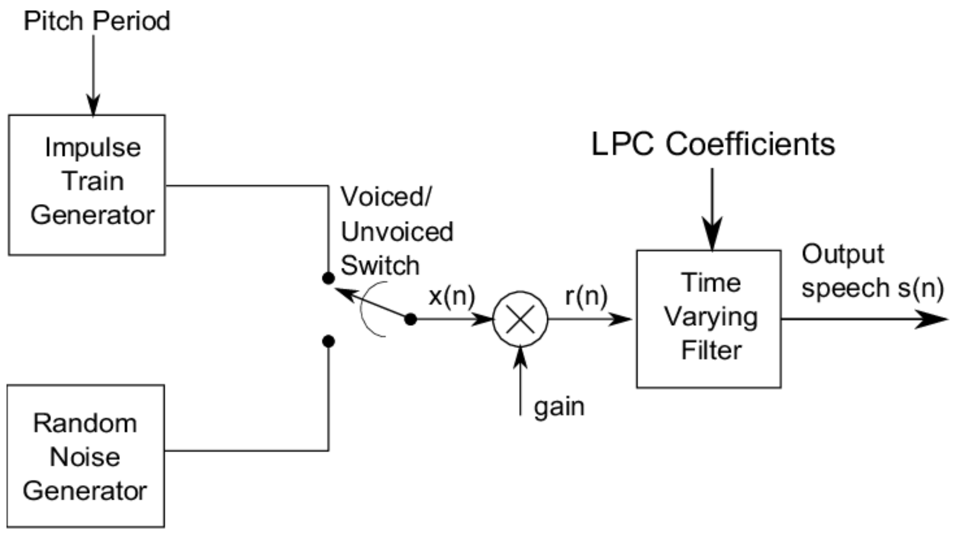

Fig:1.4: Human speech model

Video codec

Video conferencing has become very popular in recent years. Video occupies very large bandwidth however and to transmit video over the internet, video signals must be compressed to reduce the data Standards such as MPEG and JPEG are used to achieve video compression. To compress the video signal a video coder is used and to bring to the original signal a decoder is used. These embedded systems use DSP to implement video compression Algorithm

IVR System

It is a stand alone embedded system connected to the computer through a parallel port or USB port or it can be implemented on a PC with an add on card. IVR system is an embedded system connected to the computer holding the bank database. IVR system also has a telephone interface and it is connected in parallel to a telephone line. Once the bank assigns a specific number to the IVR system any subscriber can call this number to get the information about his/her bank account details. IVR system comprises of PSTN interface, ADC and DAC, S to P and P to S Convertors and an interface circuitry with microphone and speaker PSTN interface receives the telephone calls and answers them. Filters limit the audio signal to the desired frequency band up to 4khz. ADC converts input to digital format and digitized voice data is converted to parallel format using S to P convertor and vice versa. FIFO are buffers that temporarily holds the speech data. An IC MT8880 is used. Using this technology coupled with speech recognition and speech synthesis we can develop applications to browse the web through voice commands

GPS System

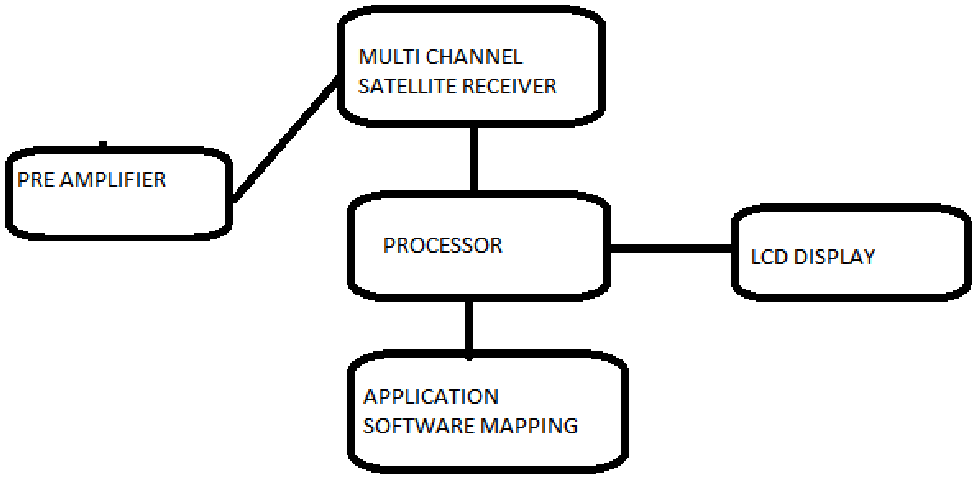
MULTI CHANNEL SATELLITE RECEIVER
PRE AMPLIFIER
PROCESSOR
LCD DISPLAY
APPLICATION SOFTWARE MAPPING

Fig:1.5:Block Diagram of GPS Receiver

It is a gift from the U.S from DOD to the humankind. Using a set of 24 NAVSTAR satellites, the DOD provides the GPS service for any moving or fixed object. A GPS receiver receives the satellite signals and process them to find the position parameters of the GPS receiver location. GPS receiver is a powerful embedded system that uses a DSP to process the satellite signals. GPS receiver computes its latitude, longitude, altitude, velocity and so on. It has an RS 232 serial communication interface or a USB interface from which the position data is available.

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Model Question Bank

Part-A

1. What is an embedded system? What are the components of embedded system?
2. What are the applications of an embedded system?
3. What are the main components of an embedded system?
4. What are the various classifications of embedded systems?
5. List the important considerations when selecting a processor
6. List the characteristics of an embedded system.
7. What is hard real time system
8. What is turnaround tim
9. What is general purpose system
10. What are the challenges of embedded system?

Part-B

1. Explain about significance of embedded system and classification of the embedded systems
2. Explain the characteristics of embedded systems
3. Explain about hard real time system and soft real time system with an example
4. Explain the major application areas of embedded systems
5. Explain in detail about the function of IVR system with necessary block diagram
6. Write about the Architecture Design of GPS System by refining the system into hardware and software components.

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UNIT –II- EMBEDDED SOFTWARE DEVELOPMENT AND TOOLS
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II EMBEDDED SOFTWARE DEVELOPMENT AND TOOLS

Software architectures, Round - Robin, Round-Robin with Interrupts, Function Queue Scheduling architecture, Introduction to assembler - Compiler -Cross compilers and Integrated Development Environment IDE, Linker/ Locators, Simulators, Getting Embedded software into target System- Debugging Strategies

A system that must respond rapid1y to many different events and that has various processing requirements, all with different deadlines and different priorities, will require a more complex architecture. We will discuss four architectures, starting with the simplest one, which others you practically no control of your response and priorities, and moving on to others that give you greater control but at the cost of increased complexity. The four are round-robin, round-robin with interrupts, function-queue-scheduling, and real-time operating system

Round-Robin Architecture

The simplest possible software architecture is called "round robin." Round robin architecture has no interrupts; the software organization consists of one main loop wherein the processor simply polls each attached device in turn, and provides service if any is required. After all devices have been serviced, start over from the top. One can think of many examples where round robin is a perfectly capable architecture: A vending machine, ATM, or household appliance such as a microwave oven (check for a button push, decrement timer, update display and start over). Basically, anything where the processor has plenty of time to get around the loop, and the user won't notice the delay. The main advantage to round robin is that it's very simple, and often it's good enough. On the other hand, If a device has to be serviced in less time than it takes the processor to get around the loop, then it won't work. The worst case response time for round robin is the sum of the execution times for all of the task code

- Very simple
- No interrupts
- No shared data „
- No latency concerns

Main loop: „ checks each I/O device in turn „ services any device requests „ E.g.:
Digital Multimeter

Round-Robin Architecture

```
        Void main( void)
{
        while(TRUE)
        {
        if (!! I/O Device A needs service)
```

```
                {
                !!Take care of I/O Device A
                !! Handle data to or from I/O Device A
                }
                if (!! I/O Device B needs service)
                {
          !!Take care of I/O Device B
          !! Handle data to or from I/O Device B
etc. etc. }
          if (!! I/O Device Z needs service)
          {
             !!Take care of I/O Device Z
             !! Handle data to or from I/O Device Z
             }
             }
             }
```

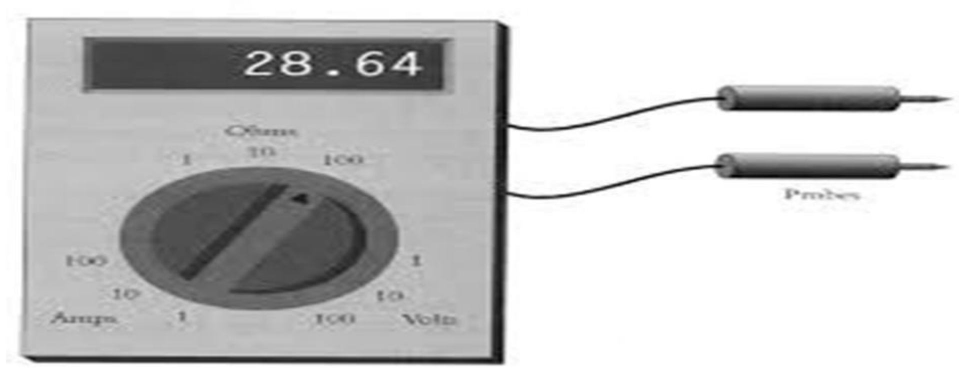


Fig:2.1: Digital Multimeter

This is a marvelously simple architecture-no interrupts, no shared data, no latency concerns—and therefore always an attractive potential architecture, as long as you can get away with it. Simple as it is, the round-robin architecture is adequate fot some jobs. Consider, for example, a digital multimeter such as the one shown in Figure. A digital multimeter measures electrical resistance, current, and potential in units of ohms, amps, and volts, each in several different ranges. A typical multimeter has two probes that the user touches to two points on the circuit to be measured, a digital display, and a big rotary switch that selects which measurement to make and in what range. The system makes continuous measurements and changes the display to reflect the most recent measurement. Each time around its loop, it checks the position of the rotary switch and then branches to code to make the appropriate measurement, to format its results, and to write the results to the display. Even a very modest microprocessor can go around this loop many times each second.

Code for Digital Multimeter

```
Void v Digital Multimeter Main( void)
                {
                  enum{OHMS_1, OHMS_10,…..VOLTS_100} eswitchPosition;
                  while(TRUE)
                  {
                   eswitchPosition = !! Read the position of the switch;
                  switch(eswitch position)
                          {
                           case OHMS_1;
                          !!Read hardware to measure ohms
                          !! Format result
                          break;
                           }
                case OHMS_10;
                          !!Read hardware to measure ohms
                          !! Format result break;
                           .
                           .
                           .
                case VOLTS_100;
                          !!Read hardware to measure volts
                          !! Format result break;
                  }
                  !!write result to display
                      }
                 }
```

- This architecture is fragile.
- Even if you manage tune it up so that the microprocessor gets around the loop quickly enough to satisfy all the requirements
- A single additional device or requirement may break everything
- Because of these shortcomings, a round robin architecture is probably suitable only for very simple devices such as digital watches and microwave ovens

Round-Robin with Interrupt Architecture

This is somewhat more sophisticated architecture, which we will call as round robin with interrupts. In this architecture interrupt routines deal with very urgent needs of the hardware and then set flags. The main loop polls the flags and does not follow up processing required by the interrupts. This interrupt gives a little more control over priorities. The interrupt routines can get good response because the hardware interrupt signal causes the microprocessor to stop whatever it is doing in the main function and execute the interrupt routine instead.

Effectively, all of the processing that you put into the interrupt routines has a higher priority than the task code in the main routine. Further, since you can usually assign priorities to the various interrupts in your system.

In this, urgent tasks get handled in an interrupt service routine, possibly with a flag set for follow-up processing in the main loop. If nothing urgent happens (emergency stop button pushed, or intruder detected), then the processor continues to operate round robin, managing more mundane tasks in order around the loop. The obvious advantage to round robin with interrupts is that the response time to high-priority tasks is improved, since the ISR always has priority over the main loop (the main loop will always stop whatever it's doing to service the interrupt), and yet it remains fairly simple. The worst case response time for a low priority task is the sum of the execution times for all of the code in the main loop plus all of the interrupt service routines.

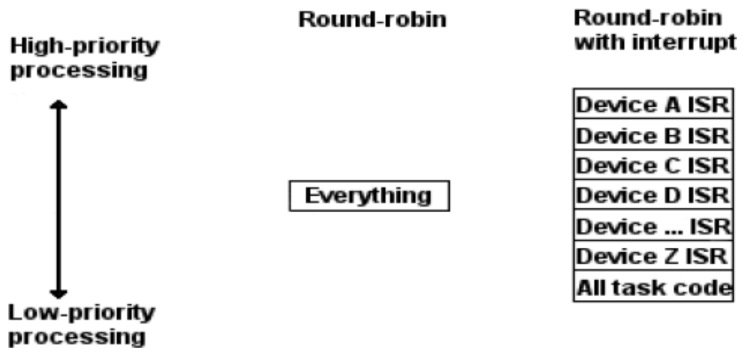


Fig:2.2: Priority levels for Round robin Architecture

It offers more control over priorities via hardware interrupts . Interrupt handlers implement higher priority functions (allowing the assignment of levels of priority among devices/handlers). The handlers set flags, which are polled by the task code to continue when the handlers complete their job

- Advantage: Setting and controlling using priorities
- Disadvantage: Danger of having shared data Priorities set in hardware
- Round robin with interrupt –A simple communication bridge

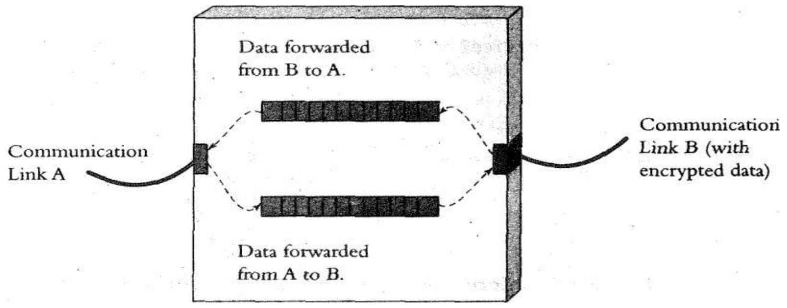

Data forwarded from B to A.
Communication Link A
Communication Link B (with encrypted data)
Data forwarded from A to B.

Fig:2.3:Communications Bridge

Whenever a character is received on one of the communication link, it causes an interrupt and that interrupt must be serviced quickly. Because the microprocessor must read character out of the I/O hardware before the next character arrives. Microprocessor must write characters to the

I/O hardware one at a time. There is no hardware deadline by which the microprocessor must write the next character to the hardware unit. The encryption and decryption routine can encrypt and decrypt characters one at a time

Round-Robin-with-Interrupts Example: The Cordless Bar- Code Scanner

Similarly, the round robin-with-interrupts architecture would work well for the cordless bar-code scanner. Although more complicated than the simple bridge the bar-code scanner is essentially a device that gets the data from the laser that reads the bar codes and sends that data out on the radio. In this system, as in the bridge, the only real response requirements are to service the hardware quickly enough. The task code processing will get done quickly enough in a round-robin loop.

Characteristics of the Round-Robin-with-Interrupts

Architecture The primary shortcoming of the round-robin-with-interrupts architecture (other than that it is not as simple as the plain round-robin architecture) is that all of the task code executes at the same priority. Suppose that the parts of the that deal with devices A, B, and C take 200 milliseconds each. If devices A, B, and C all interrupt when the microprocessor is executing the statements at the top of the loop, then the task code for device C may have to wait for 400 milliseconds before it starts to execute.

If this is not acceptable, one solution is to move the task code for device C into the interrupt routine for device C. Putting code into interrupt routines is the only way to get it to execute at a higher priority in this architecture. This, however, will make the interrupt routine for device C take 200 milliseconds more than before, which increases the response times for the interrupt routines for lower-priority devices D, E, and F by 200 milliseconds, which may also be unacceptable.

Alternatively, you could have your main loop test the flags for the devices in a sequent e something like this: A, C, B, C, D, C, E, C, ... , testing the flag more frequently. This will improve the response for the task code for device C ... at the expense the task code for every other device

Function scheduling architecture

Function queue scheduling provides a method of assigning priorities to interrupts. In this architecture, interrupt service routines accomplish urgent processing from interrupting devices, but then put a pointer to a handler function on a queue for follow-up processing. The main loop simply checks the function queue, and if it’s not empty, calls the first function on the queue. Priorities are assigned by the order of the function in the queue – there’s no reason that functions have to be placed in the queue in the order in which the interrupt occurred. They may just as easily be placed in the queue in priority order: high priority functions at the top of the queue, and low priority functions at the bottom. The worst case timing for the highest priority function is the execution time of the longest function in the queue (think of the case of the processor just starting to execute the longest function right before an interrupt places a high priority task at the front of the queue). The worst case timing for the lowest priority task is infinite: it may never get executed if higher priority code is always being inserted at the front of the queue. The advantage to function queue scheduling is that priorities can be assigned to tasks; the disadvantages are that it’s more complicated than the other architectures discussed previously, and it may be subject to shared data problems

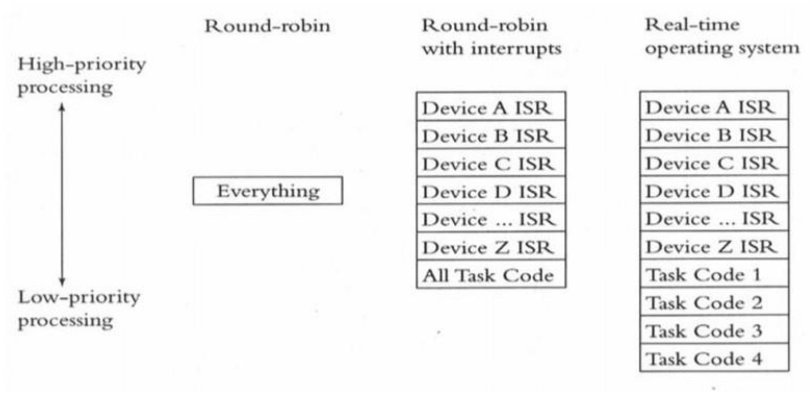


Fig:2.4:Comparison of priority level

Embedded software Development Tools

- Compiler
- Cross-compiler
- Linker
- Loader
- Locators
- Simulator and
- IDE

Compiler

A compiler is a special program that processes statements written in a particular programming language and turns them into machine language or "code" that a computer's processor uses. The name "compiler" is primarily used for programs that translate source code from a high level programming language to a lower level language (e.g., assembly language, object code, or machine code) to create an executable program.

Cross-compiler

It is a type of compiler that can create executable code for different machines other than the machine it runs on. It includes a cross-compiler, one which runs on the host but produces code for the target processor. Cross-compiling doesn’t guarantee correct target code due to (e.g., differences in word sizes, instruction sizes, variable declarations, library functions)

Cross-Assemblers

Host uses cross-assembler to assemble code in target’s instruction syntax for the target. A cross assembler which can convert instructions into machine code for a computer other than that on which it is run.

Linker

A linker or link editor is a computer system program that takes one or more object files (generated by a compiler or an assembler) and combines them into a single executable file, library file, or another 'object' file. Linking is process of collecting and maintaining piece of code and data into a single file. Linker also link a particular module into system library. It takes object modules from assembler as input and forms an executable file as output for loader

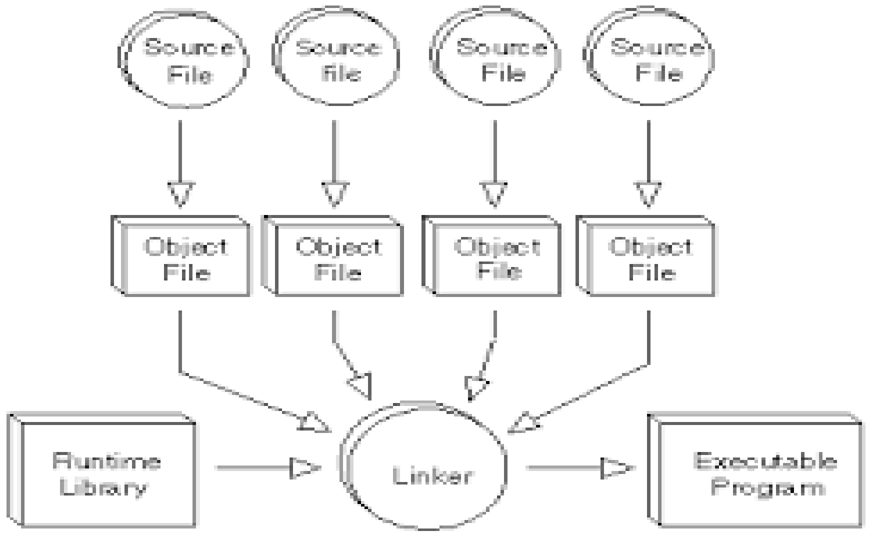


Fig:2.5:Linker Development tool

Loader and Locators:

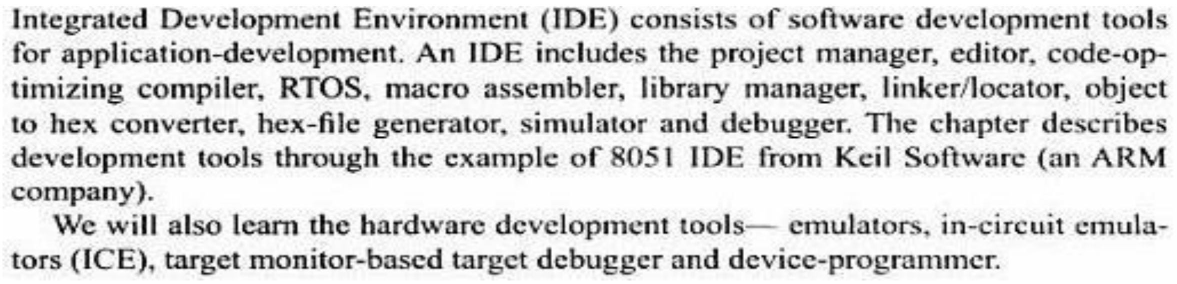
A loader is the part of an operating system that is responsible for loading programs and libraries. Once loading is complete, the operating system starts the program by passing control to the loaded program code. The locator will use this information to assign physical memory addresses to each of the code and data sections within the re locatable program. It will then produce an output file containing a binary memory image that can be loaded into the target ROM. In many cases, the locator is a separate development tool.

Simulator

It is, essentially, a program that allows the user to observe an operation through simulation without actually performing that operation. Simulation software is used widely to design equipment so that the final product will be as close to design specs as possible without expensive in process modification.

Applications of embedded system and development tools

Applications of Embedded system

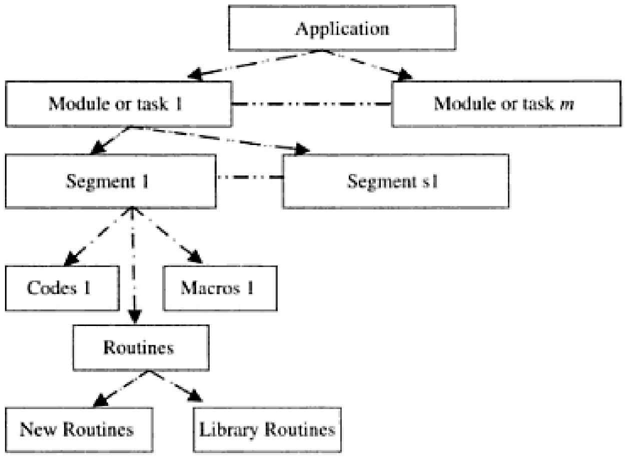


Integrated Development Environment (IDE) consists of software development tools for application-development. An IDE includes the project manager, editor, code-optimizing compiler, RTOS, macro assembler, library manager, linker/locator, object to hex converter, hex-file generator, simulator and debugger. The chapter describes development tools through the example of 8051 IDE from Keil Software (an ARM company).

We will also learn the hardware development tools— emulators, in-circuit emulators (ICE), target monitor-based target debugger and device-programmer.

Development phases of a microcontroller based system

Figure shows the contents of an application program. A module or task of an application is assumed to consist of several program segments. Each *segment* consists of the codes, macros and routines.



e Application Contents—Modules or Tasks, Segments, Codes, Macros, Routines (Functions) and Library Routines

A *macro* is a named entity. The entity corresponds to a set of codes within in a C function. Macro permits common sequence of codes to be developed only once and permits use of it as a software building block. A macro can be repeatedly used in different functions. The sequences of codes in the macros are given in the pre-processor statements. Within the functions, macro is used and the macros names are later replaced by the corresponding statements in preprocessor statements at the time of compilation.

Integrated Development Environment

An integrated development environment (IDE) is software for building applications that combines common developer tools into a single graphical user interface (GUI). An IDE, or Integrated Development Environment, enables programmers to consolidate the different aspects of writing a computer program. IDEs increase programmer productivity by combining common activities of writing software into a single application: editing source code, building executable, and debugging**.**

Getting Embedded Software into Target System

The locator will build a file as an image for the target software. There are few ways to getting the embedded software file into target system.

PROM programmers
ROM emulators
In circuit emulators
Flash
Monitors

PROM Programmers:

The classic way to get the software from the locator output file into target system by creating file in ROM or PROM. Creating ROM is appropriate when software development has been completed, since cost to build ROMs is quite high. Putting the program into PROM requires a device called PROM programmer device. PROM is appropriate if software is small enough, if you plan to make changes to the software and debug. To do this, place PROM in socket on the Target than being soldered directly in the circuit (the following figure shows). When we find bug, you can remove the PROM containing the software with the bug from target and put it into the eraser (if it is an erasable PROM) or into the waste basket. Otherwise program a new PROM with software which is bug fixed and free, and put that PROM in the socket. We need small tool called chip puller (inexpensive) to remove PROM from the socket. We can insert the PROM into socket without any tool than thumb (see figure8). If PROM programmer and the locator are from different vendors, its upto us to make them compatible.

Moving maps into ROM or PROM, is to create a ROM using hardware tools or a PROM programmer (for small and changeable software, during debugging). If PROM programmer is used (for changing or debugging software), place PROM in a socket (which makes it erasable – for EPROM, or removable/replaceable) rather than 'burnt' into circuitry. PROM's can be pushed into sockets by hand, and pulled using a chip puller. The PROM programmer must be compatible with the format (syntax/semantics) of the Map

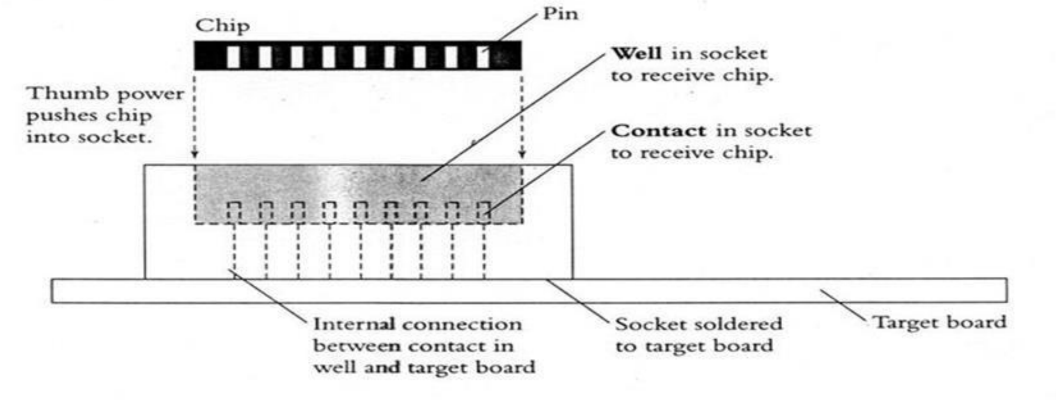

Chip
Pin
Well in socket to receive chip.
Thumb power pushes chip into socket.
Contact in socket to receive chip.
Internal connection between contact in well and target board
Socket soldered to target board
Target board

Fig: 2.5 : Schematic edge view of a socket

Getting Embedded Software into Target System – 1

ROM Emulators – Another approach is using a ROM emulator (hardware) which emulates the target system, has all the ROM circuitry, and a serial or network interface to the host system. It is used to get software into target. ROM emulator is a device that replaces the ROM into target system. It just looks like ROM, as shown figure9; ROM emulator consists of large box of electronics and a serial port or a network connection through which it can be connected to your host. Software running on your host can send files created by the locator to the ROM emulator. Ensure the ROM emulator understands the file format which the locator creates. The locator loads the Map into the emulator, especially, for debugging purposes. Software on the host that loads the Map file into the emulator must understand (be compatible with) the Map's syntax/semantics

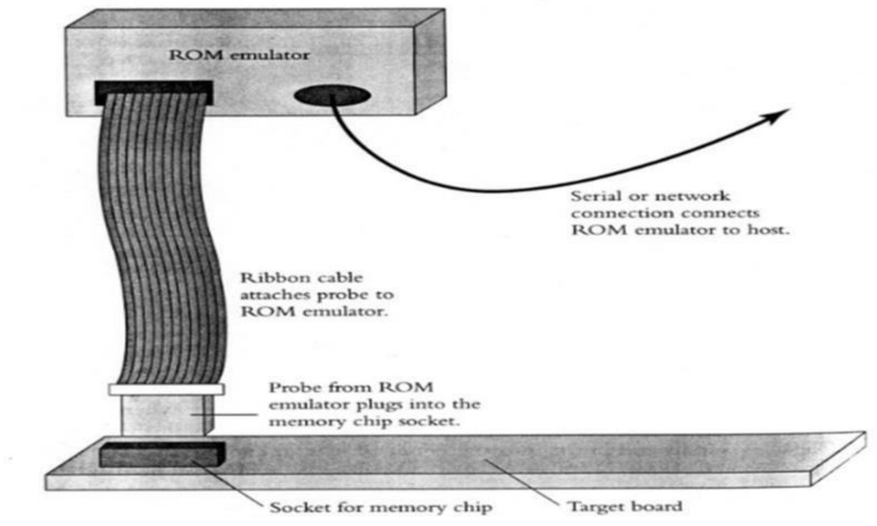

ROM emulator
Serial or network connection connects ROM emulator to host.
Ribbon cable attaches probe to ROM emulator.
Probe from ROM emulator plugs into the memory chip socket.
Socket for memory chip
Target board

Fig: 2.6: ROM Emulator

In circuit emulators: If we want to debug the software, then we can use overlay memory which is a common feature of in-circuit emulators. In-circuit emulator is a mechanism to get software into target for debugging purposes. Flash: If your target stores its program in flash memory, then one option you always have is to place flash memory in socket and treat it like an EPROM .However, If target has a serial port, a network connection, or some other mechanism for communicating with the outside world, link then target can communicate with outside world, flash memories open up another possibility: you can write a piece of software to receive new programs from your host across the communication link and write them into the flash memory. Although this may seem like difficult

The reasons for new programs from host:

• You can load new software into your system for debugging, without pulling chip out of socket and replacing.

• Downloading new software is fast process than taking out of socket, programming and returning into the socket.

• If customers want to load new versions of the software onto your product. The following are some issues with this approach:

• Here microprocessor cannot fetch the instructions from flash.

• The flash programming software must copy itself into the RAM, locator has to take care all these activities how those flash memory instructions are executing.

• We must arrange a foolproof way for the system to get flash programming software into the target i.e target system must be able to download properly even if earlier download crashes in the middle.

• To modify the flash programming software, we need to do this in RAM and then copy to flash.

Monitors: It is a program that resides in target ROM and knows how to load new programs onto the system. A typical monitor allows you to send the data across a serial port, stores the software in the target RAM, and then runs it. Sometimes monitors will act as locator also, offers few debugging services like setting break points, display memory

and register values. You can write your own monitor program
Getting Embedded Software into Target System – 2.

Using Flash Memory

For debugging, a flash memory can be loaded with target Map code using a software on the host over a serial port or network connection (just like using an EPROM)

Advantages:

- No need to pull the flash (unlike PROM) for debugging different embedded code
- Transferring code into flash (over a network) is faster and hassle-free

DEBUGGING TECHNIQUES

Testing on host machine
Using laboratory tools
An example system

Introduction: While developing the embedded system software, the developer will develop the code with the lots of bugs in it. The testing and quality assurance process may reduce the number of bugs by some factor. But only the way to ship the product with fewer bugs is to write software with few fewer bugs. The world extremely intolerant of buggy embedded systems. The testing and debugging will play a very important role in embedded system software development process.

Testing on host machine :

Goals of Testing process are
Find bugs early in the development process
Exercise all of the code
Develop repeatable , reusable tests
Leave an audit trail of test results

Find the bugs early in the development process: This saves time and money. Early testing gives an idea of how many bugs you have and then how much trouble you are in. But the target system is available early in the process, or the hardware may be buggy and unstable, because hardware engineers are still working on it.

Exercise all of the code: Exercise all exceptional cases, even though, we hope that they will never happen, exercise them and get experience how it works. It is impossible to exercise all the code in the target. For example, a laser printer may have code to deal with the situation that arise when the user presses the one of the buttons just as a paper jams, but in the real time to test this case. We have to make paper to jam and then press the button within a millisecond, this is not very easy to do. Develop reusable, repeatable tests: It is frustrating to see the bug once but not able to find it. To make refuse to happen again, we need to repeatable tests. It is difficult to create repeatable tests at target environment. Example: In bar code scanner, while scanning it will show the pervious scan results every time, the bug will be difficult to find and fix.

TEXT / REFERENCE BOOKS

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2. **David Simon, "An Embedded Software Primer", Pearson Education Asia, First Indian Reprint 2000.**
3. **Raj Kamal, 'Embedded system-Architecture, Programming, Design', Tata McGraw Hill, 2011.**
4. **Arnold Berger, "Embedded system design", CMP books, 1st Edition, 2005**
5. **Wayne Wolf, "Computers as components", Morgan Kaufmann publishers, 2nd Edition, 2008.**
6. **Tammy Noergaard, "Embedded Systems Architecture", Elsevier, 2006**

Model Question Bank

Part-A

1. Define device driver.
2. How the software is embedded on to the system?
3. Explain the need for software in embedded systems
4. What are the programming languages used in embedded systems?
5. Define ISR.
6. Compare simulator and emulator.
7. Compare linker and locators.
8. Define interrupt latency.
9. What is the use of the debugger?

PART-B

1. Explain following concepts with example program.
   a) Round robin Architecture
   b) Round robin with interrupts
2. Explain following concepts with example

a) Function queue scheduling architectures
b) Compiler and cross compiler

3. Real Time operating systems (RTOS)
4. Explain the concept of selection of architecture for saving the memory space.
5. Compare the software architectures of embedded systems.
6. What are the advantages & disadvantages of software architectures?
7. Explain the Interrupt service routines (ISRs). What are the advantages of ISR?

III EMBEDDED NETWORKING

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT –III- EMBEDDED NETWORKING SECA1603

III EMBEDDED NETWORKING

Embedded Networking: Introduction, I/O Device Ports - Serial Bus communication protocols- RS232 standard- RS485 - CAN Bus - RS485 - Serial Peripheral Interface (SPI) - Inter-Integrated Circuits (I2C) - PC Parallel port communication Protocols - Bluetooth- network using ISA, PCI- Wireless and Mobile System Protocols.

IO port types- Serial and parallel IO ports

A port is a device to receive the bytes from external peripheral(s) [or device(s) or processor(s) or controllers] for reading them later using instructions executed on the processor to send the bytes to external peripheral or device or processor using instructions executed on processor. A Port connects to the processor using address decoder and system buses. The processor uses the addresses of the port-registers for programming the port functions or modes, reading port status and for writing or reading bytes.

Example

- SI serial interface in 8051
- SPI serial peripheral interface in 68HC11
- PPI parallel peripheral interface 8255
- Ports P0, P1, P2 and P3 in 8051 or PA, PB,PC and PD in 68HC11
  - COM1 and COM2 ports in an IBM PC IO Port Types

Types of Serial ports

- Synchronous Serial Input
- Synchronous Serial Output
- Asynchronous Serial UART input
- Asynchronous Serial UART output (both as input and as output, for example,modem.)
- Types of parallel ports
- Parallel port one bit Input
- Parallel one bit output
- Parallel Port multi-bit Input
- Parallel Port multi-bit

Output Synchronous Serial Input Example

Inter-processor data transfer, reading from CD or hard disk, audio input, video input, dial tone, network input, transceiver input, scanner input, remote controller input, serial I/O bus input, writing to flash memory using SDIO (Secure Data Association IO based card).

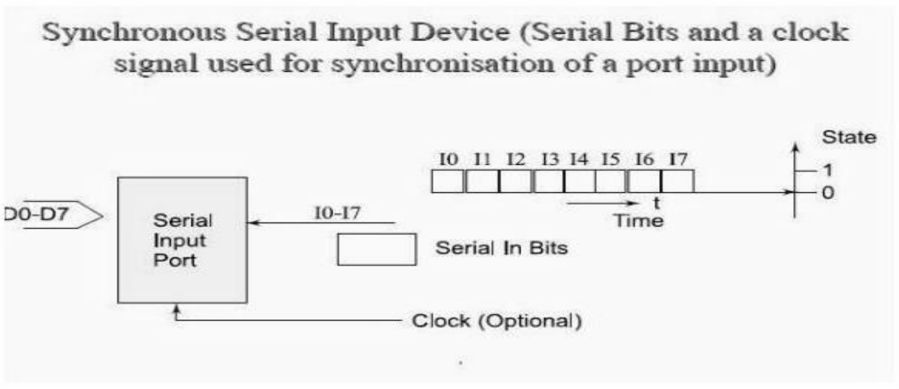

Synchronous Serial Input Device (Serial Bits and a clock signal used for synchronisation of a port input)
D0-D7
Serial Input Port
I0-I7
I0 I1 I2 I3 I4 I5 I6 I7
State
1
0
t
Time
Serial In Bits
Clock (Optional)

Fig:3.1: Synchronous Serial Input

The sender along with the serial bits also sends the clock pulses SCLK (serial clock) to the receiver port pin. The port synchronizes the serial data input bits with clock bits. Each bit in each byte as well as each byte in synchronization Synchronization means separation by a constant interval or phase difference.

If clock period = T, then each byte at the port is received at input in period = 8T. The bytes are received at constant rates. Each byte at input port separates by 8T and data transfer rate or the serial line bits is (1/T) bps. [1bps = 1 bit per s] Serial data and clock pulse-inputs On same input line − when clock pulses either encode or modulate serial data input bits suitably. Receiver detects the clock pulses and receives data bits after decoding or demodulating. On separate input line − When a separate SCLK input is sent, the receiver detects at the middle or+ ve edge or –ve edge of the clock pulses that whether the data-input is 1 or 0 and saves the bits in an 8-bit shift register. The processing element at the port (peripheral) saves the byte at a port register from where the microprocessor reads the byte.

Master output slave input (MOSI) and Master input slave output (MISO)

MOSI when the SCLK is sent from the sender to the receiver and slave is forced to synchronize sent inputs from the master as per the inputs from master clock.
MISO when the SCLK is sent to the sender (slave)from the receiver (master) and slave is forced to synchronize for sending the inputs to master as per the master clock outputs.
Synchronous serial input is used for inter processor transfers, audio inputs and streaming data inputs.

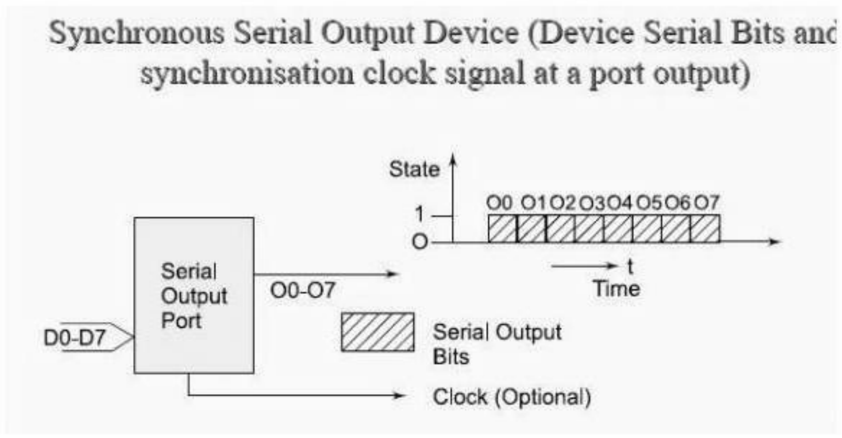

Synchronous Serial Output Device (Device Serial Bits and synchronisation clock signal at a port output)
State
1
0
O0 O1 O2 O3 O4 O5 O6 O7
t
Time
Serial Output Port
O0-O7
D0-D7
Serial Output Bits
Clock (Optional)

Fig:3.2: Synchronous Serial Output

Inter-processor data transfer, multiprocessor communication, writing to CD or hard disk, audio Input/output, video Input/output,dialer output, network device output, remote TV Control, transceiver output, and serial I/O bus output or writing to flash memory using SDIO

Synchronous Serial Output

Each bit in each byte sent in synchronization with a clock. Bytes sent at constant rates. If clock period= T, then data transfer rate is (1/T) bps.

- Sender either sends the clock pulses at SCLK pin or sends the serial data output and clock
- pulse-input through same output line with clock pulses either suitably modulate or encode the serial output bits.

Synchronous serial output using shift register

The processing element at the port (peripheral) sends the byte through a shift register at the port to where the microprocessor writes the byte. Synchronous serial output is used for inter processor transfers, audio outputs and streaming data outputs.

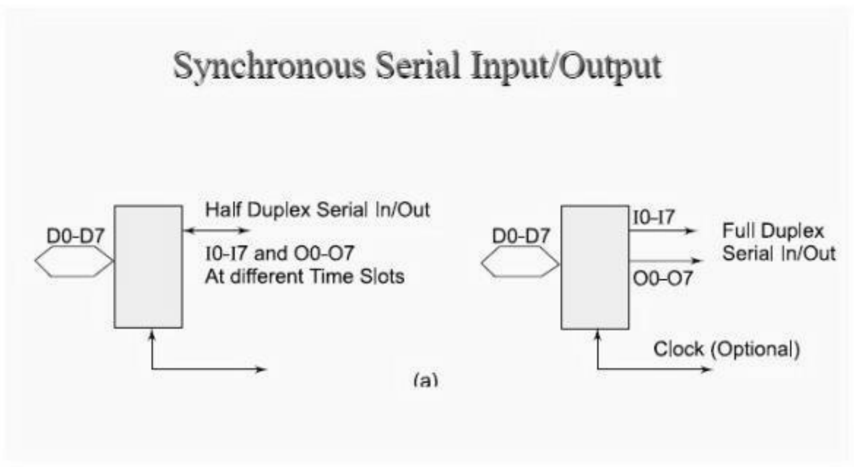


Fig:3.3: Synchronous Serial Input/output

Each bit in each byte is in synchronization at input and each bit in each byte is in synchronization at output with the master clock output. The bytes are sent or received at constant rates. The I/Os can also be on same I/O line when input/output clock pulses either suitably modulate or encode the serial input/output, respectively. If clock period= T, then data transfer rate is (1/T)bps. The processing element at the port (peripheral)sends and receives the byte at a port register to or from where the microprocessor writes or reads the byte

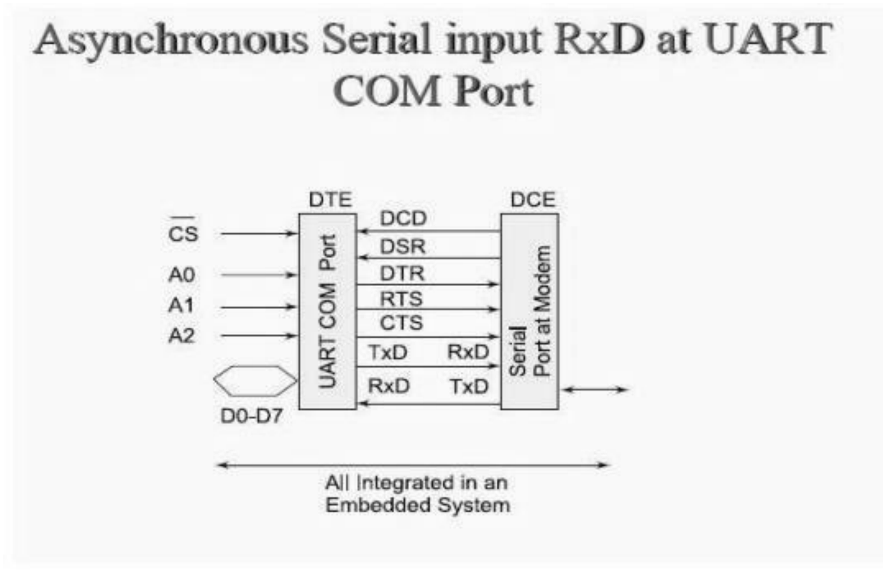

Asynchronous Serial input RxD at UART COM Port
DTE
DCE
CS
A0
A1
A2
D0-D7
UART COM Port
DCD
DSR
DTR
RTS
CTS
TxD
RxD
RxD
TxD
Serial Port at Modem
All Integrated in an Embedded System

Fig:3.4: Asynchronous Serial port line

Asynchronous Serial port line RxD (receive data). Does not receive the clock pulses or clock information along with the bits.

Each bit is received in each byte at fixed intervals but each received byte is not in synchronization. Bytes separate by the variable intervals or phase differences. Asynchronous serial input also called UART input if serial input is according to UART protocol.

Example Serial Asynchronous Input

Asynchronous serial input is used for keypad inputs and modem inputs in computers Keypad controller serial data-in, mice, keyboard controller, modem input, character send inputs on serial line [also called UART (universal receiver and transmitter) input when according to UART mode
Starting point of receiving the bits for each byte is indicated by a line transition from 1to 0 for a period = T. [T−1 called baud rate.
If senders shift-clock period = T, then a byte at the port is received at input in period=
10.T or 11.T due to use of additional bits at start and end of each byte. Receiver detects n bits at the intervals of T from the middle of the start indicating bit. The n = 0, 1, …, 10 or 11 and finds whether the data-input is 1 or 0 and saves the bits in an 8-bit shift register.
Processing element at the port (peripheral)saves the byte at a port register from where the microprocessor reads the byte.

Asynchronous Serial Output
Asynchronous output serial port line TxD(transmit data).

Each bit in each byte transmit at fixed intervals but each output byte is not in synchronization (separates by a variable interval or phase difference). Minimum separation is 1 stop bit interval TxD. Does not send the clock pulses along with the bits. Sender transmits the bytes at the minimum intervals of n.T. Bits receiving starts from the middle of the start indicating bit, n = 0, 1, …, 10 or 11 and sender sends the bits through a 10 or 11 -bit shift register. The processing element at the port(peripheral) sends the byte at a port register to where the microprocessor is to write the byte.
Synchronous serial output is also called UART output if serial output is according to UART protocol
Example Serial Asynchronous Output. Output from modem, output for printer, the output on a serial line [also called UART output when according to UART
Parallel Data Communication Half Duplex

- Half duplex means as follows: at an instant communication can only be one way (input or output) on a bi-directional line.
- An example of half-duplex mode─ telephone communication. On one telephone line, the talk can only in the half duplex way mode.

Full Duplex

- Full duplex means that at an instant,the communication can be both ways.

An example of the full duplexasynchronous mode of communicationis the communication between themodem and the computer though TxDand RxD lines or communication using
SI in modes 1, 2 and 3 in 8051

Parallel Port single bit input

- Completion of a revolution of a wheel,
- Achievingpreset pressure in a boiler,
- Exceeding the upper limit of permittedweight over the pan of an electronicbalance,
- Presence of a magnetic piece in the vicinityof or within reach of a robot arm to its endpoint and Filling of a liquid up to a fixed level.

Parallel Port Output- single bit

- PWM output for a DAC, which controlsliquid level, or temperature, or pressure, orspeed or angular position of a rotating shaftor a linear displacement of an object or ad.c. motor control
- Pulses to an external circuit
- Control signal to an external circuit

Parallel Port Input- multi-bit

- ADC input from liquid level measuringsensor or temperature sensor or pressuresensor or speed sensor or d.c. motor rpmsensor

Parallel Port Output- multi-bit

- LCD controller for Multilane LCD displaymatrix unit in a cellular phone to display onthe screen the phone number, time,messages, character outputs or pictogrambit-images for display screen or e-mail orweb page
- Print controller output
- Stepper-motor coil driving bits

Parallel Port Input-Output

- PPI 8255
- Touch screen in mobile phone

Ports or DevicesCommunication and communicationprotocols

Two Modes of communication between the devices and computer system

Full Duplex – Both devices or device and computer system simultaneously communicate each other.

Half Duplex – Only one device can communicate with another at an instance

Three ways of communication betweenthe ports or devices

1. Synchronous
2. Iso-synchronous
3. Asynchronous

1. Synchronous and Iso-synchronous Communication in Serial Ports or Devices **Synchronous Communication.**

When a byte (character) or a frame (acollection of bytes) in of the data isreceived or transmitted at the constanttime intervals with uniform phasedifferences, the communication iscalled as ***synchronous***. Bits of a fullframe are sent in a prefixed maximumtime interval.

Iso-synchronous

Synchronous communication special case−when bits of a full frame are sent in themaximum time interval, which can bevariable.

Synchronous Communication

Clock information is transmittedexplicitly or implicitly insynchronous communication. Thereceiver clock continuously maintainsconstant phase difference with thetransmitter clock. Bits of a data framemaintain uniform phase differenceand are sent within a fixed maximumtime interval.

Example of synchronous serial communication

- Frames sent over a LAN. Frames of data communicate with the constant time intervals between each frame remaining constant.
- Another example is the inter-processor communication in a multiprocessor system Optional Synchronous Code bits
- Optional Sync Code bits or bi-sync code bits orframe start and end signaling bits─ Duringcommunication few bits (each separated byinterval ΔT) sent as Sync code to enable the framesynchronization or frame start signaling.
- Code bits precede the data bits.
- May be inversion of code bits after each frame incertain protocols.
- Flag bits at start and end are also used in certainprotocols. Always present Synchronous device portdata bits

- Reciprocal of T is the bit per second(bps).
- Data bits─ *m* frame bits or 8 bitstransmit such that each bit is at the linefor time ΔT or, each frame is at the linefor time (*m*. T)*m* may be 8 or a large number. Itdepends on the protocolSynchronous device clock bits
- Clock bits ─ Either on a separate clockline or on data line such that the clockinformation is also embedded with thedata bits by an appropriate encoding ormodulation
- Generally not optional

Two characteristics of asynchronouscommunication

1. Bytes (or frames) need not maintain a constantphase difference and are asynchronous, i.e., notin synchronization. There is permission to sendeither bytes or frames at variable timeintervals— This*facilitates in-betweenhandshaking* between the serial transmitter portand serial receiver port

2. Though the *clock* must ticking at a certain ratealways has to be there to transmit the bits of asingle byte (or frame) serially, it is *alwaysimplicit* to the asynchronous data receiver and isindependent of the transmitter

Clock Features

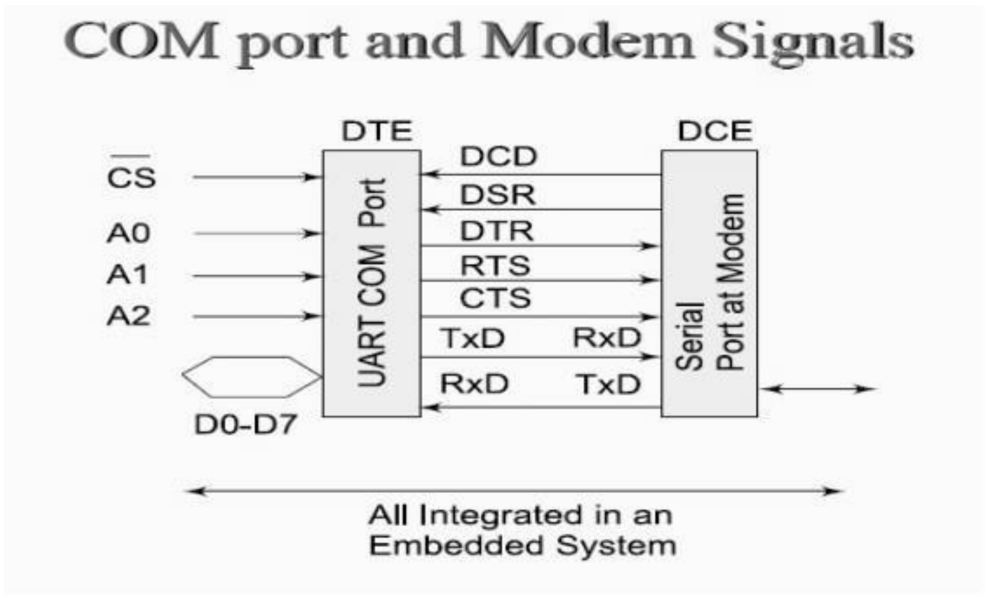
_ The transmitter *does not transmit* (neitherseparately nor by encoding using modulation)along with the serial stream of bits any *clockrate information* in the asynchronouscommunication and *receiver clock thus is notable to maintain identical frequency andconstant phase difference* with transmitter clock

Example: IBM personal computer has two COMports (communication ports)

- _ COM1 and COM2 at IO addresses 0x2F8-0xFFand 0xx38-0x3FF
- _ Handshaking signals— RI, DCD, DSR, DTR,RTS, CTS, DTR
- _ Data Bits— RxD and TxDExample: COM port and Modem Handshakingsignals
- _ When a modem connects, modem sends*data carrier detect* DCD signal at aninstance t0.
- _ Communicates *data set ready* (DSR)signal at an instance t1 when it receives thebytes on the line.
- _ Receiving computer (terminal) responds atan instance t2 by data terminal ready(DTR) signal.

After DTR, *request to send* (RTS) signal is sent at aninstance t3

- _ Receiving end responds by *clear to send* (CTS) signalat an instance t4. After the response CTS, the data bitsare transmitted by modem from an instance t5 to thereceiver terminal.
- _ Between two sets of bytes sent in asynchronous mode,the handshaking signals RTS and CTS can again beexchanged. This explains why the bytes do not remainsynchronized during asynchronous transmission.



3. Communication Protocols

1. Protocol

A protocol is a standard adopted,which tells the way in which the bits ofa frame must be sent from a device (orcontroller or port or processor) toanother device or system

[Even in personal communication wefollow a protocol – we say Hello! Thentalk and then say good bye!]

A protocol defines how are the framebits:

1) sent− synchronously or Isosynchronouslyor asynchronously and at what rate(s)?
2) preceded by the header bits?How the receiving device addresscommunicated so that only destineddevice activates and receives the bits?
   [Needed when several devicesaddressed though a common line(bus)]

3) How can the transmitting deviceaddress defined so that receivingdevice comes to know the sourcewhen receiving data from severalsources?
4) How the frame-length defined so thatreceiving device know the frame-sizein advance?
5) Frame-content specifications –Arethe sent frame bits specify the controlor device configuring or commend ordata?
6) Are there succeeding to frame thetrailing bits so that receiving devicecan check the errors, if any inreception before it detects end of theframe ?

A protocol may also define:

7) Frame bits minimum and maximumlength permitted per frame

8) Line supply and impedances andline-Connectors specifications

Specified protocol at an embedded systemport or communication deviceIO port bits sent after first formattedaccording to a specified protocol, whichis to be followed when communicatingwith another device through an IO portor channel

Protocols

- _ HDLC, Frame Relay, for synchronouscommunication
- _ For asynchronous transmission from a deviceport– RS232C, UART, X.25, ATM, DSL and

ADSL

- _ For networking the physical devices intelecommunication and computer networks –

Ethernet and token ring protocols used in LANNetworks

Protocols in embedded network devices

  - _ For Bridges and routers
  - _ Internet appliances application protocolsand Web protocols —HTTP (hyper texttransfer protocol), HTTPS (hyper texttransfer protocol Secure Socket Layer),SMTP (Simple Mail Transfer Protocol),POP3 (Post office Protocol version 3),ESMTP (Extended SMTP),

File transfer, Boot Protocols in embedded devicesnetwork

  - _ TELNET (Tele network),
  - _ FTP (file transfer protocol),
  - _ DNS (domain network server),
  - _ IMAP 4 (Internet Message ExchangeApplication Protocol) and
  - _ Bootp (Bootstrap protocol).Wireless Protocols in embedded devices network
  - _ Embedded wireless appliances useswireless protocols— WLAN 802.11,802.16, Bluetooth, ZigBee, WiFi, WiMax,

Serial Data Communication

Data Communication is one of the most challenging fields today as far as technology development is concerned. Data, essentially meaning information coded in digital form, that is, 0s and 1s, is needed to be sent from one point to the other either directly or through a network. And when many such systems need to share the same information or different information through the same medium, there arises a need for proper organization (rather, “socialization”) of the whole network of the systems, so that the whole system works in a cohesive fashion. Therefore, in order for a proper interaction between the data transmitter (the device needing to commence data communication) and the data receiver (the system which has to receive the data sent by a transmitter) there has to be some set of rules or (“protocols”) which all the interested parties must obey. The requirement above finally paves the way for some data communication standards.

Depending on the requirement of applications, one has to choose the type of communication strategy. There are basically two major classifications, namely SERIAL and PARALLEL, each with its variants.

Serial data communication strategies and, standards are used in situations having a limitation of the number of lines that can be spared for communication. This is the primary mode of transfer in long-distance communication. But it is also the situation in embedded systems where various subsystems share the communication channel and the speed is not a very critical issue. Standards incorporate both the software and hardware aspects of the system while buses mainly define the cable characteristics for the same communication type. Serial data communication is the most common low-level protocol for communicating between two or more devices. Normally, one device is a computer, while the other device can be a modem, a printer, another computer, or a scientific instrument such as an oscilloscope or a function generator. As the name suggests, the serial port sends and receives bytes of information, rather characters (used in the other modes of communication), in a serial fashion - one bit at a time. These bytes are transmitted using either a binary (numerical) format or a text format.

The most common serial communication system protocols can be studied under the following categories: Asynchronous, Synchronous and Bit-Synchronous communication standards

RS-232

This is the original serial port interface “standard” and it stands for “Recommended Standard Number 232” or more appropriately EIA Recommended Standard 232 is the oldest and the most popular serial communication standard. It was first introduced in 1962 to help ensure connectivity and compatibility across manufacturers for simple serial data communications.

Applications

Peripheral connectivity for PCs (the PC COM port hardware), which can range beyond modems and printers to many different handheld devices and modern scientific instruments.

All the various characteristics and definitions pertaining to this standard can be summarized according to the following

The maximum bit transfer rate capability and cable length. • Communication Technique: names, electrical characteristics and functions of signals. • The mechanical connections and pin assignments.

The Standard

Maximum Bit Transfer Rate, Signal Voltages and Cable Length

- RS-232‟s capabilities range from the original slow data rate of up to 20 kbps to over 1Mbps for some of the modern applications.
- RS-232 is mainly intended for short cable runs, or local data transfers in a range up to 50 feet maximum, but it must be mentioned here that it also depends on the Baud Rate
  It is a robust interface with speeds to 115,200 baud, and
- It can withstand a short circuit between any 2 pins.
- It can handle signal voltages as high / low as ±15 volts.

Signal States and the Communication Technique Signals can be in either an active state or an inactive state. RS232 is an Active LOW voltage driven interface where:

ACTIVE STATE: An active state corresponds to the binary value 1. An active signal state can also be indicated as logic “1”, “on”, “true”, or a “mark”.

INACTIVE STATE: An inactive signal state is stated as logic “0”, “off”, “false”, or a “space”.

• For data signals, the “true” state occurs when the received signal voltage is more negative than -3 volts, while the "false" state occurs for voltages more positive than 3 volts.

• For control signals, the "true" state occurs when the received signal voltage is more positive than 3 volts, while the "false" state occurs for voltages more negative than -3 volts.

Transition or “Dead Area”

Signal voltage region in the range >-3.0V and < +3.0V is regarded as the 'dead area' and allows for absorption of noise. This same region is considered a transition region, and the signal state is undefined.

To bring the signal to the "true" state, the controlling device un asserts (or lowers) the value for data pins and asserts (or raises) the value for control pins. Conversely, to bring the signal to the "false" state, the controlling device asserts the value for data pins and unasserts the value for control pins. The "true" and "false" states for a data signal and for a control signal are as shown below.

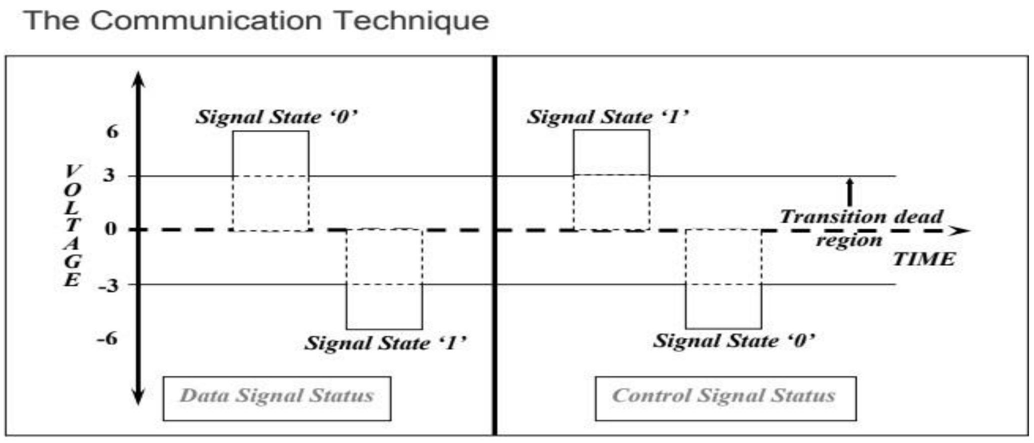


Fig:3.5: Graphical representation of communication technique

A factor that limits the distance of reliable data transfer using RS-232 is the signaling technique that it uses.

This interface is "single-ended" meaning that communication occurs over a SINGLE WIRE referenced to GROUND, the ground wire serving as a second wire. Over that single wire, marks and spaces are created. • While this is very adequate for slower applications, it is not suitable for faster and longer applications.

The communication technique

RS-232 is designed for a unidirectional half-duplex communications mode. That simply means that a transmitter (driver) is feeding the data to a receiver over a copper line. The data always follows the direction from driver to receiver over that line. If return transmission is desired, another set of driver- receiver pair and separate wires are needed. In other words, if bi-directional or full-duplex capabilities are needed, two separate communications paths are required.

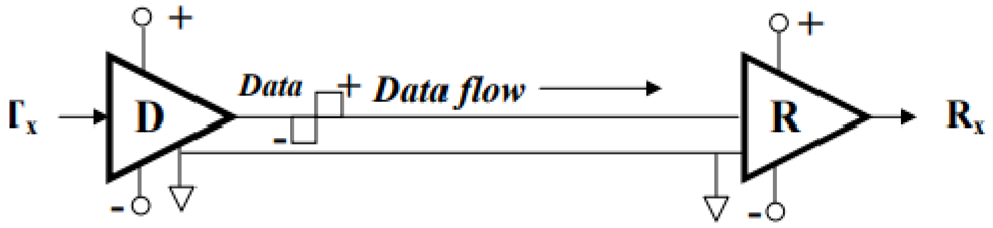


Fig:3.7: Single ended, Unidirectional, Half Duplex

Disadvantages

Being a single-ended system it is more susceptible to induced noise, ground loops and ground shifts, a ground at one end not the same potential as at the other end of the cable
e.g. in applications under the proximity of heavy electrical installations and machineries **Some**

Modern Perspectives/Advantages

Most applications for RS-232 today are for data connectivity between portable handheld devices and a PC. Some of the differences between the modern RS-232 integrals from the older versions are:

- Such devices require that the RS-232 IC to be very small, have low current drain, operate from a +3 to +5-V supply.
- They provide ESD protection on all transmit and receive pins. For example, some RS232 interfaces have specifically been designed for handheld devices and support data rates greater than 250 kbps, can operate down to +2.7 V.
- They can automatically go into a standby mode drawing very small currents of the order of only 150 nA when not in use, provide 15 kV ESD protection on data pins and are in the near- chip-scale 5 X 5 mm quad flat no-lead package. Nevertheless, for portable and handheld applications the older RS-232 is still the most popular one.

RS-485

This is an improved RS-422 with the capability of connecting a number of devices (transceivers) on one serial bus to form a network.
The Standard Maximum Bit Transfer Rate, Signal Voltages and Cable Length
Such a network can have a "daisy chain" topology where each device is connected to two other devices except for the devices on the ends.
• Only one device may drive data onto the bus at a time. The standard does not specify the rules for deciding who transmits and when on such a network. That solely

depends upon the system designer to define.

• Variable data rates are available for this standards but the standard max. data rate is 10 Mbps, however ,some manufacturers do offer up to double the standard range i.e. around 20 Mbps,but of course, it is at the expense of cable width.

• It can connect upto 32 drivers and receivers in fully differential mode similar to the RS – 422.

Communication Technique

EIA Recommended Standard 485 is designed to provide bi-directional half-duplex multi- point data communications over a single two-wire bus.

- Like RS-232 and RS-422, full-duplex operation is possible using a four-wire, two-bus network but the RS-485 transceiver ICs must have separate transmit and receive pins to accomplish this.
- RS-485 has the same distance and data rate specifications as RS-422 and uses differential signaling but, unlike RS-422, allows multiple drivers on the same bus. As depicted in the Figure below, each node on the bus can include both a driver and receiver forming a multi- point star network. Each driver at each node remains in a disabled high impedance state until called upon to transmit. This is different than drivers made for RS422 where there is only one driver and it is always enabled and cannot be disabled.
- With automatic repeaters and tri-state drivers the 32-node limit can be greatly exceeded. In fact, the ANSI-based SCSI-2 and SCSI-3 bus specifications use RS-485 for the physical (hardware) layer.

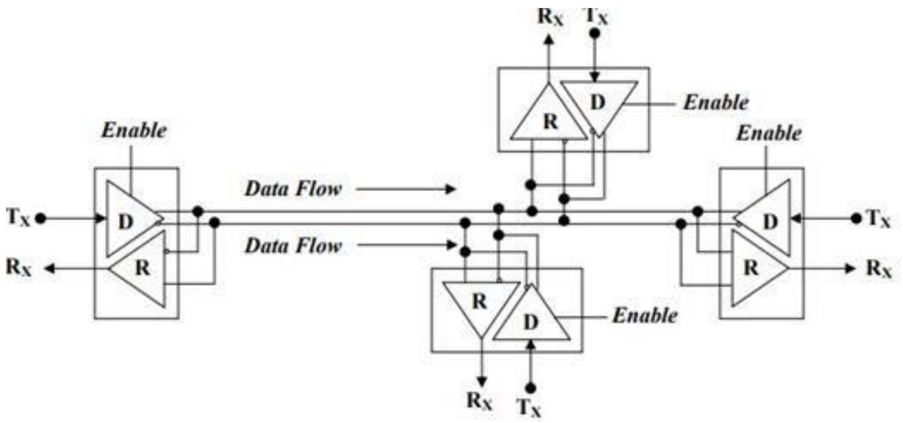


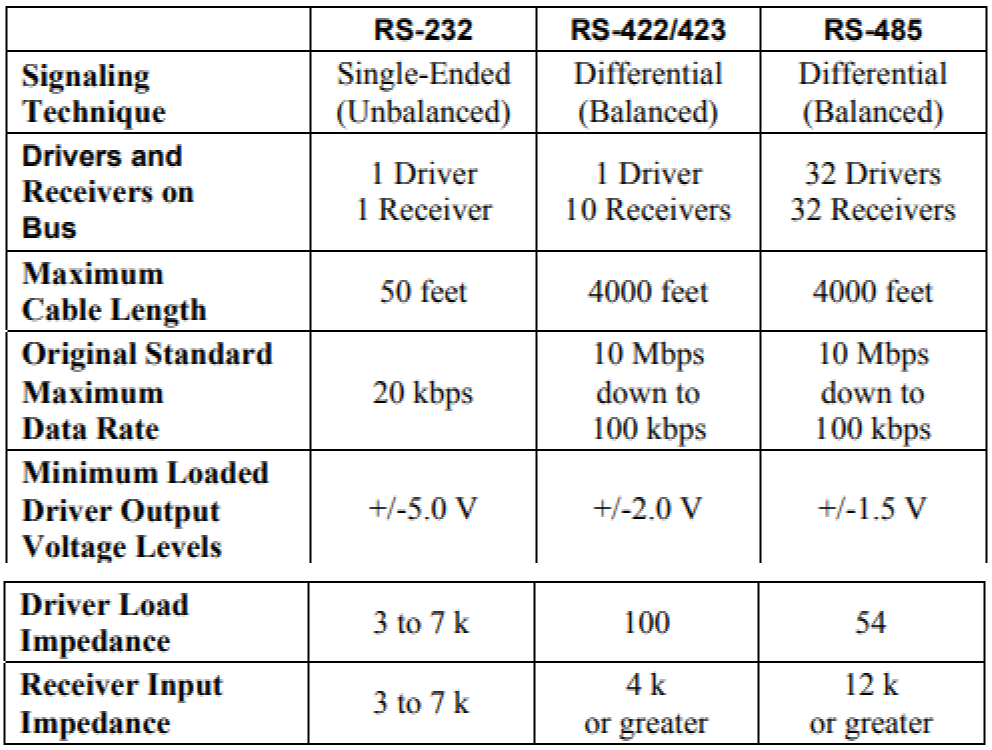
Fig:3.8:RS 485-Differential signaling, Bidirectional, Half duplex, Multipoint

Advantages

- Among all of the asynchronous standards mentioned above this standard offers the maximum data rate.
- Apart from that special hardware for avoiding bus contention and ,
- A higher receiver input impedance with lower Driver load impedances are its other assets.

Differences between the various standards at a glance

All together the important electrical and mechanical characteristics for application purposes may be classified and summarized according to the table below.



	RS-232	RS-422/423	RS-485
Signaling Technique	Single-Ended (Unbalanced)	Differential (Balanced)	Differential (Balanced)
Drivers and Receivers on Bus	1 Driver 1 Receiver	1 Driver 10 Receivers	32 Drivers 32 Receivers
Maximum Cable Length	50 feet	4000 feet	4000 feet
Original Standard Maximum Data Rate	20 kbps	10 Mbps down to 100 kbps	10 Mbps down to 100 kbps
Minimum Loaded Driver Output Voltage Levels	+/-5.0 V	+/-2.0 V	+/-1.5 V
Driver Load Impedance	3 to 7 k	100	54
Receiver Input Impedance	3 to 7 k	4 k or greater	12 k or greater

Data Communication buses

The role of networking in present-day data communication hardly needs any elaboration. The situation is also similar in the case of embedded systems, particularly those which are distributed over a larger geographical region – the so-called distributed embedded systems. Unfortunately, the most common network standard, namely the Ethernet, is not suitable for such distributed systems, especially when there are real- time constraints to be satisfied. This is due to the lack of any service time guarantee in the Ethernet standard. On the other hand, alternatives like Token Ring, which do provide a service-time guarantee, are not very suitable because of the requirement of a ring-type topology not very convenient to implement in the industrial environment. The industry therefore proposed a standard called „Token-bus‟ (and got it approved as the IEEE 802.5 specification) to cater to such requirements. However, the standard became too complex and inefficient as a result. Subsequently different manufacturers have come up with their own standards, which are being implemented in specific applications. In this lesson we learn about three such standards, namely

- I 2 C Bus
- Field Bus
- CAN Bus

CAN BUS

CAN was the solution developed by Robert Bosch GmbH, Germany in 1986 for the development of a communication system between three ECUs (electronic control units) in vehicles being designed by Mercedes. The UART, which had been in use for, long, had been rendered unsuitable in their situation because of its point-to-point communication methodology. The need for a multi-master communication system became a stringent requirement. Intel then fabricated the first CAN in 1987. Controller Area Network (CAN) is a very reliable and message-oriented serial network that was originally designed for the automotive industry, but has become a sought after bus in industrial automation as well as other applications. The CAN bus is primarily used in embedded systems, and is actually a network established among micro controllers. The main features are a two-wire, half duplex, high-speed network system mainly suited for high-speed applications using short messages. Its robustness, reliability and compatibility to the design issues in the semiconductor industry are some of the remarkable aspects of the CAN technology.

Main Features

1. CAN can link up to 2032 devices (assuming one node with one identifier) on a single network. But accounting to the practical limitations of the hardware (transceivers), it may only link up to110 nodes (with 82C250, Philips) on a single network. ‰
2. It offers high-speed communication rate up to 1 Mbits/sec thus facilitating real- time control. ‰
3. It embodies unique error confinement and the error detection features making it more trustworthy and adaptable to a noise critical environment.

CAN Versions

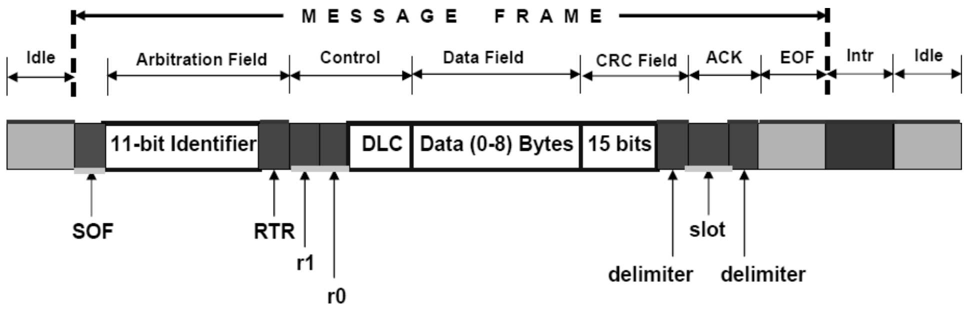
- Originally, Bosch provided the specifications. However the modern counterpart is designated as Version 2.0 of this specification, which is divided into two parts:
- Version 2.0A or Standard CAN; Using 11 bit identifiers.
- Version 2.0B or Extended CAN; Using 29 bit identifiers.

The main aspect of these Versions is the formats of the MESSAGE FRAME; the main difference being the IDENTIFIER LENGTH.
CAN Standards
There are two ISO standards for CAN. The two differ in their physical layer descriptions.

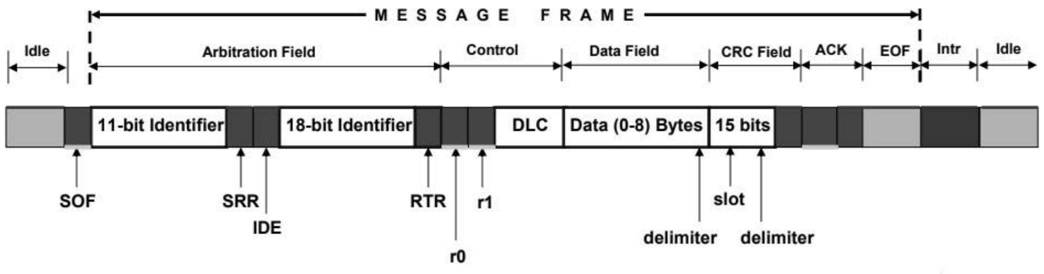
1. ISO 11898 handles high-speed applications up to 1Mbit/second.
2. ISO 11519 can go upto an upper limit of 125kbit/second. The Can Protocol/Message Formats

In a CAN system, data is transmitted and received using Message Frames.
Message Frames carry data from any transmitting node to single or multiple receiving nodes.
CAN protocol can support two Message Frame formats:

Version 2.0A - Standard CAN



Version 2.0B - Extended CAN



BASIC CAN Controller

The basic topology for the CAN Controller has been shown in figure 2 below. The basic controller involves FIFOs for message transfers and it has an enhanced counterpart in Full-CAN controller, which uses message BUFFERS instead.

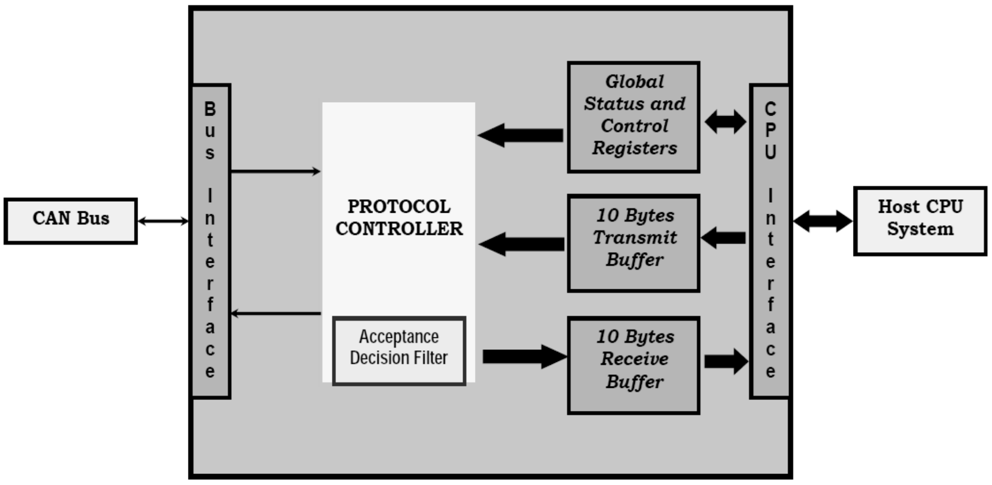


Fig:3.9: Basic CAN Controller

Distributed Control Area Network example - a network of embedded systems in automobile

CAN-bus line usually interconnects to a CAN controller between line and host at the node. It gives the input and gets output between the physical and data link layers at the host node.
The CAN controller has a BIU (bus interface unit consisting of buffer and driver), protocol controller, status-cum control registers, receiver-buffer and message objects. These units connect the host node through the host interface circuit

- Wireless and mobile system protocols Wireless Personal Area Network (WPAN)
- IrDA (Infrared Data Association) Bluetooth 2.4 GHz
- 802.11 WLAN and 802.11b WiFi ZigBee 900 MHz
- IrDA (Infrared Data Association)
- Used in mobile phones, digital cameras, keyboard, mouse, printers to communicate to laptop computer and for data and pictures download and synchronization.
- Used for control TV, air-conditioning, LCD projector, VCD devices from a distance
- Use infrared (IR) after suitable modulation of the data bits.
- Communicates over a line of sight Phototransistor receiver for infrared rays

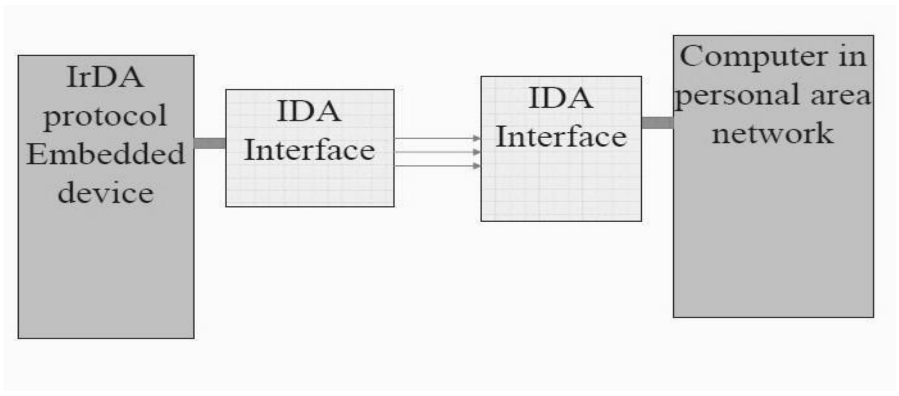

IrDA protocol Embedded device
IDA Interface
IDA Interface
Computer in personal area network

Fig:3.10: Block diagram of IrDA

IrDA protocol suite

- Supports data transfer rates of up to 4 Mbps
- Supports bi-directional serial communication over viewing angle between ± 15° and distance of nearly 1 m
- At 5 m, the IR transfer data can be up to data transfer rates of 75 kbps
- Should be no obstructions or wall in between the source and receiver

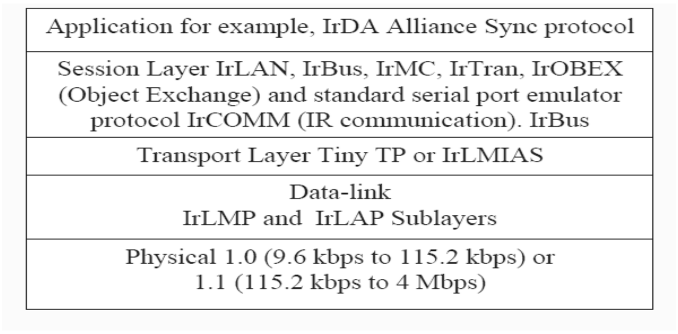
Five levels of communication

Level 1— minimum required communication.
Level 2 — access-based communication.
Level 3 —index-based communication.
Level 4 — sync communication. Synchronization software, for example, ActiveSync or HotSync is used.
Level 5 — SyncML (synchronization markup language) based communication. A SyncML protocol is used for device management and synchronization with server and client devices connected by IrDA.

IrDA Physical Layer

Lower layer— physical layer 1.0 or 1.1.
1.0— supports data transfer rates of 9.6 kbps to 115.2 kbps 1.1— 115.2 kbps to 4 Mbps

5 layers of IrDA



Application for example, IrDA Alliance Sync protocol
Session Layer IrLAN, IrBus, IrMC, IrTran, IrOBEX (Object Exchange) and standard serial port emulator protocol IrCOMM (IR communication). IrBus
Transport Layer Tiny TP or IrLMIAS
Data-link IrLMP and IrLAP Sublayers
Physical 1.0 (9.6 kbps to 115.2 kbps) or 1.1 (115.2 kbps to 4 Mbps)

Two sub-layers at IrDA data-link layer

- IrLMP (IR link management protocol) upper sub-layer
- IrLAP (IR link access protocol) lower sub-layer.
- IrLAP─ HDLC synchronous communication

IrDA upper layer protocols

- for Transport
- for Session
- for Application

IrDA Transport layer protocol During transmission specifies ways of flow control, segmentation of data and packetization.

- During reception, specifies assembling of the segments and packets.
- Tiny TP (transport protocol).
- IrLMIAS (IR Link Management Information Access Service Protocol).

IrDA Session Layer

- IrLAN
- IrBus
- IrMC
- IrTran
- IrOBEX (Object Exchange) and
- IrCOMM (IR communication) standard serial port emulator protocol
- IrBus to provide serial bus access to game ports, joysticks, mice and keyboard.

IrDA Application layer protocol

- Specifies security and application
- For example, IrDA Alliance Sync protocol used to synchronize mobile devices personal information manager (PIM) data─supports Object Push (PIM) or Binary File Transfer.

Windows and the several operating systems support

- Infrared Monitor in Windows monitors the IR port of the IR device.
- Detects a nearby IR source.
- Controls, detects and selects the IR communication activity.
- On command, the device sets up connection using IrDA.
- On command starts the IR communication.
- When IR communication is inactive, the Monitor enables plug and play (unless disabled).

Advantages:

- IrDA protocol overhead between 2% to 50% of Bluetooth device overhead. Communication setup latency is just few milliseconds.

Disadvantages:

Line of sight and unobstructed communication
ZigBee Wireless Personal Area connected devices

- IEEE standard 802.15.4 protocol.
- Physical layer radio operates 2.4 GHz band carrier frequencies with DSSS
- (direct sequence spread spectrum).
- Supports range up to 70 m.
- Data transfer rate supported 250 kbps.
- Supports sixteen channels.

ZigBee network feature
Self-organising and supports peer-to-peer and mesh networks. Self-organising means detects nearby Zigbee device and establishes communication and network.

Peer-to-peer and mesh network

- Each node at network function as requesting device as well as responding device.
- Mesh network means the each nodes network function as a mesh.
- A node can connect to another directly or through mutually interconnected intermediate nodes. Data transfer is between two devices in Peer-to-Peer or between a device

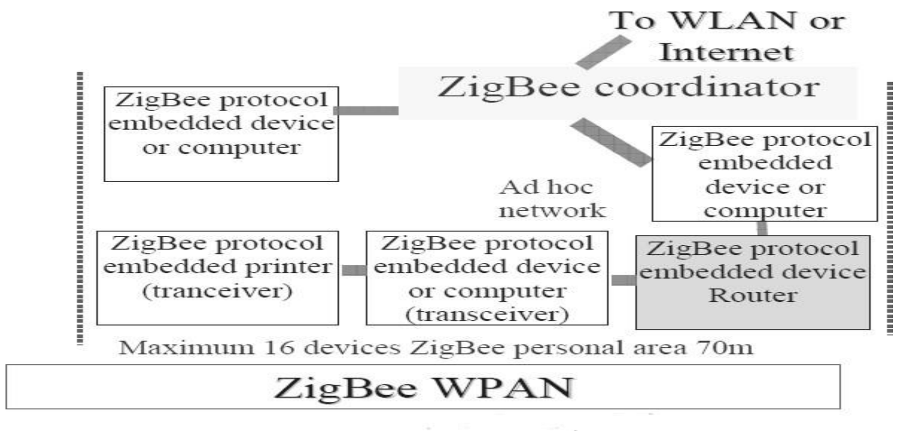

To WLAN or Internet
ZigBee coordinator
ZigBee protocol embedded device or computer
ZigBee protocol embedded device or computer
Ad hoc network
ZigBee protocol embedded printer (tranceiver)
ZigBee protocol embedded device or computer (transceiver)
ZigBee protocol embedded device Router
Maximum 16 devices ZigBee personal area 70m
ZigBee WPAN

Fig:3.11: ZigBee supporting devices

ZigBee protocol supports large number of sensors, lighting devices, air conditioning, industrial controller and other devices for home and office automation and their remote control and formation of WPAN (wireless personal area network).

ZigBee network

- Zigbee router - Transfers packets received from a neighboring source to nearby node in the path to destination.
- Zigbee coordinator - Connects one Zigbee network with another, or connects to WLAN or cellular network.
- Zigbee end devices – Transceiver of data

ZigBee features

- Communication latency 30 ms
- Protocol stack overhead 28 kB

802.11 Wireless LAN connected devices

- IEEE standards 802.11a to 802.11g
- 802.11a data transfer rates─ 1 Mbps and 2 Mbps
- 802.11b data transfer rates─ 5.5 Mbps and 2 Mbps
- FHSS or DSSS or Infrared 250 ns

802.11b

- Called wireless fidelity (WiFi)
- 802.11b support data rates of 5.5 Mbps by mapping 4 bits
- 11 Mbps mapping 8 bits simultaneously during modulation.

Basic service set (BSS)

- Has one wireless station, which communicates to an access point, also called hotspot.
- BSS support ad-hoc network, which as and when node come nearby in range of access point it forms the network through extended service set (ESS).
- A node free to move from one BSS to another.

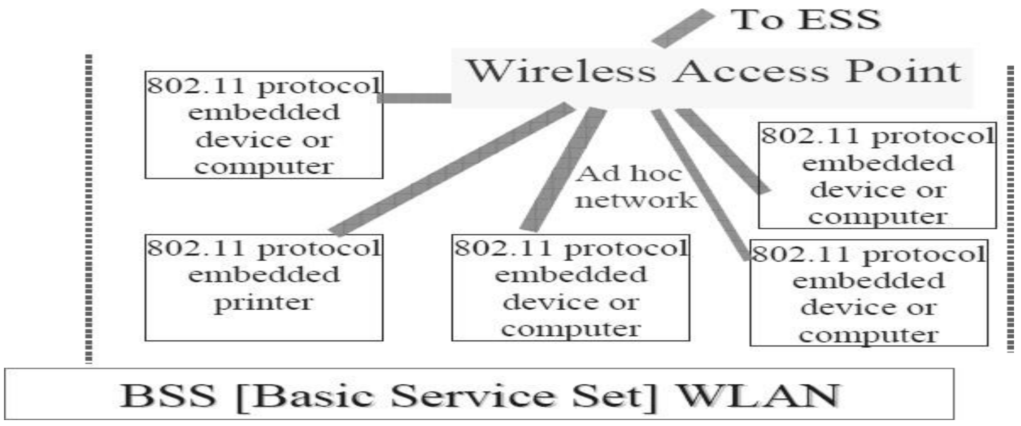

To ESS
Wireless Access Point
802.11 protocol embedded device or computer
Ad hoc network
802.11 protocol embedded device or computer
802.11 protocol embedded printer
802.11 protocol embedded device or computer
802.11 protocol embedded device or computer
BSS [Basic Service Set] WLAN

Fig:3.12: Basic service set

Independent basic service set (IBSS)

- No access point.
- Does not connect to the distribution system.
- May have multiple stations, which also cannot communicate among themselves.
- IBSS support ad-hoc network, which as and when nodes come nearby in range they form the network

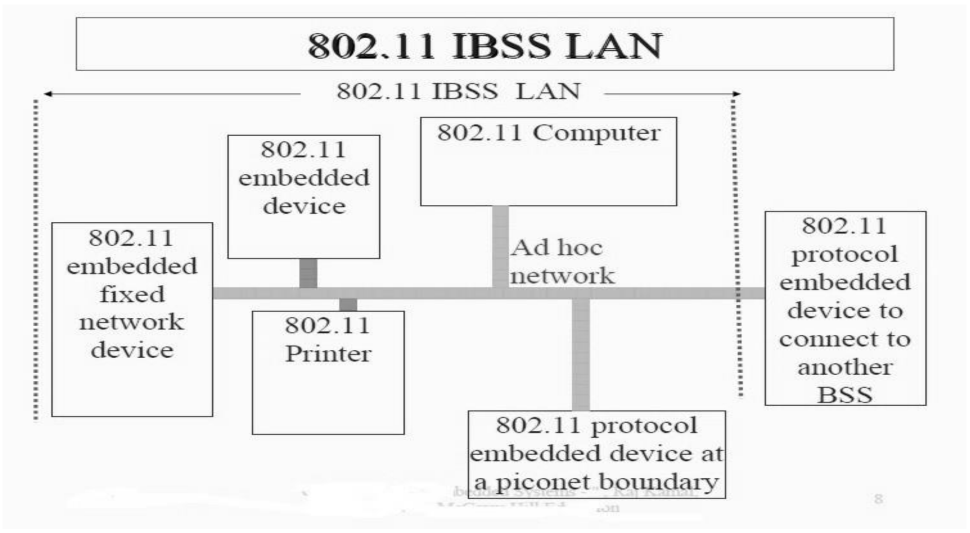

802.11 IBSS LAN
802.11 IBSS LAN
802.11 embedded device
802.11 Computer
Ad hoc network
802.11 embedded fixed network device
802.11 Printer
802.11 protocol embedded device to connect to another BSS
802.11 protocol embedded device at a piconet boundary

Fig:3.13: Independent basic service set

LAN-station access-points networked together

- Called extended service set (ESS)
- Backbone distribution system.
- A backbone set may network through Internet
- ESS support fixed infrastructure network

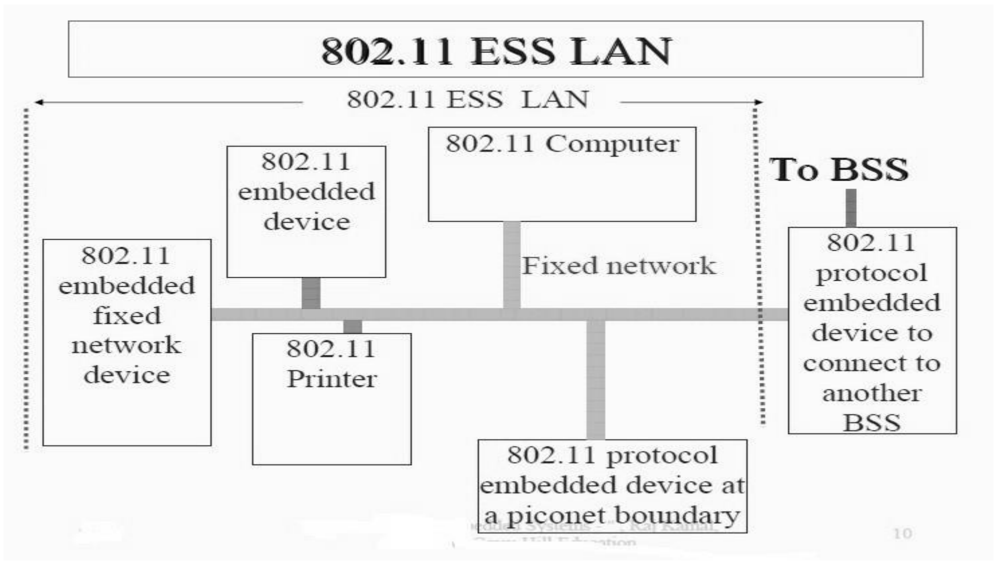

802.11 ESS LAN
802.11 ESS LAN
802.11 embedded device
802.11 Computer
To BSS
Fixed network
802.11 embedded fixed network device
802.11 Printer
802.11 protocol embedded device to connect to another BSS
802.11 protocol embedded device at a piconet boundary

Fig:3.14: Called extended service set

802.11 protocol data link layer

- Specifies a MAC layer
- MAC layer specifies power management, handover and registration of roaming mobile node within the backbone network at a new BSS within the ESS

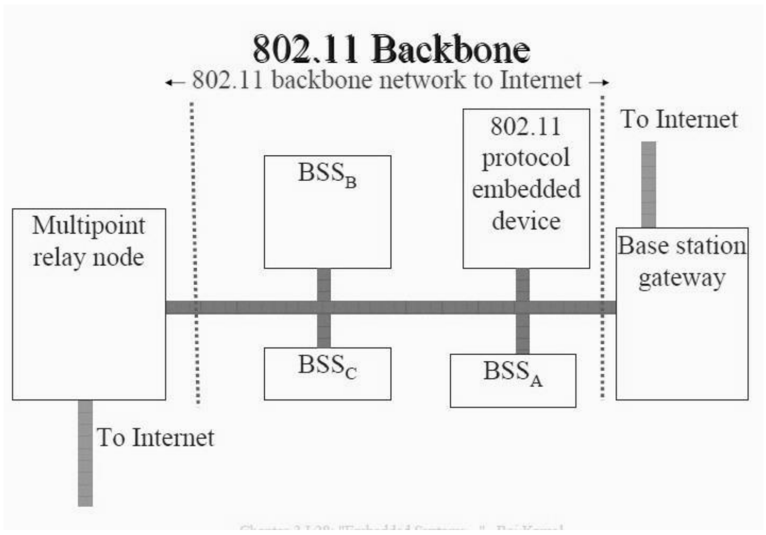


Fig:3.15: 802.11 physical and data link layers

802.11 packet for MAC

- Packet called request to send (RTS), which is first sent
- If other end responses by the packet called clear to send (CTS), then the layer data is transmitted.

MAC layer

- Uses carrier sense multiple access and collision avoidance (CSMA/CA) protocol.
- A station listens to the presence of carrier during a time interval is called distributed
- inter-frame spacing (DIFS) interval.
- If carrier is not sensed (detected) during DIFS then the station backs off for a random time interval to avoid collision and retries after that interval.

802.11 protocol MAC Acknowledgment

- A receiver always acknowledges within a short inter-frame spacing (SIFS)
- Acknowledgment after successful CRC (cyclic redundancy check)
- If there is no acknowledgement within SIFS, then transmitter retransmits and upto 7 retransmission attempts are made

802.11 Physical Layer communication methods

- Three─ FHSS or DSSS or Infrared 250 ns pulses.
- 802.11a Physical layer has two sublayers
- One is Physical Medium Dependent (PMD) protocol, Physical Layer Convergence Protocol (PLCP)
- 802.11b additional sub-layer for specifying Complementary Code Keying (CCK)

Physical Medium Dependent (PMD) protocol 802.11 sublayer - Specifies the modulation and coding methods.
Physical Layer Convergence Protocol (PLCP) 802.11 sub-layer - Specifies the header and payload for transmission. It specifies the sensing of the carrier at receiver. It specifies how packet formation takes place at the transmitter and packets assemble at the receiver. It specifies ways to converge MAC (Medium Access Control) to PMD at transmitter and separate MAC (Medium Access Control) from PMD at the receiver.
An additional sub-layer in 802.11b- Specifying Complementary Code Keying (CCK).

BLUETOOTH
Bluetooth enabled devices:

- Synchronizing music, image, PIM (personal information manager) files with Computer using Serial emulator at Bluetooth device
- Large number of CD players mobile devices are Bluetooth Digital camera
- Bluetooth enabled ear buds─ Hands free listening of Bluetooth enabled iPod or CD music player or mobile phone.

Bluetooth - serial COM port interface

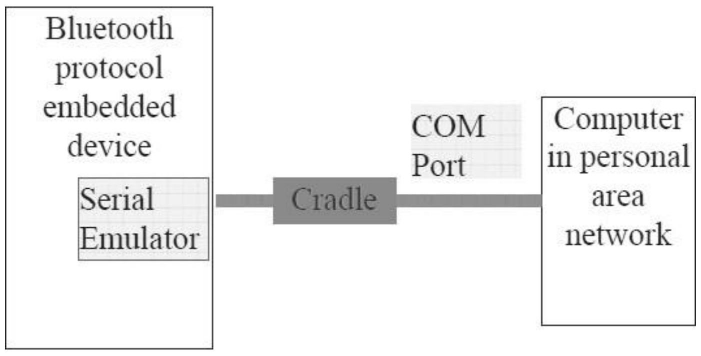

Bluetooth protocol embedded device
Serial Emulator
Cradle
COM Port
Computer in personal area network

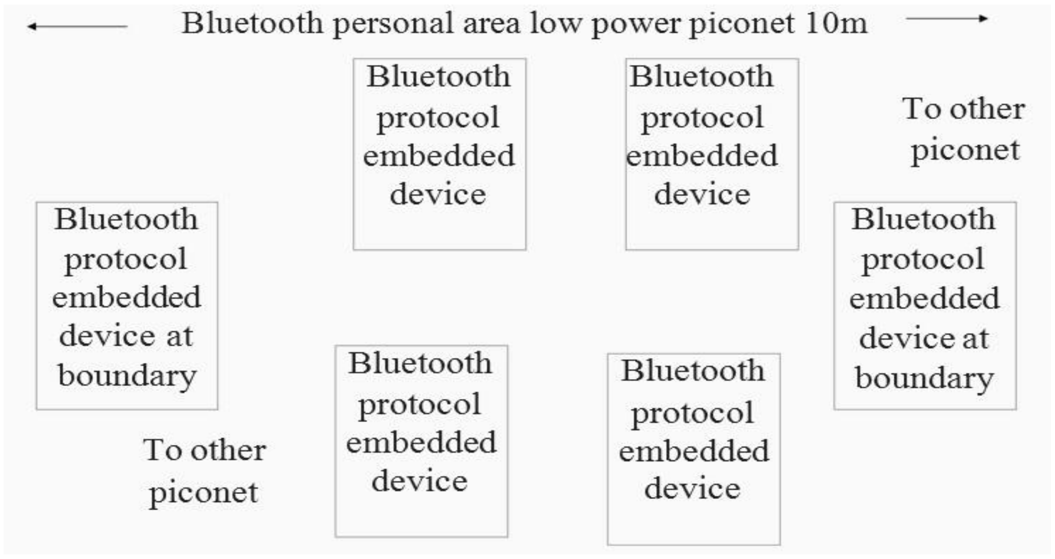
Fig:3.16: Bluetooth wireless protocol

WPAN using Bluetooth wireless protocol

- Software embeds in the system to support WPAN using Bluetooth wireless protocol
- Bluetooth devices─ piconet within 10m
- Bluetooth devices─ scatternet within 100m

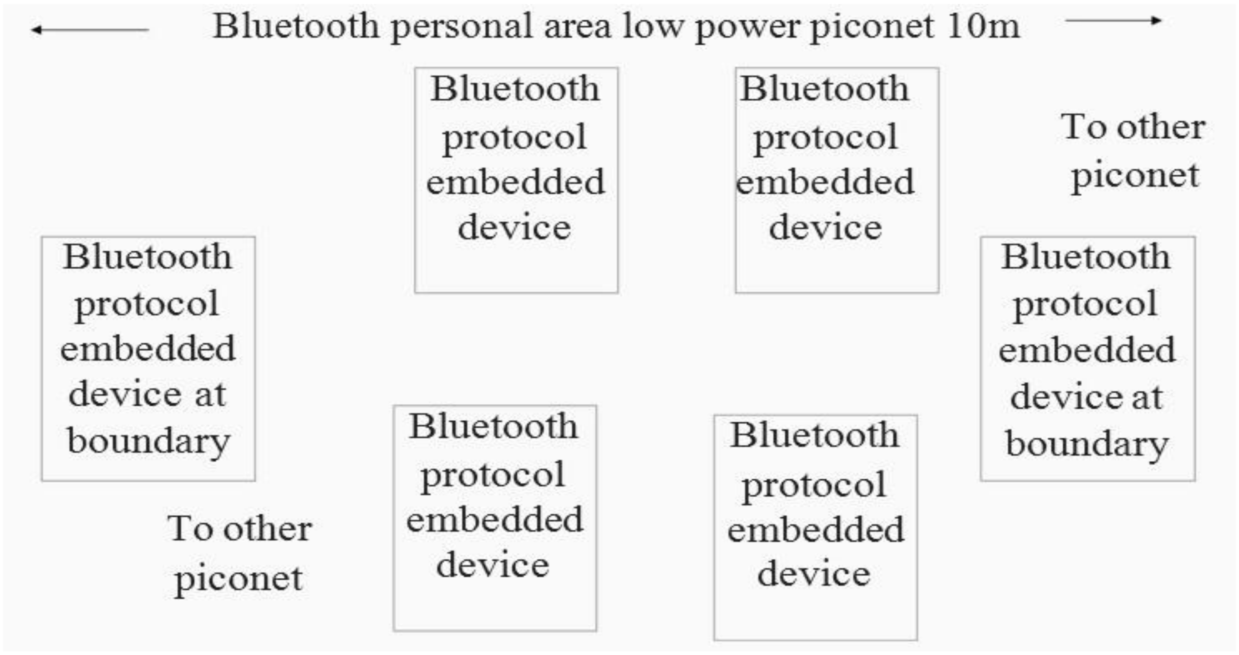
- Data transfer between two devices or between a device and multiple devices

Bluetooth PICONET



Bluetooth personal area low power piconet 10m
Bluetooth protocol embedded device
Bluetooth protocol embedded device
To other piconet
Bluetooth protocol embedded device at boundary
Bluetooth protocol embedded device at boundary
Bluetooth protocol embedded device
Bluetooth protocol embedded device
To other piconet

Fig:3.17: Bluetooth PICONET



Bluetooth personal area low power piconet 10m
Bluetooth protocol embedded device
Bluetooth protocol embedded device
To other piconet
Bluetooth protocol embedded device at boundary
Bluetooth protocol embedded device at boundary
Bluetooth protocol embedded device
Bluetooth protocol embedded device
To other piconet

Fig:3.18:Bluetooth scatternet

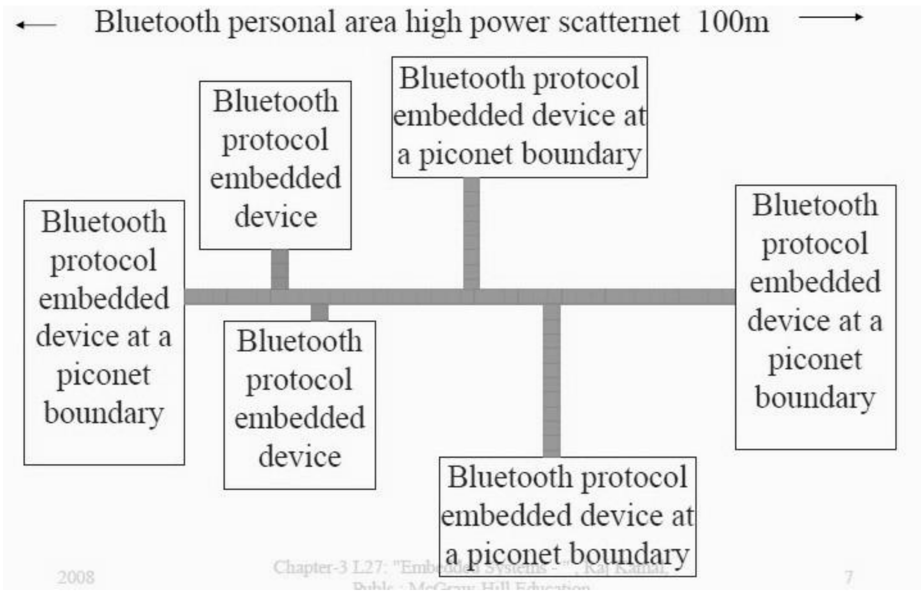

Bluetooth personal area high power scatternet 100m
Bluetooth protocol embedded device
Bluetooth protocol embedded device at a piconet boundary
Bluetooth protocol embedded device at a piconet boundary
Bluetooth protocol embedded device at a piconet boundary
Bluetooth protocol embedded device
Bluetooth protocol embedded device at a piconet boundary
2008
Chapter-3 L27: "Embedded Systems - ", Raj Kamal, Publs.: McGraw-Hill Education
7

Fig:3.19:Bluetooth Protocol

- Hopping interval is 625 µs and number of hopped frequencies are 79
- Bluetooth 1.x data transfer rate supported = 1 Mbps
- Bluetooth 2.0 enhanced maximum data rate of 3.0 Mbps over 100 m
- IEEE standard 802.15.1 protocol
- Physical layer radio communicates at carrier frequencies in 2.4 GHz band with FHSS (frequency hopping spread spectrum)

Bluetooth Protocol Features

•Supports automatic self-discovery
•Supports self-organization of network in number of devices.
•Bluetooth device self discovers nearby devices (< 10m) and they synchronize and form WPAN (wireless personal area network).
•Bluetooth protocol supports power control so that the devices communicate at minimum required power level
•This prevents drowning of signals by superimpositions of high power signals with lower level signals

Bluetooth protocol Power control features

- Bluetooth protocol supports power control so that the devices communicate at minimum required power level
- This prevents drowning of signals by superimpositions of high power signals with lower level signals

Bluetooth Physical Layer

- Three sub-layers- radio, baseband and link manager or host controller interface
- There are two types of links, best effort traffic links and real-time voice traffic

links
- The real-time traffic uses reserved bandwidth. Packet is of about 350 bytes
- Physical layer─ radio, baseband and link manager or host controller interface

Link manager sub-layer

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- Specifies formation of device pairs for Bluetooth communication.
- Gives specifications for state transmission mode, supervision, power level monitoring, synchronization, and exchange of capability, packet flow latency, peak data rate, average data rate, maximum burst size parameters from lower and higher layers.
- Manages the master and slave link
- Specifies data encryption and device authentication handling.

Host Controller Interface (HCI) interface
- Provides for emulation of serial port, for example, 3-wire UART emulation.
- Hardware abstraction sub-layer
- Used in place of link manager sub-layer
- Bluetooth device can thus interface to COM port of computer

Bluetooth protocol features
- Communication latency is 3 s.
- Large protocol stack overhead of 250kB.
- Provision of encrypted secure communication, self-discovery and self- organization and radio based communication between tiny antennae are three main features of Bluetooth

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Model Question Bank
Part-A

1. Analyze the concept of RS232 standard.
2. Distinguish between Synchronous and Asynchronous communication.
3. Define half duplex and full duplex communication
4. Discuss few serial bus communication protocols.
5. Distinguish the differentiate between RS232 and RS485.
6. Define synchronous communication.
7. Explain about the limitations of I2C.
8. Illustrate the features of CAN and SPI serial interfaces.

Part-B

1. Illustrate the synchronous and asynchronous communications from serial devices.
2. Discuss the types of serial port devices.
3. Elaborate the architecture of CAN with necessary sketches
4. Describe one type of serial communication bus with its communication protocol
5. Explain in detail about SPI communication protocol and its interfacing techniques.
6. Illustrate the signal using a transfer of byte when using the I 2C bus and also the format of bits at the I2C bus with diagram.
7. Discuss the I/O devices & its interfacing concepts?

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SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT –IV- EMBEDDED PROGRAMMING
SECA1603

IV EMBEDDED PROGRAMMING

Programming in assembly language (ALP) vs High Level Language - C Program Elements:- Macros and functions, Use of Date Types, Structure, Pointers, Function Calls - Concepts of Embedded Programming in C++- Objected Oriented Programming, Embedded Programming in C++,„C" Program compilers - Cross compiler - Optimization of memory needs-Java programming advantages, disadvantages and J2ME concept.

SOFTWARE PROGRAMMING IN ASSEMBLY LANGUAGE (ALP) AND IN HIGH LEVEL LANGUAGE „C"

Assembly language coding of an application has the following advantages:

1. *It gives a precise control* of the processor internal devices and full use of processor specific features in its instruction set and its addressing modes.
2. The machine codes are compact. This is because the codes for declaring the conditions, rules, and data type do not exist. The system thus needs a smaller memory. Excess memory needed does not depend on the programmer data type selection and rule-declarations. It is also not the compiler specific and library functions specific.
3. Device driver codes may need only a few assembly instructions. For example, consider a small-embedded system, a timer device in a microwave oven or an automatic washing machine or an automatic chocolate vending machine. Assembly codes for these can be compact and precise,
   and are conveniently written.
   It becomes convenient to develop the *source files* in C or C++ or Java for complex systems because of the following advantages of high-level languages for such systems.

-

1. *The development cycle is short for complex systems* due to the use of functions (procedures),standard library functions, modular programming approach and top down design. Application programs are structured to ensure that the software is based on sound software engineering principles.

(a) Let us recall Example 4.8 of a UART serial line device driver. Direct use of this function makes the repetitive coding redundant as this device is used in many systems. We simply change some of the arguments (for the variables) passed when needed and use it at another instance of the device use.

(b) Should the square root codes be written again whenever the square root of another value (argument) is to be taken? The use of the standard library *function*, square root ( ), saves the programmer time for coding. New sets of library functions exist in an embedded system specific C or C++ compiler. Exemplary functions are the delay ( ), wait ( ) and sleep ( ).

(c) Modular programming approach is an approach in which the building blocks are reusable software components. Consider an analogy to an IC (Integrated Circuit). Just as an IC has several circuits integrated into one, similarly a building block may call several functions and library functions. A module should however, be well tested. It must have a well-defined goal and the well- defined data inputs and outputs. It should have only one calling procedure. There should be one return point from it. It should not affect any data other than that which is targeted. [Data Encapsulation.] It must return (report) error conditions encountered during its execution.

(d) Bottom up design is a design approach in which programming is first done for the sub-modules of the specific and distinct sets of actions. An example of the modules for specific sets of actions is a program for a software timer, RTCSWT:: run. Programs for delay, counting, finding time intervals and many applications can be written. Then the final program is designed. The approach to this way of designing a program is to first code the basic functional modules and then use these to build a bigger module.

(a) Top-Down design is another programming approach in which the *main* program is first designed, then its modules, sub-modules, and finally, the functions.

2. Data type declarations provide programming ease. For example, there are four types of integers, *int*, *unsigned int*, *short* and *long*. When dealing with positive only values, we declare a variable as *unsigned int*. For example, numTicks (Number of Ticks of a clock before the timeout) has to be unsigned. We need a signed integer, *int* (32 bit) in arithmetical calculations. An integer can also be declared as data type, *shor*t (16 bit) or *long* (64 bit).To manipulate the text and strings for a character, another data type is *char*. *Each data type is an abstraction for the methods to use, to manipulate, to represent, and for a set of permissible operations*.
3. *Type checking* makes the program less prone to error. For example, type checking does not permit subtraction, multiplication and division on the *char* data types. Further, it lets + be used for concatenation. [For example, micro + controller concatenates into microcontroller, where micro is an array of *char* values and controller is another array of *char* values.]
4. Control Structures (for examples, *while*, *do - while*, *break* and *for*) and Conditional Statements (for examples, *if*, *if- else*, *else - if* and *switch - case*) make the program-flow path design tasks simple.
5. Portability of non-processor specific codes exists. Therefore, when the hardware changes, only the modules for the device drivers and device management, initialization and locator modules [Section 2.5.2] and initial boot up record data need modifications.

Additional advantages of C as a high level languages are as follows:

It is a language between low (assembly) and high level language. Inserting the assembly language codes in between is called in-line assembly. A direct hardware
Control is thus also feasible by inline assembly and the complex part of the program can be in high-level language. Example 4.5 showed the use of in-line assembly codes in C for a Port A Driver Program.
High level language programming makes the program development cycle short, enables use of the modular programming approach and lets us follow sound software engineering principles. It facilitates the program development with Bottom up design" and „top down design" approaches. Embedded system programmers have long preferred C for the following reasons: (i) The feature of embedding assembly codes using in-line assembly. (ii) Readily available modules in C compilers for the embedded system and library codes that can directly port into the system- programmer codes.

PROGRAM ELEMENTS: MACROS ANDFUNCTIONS

Preprocessor Macros: A macro is a collection of codes that is defined in a program by a name. It differs from a function in the sense that once a macro is defined by a name, the compiler puts the corresponding codes for it at every place where that macro name appears. The „enable_Maskable_Intr ( )" and „disable_Maskable_Intr ( )" are the macros [The pair of brackets is optional. If it is present, it improves readability as it distinguishes a macro from a constant]. Whenever the name enable_Maskable_Intr appears, the compiler places the codes designed for it. Macros, called test macros or test vectors are also designed and used for debugging a system.

How does a macro differ from a function? The codes for a function are compiled once only. On calling that function, the processor has to save the context, and on return restore the context. Further, a function may return nothing (*void* declaration case) or return a Boolean value, or an integer or any primitive or reference type of data. [Primitive means similar to an integer or character. Reference type means similar to an array or structure.] The enable_PortA_Intr ( ) and disable_PortA_Intr ( ) are the function calls . [The brackets are now not optional]. Macros are used for short codes only. This is because, if a function call is used instead of macro, the overheads (context saving and other actions on function call and return) will take a time, $T_{overheads}$ that is the same order of magnitude as the time, T_{exec} for execution of short codes within a function. We use a function when the $T_{overheads} << T_{exec}$, and a macro when $T_{overheads} \sim=$ or $> T_{exec}$.

Macros and functions are used in C programs. Functions are used when the requirement is that the codes should be compiled once only. However, on calling a function, the processor has to save the context, and on return, restore the context. Further, a function may return nothing (void declaration case) or return a Boolean value, or an integer or any primitive or reference type of data. Macros are used when short functional codes are to be inserted in a number of places or functions.

Use of Data Types

Whenever a data is named, it will have the address(es) allocated at the memory. The number of addresses allocated depends upon the data type. „C"" allows the following primitive data types. The *char* (8 bit) for characters, *byte* (8 bit), *unsigned short* (16 bit), *short* (16 bit), *unsigned int* (32 bit), *int* (32 bit),*long double* (64 bit), *float* (32 bit) and *double* (64 bit). [Certain compilers do not take the „byte" as a data type definition. The char" is then used instead of „byte"". Most C compilers do not take a Boolean variable as data type. As in second line of Example 4.6, *typedef*is used to create a Boolean type variable in the C program.]

A data type appropriate for the hardware is used. For example, a 16-bit timer can have only the unsigned short data type, and its range can be from 0 to 65535 only. The typedef is also used. It is made clear by the following example. A compiler version may not process the declaration as an unsigned byte. The „unsigned character" can then be used as a data type. It can then be declared as follows:

typedef unsigned character portAdata #define Pbyte portAdata Pbyte = 0xF1

Use of Data Structures: Queues, Stacks, Lists and Trees

Marks (or grades) of a student in the different subjects studied in a semester are put in a proper table. The table in the mark-sheet shows them in an organised way. When there is a large amount of data, it must be organised properly. A data structure is a way of organising large amounts of data. A data element can then be identified and accessed with the help of a few pointers and/or indices and/or functions. [The reader may refer to a standard textbook for the data structure algorithms in C and C++. For example, “Data Structures and Algorithms in C++” by Adam Drozdek from Brooks/Cole Thomson Learning (2001).]

The queues, stacks and lists, respectively. Table 5.2 gives the uses and show exemplary uses of queues, stacks, arrays, lists and trees.

Table:5.1:Use of the various data structures in a program element

Table 5.1

Uses of the Various Data Structures in a Program Element

Data Structure	Definition and when used	Example (s) of its use
Queue	It is a structure with a series of elements with the first element waiting for an operation. An operation can be done only in the first in first out (FIFO) mode. It is used when an element is not to be accessible by any index and pointer directly, but only through the FIFO. An element can be inserted only at the end in the series of elements waiting for an operation. There are two pointers, one for deleting after the operation and other for inserting. Both increment after an operation.	(1) Print buffer. Each character is to be printed in FIFO mode. (2) Frames on a network [Each frame also has a queue of a stream of bytes.] Each byte has to be sent for receiving as a FIFO. (3) Image frames in a sequence. [These have to be processed as a FIFO.]
Stack	It is a structure with a series of elements with its last element waiting for an operation. An operation can be done only in the last in first out (LIFO) mode. It is used when an element is not to be accessible by any index or pointer directly, but only through the LIFO. An element can be pushed (inserted) only at the top in the series of elements still waiting for an operation. There is only one pointer used for pop (deleting) after the operation as well as for push	(1) Pushing of variables on interrupt or call to another function. (2) Retrieving the pushed data onto a stack.

	(inserting). Pointers increment or decrement after an operation. It depends on insertion or deletion.	
Array (one dimensional vector)	It is a structure with a series of elements with each element accessible by an identifier name and an index. Its element can be used and operated easily. It is used when each element of the structure is to be given a distinct identity by an index for easy operation. Index stars from 0 and is +ve integers.	*ts* = 12 * s(1); Total salary, *ts* is 12 times the first month salary. marks_weight [4] = marks_weight [0]; Weight of marks in the subject with index 4 is assigned the same as in the subject with index 0.
Multi-dimensional array	It is a structure with a series of elements each having another sub-series of elements. Each element is accessible by identifier name and two or more indices. It is used when every element of the structure is to be given a distinct identity by two or more indices for easy operation. The dimension of an array equals the number of indices that are needed to distinctly identify an array-element. Indices start from 0 and are +ve integers.	Handling a matrix or tensor. Consider a pixel in an image frame. Consider Quarter-CIF image pixel in 144 x 176 size image frame. [Recall Section 1.2.7.] *pixel* [108, 88] will represent a pixel at 108-th horizontal row and 88-th vertical column. #See following note also.
List	Each element has a pointer to its next element. Only the first element is identifiable and it is done by list-top pointer (Header). No other element is identifiable and hence is not accessible directly. By going through the first element, and then consecutively through all the succeeding elements, an element can be read, or read and deleted, or can be added to a neighbouring element or replaced by another element.	A series of tasks which are active Each task has pointer for the next task. Another example is a menu that point to a submenu.

Data Structure	Definition and when used	Example (s) of its use
Tree	There is a root element. It has two or more branches each having a daughter element. Each daughter element has two or more daughter elements. The last one does not have daughters. Only the root element is identifiable and it is done by the treetop pointer (Header). No other element is identifiable and hence is not accessible directly. By traversing the root element, then proceeding continuously through all the succeeding daughters, a tree element can be read or read and deleted, or can be added to another daughter or replaced by another element. A tree has data elements arranged as branches. The last daughter, called node has no further daughters. A binary tree is a tree with a maximum of two daughters (branches) in each element.	An example is a directory. It has number of file-folders. Each file-folder has a number of other file folders and so on In the end is a file.

Use of Pointers, NULL Pointers

Pointers are powerful tools when used correctly and according to certain basic principles. Exemplary uses are as follows. Let a byte each be stored at a memory address.

1. Let a port *A* in system have a buffer register that stores a byte. Now a program using a pointer declares the byte at port A as follows: „unsigned byte *portA‟. [or Pbyte *portA.] The * means „the contents at‟. This declaration means that there is apointer and an unsigned byte for portA, The compiler will reserve one memory address for that byte. Consider „unsigned short **timer1*‟. A pointer *timer1* will point to two bytes, and the compiler will reserve two memory addresses for contents of *timer1*.
2. Consider declarations as follows. void *portAdata; The void means the undefined data type for portAdata. The compiler will allocate for the *portAdata without any type check.
3. A pointer can be assigned a constant fixed address as in Example 4.5. Recall two preprocessor directives: „# define portA (volatile unsigned byte *) 0x1000‟ and „# define PIOC (volatile unsigned byte *) 0x1001‟. Alternatively, the addresses in afunction can be assigned as follows. „volatile unsigned byte * portA = (unsigned byte *) 0x1000‟ and „volatile unsigned byte *PIOC =(unsigned byte *) 0x1001‟. An instruction, „portA ++;‟ will make the portA pointer point to the next address and to which is the PIOC.

4. Consider, unsigned byte portAdata; unsigned byte *portA = &portAdata. The first statement directs the compiler to allocate one memory address for portAdata because there is a byte each at an address. The & (ampersand sign) means „at the address of". This declaration means the positive number of 8bits (byte) pointed by portA is replaced by the byte at the address of portAdata. The right side of the expression evaluates the contained byte from the address, and the left side puts that byte at the pointed address. Since the right side variable portAdata is not a declared pointer, the ampersand sign is kept to point to its address so that the right side pointer gets the contents (bits) from that address. [Note: The equality sign in a program statement means „is replaced by"].
5. Consider two statements, „*unsigned short *timer1;*" and „*timer1++;*". The second statement adds 0x0002 in the address of timer1. Why? timer1 ++ means point to next address, and unsigned short declaration allocated two addresses for timer1. [timer1 ++; or timer1 +=1 or timer = timer +1; will have identical actions.] Therefore, the next address is 0x0002 more than the address of timer1 that was originally defined. Had the declaration been „unsigned int" (in case of 32 bit timer), the second statement would have incremented the address by 0x0004.

When the index increments by 1 in case of an array of characters, the pointer to the previous element actually increments by 1, and thus the address will increment by 0x0004 in case of an array of integers. For array data type, * is never put before the identifier name, but an index is put within a pair of square brackets after the identifier. Consider a declaration, „*unsigned charportAMessageString [80];*". The port A message is a string, which is an array of 80 characters.Now, portAMessageString is itself a pointer to an address without the star sign before it. [Note: Array is therefore known as a reference data type.] However,
*portAMessageString will now
refer to all the 80 characters in the string. portAMessageString [20] will refer to the twentieth element (character) in the string. Assume that there is a list of RTCSWT (Real Time Clock interrupts triggered Software Timers) timers that are active at an instant. The top of the list can be pointed as „*RTCSWT_List.top" using the pointer. RTCSWT_List.top is now the pointer to the top of the contents in a memory for a list of the active RTCSWTs. Consider the statement „*RTCSWT_List.top ++;*" It increments this pointer in a loop. It *will not point* to the next top of another object in the list (another RTCSWT) but to some address that depends on the memory addresses allocated to an item in the RTCSWT_List. Let *ListNow* be a pointer within the memory block of the list top element. A statement
„**RTCSWT_List. ListNow =*RTCSWT_List.top;*" will do the following. RTCSWT_List pointer is now replaced byRTCSWT list-top pointer and now points to the next list element (object). [Note: RTCSWT_List.top ++ for pointer to the next list-object can only be used when RTCSWT_List elements are placed in an array. This is because an array is analogous to consecutively located elements of the list at the memory. Recall Table 5.2.]

1. A NULL pointer declares as following: „*#define NULL (void*) 0x0000*". [We can assign any address instead of 0x0000 that is not in use in a given hardware.] NULL pointer is very useful. Consider a statement: „*while (* RTCSWT_List. ListNow ->state != NULL) { numRunning++;*". When a pointer to ListNow in a list of software timers that are running at present is notNULL, then only execute the set of statements in the given pair of opening and closing curly braces. One of the important uses of the NULL pointer is in a list. The last element to point to the end of a list, or to no more contents in a queue or empty stack, queue or list.

Use of Function Calls

There are functions and a special function for starting the program execution, *void main (void)*‟. Given below are the steps to be followed when using a function in the program.

1. *Declaring a function:* Just as each variable has to have a declaration, each function must be declared. Consider an example. Declare a function as follows: „*int*run (int *indexRTCSWT*,unsigned int *maxLength*, unsigned int *numTicks*, SWT_Type *swtType*, SWT_Action *swtAction*, boolean *loadEnable*);‟. Here *int* specifies the returned data type. The run is the function name. There are arguments inside the brackets. Data type of each argument is also declared. A modifier is needed to specify the data type of the returned element (variable or object) from any function. Here, the data type is specified as an integer. [A modifier for specifying the returned element may be also be *static*, *volatile*, *interrupt* and *extern*.]
2. *Defining the statements in the function:* Just as each variable has to be given the contents orvalue, each function must have its statements. Consider the statements of the function „run‟. These are *within a pair of curly braces* as follows: „*int RTCSWT:: run (int indexRTCSWT,unsigned int maxLength, unsigned int numTicks, SWT_Type swtType, SWT_Action swtAction, boolean loadEnable) {...};*‟. The last statement in a function is for the *return* and may also befor returning an element.
3. *Call to a function:* Consider an example:„if (delay_F = = true && SWTDelayIEnable = = true)ISR_Delay ( );‟. There is a call on fulfilling acondition. The call can occur several times and can be repeatedly made. On each *call*, the values of the arguments given within the pair of bracket pass for use in the function statements.

(i) Passing the Values (elements)

The values are copied into the arguments of the functions. When the function is executed in this way, it does not change a variable‟s value at the*called* program. Afunction can only use the copied values in its own variables through the arguments. Consider a statement, „run (int *indexRTCSWT*, unsigned int *maxLength*, unsigned int *numTicks*, SWT_Type *swtType*, SWT_Action *swtAction*, boolean*loadEnable*) {...}‟. Function „run‟ arguments *indexRTCSWT*, *maxLength*, *numTick*, *swtType*, and *loadEnable* original values in the calling program during execution of the codes will remain unchanged.The advantage is that the same values are present on return from the function. The arguments that are *passed by the values* are saved temporarily on a stack and retrieved on return from the function.

(ii) Reentrant Function

Reentrant function is usable by the several tasks and routines synchronously (at the same time). This is because all its argument values are retrievable from the stack. A function is called*reentrant function* when the following three conditions are satisfied.

1. All the arguments pass the values and none of the argument is a pointer (address) whenever a calling function calls that function. There is no pointer as an argument in the above example offunction „run‟.
2. When an operation is not atomic, that function should not operate on any variable, which is declared outside the function or which an interrupt service routine uses or which is a global variable but passed by reference and not passed by value as an argument into the function. [The value of such a variable or variables, which is not local, does not save on the stack when there is call to another program.]

The following is an example that clarifies it further. Assume that at a server (software), there is a 32 bit variable *count* to count the number of clients (software) needing service. There is no option except to declare the *count* as a global variable that shares with all clients. Each client on a connection to a server sends a call to increment the *count*. The implementation by the assembly code for increment at that memory location is non-atomic when (*i*) the processor is of eight bits, and (ii) the server-compiler design is such that it does not account for the possibility of interrupt in-between the four instructions that implement the increment of 32-bit count on 8-bit processor. There will be a wrong value with the server after an instance when interrupt occurs midway during implementing an increment of *count*.

1. That function does not call any other function that is not itself Reentrant. Let RTI_Count be aglobal declaration. Consider an ISR, *ISR_RTI*. Let an„*RTI_Count ++;*" instruction be where the RTI_Count is variable for counts on a real- time clock interrupt. Here *ISR_RTI* is a not a Reentrant routine because the second condition may not be fulfilled in the given processor hardware. There is no precaution that may be taken here by the programmer against shared data problems at the address of the *RTI_Count* because there may be no operation that modifies RTI_Counts in any other routine or function than the *IST_RTI*. But if there is another operation that modifies the RTI_Count the shared-data problem will arise.

Passing the References

When an argument value to a function passes through a pointer, the function can change this value. On returning from this function, the new value will be available in the calling program or another function called by this function. [There is no saving on stack of a value that either (*a*) *passes through a pointerin the function- arguments* or (*b*) operates in the function as a global variable or (c) operates through a variable declared outside the function block.4.7 Multiple Function Calls in Cyclic Order in the Main

One of the most common methods is for the multiple function-calls to be made in a cyclic order in an infinite loop of the *main*. Recall the 64 kbps network problem. Let us design the C codes for an infinite loop for this problem. Example 5.4 shows how the multiple function calls are defined in the main for execution in the cyclic orders. Figure 5.1 shows the model adopted here.

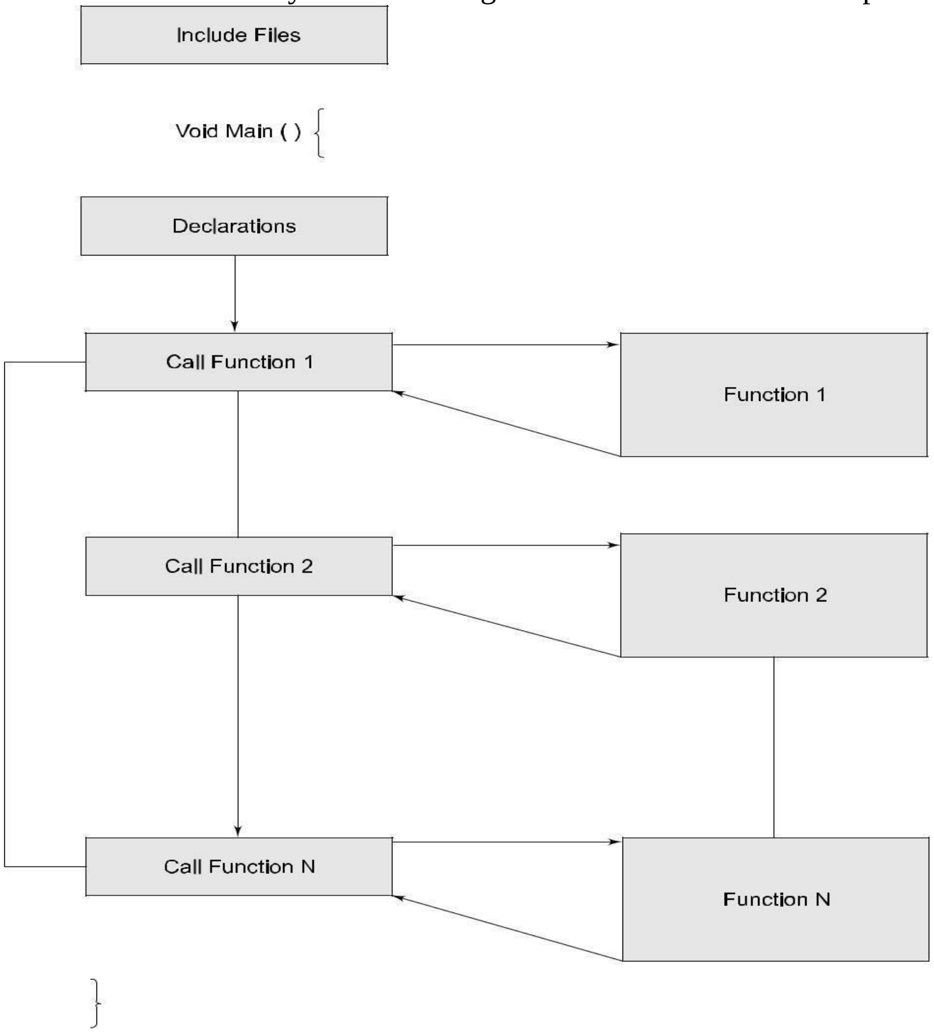

Fig:5.1: Programming model for multiple function calls

.

Example 5.4

typedef unsigned char
int8bit; # define int8bit
boolean
# define false 0
# define true 1
void main (void) {
/* The Declarations of all variables, pointers, functions here and also initializations here */
unsigned char *portAdata;

```
boolean          charAFlag;
boolean checkPortAChar ( );
void inPortA (unsigned char
*);
void decipherPortAData (unsigned char
*); void encryptPortAData (unsigned
char *); void outPortB (unsigned char
*);
.
while (true) {
/* Codes that repeatedly execute */
/* Function for availability check of a
 character at port A*/ while (charAFlag !=
 true) checkPortAChar ( );
/* Function for reading PortA
 character*/ inPortA (unsigned char
 *portAdata);
/* Function for deciphering */
 decipherPortAData (unsigned char *portAdata);
/* Function for encoding */
 encryptPortAData          (unsigned char  *portAdata);
/* Function for retransmit output to
 PortB*/ outPort B (unsigned char
 *portAdata);
 };
}
```

Function Pointers, Function Queues and Interrupt Service Routines Queues

Let the * sign not be put before a function name, but there are arguments within the pair of brackets, and the statements for those executed on a call for the function. The statements are inside a pair of the curly braces. Consider a declaration in the Example 5.4, „*boolean checkPortAChar* ( );".„*checkPortAChar*" is a function, which returns a *Boolean* value. Now, *checkPortAChar* is itself a pointer to the starting address of the statements of the function inside the curly braces without the star sign before it. The program counter will fetch the address of *checkPortAChar*, and CPU sequentially executes the function-statements from here.
Now, let the * sign be put before the function. „* *checkPortAChar*" will now refer to all the compiled form statements in the memory that are specified within the curly braces. Consider a declaration in the example, „void *inPortA* (unsigned char *);"'.

1. *inPortA*means a pointer to the statements of the function. Inside the bracket, there is anunsigned character pointed by some pointer.
2. **inPortA* will refer to all the compiled form statements of *inPortA*.
3. (* *inPortA*) will refer to calls to the statements of *inPortA*.
4. What will a statement, „void *create* (void (**inPortA*) (unsigned char *), void *portAStack, unsigned char port Apriority);"' mean?
   (a) First modifier „void"' means *create* function does not return anything.
   (b) „create"' is another function.
   (c) Consider the argument of this function „void (**inPortA*) (*unsigned char *portAdata*)"'. (**inPortA*) means call the statements of *inportA* the argument of which is „unsigned char *portAdata"'.
   (d) The second argument of *create* function is a pointer for the portA stack at the memory.
   (e) The third argument of *create* function is a byte that defines the portA priority.

An important lesson to be remembered from above discussion is that a returning data type specifi-cation (for example, void) followed by „*(*functionName) (functionArguments)*" calls the statements of the *functionName* using the *functionArguments*, and on a return it returns the specified data object.

We can thus use the function pointer for invoking a call to the function.When there are multiple ISRs, a high priority interrupt service routine is executed first and the lowest priority, last. [Refer Section 4.6.4.] It is possible that function calls and statements in any of the higher priority interrupts may block the execution of low priority ISR within the deadline. How is the deadline problem for low priority routines to be solved? One solution is by using the function pointers in the routines, and forming a queue for them. The functions are then executed at a later stage. Pointers are needed in number of situations, for example, port bit manipulation and read or write. Software designers must learn the uses of pointers in depth. An innovative concept is use of function queues and the queues of the function pointers built by the ISRs. It reduces significantly the ISR latency periods. Each device ISR is therefore able to execute within its stipulated deadline.

Objected Oriented Programming

An objected oriented language is used when there is a need for re-usability of the defined object or set of objects that are common within a program or between the many *applications*. When a large pro-gram is to be made, an object-oriented language offers many advantages. Data encapsulation, design of reusable software components and inheritance are the advantages derived from the OOPs.

An object-oriented language provides for defining the objects and methods that manipulate the objects without modifying their definitions. It provides for the data and methods for encapsulation. An object can be characterized by the following:

An i*dentity* (a reference to a memory block that holds its state and behavior). A *state* (its data, property, fields and attributes).
A *behavior* (method or methods that can manipulate the *state* of the object).

In a procedure-based language, like FORTRAN, COBOL, Pascal and C, large programs are split into simpler functional blocks and statements. In an object- oriented language like Smalltalk, C++ or Java, logical groups (also known as *classes*) are first made. Each group defines the data and the methods of using the data. A set of these groups then gives an application program. Each group has internal user-level fields for the data and the methods of processing that data at these fields. Each group can then create many objects by copying the group and making it functional. Each object is functional. Each object can interact with other objects to process the user‟s data. The language pro-vides for formation of classes by the definition of a group of objects having similar attributes and common behavior. A class *creates the objects. An object is an instance of a class.*

Embedded Programming in C++

1. What are programming advantages of C++?

C++ is an *object oriented Program (OOP) language, which in addition, supports the procedure ori-ented codes of C.* Program coding in C++ codes provides the advantage of objected oriented program-ming as well as the advantage of C and in-line assembly. Programming concepts for embedded pro-gramming in C++ are as follows:

(i) A class binds all the member functions together for creating objects. The objects will have memory allocation as well as default assignments to its variables that are not declared*static*. Let us assume that each software timer that gets the count input from a real time clock is an object. Now consider the codes for a C++ *class RTCSWT*. A number of software timer objects can be created as the instances of *RTCSWT*.

(ii) A class can derive (inherit) from another class also. Creating a *child* class from RTCSWT as a *parent* class creates a new application of the RTCSWT.

(iii) Methods (C functions) can have same name in the inherited class. This is called method over loading. Methods can have the same name as well as the same number and type of arguments in the inherited class. This is called *method overriding*. These are the two significant features that are extremely useful in a large program.

(*iv*) Operators in C++ can be overloaded like in method overloading. Recall the following statements
and expressions in Example 5.8. The operators ++ and ! are overloaded to perform a set of
operations. [Usually the++ operator is used for post-increment and pre-increment
and the !
operator is used for a *not* operation.]
const OrderedList & operator ++ ( ) {*if* (ListNow != NULL) ListNow = ListNow -
> pNext;
return *this;}
boolean int OrderedList & operator ! ( ) const {return (ListNow != NULL) ;};

[Java does not support operator overloading, except for the + operator. It is used for summation as well string-concatenation.]

There is *struct* that binds all the member functions together in C. But a C++ *class* has object features. It can be extended and child classes can be derived from it. A number of child classes can be derived from a common class. This feature is called polymorphism. A class can be declared as public or private. The data and methods access is restricted when a class is declared private. *Struct* does not have these features.

2. What are then the disadvantages of C++ ?

Program codes become lengthy, particularly when certain features of the standard C++ are used.

Examples of these features are as follows:

(a) Template.
(b) Multiple Inheritance (Deriving a class from many parents).
(c) Exceptional handling.
(d) Virtual base classes.
(e) Classes for IO Streams. [Two library functions are *cin* (for character (s) in) and *cout* (for character (s) out). The I/O stream class library provides for the input and output streams of characters (bytes). It supports *pipes*, *sockets* and *file management features*. Refer to Section 8.3 for the use of these in inter task communications.]

3. Can optimization codes be used in Embedded C++ programs to eliminate the disadvan-tages?

Embedded system codes can be optimised when using an OOP language by the following

(a) Declare private as many classes as possible. It helps in optimising the generated codes.
(b) Use *char*, *int* and *boolean* (scalar data types) in place of the objects (reference data types) as arguments and use local variables as much as feasible.
(c) Recover memory already used once by changing the reference to an object to NULL.

A *special compiler for an embedded system* can facilitate the disabling of specific features provided in C++. Embedded C++ is a version of C++ that provides for a selective disabling of the above features so that there is a less runtime overhead and less runtime library. The solutions for the library functions are available and ported in C directly. The IO stream library functions in an embedded C++ compiler are also reentrant. So using embedded C++ compilers or the special compilers make the

C++ a significantly more powerful coding language than C for embedded systems.

GNU C/C++ compilers (called *gcc*) find extensive use in the C++ environment in embedded soft-ware development. Embedded C++ is a new programming tool with a compiler that provides a small runtime library. It satisfies small runtime RAM needs by selectively de-configuring features like, tem-plate, multiple inheritance, virtual base class, etc. when there is a less runtime overhead and when the less runtime library using solutions are available. Selectively removed (de-configured) features could be template, run time type identification, multiple Inheritance, exceptional handling, virtual base classes, IO streams and foundation classes. [Examples of foundation classes are GUIs (graphic user interfaces). Exemplary GUIs are the buttons, checkboxes or radios.]

An embedded system C++ compiler (other than *gcc*) is Diab compiler from Diab Data. It also provides the target (embedded system processor) specific optimisation of the codes. [Section 5.12] The run-time analysis tools check the expected run time error and give a profile that is visually interactive.

Embedded C++ is a C++ version, which makes large program development simpler by providing object-oriented programming (OOP) features of using an object, which binds state and behavior and which is defined by an instance of a class. We use objects in a way that minimizes memory needs and run-time overheads in the system. Embedded system programmers use C ++ due to the OOP features of software re-usability, extendibility, polymorphism, function overriding and overloading along portability of C codes and in-line assembly codes. C++ also provides for overloading of operators. A compiler, gcc, is popularly used for embedded C++ codes compilation. Diab compiler has two special features: (i) processor specific code optimization and (ii) Run time analysis tools for finding expected run-time errors.

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2. A state
3. A behavior

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Embedded Programming in C++

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Disadvantages of C++

Program codes become lengthy particularly when certain features of the standard used. Example of these features are as follows;

a. Template
b. Multiple inheritance
c. Exceptional handling
d. Virtual base classes
e. Classes for IO streams

Embedded system codes can be optimized when using the OOP language

i. Declare private as many classes as possible. It helps in optimizing the generated codes
ii. Use „char‟, int and Boolean in place of the objects as arguments and use local variables as much as feasible
iii. Recover memory already used once by changing the reference to an object to NULL

A Special compiler for an embedded system can facilitate the disabling of specific features provided in C++. The solution for the library functions are available and ported in C directly. The IO stream library function is an embedded C++ compiler are also reentrant. So using embedded C++ compilers or the special compilers make the C++ significantly more powerful coding language than C for embedded systems

4.2 C Program compilers and cross compilers

Two compilers are needed. One is c program compiler and the other one is cross compiler. Compiler is for the host computer which does the development and design and also the testing and debugging.

The second compiler is the cross compiler. The cross compiler runs on the host but develops the machine codes for a targeted system. There is a popular free ware called GNU. A GNU compiler is configurable both as host compiler as well as cross compiler. A compiler generates an object file. For compilation of the host alone the compiler can be turbo C, turbo C++ and Borland C++. The target system specific or multi choice cross compilers that are available commercially may be used. These are available for most of the embedded systems, microprocessor and microcontrollers. The host runs the cross compilers that offer an integrated development environment. It means that a target system can emulate and simulate the application system on the host.

Use of appropriate compilers and cross compilers is essential in any embedded software development

Optimization of memory needs

When codes are made compact and fitted in small memory areas without affecting the code performance, it is called memory optimization. It also reduces the total number of CPU cycles and thus the total energy requirements. The following are used to optimize the use of memory in a system;

i. Use declaration as unsigned byte if there is a variable, which always has a value between 0 and 255. When using the data structures, limit the maximum size of queues, list and stacks size to 256. Byte arithmetic takes less time than integer arithmetic
ii. Avoid use of library functions if a simpler coding is possible. Library functions are the general functions. Use of general function needs more memory in several cases
iii. When the software designer knows fully the instruction set of the target processor, assembly codes must be used. This also allows the efficient use of memory. The device driver programs in assembly especially provides efficiency due to the need to use the bit set-reset instruction for the control and status registers. Only the few assembly codes for using the device IO port, addresses and control and status registers are needed. Assembly coding also helps in coding for atomic operations. A modifier register can be used in the C program for a fast access to a frequently used variable
iv. Calling a function causes context saving on a memory stack and on return the context is retrieved. This involves time and can increase the worst case interrupt-latency. There is a modifier in-line. When the in-line modifier is used the compiler inserts the actual code at all the places where these operations are used. This reduces the time and stack overheads in the function call and return. Using modifier directs the compiler to put the codes for the function instead of calling that function
v. As long as shared data problem doesnot arise, the use of global variables can be optimized. These are not used as the arguments for passing the values. A good function is one that has no arguments to be passed. The passed values are saved on the stacks in case of interrupt service calls and other function calls. Besides obviating the need for repeated declaration the use of global variables will thus reduce the worst case interrupt latency and the time and the stack overheads in the function call and return. But this is at the cost of the codes for eliminating shared data problem. When a variable is declared static the processor access with less instruction than from the stack.
vi. Combine two function if possible. The search function for finding pointers to a list item and pointers of previous list items combine into one. It present is false the pointer of the previous list item retrieves the one that has the item
vi. All the timers and a conditional statement that changes the count input in case of a running count and does not change it in case of ideal state timers could have also been used. More number of calls will however be needed and not once but repeatedly on each real time clock interrupt tick. The RAM memory needed will be more. Their fore creating a list of running counts is a more efficient way, similarly bringing the task first into an initiated task list will reduce the frequent

interaction with the OS and context savings and retrieval stack and time overheads.

viii. Use of feasible alternatives to the switch statements with a table of pointers to the functions. This saves processor time in deciding which set of statements to execute while performing the conditional tests all down a chain.

ix. Use the delete function when there is no longer a need for a set of statements after that execute. As a rule to free the RAM used by a set of statements use the delete function and destructor functions.

x. When using C++, configure the compiler for not permitting the multi- inheritance, templates,exceptional handling,new style casts, virtual base classes and name spaces.

Embedded programming in Java Java programming advantages

Java has advantages for embedded programming as

- **i.** Java is completely an OOP language
- **ii.** Java has an in-built support for creating multiple threads. It obviates the need for an operating system based scheduler for handling the tasks.
- **iii.** Java is the language for the most web applications and allows machines of different types to communicate on the web.
- **iv.** There is a huge class library on the network that makes program development quick.
- **v.** Platform independence in hosting the compiled codes on the network is because java generates the byte codes. These are executed on an installed JVM (Java Virtual Machine) on a machine. Platform independence gives portability with respect to the processor used.
- **vi.** Java doesnot permit pointer manipulation instructions. So it is robust in the sense that memory leaks and memory related errors do not occur. A memory leak occurs, for example when attempting to write to the end of a boundary array
- **vii.** Java byte codes that are generated need a large memory when a method has more than three or four local variables
- **viii.** Java being platform independent is expected to run on a machine with an RISC like instruction execution with few addressing modes only.

Java programming disadvantages

Use of J2ME (Java 2 Micro Edition) or java card or embedded java helps in reducing the code size to 8KB for the usual applications like smart card.

- **i.** Use core classes only. Classes for basic run time environment form the VM internal format and only the programmers new java classes are not in internal format.
- **ii.** Provide for configuring the run time environment.
- **iii.** Create one object at a time when running the multiple threads.
- **iv.** Reuse the objects instead of using a larger number of objects
- **v.** Use scalar type only as long as feasible

A smart card is an electronic circuit with a memory and CPU or a synthesized VLSI circuit. It is packed like an ATM card. For smart cards, there is Java card technology. Internal formats for the run time environment are available mainly for the few classes in Java card technologies. Java classes used are the connections, data grams, input, output and streams, security and cryptography. Hence these are the advantages and disadvantages of Java applications in the embedded system. Java card, embedded Java and J2ME are the three versions of Java that generate a reduced code size. Cons.

Consider an embedded system such as a smart card, it is a simple application that uses a running Java card. The Java advantage of platform independency in byte codes is an asset. The smart card connects to a remote server. The card stores the user account past balance and user details for the remote server information in an encrypted format. It deciphers and communicates to the server the user needs after identifying and certifying the user. The intensive codes for the complex applications run at the server. A restricted run time environment exist in java classes for connections, datagrams, character input, output and streams, security and cryptography only

J2ME (Java 2 Micro Edition) concept

J2ME provides the optimized run time environment. Instead of the use of packages, J2ME provides for the codes for the core classes only. These codes are stored at the ROM of the embedded system. It provides for two alternative configurations.

- Connected Device Configuration(CDC) and
- Connected Limited Device Configuration (CLDC).

CDC inherits a few classes from packages for net, security, input output, reflect, until, jar and zip. CLDC doesnot provide for the applets, beans, math, security and text packages in java. Lang. A Personal Digital Assistant uses CDC or CLDC.

There is a scalable OS feature in J2ME. There is a new virtual machine, KVM as an alternative to JVM. When using the KVM, the system needs a 64KB instead of 512KB run time environment.

J2ME need not be restricted to configure the SVM to limit the classes. The configuration can be augmented by profiler classes. For example Mobile Information Device Profiler (MIDP). A profile defines the support of Java to a device family. The profiler is a layer between the application and the configuration. For example MIDP is between CLDC and application. Between the devices and configuration there is an OS, which is specific to the device needs

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Question Bank

Part-A

1. List the advantages of assembly language coding.
2. Define Macros.
3. What are the primitive data types of C?
4. What is a queue?
5. What is reentrant function?
6. List of the disadvantages of C++.
7. Define Cross Compiler.
8. What are the needs of good program level performance analysis?

9. What is schedule program index?
10. List out the different types of validation testing.

Part-B

1. Explain briefly about program level analysis.
2. Describe in detail about user function calls.
3. Explain various data structures used with example.
4. Elaborate in detail about the pointers.
5. Explain importance of validation testing and its types.

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UNIT –V- ARDUINO
SECA1603

V ARDUINO

Introduction to ARDUINO, Architecture, overview of its I/O Ports, Serial Ports, PWM, ADC, Interfacing with different type of Sensors and Communication modules, Hardware timers, watchdogs and interrupt handling in Arduino. Controlling embedded system based devices using Arduino.

Introduction to ARDUINO

Arduino is a prototype platform (open-source) based on an easy-to-use hardware and software. It consists of a circuit board, which can be programed (referred to as a microcontroller) and a ready-made software called Arduino IDE (Integrated Development Environment), which is used to write and upload the computer code to the physical board.

The key features are:

• Arduino boards are able to read analog or digital input signals from different sensors and turn it into an output such as activating a motor, turning LED on/off, connect to the cloud and many other actions.

• You can control your board functions by sending a set of instructions to the microcontroller on the board via Arduino IDE (referred to as uploading software).

• Unlike most previous programmable circuit boards, Arduino does not need an extra piece of hardware (called a programmer) in order to load a new code onto the board. You can simply use a USB cable.

• Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program. • Finally, Arduino provides a standard form factor that breaks the functions of the microcontroller into a more accessible package.

Architecture

Basically, the processor of the Arduino board uses the Harvard architecture where the program code and program data have separate memory. It consists of two memories such as program memory and data memory. Wherein the data is stored in data memory and the code is stored in the flash program memory. The Atmega328 microcontroller has 32kb of flash memory, 2kb of SRAM 1kb of EPROM and operates with a 16MHz clock speed.

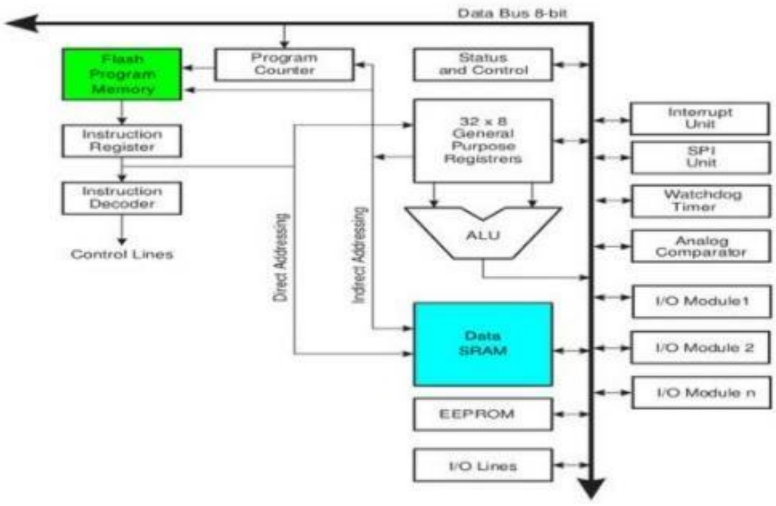


Figure 5.1 Arduino Architecture

The Arduino Uno is an open-source microcontroller board that is based on the Microchip ATmega328P (for Arduino UNO R3) or Microchip ATmega4809 (for Arduino UNO WIFI R2) micro-controller by Atmel and was the first USB powered board developed by Arduino. Atmega 328P based Arduino UNO pinout and specifications are given in figure below. Both Atmega328 and ATmega4809 have a built-in bootloader, which makes it very convenient to flash the board with our code. Like all Arduino boards, we can program the software running on the board using a language derived from C and C++. The easiest development environment is the Arduino IDE

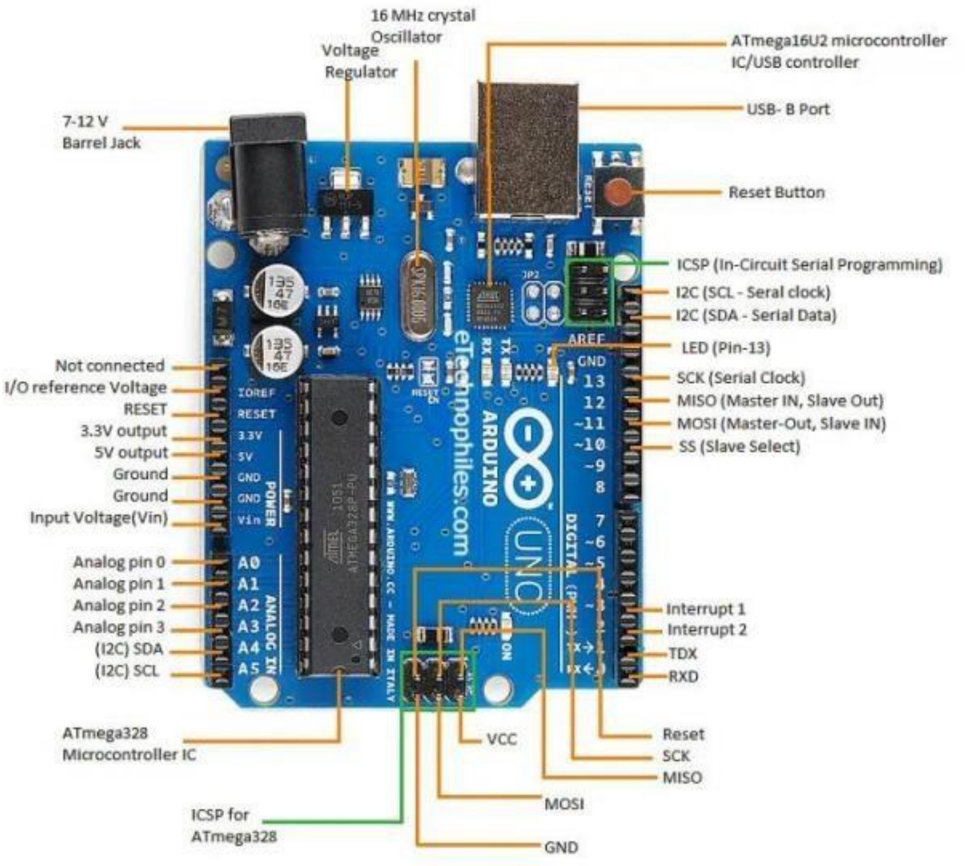


Figure 5.2 Pin details of Arduino Uno Board

Analog pins

The Arduino UNO board has five analog input pins A0 through A5. These pins can read the signal from an analog sensor like the humidity sensor or temperature sensor and convert it into a digital value that can be read by the microprocessor.

Main microcontroller

Each Arduino board has its own microcontroller (11). You can assume it as the brain of your board. The main IC (integrated circuit) on the Arduino is slightly different from board to board. The microcontrollers are usually of the ATMEL Company. You must know what IC your board has before loading up a new program from the Arduino IDE. This information is available on the top of the IC. For more details about the IC construction and functions, you can refer to the data sheet.

ICSP pin

Mostly, ICSP (12) is an AVR, a tiny programming header for the Arduino consisting of MOSI, MISO, SCK, RESET, VCC, and GND. It is often referred to as an SPI (Serial Peripheral Interface), which could be considered as an "expansion" of the output. Actually, you are slaving the output device to the master of the SPI bus.

Power LED indicator
This LED should light up when you plug your Arduino into a power source to indicate that your board is powered up correctly. If this light does not turn on, then there is something wrong with the connection. TX and RX LEDs
On your board, you will find two labels: TX (transmit) and RX (receive). They appear in two places on the Arduino UNO board. First, at the digital pins 0 and 1, to indicate the pins responsible for serial communication. Second, the TX and RX led (13). The TX led flashes with different speed while sending the serial data. The speed of flashing depends on the baud rate used by the board. RX flashes during the receiving process.Digital I/O
The Arduino UNO board has 14 digital I/O pins [numbered 0-13] of which 6 provide PWM (Pulse Width Modulation) output. These pins can be configured to work as input digital pins to read logic values (0 or 1) or as digital output pins to drive different modules like LEDs, relays, etc. The pins labeled –~‖ can be used to generate PWM.

AREF

AREF stands for Analog Reference. It is sometimes, used to set an external reference voltage (between 0 and 5 Volts) as the upper limit for the analog input pin.

Pins Configured as INPUT
Arduino pins are by default configured as inputs, so they do not need to be explicitly declared as inputs with **pinMode()** when you are using them as inputs. Pins configured this way are said to be in a high-impedance state. Input pins make extremely small demands on the circuit that they are sampling, equivalent to a series resistor of 100 megaohm in front of the pin.
This means that it takes very little current to switch the input pin from one state to another. This makes the pins useful for such tasks as implementing a capacitive touch sensor or reading an LED as a photodiode.
Pins configured as pinMode(pin, INPUT) with nothing connected to them, or with wires connected to them that are not connected to other circuits, report seemingly random changes in pin state, picking up electrical noise from the environment, or capacitively coupling the state of a nearby pin.

Pull-up Resistors

Pull-up resistors are often useful to steer an input pin to a known state if no input is present. This can be done by adding a pull-up resistor (to +5V), or a pull-down resistor (resistor to ground) on the input. A 10K resistor is a good value for a pull-up or pull-down resistor.

Using Built-in Pull-up Resistor with Pins Configured as Input

There are 20,000 pull-up resistors built into the Atmega chip that can be accessed from software. These built-in pull-up resistors are accessed by setting the **pinMode()** as INPUT_PULLUP. This effectively inverts the behavior of the INPUT mode, where HIGH means the sensor is OFF and LOW means the sensor is ON. The value of this pull-up depends on the microcontroller used. On most AVR-based boards, the value is guaranteed to be between 20kΩ and 50kΩ. On the Arduino Due, it is between 50kΩ and 150kΩ. For the exact value, consult the datasheet of the microcontroller on your board.

When connecting a sensor to a pin configured with INPUT_PULLUP, the other end should be connected to the ground. In case of a simple switch, this causes the pin to read HIGH when the switch is open and LOW when the switch is pressed. The pull-up resistors provide enough current to light an LED dimly connected to a pin configured as an input. If LEDs in a project seem to be working, but very dimly, this is likely what is going on.

Same registers (internal chip memory locations) that control whether a pin is HIGH or LOW control the pull-up resistors. Consequently, a pin that is configured to have pull-up resistors turned on when the pin is in INPUTmode, will have the pin configured as HIGH if the pin is then switched to an OUTPUT mode with pinMode(). This works in the other direction as well, and an output pin that is left in a HIGH state will have the pull-up resistor set if switched to an input with pinMode().

Pins Configured as OUTPUT

Pins configured as OUTPUT with pinMode() are said to be in a low-impedance state. This means that they can provide a substantial amount of current to other circuits. Atmega pins can source (provide positive current) or sink (provide negative current) up to 40 mA (milliamps) of current to other devices/circuits. This is enough current to brightly light up an LED (do not forget the series resistor), or run many sensors but not enough current to run relays, solenoids, or motors.

Attempting to run high current devices from the output pins, can damage or destroy the output transistors in the pin, or damage the entire Atmega chip. Often, this results in a "dead" pin in the microcontroller but the remaining chips still function adequately. For this reason, it is a good idea to connect the OUTPUT pins to other devices through 470Ω or 1k resistors, unless maximum current drawn from the pins is required for a particular application.

pinMode() Function

The pinMode() function is used to configure a specific pin to behave either as an input or an output. It is possible to enable the internal pull-up resistors with the mode INPUT_PULLUP. Additionally, the INPUT mode explicitly disables the internal pull-ups.

Serial

Serial communication on pins TX/RX uses TTL logic levels (5V or 3.3V depending on the board). Don't connect these pins directly to an RS232 serial port; they operate at +/- 12V and can damage your Arduino board. Serial is used for communication between the Arduino board and a computer or other devices. All Arduino boards have at least one serial port (also known as a UART or

USART): Serial. It communicates on digital pins 0 (RX) and 1 (TX) as well as with the computer via USB. Thus, if you use these functions, you cannot also use pins 0 and 1 for digital input or output.

You can use the Arduino environment's built-in serial monitor to communicate with an Arduino board. Click the serial monitor button in the toolbar and select the same baud rate used in the call to begin ().

The Arduino Mega has three additional serial ports: Serial1 on pins 19 (RX) and 18 (TX), Serial2 on pins 17 (RX) and 16 (TX), Serial3 on pins 15 (RX) and 14 (TX). To use these pins to communicate with your personal computer, you will need an additional USB-to-serial adaptor, as they are not connected to the Mega's USB-to-serial adaptor. To use them to communicate with an external TTL serial device, connect the TX pin to your device's RX pin, the RX to your device's TX pin, and the ground of your Mega to your device's ground.

The Arduino Due has three additional 3.3V TTL serial ports: Serial1 on pins 19 (RX) and 18 (TX); Serial2 on pins 17 (RX) and 16 (TX), Serial3 on pins 15 (RX) and 14 (TX). Pins 0 and 1 are also connected to the corresponding pins of the ATmega16U2 USB-to-TTL Serial chip, which is connected to the USB debug port. Additionally, there is a native USB-serial port on the SAM3X chip, *SerialUSB*'.

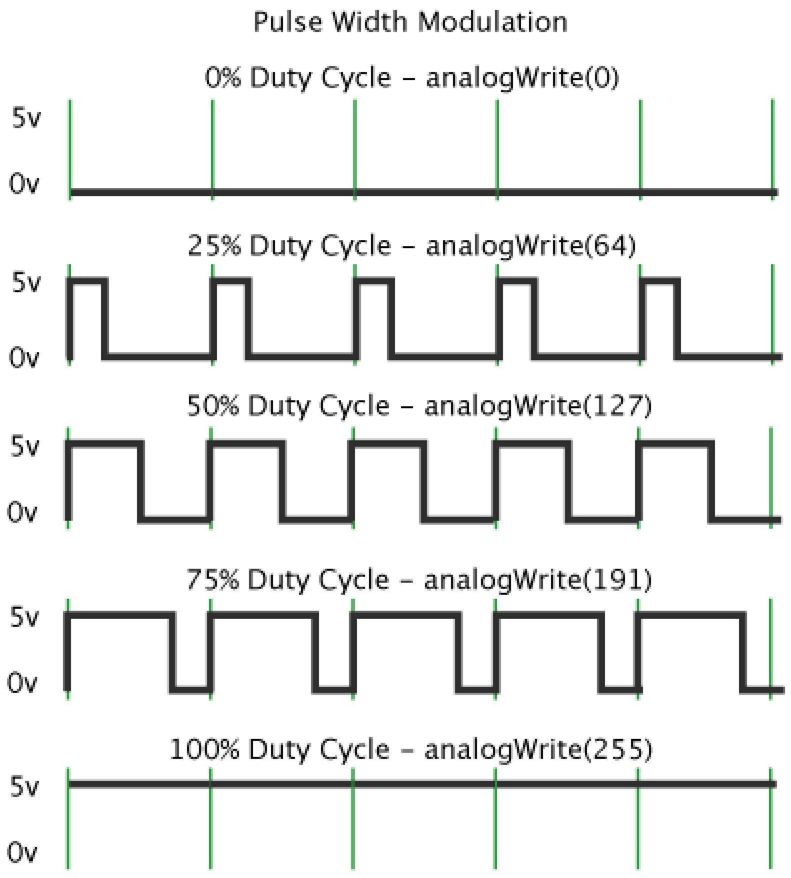
The Arduino Leonardo board uses Serial1 to communicate via TTL (5V) serial on pins 0 (RX) and 1 (TX). Serial is reserved for USB CDC communication. For more information, refer to the Leonardo getting started page and hardware page.

PWM

The Fading example demonstrates the use of analog output (PWM) to fade an LED. It is available in the File->Sketchbook->Examples->Analog menu of the Arduino software.

Pulse Width Modulation, or PWM, is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off. This on-off pattern can simulate voltages in between the full Vcc of the board (e.g., 5 V on Uno, 3.3 V on a MKR board) and off (0 Volts) by changing the portion of the time the signal spends on versus the time that the signal spends off. The duration of "on time" is called the pulse width. To get varying analog values, you change, or modulate, that pulse width. If you repeat this on-off pattern fast enough with an LED for example, the result is as if the signal is a steady voltage between 0 and Vcc controlling the brightness of the LED.

In the graphic below, the green lines represent a regular time period. This duration or period is the inverse of the PWM frequency. In other words, with Arduino's PWM frequency at about 500Hz, the green lines would measure 2 milliseconds each. A call to analogWrite() is on a scale of 0 - 255, such that analogWrite(255) requests a 100% duty cycle (always on), and analogWrite(127) is a 50% duty cycle (on half the time) for example.


Pulse Width Modulation
0% Duty Cycle - analogWrite(0)
5v
0v
25% Duty Cycle - analogWrite(64)
5v
0v
50% Duty Cycle - analogWrite(127)
5v
0v
75% Duty Cycle - analogWrite(191)
5v
0v
100% Duty Cycle - analogWrite(255)
5v
0v

Once you get this example running, grab your arduino and shake it back and forth. What you are doing here is essentially mapping time across the space. To our eyes, the movement blurs each LED blink into a line. As the LED fades in and out, those little lines will grow and shrink in length. Now you are seeing the pulse width.

ADC on the Arduino

It can vary greatly between microcontroller. The ADC on the Arduino is a 10-bit ADC meaning it has the ability to detect 1,024 (2^10) discrete analog levels. Some microcontrollers have 8-bit ADCs (2^8 = 256 discrete levels) and some have 16-bit ADCs (2^16 = 65,536 discrete levels).

The way an ADC works is fairly complex. There are a few different ways to achieve this feat (see Wikipedia for a list), but one of the most common technique uses the analog voltage to charge up an internal capacitor and then measure the time it takes to discharge across an internal resistor. The microcontroller monitors the number of clock cycles that pass before the capacitor is discharged. This number of cycles is the number that is returned once the ADC is complete.

Interfacing with different type of Sensors and Communication modules

1. **Bluetooth Module**

Bluetooth module HC-05 is a MASTER/SLAVE module. The Role of the module (Master or Slave) can be configured only by AT COMMANDS It provides full duplex wireless communication. The slave modules cannot initiate a connection to another Bluetooth device, but can accept connections. Master module can initiate a connection to other devices. The user can use it simply for a serial port replacement to establish connection between MCU and GPS, PC This module can also be used to communicate between two microcontrollers like Arduino Uno. Or the microcontroller can communicate with Bluetooth enabled devices like phone or laptop. The module uses USART at 9600 baud rate for communication. Bluetooth network can be established in a point to point master-slave method, master and upto 7 slave piconet networks and scatter net.

2. **ZigBee**

It is mainly built to control the sensor networks and follows IEEE 802.15.4 standard for wireless area network (WPAN). It uses physical and media access control layer in order to handle many devices at low data rates. It is low cost and low powered with mesh network which can be deployed for controlling and monitoring the application. It covers a range of 10 100 meters. Zigbee system structure consist of three different types of devices such as ZigBee coordinator, router and end device. Coordinator is responsible for handling and storing the information. While performing receiving and data operations. Zigbee routers acts as intermediate devices that permit the data to pass to and fro from them to other devices. End devices has limited functionality to communicate to the parent nodes. ZigBee supports multiple network structures, which mainly include star, tree, and mesh network

3. Wi-Fi Module

ESP8266 is a self-contained SOC (system on chip). It has an integrated TCP/IP stack. It is also a 32-bit microcontroller. Using the TCP/IP protocol the microcontroller can access Wi-Fi network. ESP8266 is an extremely cost effective board and is powerful enough on board processing and storage capability. So that it can be integrated with the sensors and other application specific devices through its GPOIs.

4. RF-Module

RF module is an electronic device which is used to transmit or receive radio signals between two devices wirelessly. RF communication has two components transmitter and receiver. It can transmit up to a range of 500 feet. Frequency ranges from 30Khz to 300Ghz. Signals. Since RF signals can travel long distances it is suitable for long range application and also RF transmission is stronger than IR. And it is also reliable. Also RF communication uses specific frequency.

What is a timer?

A timer or to be more precise a timer / counter is a piece of hardware builtin the Arduino controller (other controllers have timer hardware, too). It is like a clock, and can be used to measure time events.
The timer can be programmed by some special registers. You can configure the prescaler for the timer, or the mode of operation and many other things.
The controller of the Arduino is the Atmel AVR ATmega168 or the ATmega328. These chips are pin compatible and only differ in the size of internal memory. Both have 3 timers, called timer0, timer1 and timer2. Timer0 and timer2 are 8bit timer, where timer1 is a 16bit timer. The most important difference between 8bit and 16bit timer is the timer resolution. 8bits means 256 values where 16bit means 65536 values for higher resolution.
The controller for the Arduino Mega series is the Atmel AVR ATmega1280 or the ATmega2560. Also identical only differs in memory size. These controllers have 6 timers. Timer 0, timer1 and timer2 are identical to the ATmega168/328. The timer3, timer4 and timer5 are all 16bit timers, similar to timer1.
All timers depends on the system clock of your Arduino system. Normally the system clock is 16MHz, but for the Arduino Pro 3,3V it is 8Mhz. So be careful when writing your own timer functions.
The timer hardware can be configured with some special timer registers. In the Arduino firmware all timers were configured to a 1kHz frequency and interrupts are gerally enabled.

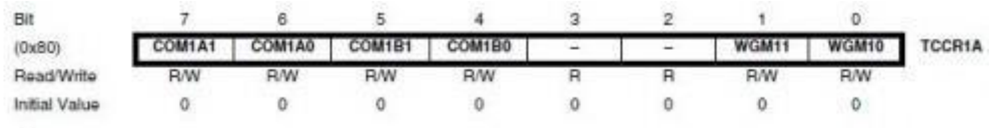
Timer0:
Timer0 is a 8bit timer.
In the Arduino world timer0 is been used for the timer functions,
like delay() 986, millis() 2.2k and micros() 989. If you change timer0 registers, this may influence the Arduino timer function. So you should know what you are doing.

Timer1:
Timer1 is a 16bit timer.
In the Arduino world the Servo library 1.5k uses timer1 on Arduino Uno (timer5 on Arduino Mega).

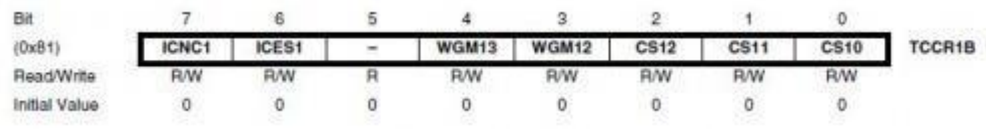
Timer2:
Timer2 is a 8bit timer like timer0.
In the Arduino work the tone() 1.3k function uses timer2.

Timer3, Timer4, Timer5:
Timer 3,4,5 are only available on Arduino Mega boards. These timers are all 16bit timers.

Timer Register
You can change the Timer behaviour through the timer register. The most important timer registers are:
TCCRx - Timer/Counter Control Register. The prescaler can be configured here.



Bit	7	6	5	4	3	2	1	0	
(0x80)	COM1A1	COM1A0	COM1B1	COM1B0	–	–	WGM11	WGM10	TCCR1A
Read/Write	R/W	R/W	R/W	R/W	R	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	



Bit	7	6	5	4	3	2	1	0	
(0x81)	ICNC1	ICES1	–	WGM13	WGM12	CS12	CS11	CS10	TCCR1B
Read/Write	R/W	R/W	R	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

TCNTx - Timer/Counter Register. The actual timer value is stored here. OCRx - Output Compare Register
ICRx - Input Capture Register (only for 16bit timer)
TIMSKx - Timer/Counter Interrupt Mask Register. To enable/disable timer interrupts. TIFRx - Timer/Counter Interrupt Flag Register. Indicates a pending timer interrupt.

Clock select and timer frequency

Different clock sources can be selected for each timer independently. To calculate the timer frequency (for example 2Hz using timer1) you will need:

1. CPU frequency 16Mhz for Arduino
2. maximum timer counter value (256 for 8bit, 65536 for 16bit timer)
3. Divide CPU frequency through the choosen prescaler (16000000 / 256 = 62500)
4. Divide result through the desired frequency (62500 / 2Hz = 31250)
5. Verify the result against the maximum timer counter value (31250 < 65536 success) if fail, choose bigger prescaler.

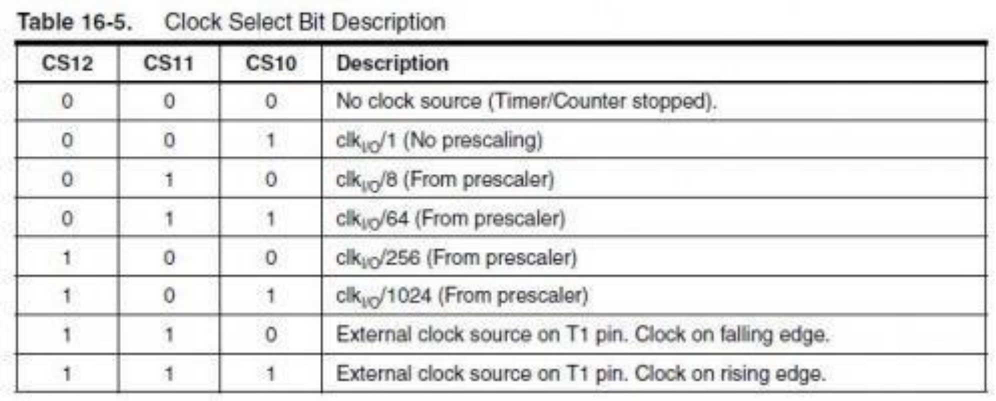


Table 16-5. Clock Select Bit Description

CS12	CS11	CS10	Description
0	0	0	No clock source (Timer/Counter stopped).
0	0	1	$clk_{I/O}$/1 (No prescaling)
0	1	0	$clk_{I/O}$/8 (From prescaler)
0	1	1	$clk_{I/O}$/64 (From prescaler)
1	0	0	$clk_{I/O}$/256 (From prescaler)
1	0	1	$clk_{I/O}$/1024 (From prescaler)
1	1	0	External clock source on T1 pin. Clock on falling edge.
1	1	1	External clock source on T1 pin. Clock on rising edge.

Timer modes

Timers can be configured in different modes.
PWM mode. Pulth width modulation mode. the OCxy outputs are used to generate PWM signals
CTC mode. Clear timer on compare match. When the timer counter reaches the compare match register, the timer will be cleared.

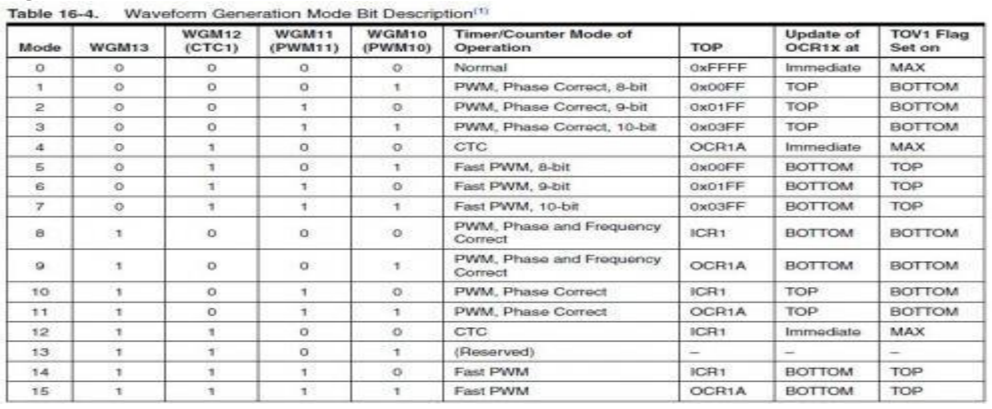


Table 16-4. Waveform Generation Mode Bit Description[1]

Mode	WGM13	WGM12 (CTC1)	WGM11 (PWM11)	WGM10 (PWM10)	Timer/Counter Mode of Operation	TOP	Update of OCR1x at	TOV1 Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCR1A	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICR1	BOTTOM	BOTTOM
9	1	0	0	1	PWM, Phase and Frequency Correct	OCR1A	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICR1	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCR1A	TOP	BOTTOM
12	1	1	0	0	CTC	ICR1	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICR1	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCR1A	BOTTOM	TOP

A **watchdog timer (WDT)** is a hardware timer that automatically generates a system reset if the main program neglects to periodically service(reset) it. The Watchdog Timer is clocked from a separate On-chip Oscillator which runs at 1 MHz. This is the typical value at V CC = 5V. It is often used to automatically reset an Arduino that hangs because of a software or hardware fault. Some systems may also refer to it as a computer operating properly (COP) timer. All Arduino boards have watchdog timer hardware.

What is an interrupt?
The program running on a controller is normally running sequentially instruction by instruction. An interrupt is an external event that interrupts the running program and runs a special interrupt service routine (ISR). After the ISR has been finished, the running program is continued with the next instruction. Instruction means a single machine instruction, not a line of C or C++ code.
Before an pending interrupt will be able to call a ISR the following conditions must be true:

- Interrupts must be generally enabled
- the according Interrupt mask must be enabled

Interrupts can generally enabled / disabled with the
function interrupts() 402 / noInterrupts() 93. By default in the Arduino firmware interrupts are enabled. Interrupt masks are enabled / disabled by setting / clearing bits in the Interrupt mask register (TIMSKx).
When an interrupt occurs, a flag in the interrupt flag register (TIFRx) is been set. This interrupt will be automatically cleared when entering the ISR or by manually clearing the bit in the interrupt flag register.The Arduino functions attachInterrupt() 476 and detachInterrupt() 82 can only be used for external interrupt pins. These are different interrupt sources, not discussed here.

Timer Interrupts
A timer can generate different types of interrupts. The register and bit definitions can be found in the processor data sheet (Atmega328 463 or Atmega2560 439) and in the I/O definition header file (iomx8.h for Arduino, iomxx0_1.h for Arduino Mega in the hardware/tools/avr/include/avr folder). The suffix x stands for the timer number (0..5), the suffix y stands for the output number (A,B,C), for example TIMSK1 (timer1 interrupt mask register) or OCR2A (timer2 output compare register A).

Timer Overflow:
Timer overflow means the timer has reached is limit value. When a timer overflow interrupt occurs, the timer overflow bit TOVx will be set in the interrupt flag register TIFRx. When the timer overflow interrupt enable bit TOIEx in the interrupt mask register TIMSKx is set, the timer overflow interrupt service routine ISR(TIMERx_OVF_vect) will be called.

Output Compare Match:
When a output compare match interrupt occurs, the OCFxy flag will be set in the interrupt flag register TIFRx . When the output compare interrupt enable bit OCIExy in the interrupt mask register TIMSKx is set, the output compare match interrupt service ISR(TIMERx_COMPy_vect) routine will be called.

Timer Input Capture:
When a timer input capture interrupt occurs, the input capture flag bit ICFx will be set in the interrupt flag register TIFRx. When the input capture interrupt enable bit ICIEx in the interrupt mask register TIMSKx is set, the timer input capture interrupt service routine ISR(TIMERx_CAPT_vect) will be called.

PWM and timer
There is fixed relation between the timers and the PWM capable outputs. When you look in the data sheet or the pinout of the processor these PWM capable pins have names like OCRxA, OCRxB or OCRxC (where x means the timer number 0..5). The PWM functionality is often shared with other pin functionality.
The Arduino has 3Timers and 6 PWM output pins. The relation between timers and PWM outputs is:
Pins 5 and 6: controlled by timer0
Pins 9 and 10: controlled by timer1

Pins 11 and 3: controlled by
timer2On the Arduino Mega we have
6 timers and 15 PWM outputs:
Pins 4 and 13: controlled by timer0
Pins 11 and 12: controlled by timer1
Pins 9 and10: controlled by timer2
Pin 2, 3 and 5: controlled by timer 3
Pin 6, 7 and 8: controlled by timer 4
Pin 46, 45 and 44:: controlled by timer 5

PWM and timer
There is fixed relation between the timers and the PWM capable outputs. When you look in the data sheet or the pinout of the processor these PWM capable pins have names like OCRxA, OCRxB or OCRxC (where x means the timer number 0..5). The PWM functionality is often shared with other pin functionality.
The Arduino has 3Timers and 6 PWM output pins. The relation between timers and PWM outputs is:
Pins 5 and 6: controlled by timer0
Pins 9 and 10: controlled by timer1
Pins 11 and 3: controlled by timer2

Controlling Embedded system based devices

The following example reads a pushbutton connected to a digital input and turns on an LED connected to a digital output when the button is pressed. The circuit is shown in Fig. 5.3

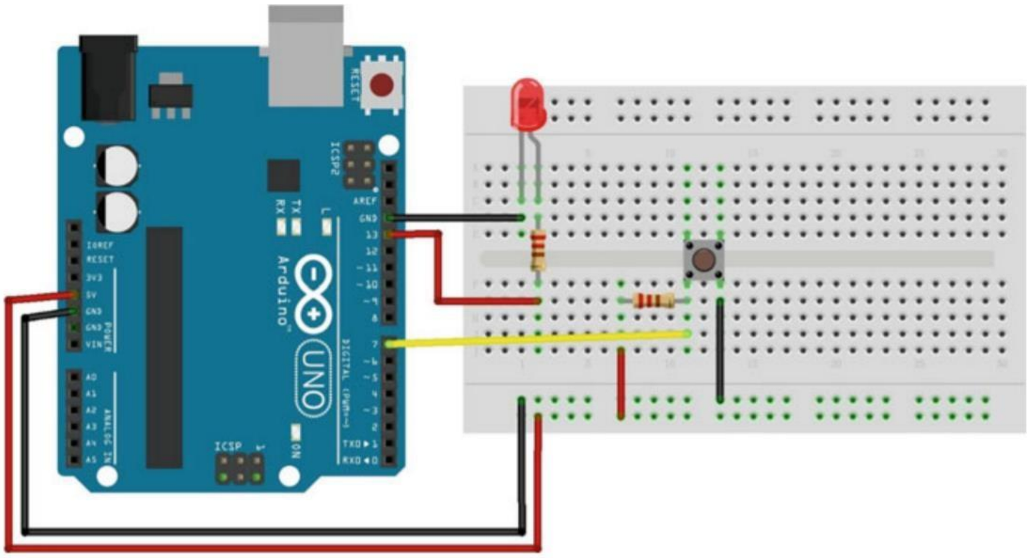


Figure 5.3 Circuit layout for digital signal read and write

```
int led = 13;   // connect LED to pin 13
int pin = 7;    // connect pushbutton to pin 7
int value = 0; // variable to store the read value

void setup() {
  pinMode(led, OUTPUT);   // set pin 13 as output
  pinMode(pin, INPUT);    // set pin 7 as input
}
void loop() {
  value = digitalRead(pin); // set value equal to the pin 7 input
  digitalWrite(led, value); // set LED to the pushbutton value
}

```

The following example reads an analog value from an analogy input pin, converts the value by dividing by 4, and outputs a PWM signal on a PWM pin (Fig. 5.4).

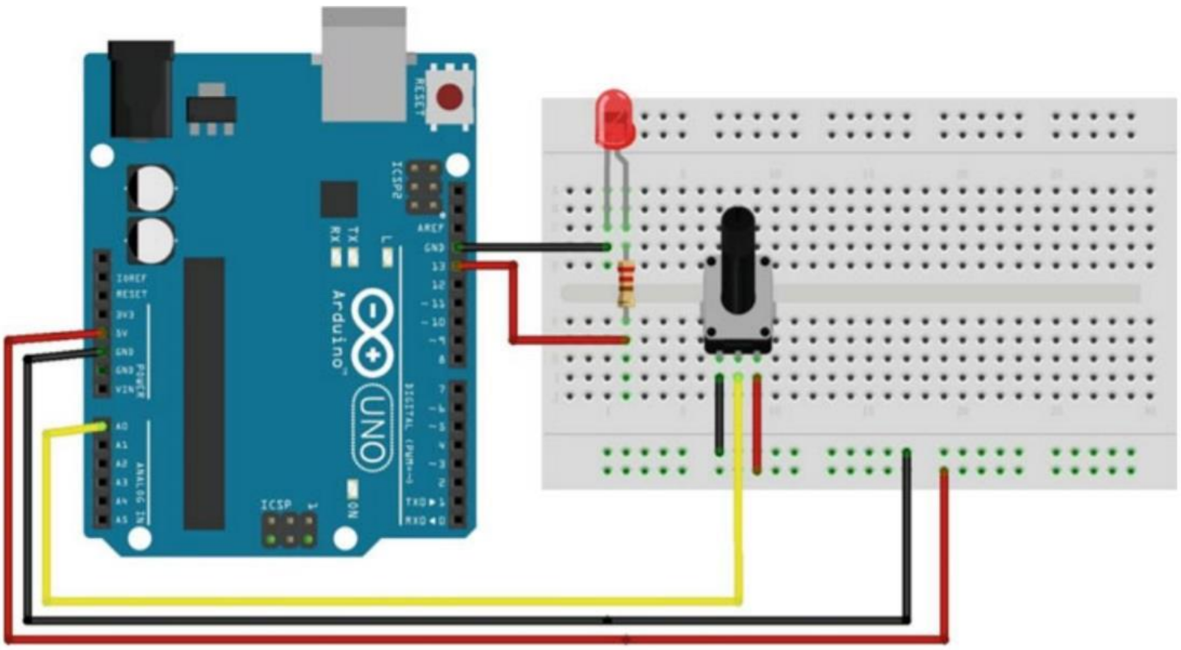


Figure 5.4 Circuit layout for analogy signal read and write

```
int led = 13;   // connect LED to pin 13
int pin = 0;    // potentiometer on analogy pin 0
int value = 0; // variable to store the read value

void setup() {
}
void loop() {
  value = analogRead(pin); // set value equal to the pin 0’s input
  value /= 4;               // converts 0-1023 to 0-255
  analogWrite(led, value); // output PWM signal to LED
}
```

In this example, we will be using the 74HC595 8-bit shift register, which you can pick up from most places at a very reasonable price. This shift register will provide us with a total of eight extra pins to use. The layout is as follows (Fig. 5.5). In this example, we increment the currentLED variable and pass it to the bitSet method. The bit is set to the left of the previous one to 1 every time, thereby informing the shift register to activate the output to the left of the previous one. As a result, the LEDs light up one by one.

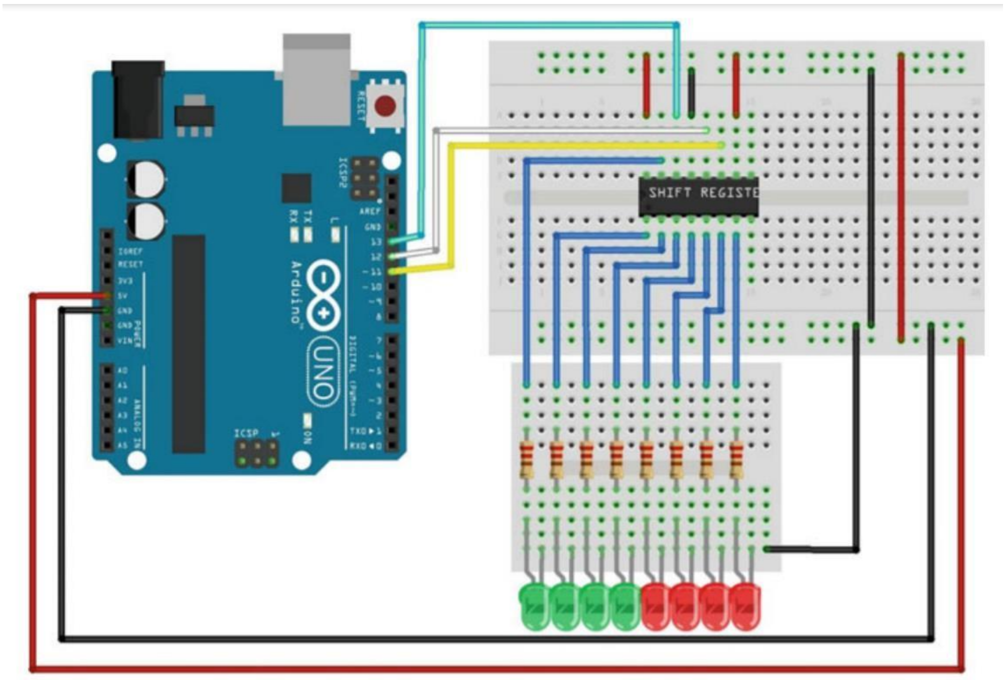
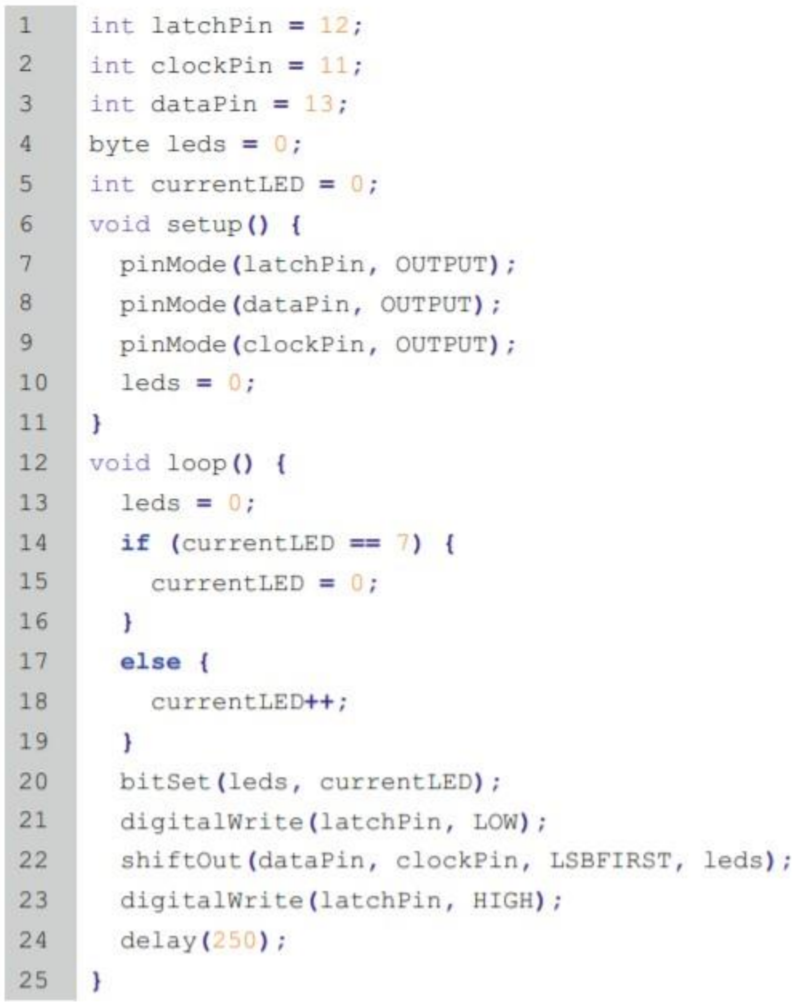


Figure 5.5 Circuit layout for the shift register



```
int latchPin = 12;
int clockPin = 11;
int dataPin = 13;
byte leds = 0;
int currentLED = 0;
void setup() {
  pinMode(latchPin, OUTPUT);
  pinMode(dataPin, OUTPUT);
  pinMode(clockPin, OUTPUT);
  leds = 0;
}
void loop() {
  leds = 0;
  if (currentLED == 7) {
    currentLED = 0;
  }
  else {
    currentLED++;
  }
  bitSet(leds, currentLED);
  digitalWrite(latchPin, LOW);
  shiftOut(dataPin, clockPin, LSBFIRST, leds);
  digitalWrite(latchPin, HIGH);
  delay(250);
}
```

In this example, we blink the built-in LED every 500 ms, during which time both interrupt pins are monitored. When the button on the interrupt 0 is pressed, the value for micros() is displayed on the Serial Monitor, and when the button on the interrupt 1 is pressed, the value for millis() is displayed (Fig. 5.6).

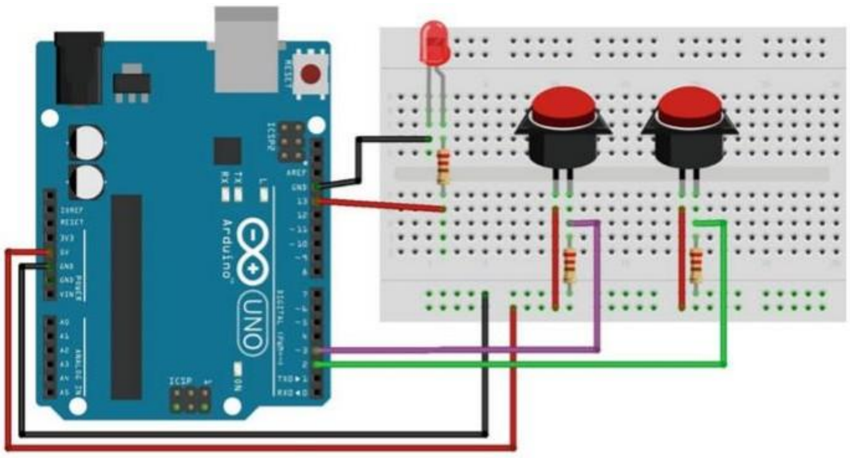
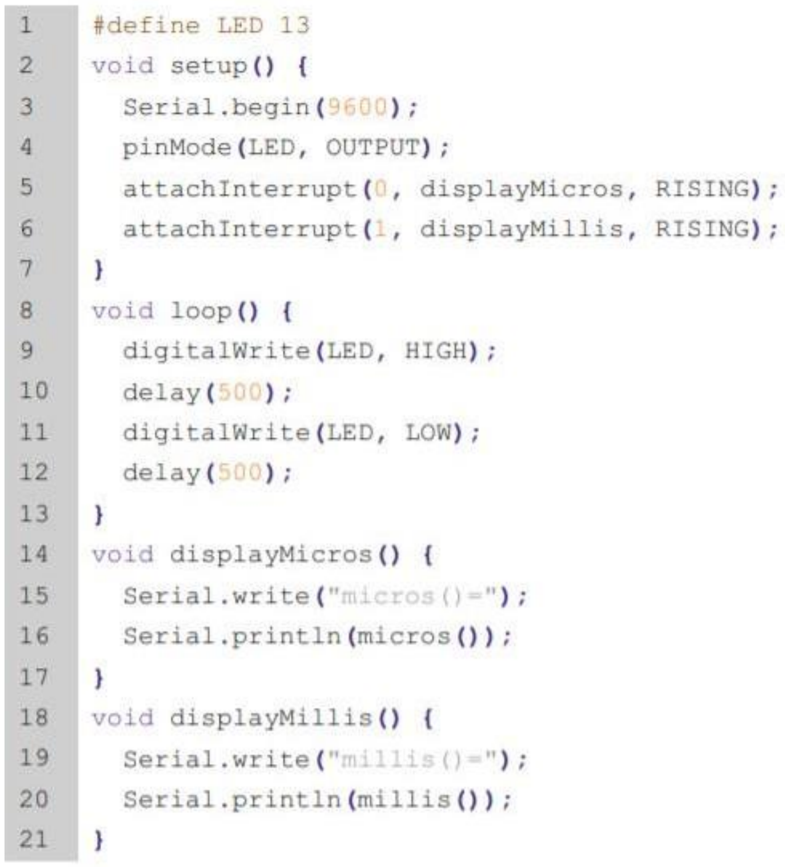


Figure 5.6 The circuit for interrupts and time functions



```
#define LED 13
void setup() {
  Serial.begin(9600);
  pinMode(LED, OUTPUT);
  attachInterrupt(0, displayMicros, RISING);
  attachInterrupt(1, displayMillis, RISING);
}
void loop() {
  digitalWrite(LED, HIGH);
  delay(500);
  digitalWrite(LED, LOW);
  delay(500);
}
void displayMicros() {
  Serial.write("micros()=");
  Serial.println(micros());
}
void displayMillis() {
  Serial.write("millis()=");
  Serial.println(millis());
}
```

Light Sensitive Sensors

Introduction Light sensitive sensors are electromagnetic radiation detectors that function in the ultraviolet to far infrared spectral range. The electric signal of a light sensor can be produced by either a quantum or thermal response from a sensing material when photons are absorbed by such material. Therefore, light sensors can be divided into two major groups, quantum and thermal. Light sensors rely on the interaction of individual photons with a crystalline lattice of semiconductor materials. Their operations are based on the photo-effect, which requires, at the least, the energy of a single photon concentrated into localized bundles under certain circumstances.

Photodiodes

A photodiode is a reverse-biased semiconducting optical sensor that is biased against its easy flow direction so that the current is very low. Such a device has a band structure (such as a P-N junction) in which the permitted energies in the structure change. In a photodiode, an electron is freed when a photon is absorbed, it may pass over the energy barrier if it possesses enough energy. In this respect, the photodiode only produces a current if the absorbed photon has more energy than that needed to traverse the P-N junction. The photodiode is said to have a cutoff wavelength because the lesser the wavelength of light responses the greater the energy. Therefore, a photodiode produces detectable currents for photons with wavelength less than the cutoff, while a current is not produced if the wavelengths of the photons are greater than the cutoff. The voltage of the PIN port changes when Q1 absorbs photons with wavelengths greater than the cutoff. Else, Q1 is not available for the current conduction.

Demonstration

Components

1. • DFRobot UNO R3 board and USB cable 1.
2. • DFR0026 (analog ambient light sensor) 1.
3. • LED 1. • Resistor (220 X) 1.
4. • Jumper wires n.

Hardware Setting

DFR0026 has three pins: VCC, Output, and GND. The VCC should be connected to 5 V and the GND to a common ground with your Arduino. The Output pin of DFR0026 should be plugged into a defined pin on the DFRobot UNO R3 board (here, analog input PIN 0)

3. Sample Codes

```
int LED = 13; //define LED digital pin 13
int LIGHT = 0; //define light analog pin 0
int val = 0; //define the voltage value
void setup() {
  pinMode(LED, OUTPUT); //Configure LED as output mode
  Serial.begin(9600); //Configure baud rate 9600
}
void loop() {
  val = analogRead(LIGHT); // Read voltage value (0 - 1023)
  Serial.println(val); // read voltage value from serial monitor
  if (val < 700) { // If lower than 700, turn off LED
    digitalWrite(LED, LOW);
  }
  else { // Otherwise turn on LED
    digitalWrite(LED, HIGH);
  }
  delay(10); // delay for 10ms
}
```

Results

After uploading the code, you can shine a flashlight on the photodiode to alter the light levels in the environment. When it is dark, the LED should light up. When it is bright, the LED should turn off. Light Sensitive Sensors 47 Furthermore, you can open the serial monitor (Baudrate = 9600) and see what outputs the photodiode provides. Then, use the number you receive as a comparison number to alter the sensitivity of the circuit (Fig. 5.7).

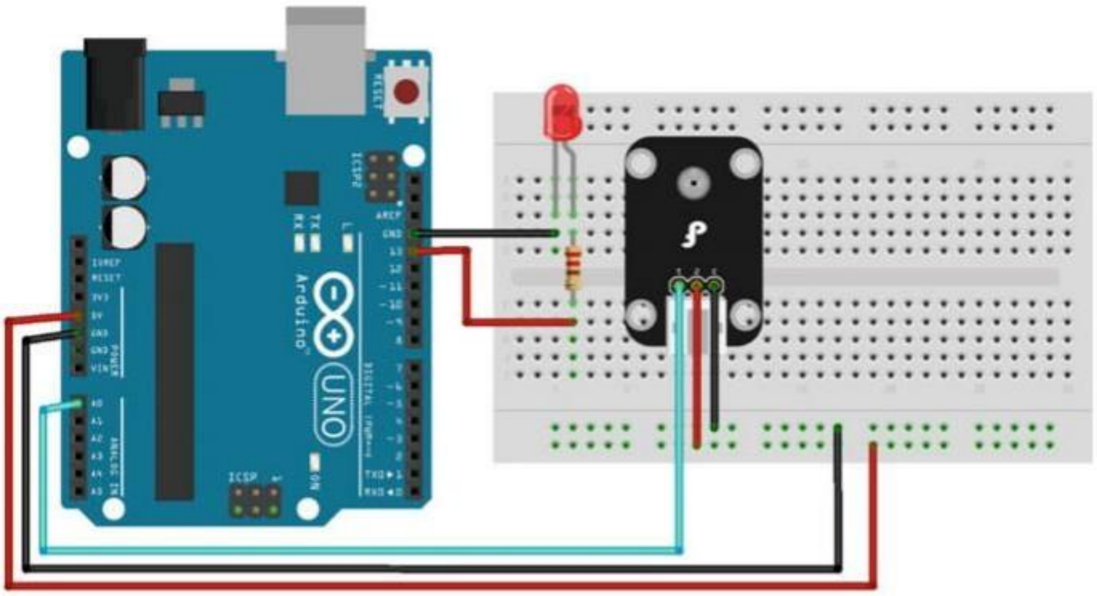
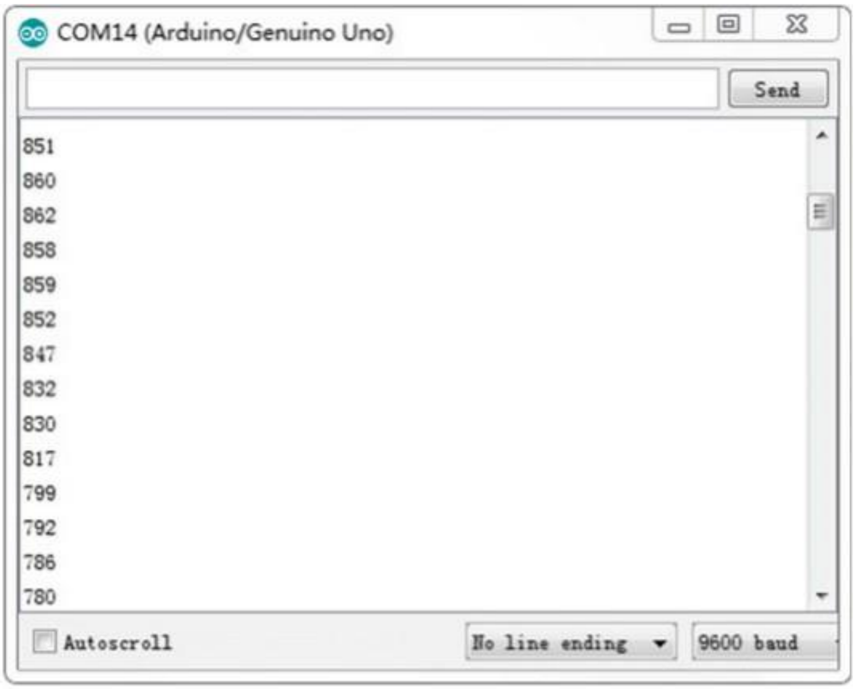


Figure 5.7 A diagram of the layout of the DFR0026 and UNO R3



```
851
860
862
858
859
852
847
832
830
817
799
792
786
780
```

Log messages from Arduino using DFR0026

Figure 5.8 Output specifications

Electromechanical Control Using the Arduino

DC Motor

DC motors are becoming increasingly common in a variety of motor applications such as fans, pumps, appliances, automation, and automotive drive. The reasons for their increased popularity are better speed versus torque characteristics, high efficiency, long operating life, and noiseless operation. In addition to these advantages, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. This makes them attractive options for designers who are interested in robotics. You can run a DC motor by supplying a voltage difference across its leads. However, you need to overcome certain challenges in order to drive them effectively. The most common goals are variable speed and direction. To control the direction of the spin of DC motors, without changing the way that the leads are connected, an H-Bridge is commonly used.

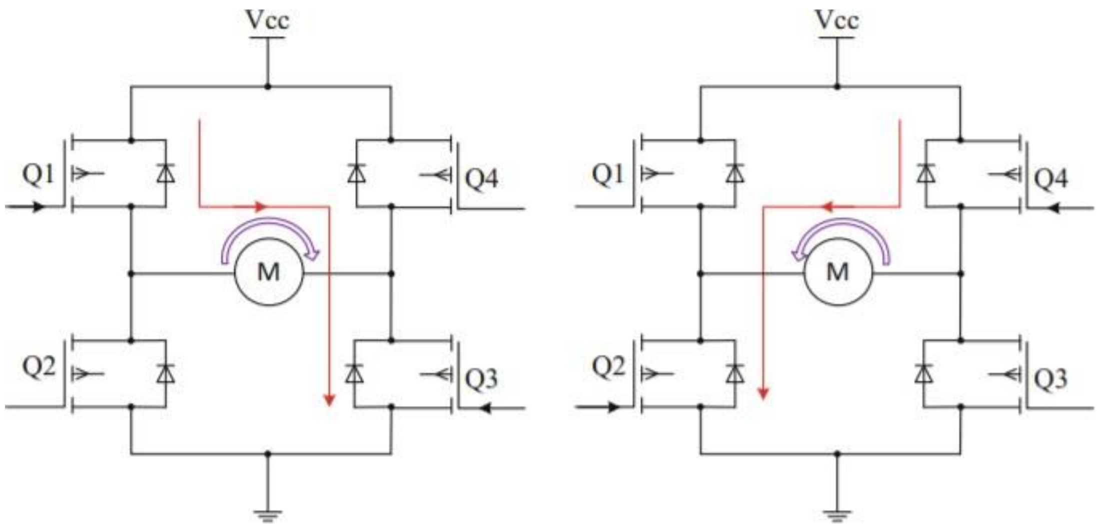


Figure 5.9 H Bridge

An H-bridge is an electronic circuit that can drive the motor in both directions. As shown in Fig. 5.9n, one H-bridge uses four transistors connected in such a way that the schematic diagram appears like an ―H‖. The basic operating mode of an H-bridge is fairly simple: if Q1 and Q3 are turned on, the left lead of the motor is connected to the power supply, while the right lead is connected to the ground. Current starts flowing through the motor, which energizes the motor in (let us say) the forward direction and the motor shaft starts spinning. If Q4 and Q2 are turned on, the reverse happens, the motor gets energized in the reverse direction, and the shaft will start spinning backwards.

In a bridge, you should never ever close both Q1 and Q2 (or Q3 and Q4) at the same time. If you did that, you may create a really low-resistance path between the power and GND, effectively short-circuiting your power supply. This condition is called ―shoot-through‖ and is an almost guaranteed way to quickly destroy your bridge, or something else in your circuit.

Driven Circuit Design

In a number of cases, especially for little toy motors, you do not need to build a whole H-bridge circuit from scratch. In fact, using a chip can save you a considerable amount of trouble with regard to offset voltages; if you have a different motor supply voltage than your logic voltage, you will need drivers between the logic and the power transistors. There are several packaged IC chips (such as L293D, L298N, TA7257P, SN754410, etc.) that are inexpensive and easy to build into a circuit. The common L293N dual motor controller is a 16-DIP IC chip that contains two protected driver circuits capable of delivering up to 600 mA of continuous current to each motor at up to 36 VDC (see Fig. 5.10). L298N is a similar chip that can deliver 2 amps to each motor. These chips (and others) accept standard 0–5 V input signals and have internal logic gates to prevent accidental overloading and commanding the controller into a destructive state. Notice in Fig. 5.10 that there are six pins labeled IN1, IN2, IN3, IN4, ENA, and ENB. You can use digital pins on the Arduino to control the four input pins and set the motor direction, while using a PWM signal on each enable pin (ENA and ENB) to set the speed of each motor. It should be pointed out that L298N does not have

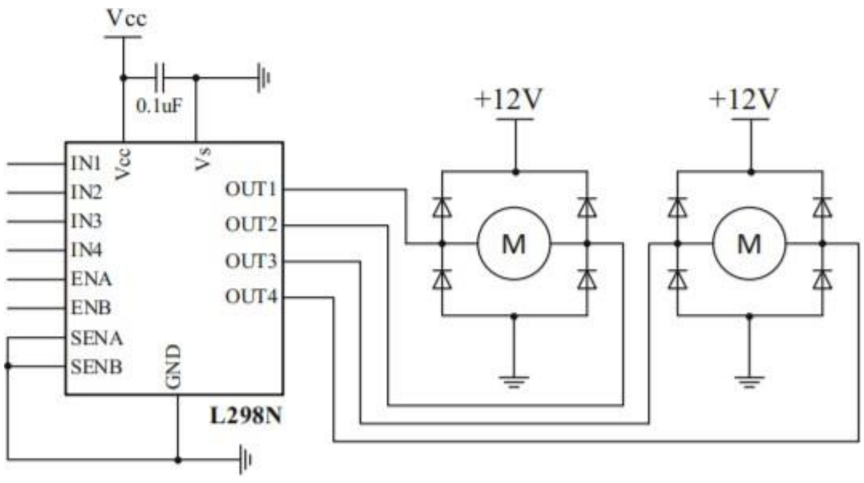
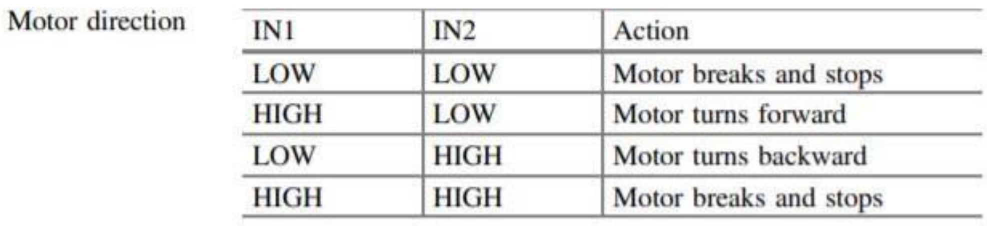


Figure 5.10 Schematic of L298N driven circuit


Motor direction

IN1	IN2	Action
LOW	LOW	Motor breaks and stops
HIGH	LOW	Motor turns forward
LOW	HIGH	Motor turns backward
HIGH	HIGH	Motor breaks and stops

built-in protection diodes, so you will need to add those. The datasheet for the L298N specifies –fast recovery‖ 1-amp diodes; an inexpensive selection is the 1N4933, available from most online electronic parts outlets. Let us look at how to control just one of the motors, Motor1. In order to activate the motor, the pin ENA must be high. You then control the motor and its direction by applying a low or high signal to the Input1 and Input2 lines, as shown in Table .

The L298N H-bridge module can be used with motors that have a voltage of between 5 and 35 V DC.

Demonstration

Components • DFRobot Romeo board and USB cable 1 • DC motor 1 • 9 V battery 1 • Jumper wires n

Hardware Setting

Connect four motor wires to motor terminal. Then, apply power through the motor power terminal (Fig. 5.11). The PWM DC motor control is implemented by manipulating two digital IO pins and two PWM pins. As illustrated in the diagram above (Fig. 5.11), Pins 4 and 7 are motor direction control pins, Pins 5 and 6 are motor speed control pins (shown in Table 5.11).

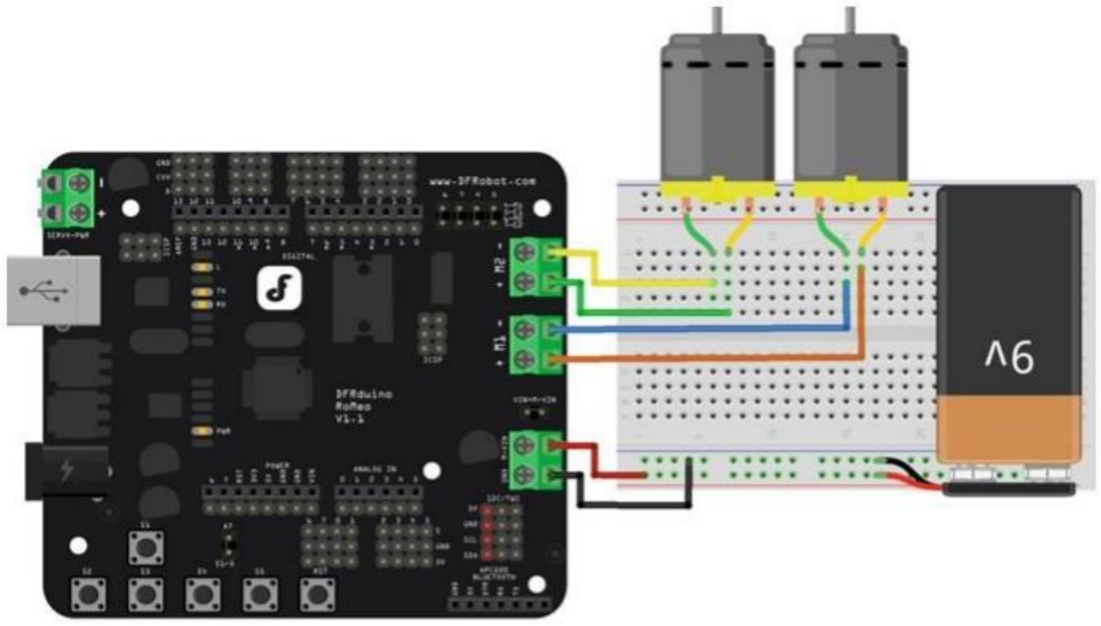
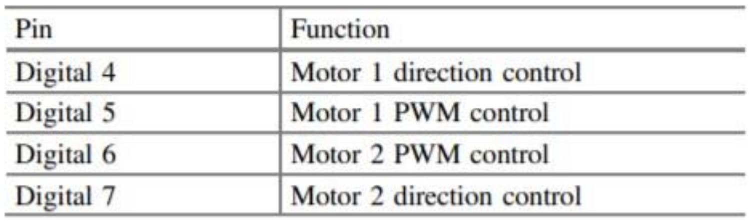


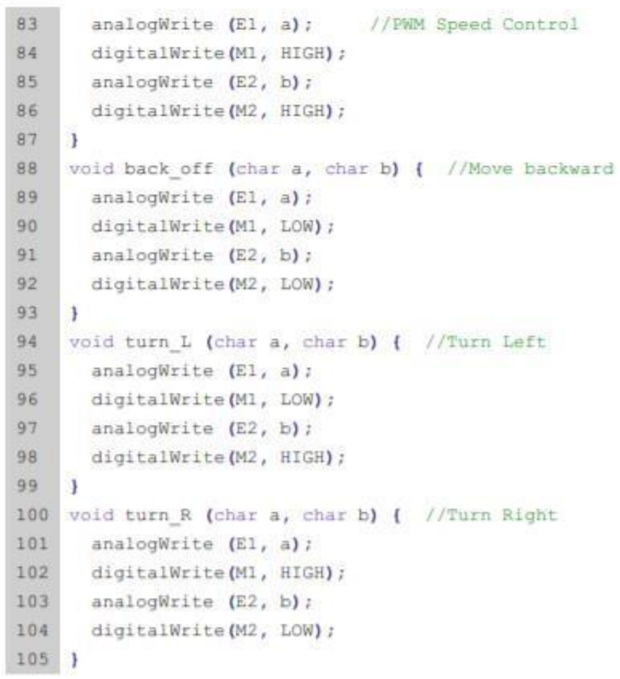
Figure 5.11 Motor connection diagram

PWM mode



Pin	Function
Digital 4	Motor 1 direction control
Digital 5	Motor 1 PWM control
Digital 6	Motor 2 PWM control
Digital 7	Motor 2 direction control

```
#define keyPin A0;  // analogy key input
int E1 = 5;  //M1 Speed Control
int E2 = 6;  //M2 Speed Control
int M1 = 4;  //M1 Direction Control
int M2 = 7;  //M2 Direction Control
unsigned long sampleTime;
unsigned int SampleInterval = 100;    // sampling time is 0.1s
int adc_key_val[5] = {50, 200, 400, 600, 800 }; // threshold for
comparison
boolean blnKey; // flag for against key shake
int NUM_KEYS = 5; // 5 keys
int adc_key_in;
int key = -1;

void setup() {
  Serial.begin(9600); //Configure baud rate 9600
}

void loop() {
  if (millis() - sampleTime >= SampleInterval) {
    sampleTime = millis();
    adc_key_in = analogRead(A0);    // // read the key value
    if (adc_key_in < 1000) { // if key press
      if (blnKey == 0)
        blnKey = 1; // wait for debounce time
      else
        key = get_key(adc_key_in);   // convert into key press
    }
    else {
      key = -1;   // no key press
      blnKey = 0;
    }
  }
  if (key >= 0) {
    switch (key) {
      case 0: {
          Serial.println("S1 OK");
          advance (100, 100);  //move forward
          break;
        }
      case 1: {
            Serial.println("S: OK");
            back_off (100 100); // move backward
            break.'
        }
        case    {
            Serial.println("S:    ');
            turn L (100  100);    turn
            break:
        }
        case    {
            Serial.println("S OK");

            break,'







    }








    i * ( i. *.::. <  ::i' '  •:.:'' val[k]) {

    }
  }


  raturn ".'
}

void stop(void) {

  :li M-   b : (‹.'. i..:V) :
```



```
  analogWrite (E1, a);     //PWM Speed Control
  digitalWrite(M1, HIGH);
  analogWrite (E2, b);
  digitalWrite(M2, HIGH);
}
void back_off (char a, char b) {  //Move backward
  analogWrite (E1, a);
  digitalWrite(M1, LOW);
  analogWrite (E2, b);
  digitalWrite(M2, LOW);
}
void turn_L (char a, char b) {  //Turn Left
  analogWrite (E1, a);
  digitalWrite(M1, LOW);
  analogWrite (E2, b);
  digitalWrite(M2, HIGH);
}
void turn_R (char a, char b) {  //Turn Right
  analogWrite (E1, a);
  digitalWrite(M1, HIGH);
  analogWrite (E2, b);
  digitalWrite(M2, LOW);
}
```

In this example, the PWM DC motor control is implemented by manipulating two digital IO pins and two PWM pins. Furthermore, the move direction is controlled by the button-on-board:
–S0—move forward‖, –S1—move backward‖, –S2—turn left‖, –S3—turn right‖, –S4—stop‖ . The schematic of button-on-board is shown as follows. It can be seen that if no button is pressed, the voltage of Pin A0 is 5 V (1023). If any button is pressed, the voltage of Pin A0 is less than 5 V.

Key Design of Controllable Lock

The controllable lock consists of an electric bolt, Arduino, relay, and buzzer. In this section, we focus on the principle of electric bolt and the usage of relay.

1. Electric Bolt An electric bolt is an electronic control lock, and the extension or retraction of its lock tongue is determined by the on–off status of input current. When the input current is broken, the lock tongue will retract. According to the number of input wires, the electric bolt can be classified into four categories: two-wire, four-wire, five-wire, and eight-wire. Among these categories, the two-wire electric bolt is used most frequently and we also select it for our demonstration system. Figure shows a picture of a two-wire electric bolt. As its name indicates, the two-wire electric bolt has two input wires, neutral wire (black) and live wire (red). The neutral wire should be connected to ground (GND), and the live wire should be connected to the power supply. If any one of these wires is cut off, the lock tongue will retract automatically, and then the door can be opened. Because it can be easily controlled by an input current, it is frequently used on various occasions as a controllable door. Further, it is also suitable for an occasion with high security requirement owing to its characteristic of implicit installation.

2. Relay A relay is an electrically operated switch, which has a control system (also known as

the input circuit) and the controlled system (also known as the output circuit), usually used in automatic control circuit. It is an ―automatic switch‖, using a small electric current to control a larger current. Therefore, the relay has the effects of automatic adjustment, security, conversion circuit in the circuit, and so on.

Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. In the demonstration project, we select a 16A relay module of Arduino suite, and this module can be used to control solenoid valves, lamps, and other equipment. Obviously, it is suitable for controlling the electric bolt. It can be controlled through the digital I/O port of Arduino . Specification Contact Rating (Res. Load): 16A 277VAC/24VDC Maximum switching voltage: 400VAC(NO) Max. switching current: 16A Max. switching power: 4700VA Operate time (at nomi. Vot.): 10ms max Release time (at nomi. Vot.): 5ms max Type: Digital Single relay board Digital Interface Control signal: TTL level. Relay Module Pinout: There are a total of 7 pins on the relay module board. (1) Link Arduino Side: Signal, VCC, and GND. (2) Link Appliance Side

• COM (IN): Input positive wire from appliance • N/A (NC): Not connected • NC (OUT1): Normally closed, which means that when the relay is off (a digital low ―0‖ is received from Arduino) the device is on • NO (OUT2): Normally open, which means that when the relay is on (a digital high ―1‖ is received from Arduino) the device is on.

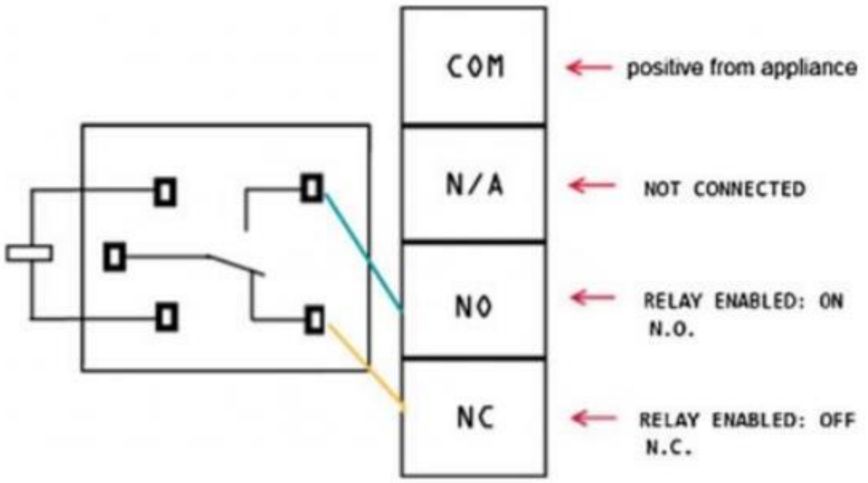


Figure 5.12 Relay control

Plugging in Electric Bolt or Lamp We will use ―out1‖ for connecting the electric bolt, use ―out2‖ to simply reverse the logic, as explained above. It gives an example of plugging in an appliance such as a lamp, we can replace the lamp to the electric bolt, and the connection relationship is the same.

Step 1: Cut and strip a portion of the positive wire so that you end up with two ends of the wire as shown in figure.

Step 2: The relay should have a positive wire of the device being used connected to –IN‖ and to ―Out 1‖ as shown in , and any digital signal pin on the Arduino end.

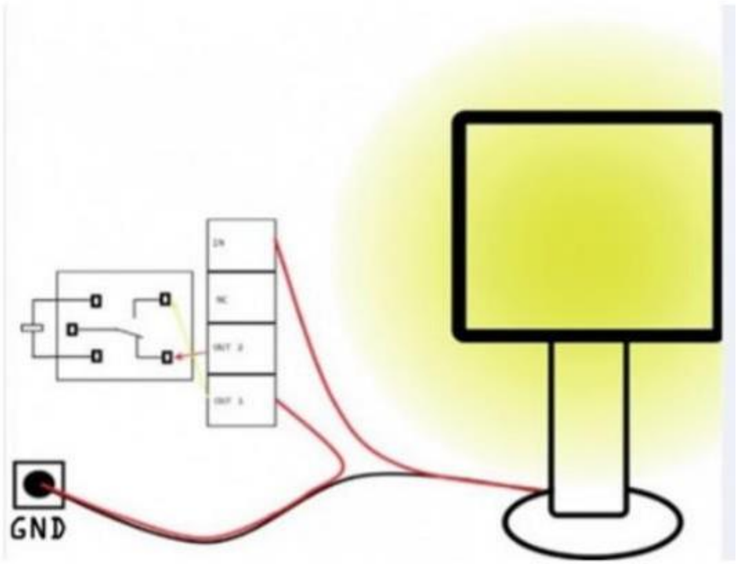
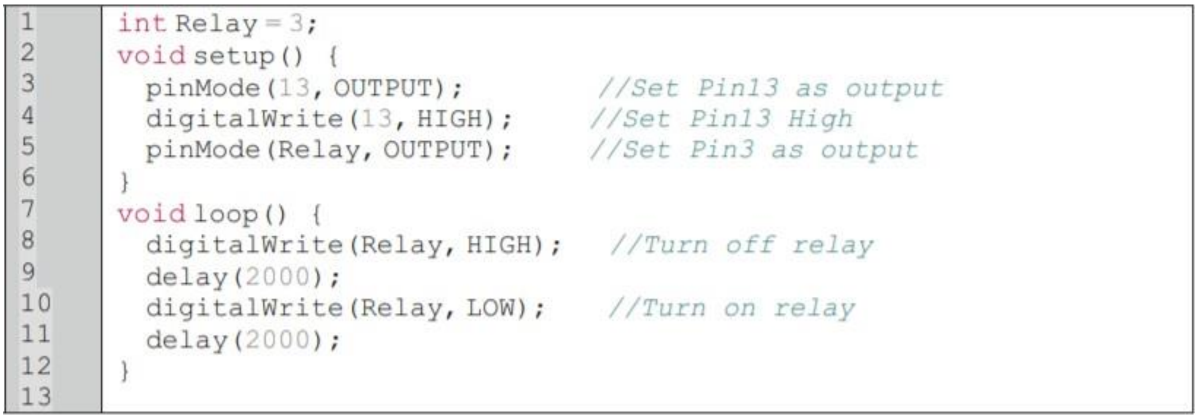


Figure 5.12 Electronic bolt with lamp

Step 3: Sending a digital high or a ―1‖ will trigger the relay. Sending a digital low or ―0‖ will disable the relay. If the relay is disabled, the lock tongue of electric bolt will retract; then, the door will be opened.

Sample Code This sample code is used to test if the relay module works normally.



```
int Relay = 3;
void setup() {
  pinMode(13, OUTPUT);          //Set Pin13 as output
  digitalWrite(13, HIGH);      //Set Pin13 High
  pinMode(Relay, OUTPUT);      //Set Pin3 as output
}
void loop() {
  digitalWrite(Relay, HIGH);    //Turn off relay
  delay(2000);
  digitalWrite(Relay, LOW);     //Turn on relay
  delay(2000);
}
```

TEXT/REFERENCE BOOKS

1. **A.Hayes,Arduino:AQuick Start Beginner’s Guide (Create Space Independent Publishing Platform, 2017)**
2. **M. Banzi, M. Shiloh, Getting Started with Arduino: The Open Source Electronics Prototyping Platform (Maker Media, Inc., 2014)**
3. **Francis,Arduino:TheCompleteBeginner’sGuide(CreateSpaceIndependent Publishing Platform, 2016)**
4. **Massimo Banzi, ―Getting Started with Arduino: The Open Source‖, Shroff Publishers & Distributors Pvt Ltd, 2014**
5. **Simon Monk, ―Programming Arduino: Getting Started with Sketches‖, McGraw-Hill Education, Second Edition,2016**
6. **Margolis, ―Arduino Cookbook‖, Shroff/O'Reilly Publication, 2nd edition 2012**
7. **https://www.arduino.cc/**

Model Question Bank

Part-A

1. Define Arduino
2. Explain how Arduino works?
3. How relays are used with an Arduino?
4. Summarize the concept of PWM on Arduino
5. A pushbutton is connected to a digital input and turns on an LED when that button is pressed-Write a Arduino code to execute the above given sequence.
6. How to calculate the timer frequency for 2Hz?
7. State and Express the concept of watchdog timer.
8. Analyse how to detect the 8 bit/16 bit ADCs levels?
9. To reads an analog value from an analogy input pin, converts the value by dividing by 4, and outputs a PWM signal on a PWM pin- Write a program using Arduino interfacing.
10. List the different type of Communication modules interfacing with Arduino
11. Interpret in your own words AREF description in Arduino Uno Board
12. Sketch the schematic of L298N driven circuit.

Part-B

1. Explain the Arduino Architecture in detail.
2. Analyse the Pin details of Arduino Uno Board
3. Design a 8-bit shift register which increment the LED variable using bit Set method.
4. Note:The bit is set to the left of the previous one to 1 every time, thereby informing the shift register to activate the output to the left of the previous one. As a result, the LEDs light up one by one.
5. Design a flashlight on the photodiode which alters the light levels in the environment using Arduino.
6. Design a DC motor electromechanical Control system Using the Arduino.
7. Design a electronic bolt with the usage of relay Using Arduino.