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TÍTOL: Radio Data Network

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DATA: 5 de Maig de 2006

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Resum

Radio Data Network és el títol d'un producte, un producte sorgit dels resultats de tres anys d'estudis d'enginyeria de Telecomunicacions, i un any més d'enginyeria Elèctrica i Electrònica a la Universitat de Gales. S'ha volgut crear una aplicació a partir de les dues branques, estudiant Radiofreqüència i al mateix temps fent servir mètodes d'electrònica per tal de crear un dispositiu capaç de ser desenvolupat en una aplicació real.

L'aplicació en qüestió es en un zoo. El producte pretén ser una tecnologia útil per a controlar l'hàbitat de tots els animals des d'un mateix lloc, com podria ser una sala de control. Mesurant temperatura ambiental, pressió atmosfèrica, humitat relativa i moltes altres variables. Fent servir els estàndards de la tecnologia 'Sensefils' (Wireless), fent servir simples circuits electrònics a cada hàbitat i utilitzant un hardware i un software d'us generalitzat, com el PC i el sistema operatiu 'Windows', per tal de controlar l'estat dels animals al zoo.

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Overview

Radio Data Network is the title of a product, a product that is the results of three years studying Telecommunications, and one more Electrical and Electronic engineering. I had pretended that the purpose was a mix of both degrees, studying Radiofrequency but at the same time using Electronic methods to create a device able to be developed in a real application.

The application in question is in a zoo, it pretends to be a useful technology to control from one place the habitat features of all the animals, measuring temperature, environmental pressure, relative humidity and more variables, using Wireless standards and simple circuitry in each habitat and common hardware and software, such as PC and operative system 'Windows', to control take care of the animals in the zoo.

Agraïments:

M’agradaria agrair al Sr. Frank Welcomme per haver-me portat aquest projecte amb la seva supervisió. També agrair el coneixement proporcionat per part del professor Sr. Des Adams en sistemes integrats i la paciència del Sr. Roy Harper amb l’administració dels components electrònics. No m’agradaria oblidar l’ajuda rebuda pels estudiants Imanol Barrigón, Sara Alyoum i Antonio Ruiz durant les sessions de laboratori. Tampoc oblidar les sugerencies per a seguir el millor camí, rebudes pels professors Sr. Jordi Berenguer i Sr. Pera Gilabert. També recordo els amics d’aquesta experiència a la Universitat de Gales i els seus ànims des de un principi fins al final. A més del suport rebut per la Srta. Iris Asensio en els moments de frustració. I el meu sempre amic Manel Toledano.

Encara que sense l’encoratjament de part de la Sra. Isabel Millan i el Sr. Angel Ampliato, els meus pares, jo no estaria aquí.

Contents

1. INTRODUCTION

In order to begin is important to explain the meaning of the title of the Project. A network is a group of stations (computers, telephones, or other devices) connected by communications facilities for exchanging information. Connection can be permanent, via cable, or temporary, through telephone or other communications links. The transmission medium can be physical (i.e. fibre optic cable) or wireless (i.e. satellite). The Project is based in a wireless network that use radio-frequency spectrum in order to transmit and to receive information, where the transmission medium is the air. The data is the information of sensors distributed in the habitat of the animals of a zoo. With these data the zoo staff can control remotely the state of the animal habitat environment, and take care of them.

1.1 Background

Distributed Control Systems (DCS) are used in industrial and civil engineering applications to monitor and automatic control distributed equipment with remote human intervention. A DCS is a process control system that uses a network to interconnect sensors, controllers, operator terminals and actuators. A DCS typically contains a single computer for control and uses proprietary interconnections.
It is generally, since the 1970s, digital and normally consists of field instruments, connected via wiring to computer buses or electrical buses to multiplexer, demultiplexers and A/Ds or analog to digital and finally the Human-Machine Interface (HMI) or control consoles.

1.2 Rationale

Three years ago I start Telecommunications degree in University of EPSC, Barcelona. Since 2002 I have waited the moment to construct the most important task in the whole degree, now I am in University of NEWI, Wrexham doing this important fact in another kind of degree, Electrical/Electronic degree.

For these reasons I wanted to work in a Project that has stages of Telecommunications and stages of Electronic, because they are my passion. And I choose after hours and hours thinking this Project. But I needed an application.

All the applications that I thought were Industrial applications, but I did not want a typical Industrial one. So I thought in other of my passions, the animals.

Hence I mix the Telecommunications with the Electronics to build my Project and I choose an animal application, something to take care of them using my degree knowledge.

DCS is a very broad umbrella that describes solutions across a large variety of industries, including:

- Electrical power distribution grids and generation plants
- Traffic signals
- Water management systems
- Refining and chemical plants
- Environmental control systems

Until now Distributed Control Systems' networks used cables for connections. He is considerable for the additional development in DCS to use radio networks technology. This Project is intended to explore it in environmental control system. Particularly it is focused in a Zoo. Where Zoo staff can remotely control the state of the environment in which are living the animals.

1.3 <u>Aims</u>

To build a system of control and data transmission for environmental control system, investigate adequate frequency range to work and create a scalable device (SCS, Scalable Control System).

1.4 <u>Objectives</u>

Investigate an application of RF (Radio Frequency) or Wi-Fi (IEEE 802.11 b/g) in WLANs (Wireless Local Area Network)

- Investigate propagation of waves and develop mathematical models
- Create a system be able to simulate a Radio Data System in real application
- Create a Project be able to solve a communication trouble or improve it
- Develop some antennas to connect devices

1.5 <u>Plans</u>

The planning of the Project will be developed in eight months approximately, Eight months in which every month a Project part will be treated as the Time Plan suggest, in chapter 1.5.2.

1.5.1 Costs

It is difficult to estimate a guess of the total price to build the system. But approximately I suppose that it cost around £30. Taking in account that for the purpose many electronic components will be used, such as resistors, condensators, integrated circuits, LEDs, LCD screen…

1.5.2 Time Plan

October	3 – 9 10 – 16	To research information to start
	17 – 23 24 – 30	To define application of Project, the main target
November	1 – 6 7 – 13 14 – 20 21 – 27 28 – 30	To collect interesting information about different parts of Project. Information about which transducers are interesting to work, characteristics about measurement systems To prepare Report and Log Book to first presentation
December	5 – 11 12 – 18 19 – 25	To summarize all researched in last two months. To begin to design different parts from Radio Data System
January	2 – 8 9 – 15 16 – 22 23 – 29	To design the whole system of measurement. To start the communication system, used to transfer the data to a device. Choose a device in which zoo staff can watch the environment. To prepare Report and Log Book to next month
February	1 – 5 6 – 12 13 – 19 20 – 26	To make tests and measurements of the operation of the design. To correct possible mistakes in the design and improve it. Interim Report and Log Book
March	1 – 5 6 – 12 13 – 19 20 – 26 27 – 31	To interconnect the different parts of the system and make tests and measurement of the whole radio data system. To follow writing the Report
April	3 – 9 10 – 16 17 – 23 24 – 30	To correct possible mistakes in design and rebuild or improve it. To prepare Final Presentation. To finalize Report. To prepare Log Book
May	1 – 4	To finish Log Book, the Report and Final Presentation in Power Point. To prepare a Demonstration of the Project showing that works.

2. THEORY & BACKGROUND RESARCH

The chapter is based in the theory needed to start the development of the Project. It began with transducers, follows with networks and explains important something to take in account before the design of the DCS in these two parts of the Project.

2.1 Transducers

A transducer is a device that responds to a stimulus, such as heat, light, or pressure, and generates a signal that can be measured or interpreted. In order to carry out the measurement it is needed a measurement system to interpret the input that the sensor has received.

The measurement system has four types of element: sensing, signal conditioning, signal processing and data presentation (e.g. display element).

In the Fig. 2.1 appears the outline design of the whole system.

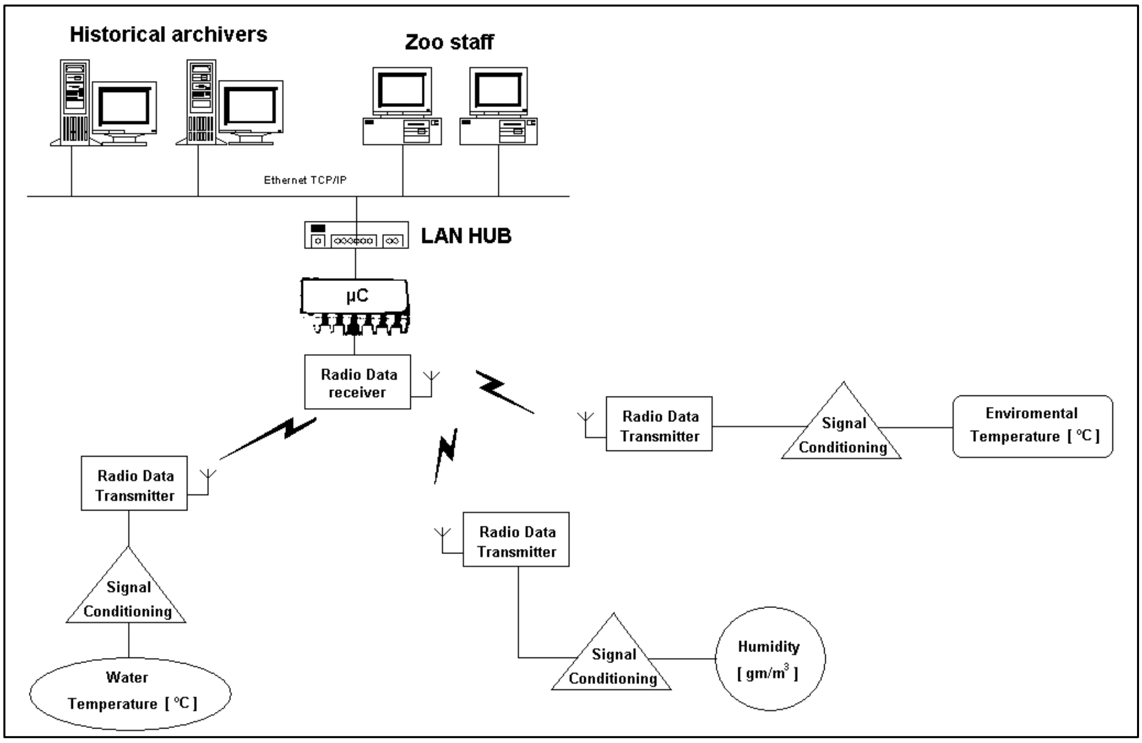


Fig. 2.1 Outline of the whole system

2.1.1 Systematic characteristics

Systematic characteristics are those that can be exactly quantified by mathematical or graphical means. These are distinct from statistical characteristics which cannot be exactly quantified.

- **Range**: The input of an element is specified by the minimum and the maximum values of I, i.e. Imin to Imax (I – Input, O – Output). Example: Input range 4 to 20 mA.

- **Span**: Is the maximum variation in input or output, i.e. input span is Imax – Imin. Example: Span 16 mA (20 mA – 4 mA).

- **Linearity**: Values of I and O lie on a straight line. The ideal straight line connects the minimum point A (Imin, Omin) to maximum point B (Imax, Omin). As is shown in Fig. 2.2.
- **Non – linearity**: When element measurement is do not follow a linearity rule. Non-linearity appear is defined in Fig. 2.2.

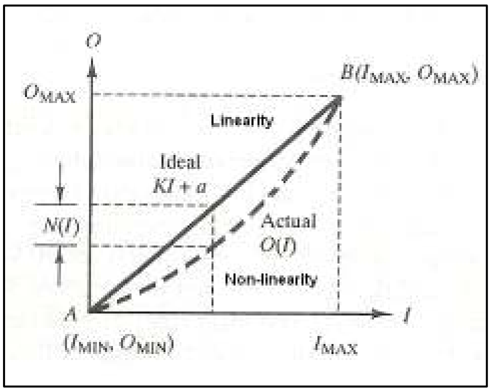


Fig. 2.2 Linearity and Non-linearity [John P. Bentley, 1995]

- **Sensitivity**: This is the rate of change of O with respect to I.
- **Hysteresis**: Is a property of systems (usually physical systems) that do not instantly follow the forces applied to them, but react slowly, or do not return completely to their original state i.e. systems whose states depend on their immediate history. For instance, if you push on a piece of putty it will assume a new shape, and when you remove your hand it will not return to its original shape, or at least not immediately and not entirely.
  Hysteresis can be used to filter a signal so that the output reacts slowly by taking recent history into account. For example, a thermostat controlling a heater may turn the heater on when the temperature drops below degrees, but not turn it off until the temperature rises above B degrees. Then the on/off output of the thermostat to the heater when the temperature is between A and B depends on the history of the temperature.
- **Resolution**: Some elements are characterized by the output increasing in a series of discrete steps or jumps in response to a continuous increase in input. Resolution is defined as the largest change in I that can occur without any corresponding change in O.

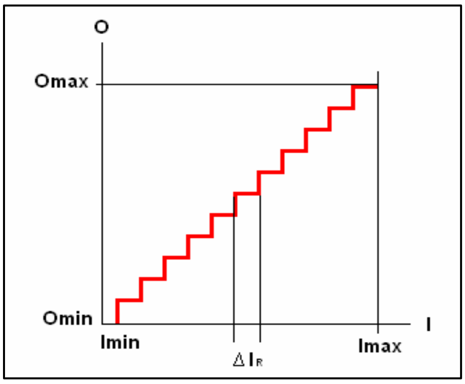


Fig. 2.3 Example of resolution

- **Error Band**: Non-linearity, hysteresis and resolution effects in many modern sensors and transducers are so small that it is difficult quantify each individual effect. In these cases the manufacture defines the performance of the element in terms of error bands. Here the manufacture states that for any value of I, the O will be within an error range (±b).

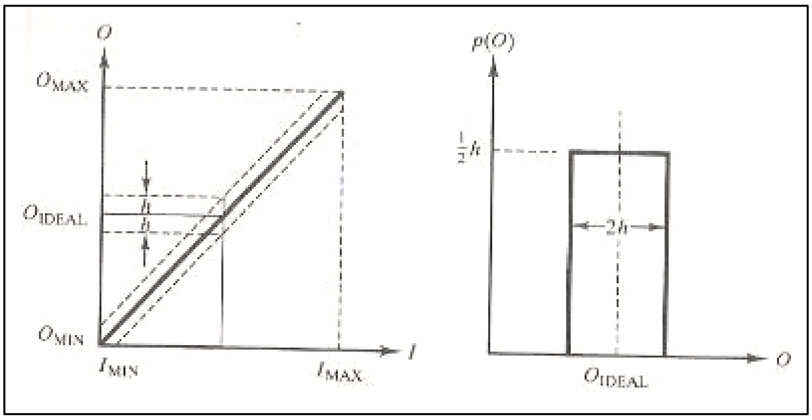


Fig. 2.4 Examples of Error bands [John P. Bentley, 1995]

2.1.2 Loading effects

One important effect is that of inter-element loading where a given element in the system may modify the characteristics of the previous element. In order to get maximum power transfer from network to load, the load impedance should be equal to the network impedance (Z_L = Z_{eq}).

2.1.3 Signals and noise in measurement systems

Unwanted random signals are usually referred to a noise signals an unwanted deterministic signals as interference signals.
In Zoo installations, source and load may be 100 meters apart and noise and/or interference voltage may also be present.

2.1.3.1 Internal noise sources

- **Johnson noise**: Temperature-induced motion of electrons and other carriers in resistors and semiconductors give rise to corresponding random voltage.
- **Shot noise**: This occurs in transistors and is due to random fluctuations in the rate at which carriers diffuse across a junction.

These two kinds can be characterized by a uniform power spectral density over a wide range of frequencies.

2.1.3.2 External noise and interference sources

- **A.C. power circuits**: Operates at 240 V, 50 Hz. These can produce corresponding sinusoidal interference signals, referred to as hum. Hum to make the droning noise of an insect in flight. E.g. turbines and generators in zoo.
- **D.C. power circuits**: Are less likely to cause interference because D.C. voltages are not coupled capacitively and inductively. But they can introduce transients in the measurement circuit when equipment are being taken off line or brought back on line.
- **Fluorescent lighting**: Fluorescent lamps operated by electronic ballast radiate electromagnetic waves at frequencies from 10 kHz to 100 MHz.
- **Radiofrequency**: Radiofrequency transmitters, welding equipment can produce radio frequency interference at frequencies of several MHz.

2.1.3.3 Coupling mechanisms to external sources

If the circuits are sufficiently close together, then there may be a significant mutual inductance between them. This means that an alternating current in the power circuit induces a series mode interference voltage in the measurement circuit.

2.1.4 Methods of reducing effects of noise and interference

There are different two types of unwanted signals in a measurement system. Deterministic signal, i.e. one whose value at any future time can be exactly predicted, such as: step, sine wave, square wave input signals and interferences. And random signal, i.e. one whose value at any future time cannot be exactly predicted e.g. aircraft speed, music sound and noise.

The effects of noise and interference voltage in the measurement can be reduced applying some methods:

2.1.4.1 Physical separations

Since mutual inductances and coupling capacitances between measurement and power circuits are inversely proportional to the distance between them.

2.1.4.2 Electromagnetic shielding

This is a simplest way of reducing the effects of inductive coupling to an external interference source. The conductors of a measurement circuit are twisted into loops approximately equal area. This arrangement is commonly known as twisted pairs. The sign of the induced voltage depends on the orientation of the conductors. Thus if an induced voltage VXY is inducted in the *jth* loop, then an opposing voltage VYZ is induced in the *(j+1)th* loop. In the ideal case of both loops having the same area and experiencing the same magnetic fields, | VXY| = | VYZ |, i.e. there is a zero resultant induced voltage, because one delete the other.

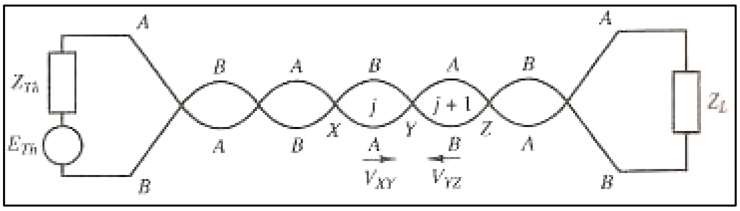


Fig. 2.5 Example of electromagnetic shielding [John P. Bentley, 1995]

2.1.4.3 Electrostatic screening and shielding

The best method of avoiding the problem of capacitive coupling to a power circuit is to enclose the measurement circuit in an earthed metal screen or shield. The screen provides a low impedance path to earth for the interfering currents; the currents through C_{SM} and C_E (see Fig. 2.6) are small thus reducing series and common mode interference.

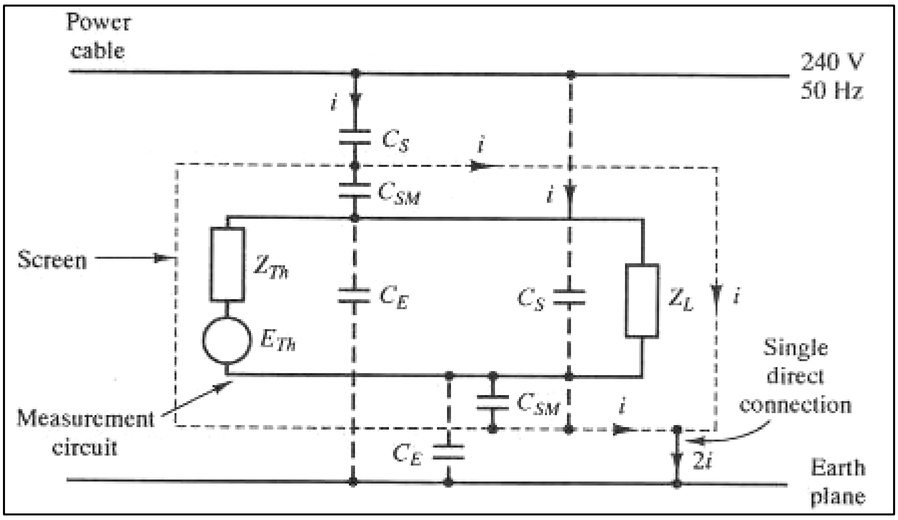


Fig. 2.6 Circuit of electrostatic shielding [John P. Bentley, 1995]

2.1.4.4 Differential amplifiers

The differential amplifier has output as equation (2.1) i.e. only the sensor voltage Eth is amplified and a small contribution proportional to VCM.

(2.1)
$$V_{OUT} = -\frac{R_F}{R_1} \cdot E_{TH} + \left(1 + \frac{R_F}{R_1}\right)\frac{V_{CM}}{CMRR}$$

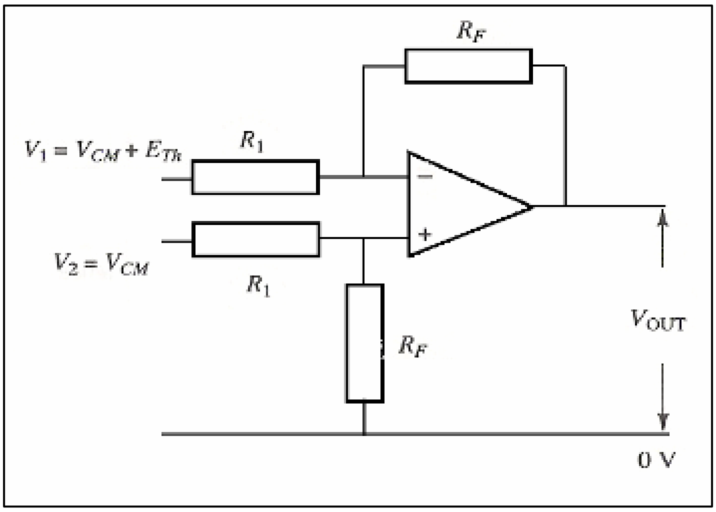


Fig. 2.7 Differential Amplifier

2.1.4.5 Filtering

A filter is an element which transmits a certain range or ranges of frequencies and rejects all other frequencies. An analogue filter is an electronic device consisting usually of resistors, capacitors and Op. amplifiers. A digital filter is usually a digital computer programmed to process sampled values of a signal. There are many types of filters, the most usual are: Low pass, High pass, Band pass and Band stop.

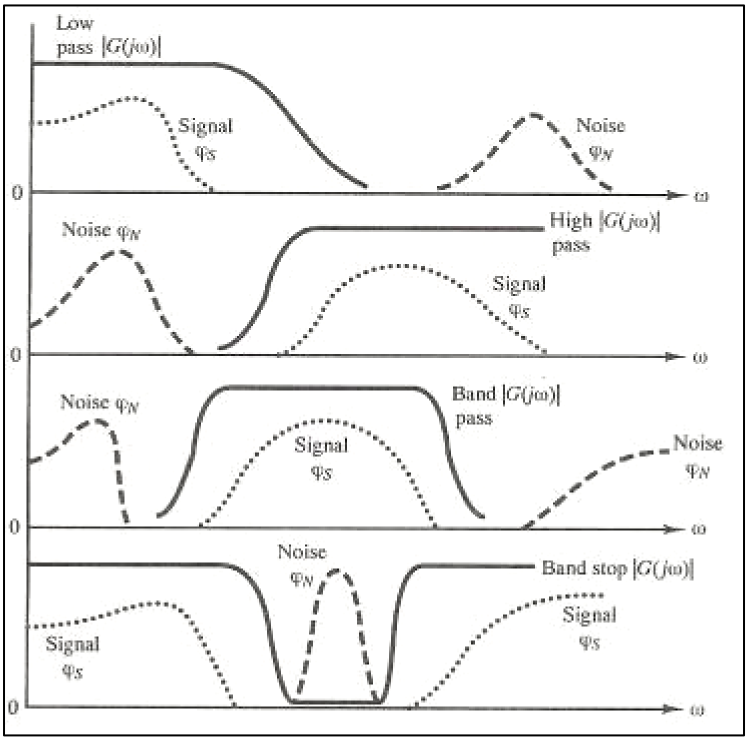


Fig. 2.8 Low pass, High pass, Band pass and Band stop filters [John P. Bentley, 1995]

2.2 <u>The Network</u>

A network is a group of stations (computers, telephones, or other devices) connected by communications facilities for exchanging information. Connection can be permanent, via cable, or temporary, through telephone or other communications links. The transmission medium can be physical (i.e. fibre optic cable) or wireless (i.e. satellite).

The last transmission medium is quite interesting since late 2002 through 2003. Because of it uses radio-frequency spectrum in order to transmit and to receive information, and this is cheaper than other networks that use wires e.g. telephone.

To develop a network is interesting to know the five characteristics: technology of connections, topology, range, and address and operation mode.

2.2.1 Technology of connections

There are three types of connections:

- **Fixed network**: is the simplest network is fixed point-to-point network. As the name implies, these are facilities that connect two or more fixed locations such as buildings. They are designed to extend data communications to locations physically separate from the rest of the network.
  These links may be familiar as the traditional microwave link. They use directional antennas in order to transmit as efficient as is possible. Depending on the frequencies selected, these links can be designed to span distances from several hundred feet (30.5 m) to 20 miles (32 Km), with capacities of under 1 Mbps to nearly 1 Gbps.

- **Nomadic Network**: is a variation of point-to-multipoint networks that directly supports individual computer users to the network. In the case of laptop or PDA. Nomadic networks are becoming quite commonplace, offering Internet access in a coffee shop. This network is designed to offer a low level of mobility to the users, and to span distances from tens (9.14 m) to hundreds of yards (90.14 m)

- **Mobile Network**: the most complex network is one designed for true mobility. Like a voice-based cellular or PCs network, the high-speed mobile data network must provide enormous coverage, and must support high velocity mobility. These requirements are not easily achieved or inexpensive. These systems will require many tens of megahertz of licensed spectrum, and will require technology expensive.

2.2.2 Topology

The physical topology of a network refers to the configuration of cables, computers, and other peripherals. Physical topology should not be confused with logical topology which is the method used to pass information between workstations.

As follows the main types of physical topologies:

- **Linear Bus**: a linear bus topology consists of a main run of cable with a terminator at each end. All nodes (file server, workstations, and peripherals) are connected to the linear cable. Ethernet and Local Talk networks use a linear bus topology.

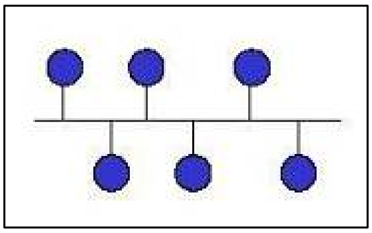


Fig. 2.9 Linear Bus

- **Star**: a star topology is designed with each node (file server, workstations, and peripherals) connected directly to a central network hub or concentrator (Fig. 2.10).

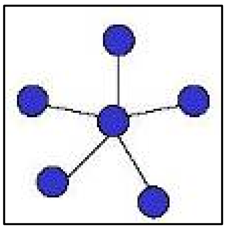


Fig. 2.10 Star

- **Star-Wired Ring**: a star-wired ring topology may appear (externally) to be the same as a star topology. Internally, the MAU (multistation access unit) of a star-wired ring contains wiring that allows information to pass from one device to another in a circle or ring (Fig. 2.11).

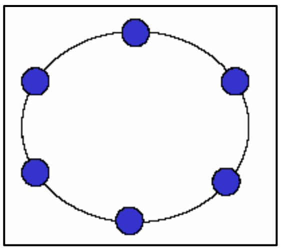


Fig. 2.11 Star-Wired Ring

- **Tree**: a tree topology combines characteristics of linear bus and star topologies. It consists of groups of star-configured workstations connected to a linear bus backbone cable (Fig. 2.12). Tree topologies allow for the expansion of an existing network, and enable schools to configure a network to meet their needs.

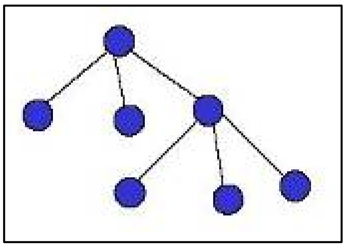


Fig. 2.12 Tree

2.2.3 Range

There are five kinds of networks, classified for them range to coverage:

- **WANs**: Wide Area Network; a network that uses high-speed, long-distance communications technology (e.g., phone lines and satellites) to connect computers over long distances.
- **MANs**: Metropolitan Area Network; A data network designed for a town or city. In terms of geographic breadth, MANs are larger than local-area networks (LANs), but smaller than wide-area networks (WANs). MANs are usually characterized by very high-speed connections using fibre optical cable or other digital media.
- **LANs**: Local Area Network. A data network intended to serve an area of only a few square kilometres or less. Because the network is known to cover only a small area, optimizations can be made in the network signal protocols that permit data rates up to 1000Mb/s.
- **PANs**: Personal Area Network typically covers the few meters surrounding a user's workspace and provides the ability to synchronize computers, transfers files and gain access to local peripherals like printers and a range of pocket hardware. A technology like Bluetooth may enable wireless PAN.
- **BANs**: Body Area Network means wireless communication between various components attached to the body, such as data spectacles, earphones, microphones and sensors for medical applications and for work and leisure.

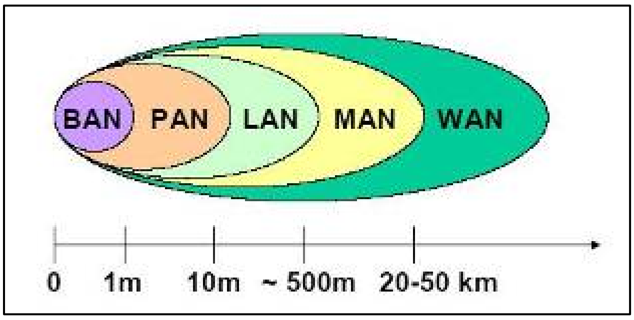


Fig. 2.13 Range of Networks [Elena López, 2004]

2.2.4 Address

There are three types of address: Unicast, Multicast and Broadcast.

- **Unicast**: one origin and one destination (e.g. to download a web site)
- **Multicast**: one origin and some destinations (e.g. e-mail)
- **Broadcast**: one origin to all destinations (e.g. television network)

2.2.5 Operation mode

Is possible to find three different operation modes, as: Simplex, Half-duplex and Full duplex.

- **Simplex**: operation mode of a communication circuit in which one end can only transmit and the other end can only receive (Fig. 2.14 (a)).
- **Half-duplex**: transfers data in both directions, but not simultaneously. Normal operation is alternate, one-way-at-a-time transmission (Fig. 2.14 (b)).
- **Full duplex**: sending data in both directions at the same time. Usually higher quality but requires more bandwidth. In videoconferencing, full duplex will be much more natural and useable. Cheap speakerphones are half-duplex, whereas more expensive ones are full duplex (Fig. 2.14 (c)).

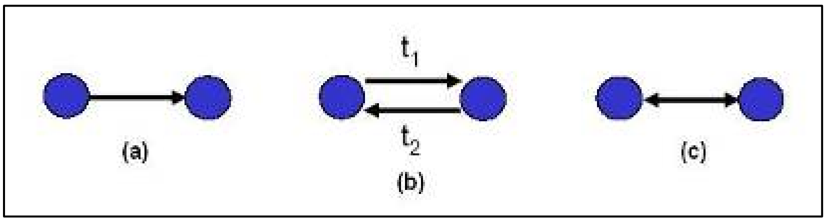


Fig. 2.14 Operation modes

2.3 Radiofrequency links

There are some radiofrequency links studied, but in this Project the interesting one is the wireless radio frequency links.

A wireless link based in radiofrequency need:

- Transmitter with an antenna
- Communication channel
- Receiver with an antenna

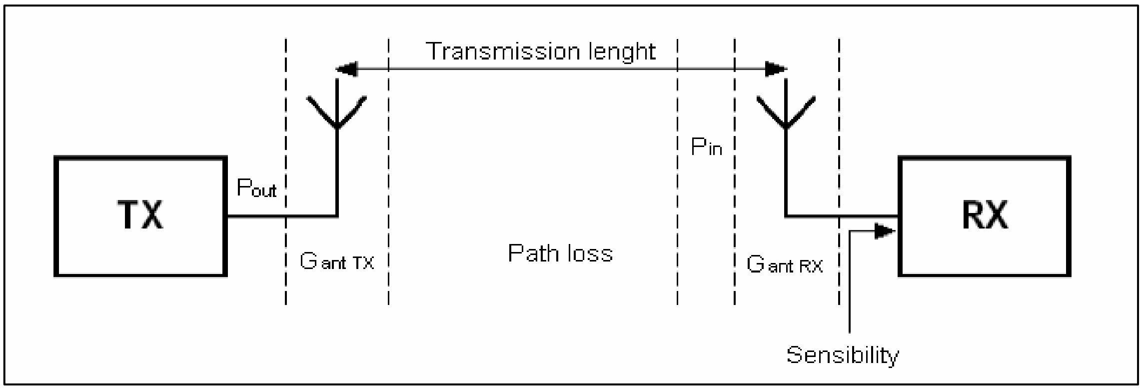


Fig. 2.15 Wireless link based in radiofrequency

As is shown in the Fig. 2.16 there are four main parameters:

- Power output of the transmitter (P_{out})
- Power input in the receiver (P_{in})
- Gain of the transmission and reception antennas ($G_{ant\ TX}$ and $G_{ant\ RX}$)
- Sensibility in reception. It is the minimum power that is necessary in the receptor to detect an acceptable signal.

2.3.1 Antennas

The antenna is the element that transforms power output in emitter into electromagnetic waves, or vice versa, transforms the electromagnetic waves that receive into a signal input.

There are two fundamental types of antennas, which, with reference to a specific three dimensional (usually horizontal or vertical) plane, are either omni-directional (radiate equally in the plane) or directional (radiates more in one direction than in the other). All antennas radiate some energy in all directions but careful construction results in large directivity in certain directions and negligible energy radiated in other directions.

The vast majority of antennas are simple vertical rods a quarter of a wavelength long. Such antennas are simple in construction, usually inexpensive, and both radiate in and receive from all horizontal directions (omni-directional). One limitation of this antenna is that it does not radiate or receive in the direction in which the rod points.

While an omni-directional antennas has usually a gain of -20 dB, whereas directional antennas has a gain around 0 dB. In this way for a better reception is better a directional one, but is also more complicated to build than the no-directional.

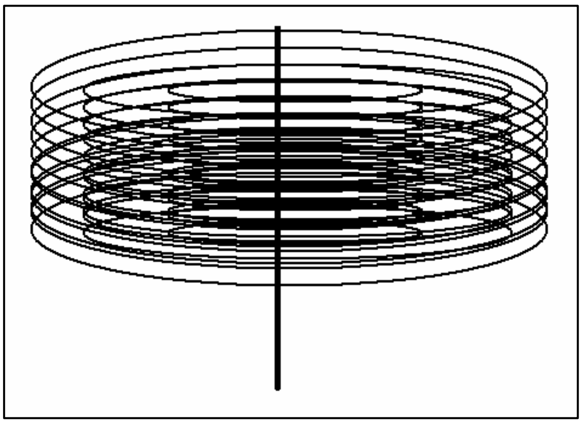


Fig. 2.16 Radiation pattern omni-directional

2.3.2 Elements that reduce the quality

In order to receive properly the signal, the power input has to be greater than the sensibility of the receptor. That means that is necessary to have *headroom*.

Headroom factor decrease for diverse causes:

- **Transmission length**: If the length increase, the power input is less and the *headroom* as well.
- **Obstacle**: The obstacles reduce the wave's propagation, in this way the power input decrease and consequently the *headroom.*
- **Multipath**: There are obstacles and reflectors in the wireless propagation channel, the transmitted signal arrivals at the receiver from various directions over a multiplicity of paths. It is an unpredictable set of reflections and/or direct waves each with its own degree of attenuation and delay.

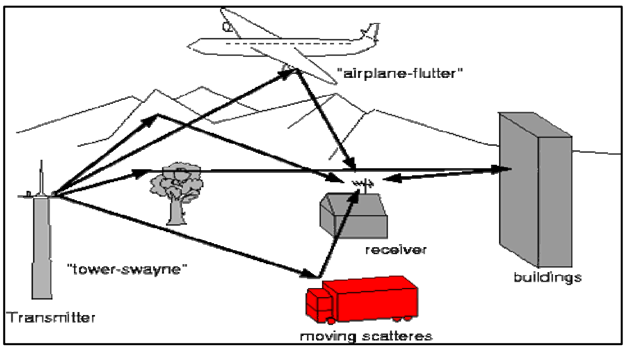


Fig. 2.17 Example of Multipath

2.3.3 Radiofrequency standards

Inside the industrial, domestic, scientific and medical fields the next standards are the main standards nowadays.

- **Wireless RF** (433 MHz to 900 MHz): It is a digital communication system via radiofrequency. In the market there are integrated transmitters, receivers or transceivers in a circuit, except the antenna, the crystal and some extern components. The length range is about few hundreds of meters.
- **Bluetooth**: A global initiative by Ericsson, IBM, Intel, Nokia and Toshiba to set a standard for cable-free connectivity between mobile phones, mobile PCs, handheld computers and other peripherals. It will use short-range radio links in the 2.4 GHz to 2.5 GHz Instrumentation Scientific and Medical (ISM) "free band".
- **DECT**: It is an ETSI standard for digital portable phones, commonly used for domestic or corporate use. The bit rate is about 1Mbps in the frequency 1.9 GHz.
- **ZigBee**: It is a published specification set of high level communication protocols designed to use small, low power digital radios based on the IEEE 802.15.4 standard for WPANs. The bit rate is about 250Kbps working in 2.4GHz.

2.3.4 Modulation

It is the process of modifying some characteristic of a wave (the carrier) so that it varies in step with the instantaneous value of another wave (the modulating wave) in order to transmit a message. The modified characteristic may be frequency, phase, and/or amplitude.
There are several reasons to modulate a signal before transmission in a medium. These include the ability of different users sharing a medium (multiple access), and making the signal properties physically compatible with the propagation medium.

2.4 <u>Control device</u>

In the Radio Data Network is necessary to have a device which controls all the data that comes directly from the transducers distributed in the animal's habitat. For this reason in this chapter will be explained the different control devices that can help in the Project, the differences between them with advantages and disadvantages and finally the chosen device that adapts better to the necessities.

The father of the small control devices is the microprocessor, for this reason will be explained basically and then the chapter will be focused in one of the several types of specialized processing devices that have followed from the microprocessor technology.

2.4.1 Microprocessor

A microprocessor is a digital electronic component with miniaturized transistors on a single semiconductor integrated circuit (IC) that have two basic functions:

The ability to execute a stored set of instructions to carry out user defined tasks.
The ability to be able to access external memory chips to both read and writes data from and to the memory

The µP is made up of three basic sections: Central Processing Unit (CPU), Input and Output (I/O) and Memory, with the addition of some support circuitry.

The CPU, is the component that interprets and executes instructions and data contained in software.

The second section, I/O, can comprise digital, analogue and special functions and the section which communicates with the outside world.

Memory is used to store the program and data, can be RAM, ROM, EPROM, EEPROM or any combination of these.

2.4.2 Microcontroller

A microcontroller is a type of microprocessor emphasizing self-sufficiency and cost-effectiveness, which have additional parts that allow them to control external devices, in contrast to a general purpose microprocessor. The MCU executes a user program which is loaded in this program memory. Under control of this program, data is received from external devices (Inputs), manipulated and then data is sent to external output devices.

A typical microcontroller contains all the memory and I/O interfaces needed, whereas a general purpose microprocessor requires additional chips to provide these necessary functions.

A microcontroller differs from a microprocessor in that the first one is easy to implement into electronic system with a minimum of external support chips. The idea is that the microcontroller will be placed in the device to control, hooked up to power and any information it needs.

A traditional µP will not allow doing this. It requires all of these tasks to be handled by other chips. For example, some number of RAM memory chips must be added. The amount of memory provided is more flexible in the traditional approach, but at least a few external memory chips must be provided, and additionally requires that many connections must made to pass the data back and forth to them with external BUS. In Fig. 2.19 is shown a traditional electronic system used by a microprocessor. See the differences between a microcontroller and a microprocessor implemented in electronic system, looking the Fig. 2.18 and 2.19.

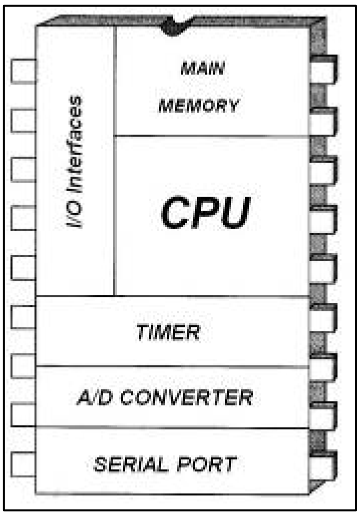


Fig. 2.18 Parts of a common µC

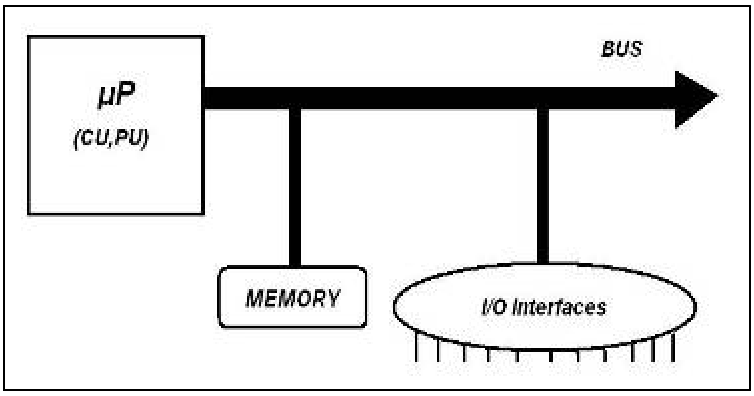


Fig. 2.19 Parts of a common microprocessor

MCU is a component in many kinds of electronic equipment, for example a typical home in the Western world is likely to have somewhere between one and two dozen microcontrollers. They can be found in almost any electrical device, washing machines, microwave ovens, telephones, toys etc.

2.4.2.1 Architectures

Basically, two types of architectures are used: Von Neumann and Harvard.

Von Neumann architecture is used by a very large percentage of microcontroller's manufacturers and here all memory space is on the same bus and instruction and data memory are treated identically. As is shown in Fig. 2.20

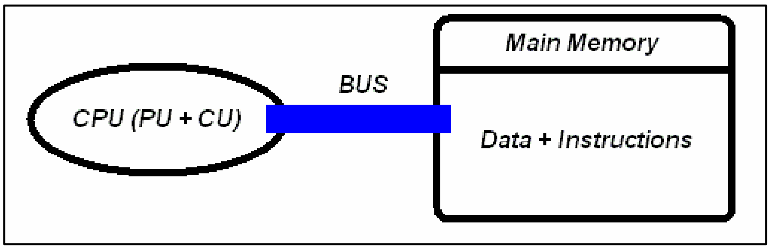


Fig. 2.20 Von Neumann architecture

While in the Harvard architecture, code and data storage are on separate buses and this allows code and data to be fetched simultaneously, resulting in a more efficient implementation.

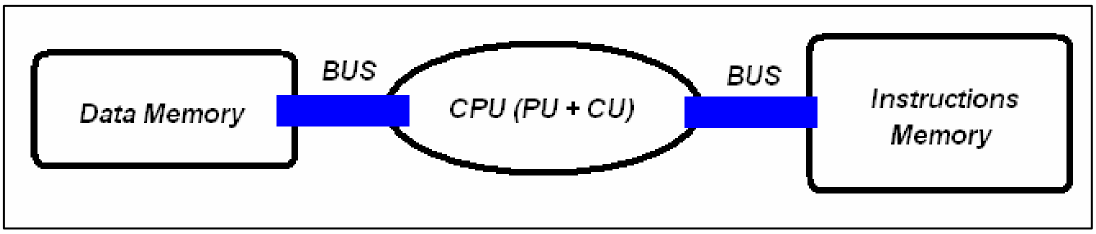


Fig. 2.21 Harvard architecture

2.4.2.2 Set of Instructions

There are three types of set of instructions:

- **CISC** (Complex Instruction Set Computer), an instruction set that has more than 80 instructions. Most of all complex instructions that need much clock cycles.
- **RISC** (Reduced Instruction Set Computer) has reduced number, about 35 instructions. Simple instructions executables in one clock cycle. So this set offer higher speeds and is easy to use.
- **SISC** (Specific Instruction Set Computer) has a much reduced number of instructions and specific of the machine which uses the instructions.

2.4.2.3 Languages to program

Originally, microcontrollers were only programmed in assembly language and later in C code.

Assembly is a programming low-level language that has the same structure and set of commands as machine languages, but it enables a programmer to use symbols (SUBQ.W #1, D4) instead of numbers (binary code, 0011100) as machine language uses to communicate with the hardware.

C code is a programming high-level language. High-level language is a language closer to human language, composed by logical words ('while' or 'if'). Also is independent of the platform on which it is programming and the platform on which will be executed. Look Fig 2.21 to understand languages levels.

The main advantages of C code over the rest of the codes is that it is easier to read, write, maintain and is one of the most widely used programming languages. C is prized for its efficiency, and is the most popular programming language for writing system software, though it is also used for writing applications. It is also commonly used in computer science education, despite not being designed for novices.

A great disadvantage to use a high-level language, is that this kind of language when speed is essential to carry on the task, the processor waste more time processing the C code than assembly code. But in Radio Data Network, the speed of processing the data that comes from the transducers not must be fast, because the weather is not a variable that change quickly.

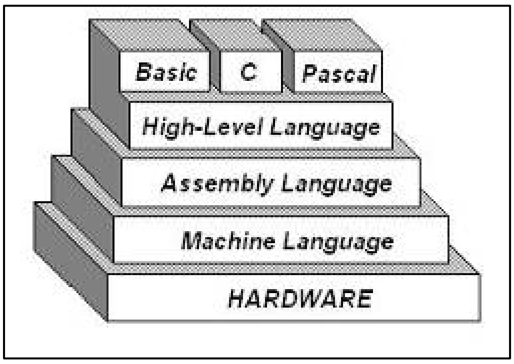


Fig. 2.22 Languages levels [Oscar Casas, 2003]

2.4.2.4 Different varieties

Microcontrollers trade away speed and flexibility to gain ease of equipment design and low cost. In this part of the chapter will be mentioned some microcontroller architectures that are available from many different suppliers.

There are three main architectures in the market, these are 8051, Z80 and PICmicro. The first one has eight manufactures, the second one has one and the last one has one as well.

- **8051**: Developed by Intel in 1980 for use in embedded products and still (2006) one of the most popular microcontrollers. The microcontroller is based on a Harvard architecture and although originally designed for single chip microcontroller applications, an expanded mode allows a full 64 kB of external ROM and 64 kB of external RAM to be addressed by means of separate chip select lines for program and data memory access. A particular feature of the 8051 is the inclusion of a Boolean processing engine which allows bit-level Boolean logic operations to be carried out directly and efficiently on internal registers and RAM. This has led to the 8051 being popular in industrial control applications and it was widely used in early programmable logic controller (PLC) designs.

- **Z8**: A family of microcontrollers from Zilog with on-chip RAM and (optional) ROM. Note that the Z8 is not related to the Zilog Z80 (uP) it uses a totally different architecture and instruction set. An 8-bit microcontroller with integrated clock oscillator, two timers/counters, serial line and 32 I/O lines (4 ports). The Z8 had separate data and program memory spaces (Harvard architecture). Internal program memory of the Z8 ranged from 0 kB (for ROMless version) to 4 kB, and it could be expanded up to 64kB of program memory using external ROM. The microcontroller had 144 8-bit registers - 4 I/O registers, 16 control registers and 124 general registers.

Data memory on the Zilog Z8 could be expanded by adding up to 62 kB of external memory. The microcontroller supported stack operations, it was possible to use general registers or external data memory to store stack data. Is able for developing applications in areas such as motor control, security systems, battery charging, power supply design, electronic cooling, small domestic appliances or personal electronic devices.

- **PICmicro**: Is a family of RISC developed in 1975 to improve performance of the overall system by offloading I/O tasks from the CPU. The PICmicro used simple microcode stored in ROM to perform its tasks, and although the term was not used at the time, it is a RISC design that runs on instruction per cycle. And varies in length from about 35 instructions for the lowed PICmicros to about 70 instructions for the high-end PICs. All is integrated in a single chip with Harvard architecture. Throughout the 1990's the PICmicro range of microcontrollers have come from virtually nowhere to become the second most popular 8 bit embedded controllers in the world market place. The Microchip PIC product range contains a vast arsenal of products from very basic micro-controllers through to highly sophisticated controllers which include A/D conversion, Pulse Width Modulation, external and internal interrupt handing, SPI, I^2C and CAN interface busses. Microchip provides freeware IDE package called MPLAB, which also includes a software simulator as well as an assembler. Third parties make C and BASIC language compilers for PICmicros. These microcontrollers are applied in motor control, automotive, home appliance or connectivity.

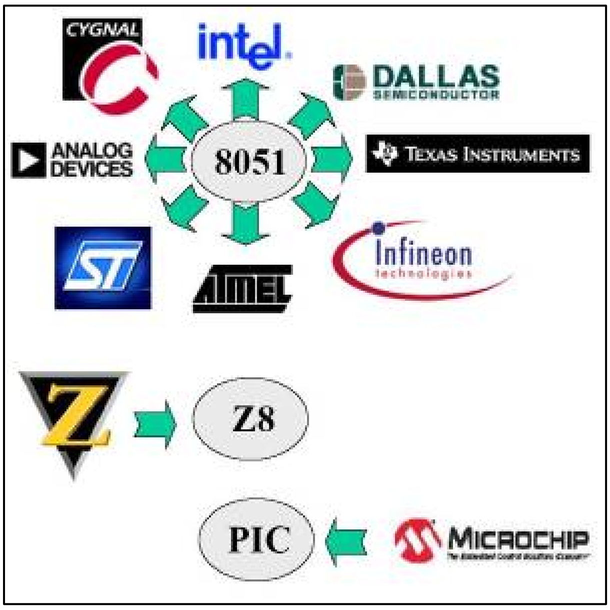


Fig. 2.23 Main types of MCUs

2.5 <u>Serial buses</u>

A serial bus is a computer bus that sends data bit by bit down one or a few wires. The object of a serial bus is to save money in an embedded system or small computer system by reducing the number of wires. As follows some of the main serial buses will be treated.

2.5.1 RS-232

The RS-232 communications standard has been in use for very many years and is one of the most widely used standards for serial data communications. There are several different specifications that are used to define RS-232: RS-232C, RS-232D; V24; V28 and V10, but they are all very similar and can be used to interface to each other. Additionally, RS232 communication can be used in either an asynchronous mode, which is the most common, or a synchronous mode. And there are two varieties of connectors, DB25 and DB9, it depends on the number of wires, 25 and 9 respectively.

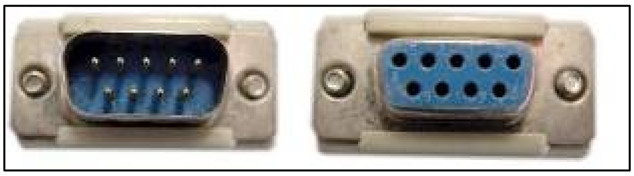


Fig 2.24 RS-232, DB9 connectors

The success of the RS232 standard has meant that it is now used for many more types of equipment. As a result many lines defined in the specification are rarely used. This means that care has to be taken when connecting any new equipment or defining which lines is to be used in a new design.

Today, RS-232 is gradually being superseded in personal computers by USB for local communications. Compared with RS-232, USB is faster, has lower voltage levels, has connectors that are simpler to connect and use. USB has software support in popular operating systems. USB is designed to make it easy for device drivers to communicate with hardware, and there is no direct analog to the terminal programs used to let users communicate directly with serial ports. However, USB is a more complex standard, requiring more software to support the protocol used. Serial ports of personal computers were also often used to directly control various hardware devices, such as relays or lamps, since the control lines of the interface could be easily manipulated by software. This isn't feasible with USB which requires some form of receiver to decode the serial data.

The RS-232 specification is still widely used. Although faster specifications exist, it is likely to remain in use for many years to come. One of the reasons for this is the fact that it is found on most of today's personal computers. Although the parallel "LPT" ports are used almost universally for printers, it still used for many other purposes, including connecting the computer to a modem.

2.5.2 USB 2.0

USB was designed to allow peripherals to be connected without the need to plug expansion cards into the computer's ISA, EISA, or PCI bus, and to improve plug-and-play capabilities by allowing devices to be hot-swapped (connected or disconnected without powering down or rebooting the computer).

USB can connect peripherals such as mice, keyboards, game pads and joysticks, scanners, digital cameras, printers, external storage, networking components, etc. For many devices such as scanners and digital cameras, USB has become the standard connection method. USB is also used extensively to connect non-networked printers, replacing the parallel ports which were widely used; USB simplifies connecting several printers to one computer. As of 2004 there were about 1 billion USB devices in the world. As of 2005, the only large classes of peripherals that cannot use USB, because they need a higher data rate than USB can provide, are displays and monitors, and high-quality digital video components.

Fig 2.25 USB connectors

USB supports three data rates:

- Low Speed rate of 1.5 Mbit/s (183 KB/s) that is mostly used for Human Interface Devices (HID) such as keyboards, mice and joysticks.

- Full Speed rate of 12 Mbit/s (1.4 MB/s). Full Speed was the fastest rate before the USB 2.0 specification and many devices fall back to Full Speed. Full Speed devices divide the USB bandwidth between them in a first-come first-served basis and it is not uncommon to run out of bandwidth with several isochronous devices. All USB Hubs support Full Speed.

- Hi-Speed rate of 480 Mbit/s (57 MB/s). Though Hi-Speed devices are commonly referred to as "USB 2.0", not all USB 2.0 devices are Hi-Speed. A USB device should specify the speed it will use by correct labelling on the box it came in or sometimes on the device itself. The USB-IF certifies devices and provides licenses to use special marketing logos for either "Basic-Speed" (low and full) or High-Speed after passing a compliancy test and paying a licensing fee. All devices are tested according to the latest spec, so recently-compliant Low Speed devices are also 2.0.

The USB specification is at version 2.0 (with revisions) as of March 2006.

2.5.3 FireWire

FireWire was developed by Apple Computer in the late 1990s. Sony's implementation of the system is known as i.Link, and uses only the four signal pins, discarding the two pins that provide power to the device in favour of a separate power connector on Sony's i.Link products.

The system is commonly used for connection of data storage devices and digital video cameras, but is also popular in industrial systems for machine vision and professional audio systems. It is used instead of the more common USB due to its faster effective speed, higher power distribution capabilities, and because it does not need a computer host. Perhaps more importantly, FireWire makes full use of all SCSI capabilities and, compared to USB 2.0 High Speed, has higher sustained data transfer rates, a feature especially important for audio and video editors.

Fig 2.26 IEE1394 connectors

FireWire 400 can transfer data between devices at 100, 200, or 400 Mbit/s data rates (actually 98.304, 196.608, or 393.216 Mbit/s, but commonly referred to as S100, S200, and S400). Although USB2 claims to be capable of higher speeds (480 Mbit/s), FireWire is, in practice, faster reference needed. Cable length is limited to 4.5 metres but up to 16 cables can be daisy chained yielding a total length of 72 meters under the specification.

To finish this part, just mention the latest variety of IEEE1394. The FireWire 800 (IEEE1394b standard) was introduced commercially by Apple in 2003. This newer 1394 specification and corresponding products allow a transfer rate of 786.432 Mbit/s with backwards compatibility to the slower rates and 6-pin connectors of FireWire 400.

2.6 Animal and its habitat

The Bonobo (Pan paniscus), until recently usually called the Pygmy Chimpanzee, is one of the two species comprising the chimpanzee genus, Pan.

Fig. 2.27 Bonobos

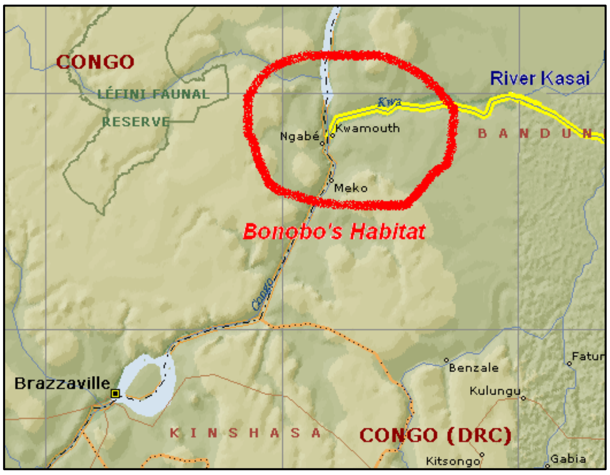


Fig. 2.28 Bonobo's habitat

Some features about the Bonobo are in the next table:

Name	Pan paniscus
Range	Central Africa
Habitat	Tropical rainforests
Size	Height: 1.0 to 1.7 m
	Weight: 26 to 70 kg
Feeding habits	Omnivores; they eat fruit, nuts, leaves, honey, eggs, bark, insects, birds, and small mammals
Life span	About 50 years
Did you know	Chimpanzees are the animals most genetically similar to humans
	Chimpanzees do not swim
	Chimpanzees sleep in nests they build in trees

The Bonobo is restricted to the lowland rainforests of the Democratic Republic of Congo (Zaire) between the Congo (Zaire) and Kasai Rivers. Even within its range, it occurs only sporadically.

Climate in the rainforests belong to the tropical wet climate group. The temperature in a rainforest rarely gets higher than 34 °C (93 °F) or drops below 20 °C (68 °F). So the temperature in the Bonobo's habitat in the Zoo should be always in the range of 20 ºC to 34 ºC.

3. SYSTEM DESIGN

The main important in the design is creating a radio data network able to transmit environmental information about animal habitat.

The system starts when a sensor, such as heat, light, or pressure, generates a signal that can be measured or interpreted. This signal is transmitted through the air to the reception circuit in the Zoo Control room.

Hence the receiver sends the information signals by cable to the computers of the Zoo Control Room. Then the data is stored in the historical archives for further studies.

In Fig. 3.1 is shown the outline draft about the whole system.

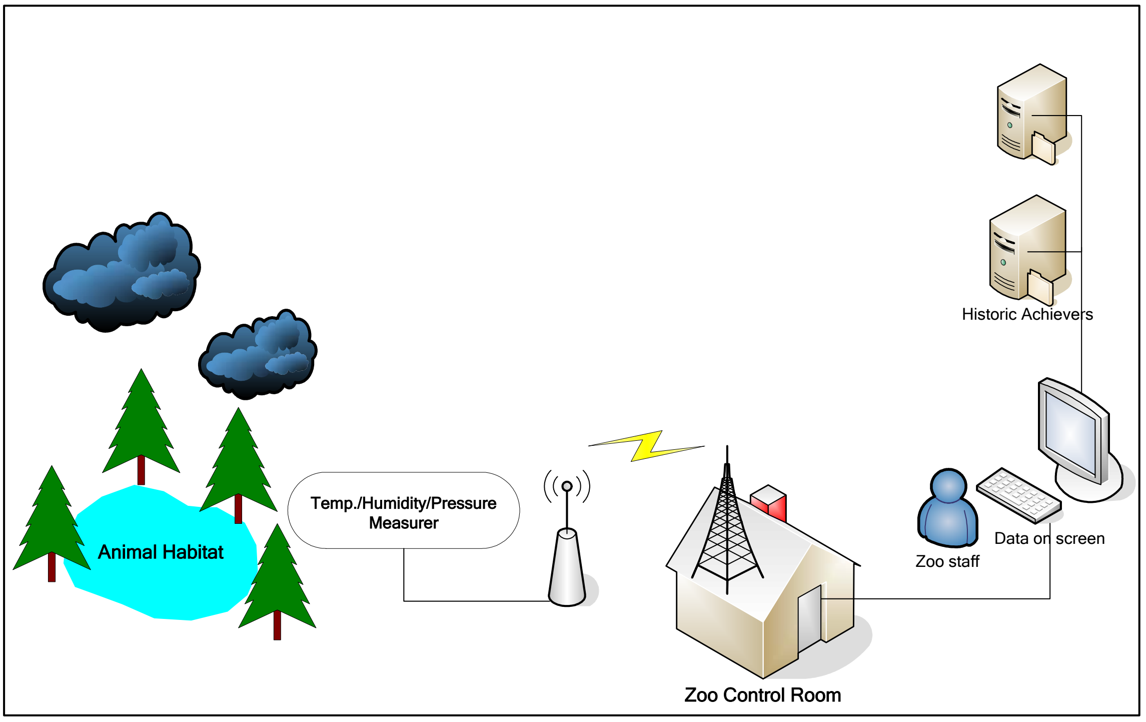


Fig. 3.1 Outline draft

In order to develop the Project will be useful divide it in some stages. In total there are seven stages, the first part begin with the sensor and its conditioning circuit, then is the transmission part, after the reception of information, the possible conditioning of the received signal, the process of information with the microcontroller, another possible conditioning for the sent signal to the next stage and finally the transmission of the environment information to the Zoo staff control.

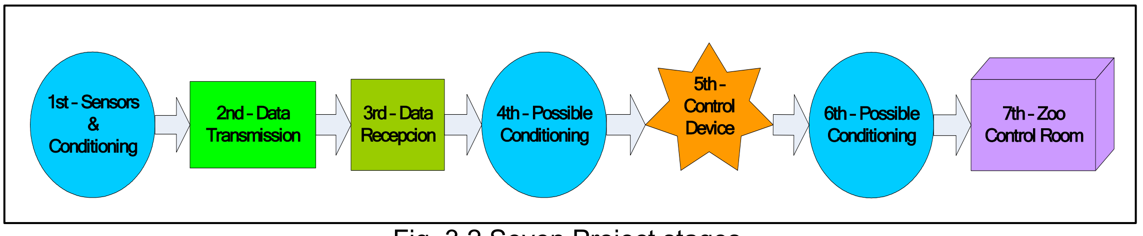


Fig. 3.2 Seven Project stages

The process of communication starts when the transducers responds to a stimulus, such as heat, light, or pressure, and generates a signal that can be measured or interpreted. Then the sensor transforms this stimulus into a signal that can be conditioning by the signal conditioning circuit. This circuit is necessary to adapt the output of the transducer to be transmitted for the radio data transmitter.

Thus the radio data transmitter has the task of transmitting that signal in electromagnetic waves and then sent to the air.

Hence the radio data receiver receives the waves and it turns them signals able to travel by a cable. Once we have the signal in the cable, the microcontroller is in charge to process them, to choose each of them has preference to be sent to the network Ethernet of zoo.

In consequence the zoo staff can watch the animal habitat, and for possible problems in the zoo, the data will be stored in historical archives.

4. DESIGN DETAILS

Firstly is important to mention that this chapter will be focused in a detailed design about a cheaper sample of the whole purpose. Because to build the whole Project it is needed more than £30.

As is mentioned above to build the Project is necessary to separate it in parts, seven in this case. So in this chapter the seven stages will be explained in detail, mentioning the components needed to carry on each part and selecting the most appropriate to the objectives. Is important to highlight that all the components for the purpose will be in the catalogue of *FarnellInOne* or *CPC*, the electronic components suppliers of the University.

The last two stages, Possible Conditioning and Zoo Control Room are treated together because the sixth part is conditioned by the last part, is necessary to know what is in the last part to prepare the data to be sent in the previous stage.

4.1 Sensors and Conditioning

To have a cheaper product a Centigrade precision sensor will be required to measure the ambient temperature and probably another sensor to measure the humidity.
In the catalogue of the electronic suppliers there are two interesting integrated circuit transducers. The first one is from *SENSIRON*, it is SH75. The other one is from *National Semiconductor,* it is LM35.

The SHT75 is a high-precision capacitive humidity and temperature sensor. The sensor comes in a high quality pin-type packaging (L=19.20 mm, W=5.08 mm, T=2.00 mm). Owing to full calibration and digital 2-wire output, the SHT75 is fully interchangeable.

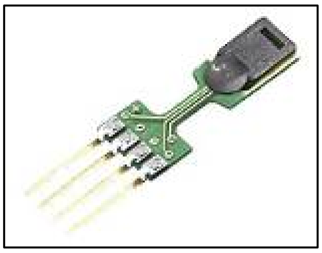


Fig. 4.1 SHT75

The LM35DZ is an integrated circuit Centigrade precision sensor that can be used to measure temperature with an electrical output proportional to the temperature. The sensor comes in a plastic packaging, T0-92 (L=19.40 mm, W=5.20 mm, T=4.19 mm).

Fig. 4.2 LM35DZ

	SHT75	LM35DZ
Temperature Range	-40ºC to +120ºC	-55ºC to +150ºC
Humidity Range	0% to 100%	-
Temperature accuracy	± 0.3ºC	± 0.5ºC
Humidity accuracy	± 1.8%	-
Supply Voltage	2.4V to 5.5V	4V to 30V
Output Signal	Digital	Analog
RoHS	No	Yes
Price (*FarnellInOne*)	£ 15.93	£ 1.46

As is shown in the table above there are some advantages and disadvantages for each transducer, but finally the decision is the LM35DZ. The reasons are:

- Commonly used and consequently more information about it
- Bigger range of temperatures
- Analog output, therefore possibility to amplify it easily
- Analog output, adequate to transmitter that works with analog signals
- Cheaper than the opponent

Once the transducer is chosen is time to design the conditioning circuit to adapt the output of it to the transmitter part that will be treated in the next chapter.

In order to develop the application the full-range of the transducer will not be used completely, so just a normal one will be enough to accomplish the purpose. A common range taking in account the features of Bonobos is -10 ºC to +40 ºC.

Hence if the sensibility of the sensor is 0.1V / ºC, that means that the output signal will be between -1V to 4V. But the input range of the transmitter step should be between 0 V to 5 V.

To carry on the conditioning is necessary to amplify the sensor output signal times 10 with an operational amplifier and add an offset that sum 1V with a voltage divider.

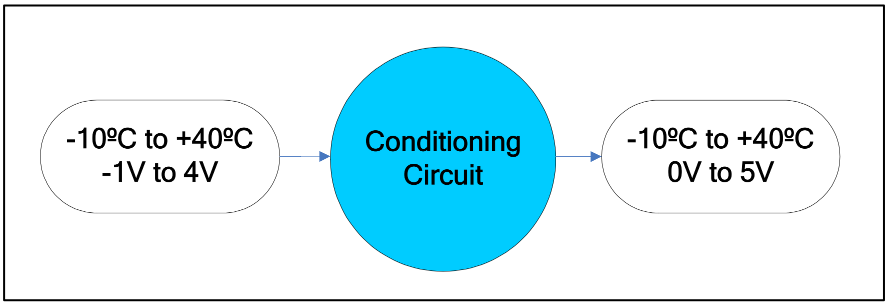


Fig. 4.3 Conditioning circuit input & output

After some calculations the conditioning circuit achieved is in the next figure, with a supply voltage of 15V, a voltage follower to avoid load effects and a Low pass filter at the end to purify the output signal that goes into the transmitter stage.

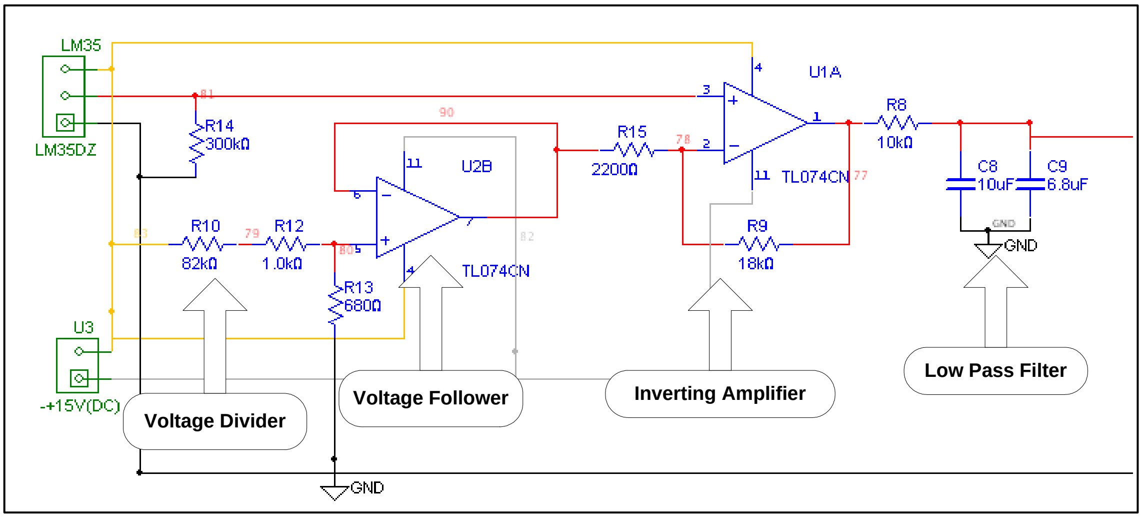


Fig. 4.4 Conditioning circuit

4.2 Data Transmission

To develop the wireless link between the transmitter and the receiver is needed an integrated radio link into the application. Radio links presents a decision, make one or buy one.

For the first option is necessary spending too much time searching and designing the final device. Hence the second option is the easier route to have more time to experiments in the laboratory than simulate in front of the computer.
There are many standards on the market these days for wireless applications, Bluetooth, 802.11, DECT etc but for general purpose Short Range Devices (SRDs) there is no standard protocol.

RF modules provide a very easy and low-cost method of sending data between microcontrollers or to a PC from 150 meters (500 feet) to 300 meters (984 feet) line-of-sight (depending on conditions). They use three bands, 433-434 MHz, 869.85 MHz and 902-928 MHz.

There are some RF modules interesting for the purpose; they are from the first band (433-434 MHz) because the other two bands up are expensive for the initial budget. The first one is ES400TS-02 by *Easy Radio*, the second one is T5-434 and the last one is RTFQ2-433R both by *RF Solutions*.
In order to choose the RF module most appropriate to the Project is important to take in account the budget, because the best one for the transmission is ES400TS-02, but also is expensive, so the RF chosen is RTFQ2-433R that has the best relation features and price.

	ES400TS-02	T5-434	RTFQ2-433R
Range	250+ meters	300 meters	250+ meters
Temp. range	-40 ºC to +85 ºC	-20 ºC to +55 ºC	-20 ºC to +85 ºC
Date Rate	19.2 Kbits/s	128 Kbits/s	9.6 Kbits/s
Supply Voltage	2.5 V to 5.5 V	4.5 V to 5.5 V	3 V to 12 V
Output Power Signal	+10 dBm	+12 dBm	+5 dBm
RoHS	Yes	Yes	Yes
Price (*FarnellInOne*)	£ 10.10	£ 13.11	£ 7.27

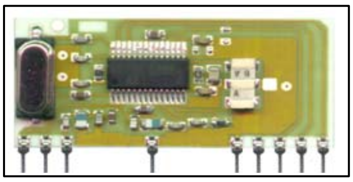


Fig. 4.5 RTFQ2-433R [Datasheet]

The RF module need a signal encoded to transmit, so that means that before the RF module in the circuit it will be an encoder to treat the signal properly to be send through the air.

As the RF module is by *RF Solutions* the same manufacturer sell an integrated circuit RF600T that is a transceiver, and then it can be an encoder in the transmitter stage and a decoder in the receiver stage.

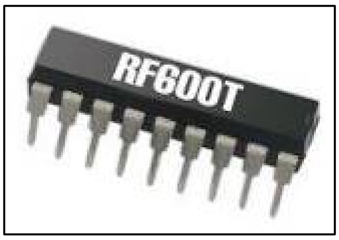


Fig. 4.6 Transceiver RF600T [Datasheet]

Nevertheless to transmit is necessary other device to add at RF module, an antenna. An omni-directional one will be better than directional one, because in the purpose could be more than one transducer and the receiver would need to detect information from all of them. The length is ¼ wavelength, in that case is 15.5 cm.

Fig. 4.7 Omni-directional Antenna

4.3 <u>Data Reception</u>

Once the transmitter stage is studied, the reception will be easy to find out. Because the RF module will be the couple of the RTFQ2-433R, this is the RRFQ2-433.

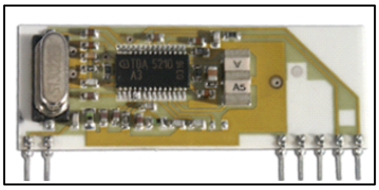


Fig. 4.8 RRFQ2-433 [Datasheet]

In this case a decoder IC will be necessary to decode the signal from the RF module to the next stage. Another RF600T will be placed into receiver circuit.

To conclude the chapter just mentions that another antenna as the showed above will be used in the reception circuit.

4.4 Possible Conditioning

In order to know if it will be necessary another conditioning circuit for the input of the control device, just mention that the control device could be a microprocessor or a microcontroller. In this case, the normal input of these devices is 0 V or 5 V.
In this way the output range of the decoder is -0.3 to VDD +0.3 and VDD is 5 V, so any conditioning circuit will be required.

4.5 Control Device

After seeing the features and the market of control devices in the theory and background research chapter, here will be discussed the better controller for the purpose.

Firstly is important to know the application of the control device in Radio Data Network. So the control system will receive data from the decoder. The data will be process by the device, detecting alarming values, incorrect values or calculating averages, through the program that controls it. Once the data has been processed, they will be sent to Zoo control room that studies of the animal's habitat environment.

Thus the purpose does not need complex programs to process the data neither powerful rate of calculations. So is needed a control device able to execute a single simple program, easy to implement into electronic system with a minimum of external support chips, easy to carry on the installation, easy to maintain or repair and cheap.

A microcontroller is the control device that adapts better to the purpose, because it is able to execute a single program. And how the application needs a simple execution of instructions, the microcontroller could be a RISC set of instructions. Another characteristic of microcontrollers is the high level of integration in electronic systems that the microprocessors does not have normally. Finally the MCUs are cheaper than the microprocessors, so for all of these reasons the control device will be a microcontroller.

Taking in account all the features of the three main microcontrollers, the type that is better to the Project must have several characteristics:

Code efficiency: Harvard architecture offers more efficient implementation than Von Neumann, because the microcontroller can access to memory and data simultaneously, and the throughput rate is better.

- **Instruction Set**: a RISC device has an acceptable number of instructions able to execute themselves in one cycle.

- **Speed**: it means the speed of the instructions per second, thus the operating frequency would be high. For example with an operating frequency of 20MHz, is possible to have a speed of 5 million instructions a second.

- **Drive Capability**: the uC must have a high output drive capability and can directly drive electronic devices.

- **Options**: A range of speed, package, I/O lines, timer functions, serial or parallel communications, A/D and memory sizes to suit all the requirements.

- **Cost**: A low cost solution is important to decide one or other product.

- **Development**: A microcontroller available in a useful Operative Systems, like Windows. With tools for development readily available. And able to programming in useful and easy code, as high-level language.
- **Security**: If is possible a code protection. Once the protection bit has been programmed, the contents of the program memory cannot be read out in a way that the program code can be reconstructed.

The manufacturer that offers all of these features and at the same time is used widely in the NEWI School of Engineering is Microchip Technology Inc. with the family of PICmicros.

4.5.1 PICmicrcontrollers

There are seven families in Microchip Technologies Inc. from 8-bit (PIC10, PIC12, PIC14, PIC16, PIC17, PIC18) to 16-bit (PIC24). But basically four families of 8-bit could be useful in the Project, from 12-bit to 16-bit program word. The families used normally in electronic control systems are:

- PIC 12CXXX, 12/14-bit program word
- PIC 16C5X 12-bit program word
- PIC 16CXXX and PIC 16FXXX 14-bit program word
- PIC 17CXXX and PIC 18CXXX 16-bit program word

After studying the main families carefully, the family most interesting is the PIC 16CXXX and PIC 16FXXX 14-bit program word. In concretely the study is focused in PICs with serial connections, because the microcontroller has to connect to a computer to show the data by screen.

	PIC 16C554	PIC 16F877	PIC 16F84
Program Mem.	512 x 14	8192 x 14	1024 x 14
Data RAM [bytes]	80	368	68
Operating Freq. [MHz]	20	20	10
I/O	13	33	13
A/D converter	-	8	-
RoHS	Yes	Yes	Yes
Price (*FarnellInOne*)	£ 2.17	£ 4.07	£ 4.29

Between the three PICs, the second one (PIC 16F877) is a sophisticated microcontroller which offers eight channels of A/D converters, 8192 x 14 program memory, USART (Universal Asynchronous Receiver Transmitter), 3 timers and other options. It is the most complete MCU in the family, over the very popular, but old PIC 16F84. Furthermore the 16F877 has more Program memory and Analogue to Digital converters, so is the microcontroller for the Radio Data Network.

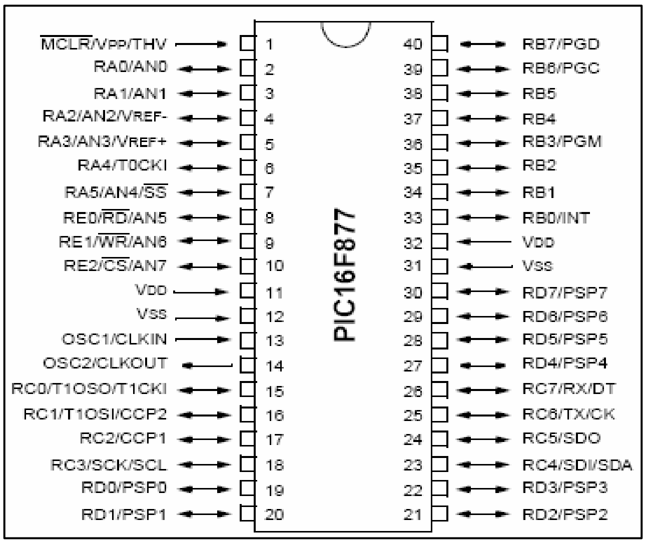


Fig. 4.9 PIC 16F877 [Datasheet]

4.6 Possible Conditioning & Zoo room control

To conclude the design this chapter is going to introduce the elements of the last stage, however not the most important, it is the most impressive for the customer. The reason is that he will see the final results.

In order to send the data from the microcontroller to the Zoo room control there are some technologies to use. Nowadays there are two technologies very implemented in connections between devices, the USB 2.0 and the FireWire (also known as i.Link or IEEE 1394). But it is important do not forget RS-232. All those buses have been explained in the second chapter.

The next table shows the main features between the three serial buses:

	RS-232	USB 2.0	IEE 1394
Cable length	1.2 meters	1 meter	1 meter
Speed Rate	76 Kbit/s	480 Mbit/s	100 Mbit/s
Software installation	No	No	No
RoHS	No	No	Yes
Price (*FarnellInOne*)	£ 12.04	£ 2.52	£ 17.66

The fastest is the USB 2.0 and also is the cheaper one, but the most implemented in laboratory solutions is the RS-232. Furthermore it is the standard used in the training board of NEWI laboratories. So it will be the serial bus to use in the application to send the results of the measurement to the computers of the Zoo control room.
Moreover to send the data from the microcontroller to the PC it will be necessary a device that converts the data from the µC into serial output data able to travel into the RS-232.

To achieve that there are some integrated circuits, called driver/receiver. One of the most commonly used is the MAX232A.
The reason to use this IC is because the manufacturer *RF Solutions* recommends in its Datasheets this chip to complete a right design. Also as it is said, is a common device used in a lot of electronic applications with computers and microcontrollers.

So now the data will be sent to a computer where the measurements will be shown on its screen by HyperTerminal. A utility from Windows that it will be explained in detail in the chapter *BUILD & TEST.*

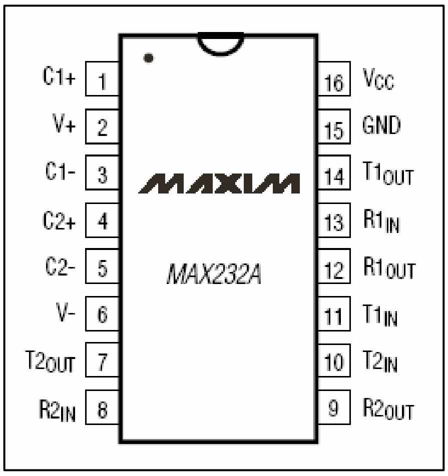


Fig. 4.10 MAX232A [Datasheet]

4.7

The whole detailed design

In conclusion there are five stages (seven before discarding the fifth one, possible conditioning) in the total Project, but in each one there are sub-stages. To have an idea of all the stages and sub-stages the next flow chart pretends to clarify the structure of the detailed design.

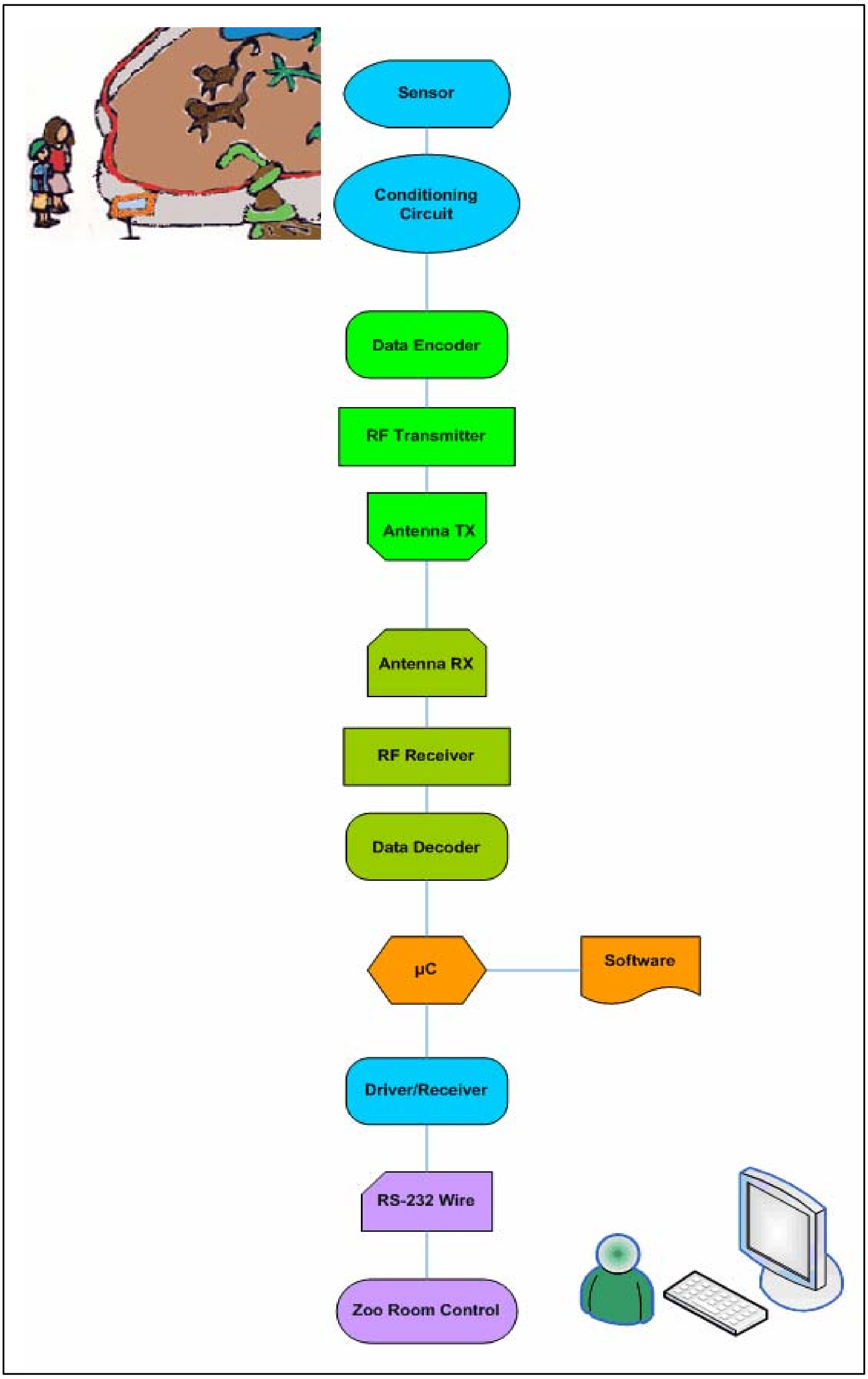


Fig. 4.11 Flow diagram about the detailed design

5. DESIGN CORRECTIONS

During the process of built and test there were some corrections in the design. Firstly it will explain the corrections in the hardware and after the corrections made it in the software. This chapter had been crated after the chapter of *RESULTS*, so probably some of the pieces of hardware changed are unknown yet, but it will be useful consult the previous and next chapters to have an idea of which part and which components of the design are being treated.

5.1 Hardware

While it was tested the radiofrequency link, it was discovered that the chips used in the second part, and in the third part to encode and to decode (RF600E & RF600D), respectively, were a chips that just works with TTL inputs, that means that just sent information when receive a ‘1’ and stop the transmission when receive a ‘0’.
Hence the design needs other chips to encode and decode the data precedent by the conditioning circuit in the transmitter, and precedent by the RF module in the receiver.
After a hard research new chips had been implemented to achieve the purpose, those chips are the RF600T in spit of the RF600E (encoder) and RF600D (decoder). Furthermore these chips can be used in both circuits, transmitter and receiver, because they are able to be used as a decoder and an encoder.

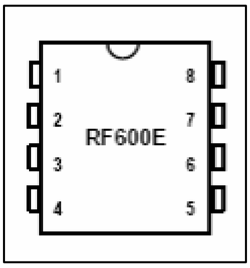


Fig. 5.1 RF600E Encoder [Datasheet]

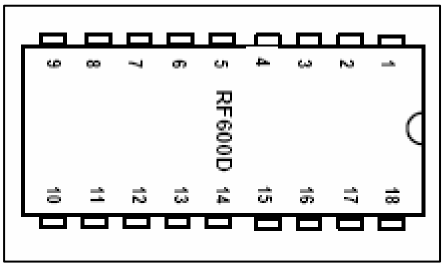


Fig. 5.2 RF600D Decoder [Datasheet]

The second trouble in the design was the connection of the Alarm LEDs, they were connected to the microcontroller output and then to the supplied voltage of 5 Volts. In the tests were tested the LEDs trying to achieve that they switched on when the temperature value had a number over a range determined (20 ºC – 34 ºC), but any of the LEDs were working.

The LEDs were changed for other new ones. But the problem was still there. So it was discovered that the microcontroller supply a little voltage to the LED instead of connect it to ground to activate the light.

Hence the connection of the LEDs were changed, and they were connected to ground not to the supplied voltage of 5 Volts.

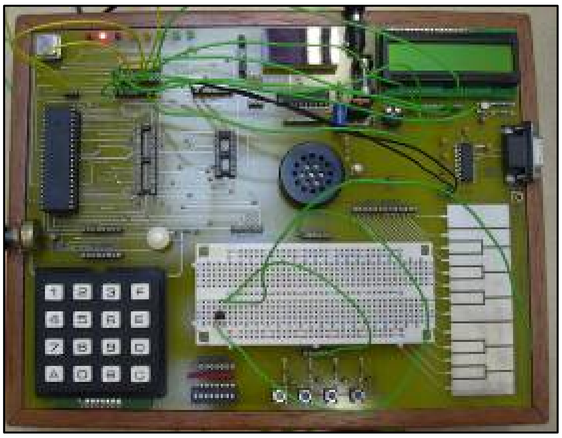


Fig. 5.3 Solve it the trouble with the LEDs

To conclude with his sub-chapter mention that a great improvement was added into the design. It was an LCD screen of 14 elements in 2 lines (14x2).

The reason to add an LCD is because during the tests it was necessary to know what exactly the product was doing without the connection via RS-232 and a computer beside the circuitry to show how is going.

And in the real world, in a real application if the circuitry needs to be maintained, the operators will be comfortable using the LCD screen as a reference.

Thus the LCD screen is the model PCI1602 as is shown in the next picture. It just costs £ 10.07.

Fig. 5.4 LCD screen used in the purpose [Datasheet]

5.2 Software

Some versions of the code program had done it before the last one. Because a long code at the beginning of the tests is tedious to proof and to correct it. For that each version has something added and the mistakes were corrected version by version.

5.2.1 Code corrections

In the first version the delays were programmed randomly and the time between the executions of the instructions was very short to be an application to control temperature periodically.

Also the position for the dates on LCD screen was wrong. Some letters and decimals of the values were missed on the screen. Another mistake in the first one was temperature measured. The value of temperature was between 2.75 and 2.76 Celsius degrees.

Really temperature in the room was around 22 ºC not 2.75-2.76 ºC. So this mistake indicates something wrong in the operation to convert the output of the analog-to-digital converter in Celsius degrees.

Version number two corrects properly the delays between different instructions, making the prototype Project better for its real application. However it was discovered that the variables that indicate the hour on LCD screen sometimes appears with letters (Fig. 5.5). It was supposed that the hour on screen will have just integers because the type of the hour variables was integers.

Fig. 5.5 Wrong Temp and hour

The solution for that trouble consists in change the type of the values that are inside the printf of the LCD display. Instead of use normal integers to print the values (%X), use unsigned integers to print them (%U). The next figure shows the wrong printf and the correct one.

```
printf(lcd_putc,"%2X:%2X",hour,min);  //it shows 0F:2F
printf(lcd_putc,"%2U:%2U",hour,min);  //it shows 10:25, right one
```

Fig. 5.6 Trouble with the hour on display

But the problem with the factor of conversion between bits and degrees still existed. As the figure above shows, temperature value was wrong.

Then the decision was taken from not correcting the problem of the calibration of the program with the sensor until finalizing with all the other primary targets. For that the next chapter is focused just in the calibration of the prototype.

Thus one of the utilities of the program can not be tested, temperature maximum and minimum. Because temperature value was 2.75-2.76 ºC and for space reason in the LCD display the maximum and minimum are integer values and were the same value all the time as shows Fig. 5.7.

Fig. 5.7 Maximum and minimum utility

The next version (three) was able to communicate with a computer via RS-232. It informed the computer about temperature in the room in Celsius and Fahrenheit degrees. Also is showed the maximum and the minimum ranges of temperature and alarms if degrees are over, below or within the right range for survive the chimpanzees in the zoo habitat (20 ºC – 34 ºC). See the pictures below.

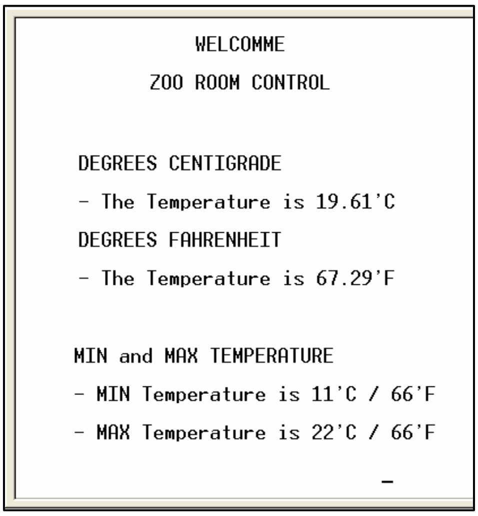


Fig. 5.8 Information

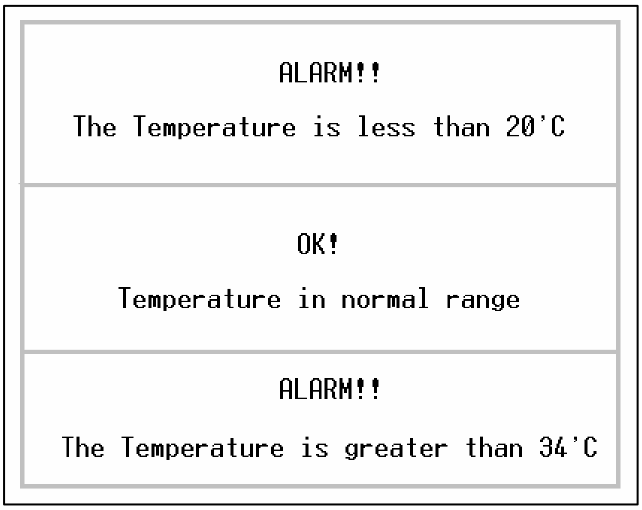


Fig. 5.9 Alarm messages

The final code has one important mistake solved, one utility working properly and some details of presentation on screen and comments to be understandable for further modifications added.

The important change was in the factor of conversion. Finally the mistake was found. But these troubles will be explained in the next chapter that is completely focused in the problem of the calibration (See next chapter).

The utility that was wrong was the maximum and minimum temperature. After the problem with the calibrations was solved, the program shows the same variable for the maximum and for minimum. The mistake was in the initialization of the values that keep the maximum and minimum temperature. The version number three had the following code:

```
min_temp=inTemp;            //inTemp is the value of current Temp
max_temp=inTemp;

      if(inTemp>max_temp)
      {
            max_temp=inTemp;
      }
      else if(inTemp<min_temp)
      {
            min_temp=inTemp;
      }
```

Fig. 5.10 Maximum and minimum of version three

This code always keeps the value of current temperature; do not store the maximum one and the minimum one. Hence to solve the bad initialization of the values the latest version has the next code:

```
min_temp=100;
max_temp=0;

if(inTemp>max_temp)
      {
            max_temp=inTemp;
      }

      if(inTemp<min_temp)
      {
            min_temp=inTemp;
      }
```

Fig. 5.11 Maximum and minimum of latest version

To finalize with programming chapter the obtained results in the laboratory, the final code is in *APPENDICES*. The fruit of the program is shown below in the LCD pictures when the measured temperature and the maximum and minimum of it are shown as well.

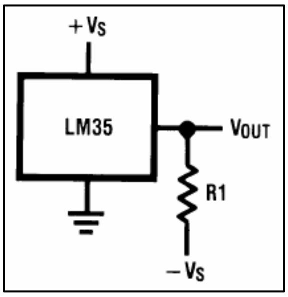
Fig. 5.12 Program tested

5.2.2 Calibrations

After the program is running properly, showing the messages on the LCD and the computer screens. The next step is to calibrate the µC program to show the correct temperature on screen.

In order to adjust the program is necessary to know the values that the analog-to-digital converter (ADC) has after the conversion of the analog value received from the sensor. Thus is necessary to have some values of the ADC in some temperatures to calibrate properly the microcontroller.

The measurements are treated on the training board with the sensor connected directly to the port A0 with a resistor of 100 kΩ in parallel. The resistor is necessary to have the range from -55 ºC to 150 ºC such as in the LM35 Datasheet explain.



$$R1 = \frac{-Vs}{50\mu A} = \frac{-5}{50\mu A} = -100k = 100k\Omega$$

Fig. 5.13 Full-Range LM35 [Datasheet]

Once the circuit is built on the training board, starts the measurement of the values. Is used the Computer screen to show them, because the LCD screen is smaller and does not store the values as HyperTerminal does.

To calibrate the response of the ADC is necessary something that converts ADC value in a Temperature value.

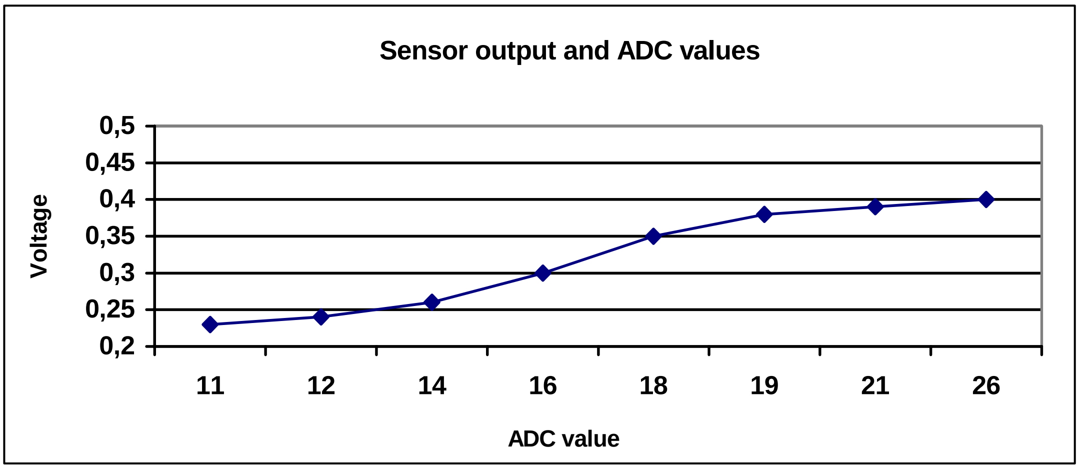
Being based on some examples of CCS compile it was created a function (void current_temp) that converts the ADC response in a temperature. It multiplies the ADC value by the scale factor (2N – 1, when N is 8 bits) and divides the result by the max value of temperature that accept the sensor (150 ºC).

```
const int scale = 255;
const float temp_max = 150.0

void current_temp (int valueADC, float &tempOK)
 {
      tempOK=(valueADC*scale)/temp_max;
 }
```

Fig. 5.14 Function of calibration

The first chart show the output tensions of the sensor (V_{out}), that represents different temperatures, and the response of the ADC with these values in port A0.

Fig.



5.15 Sensor output and ADC values

In the following graph is represented temperature showed on screen for the different ADC values.

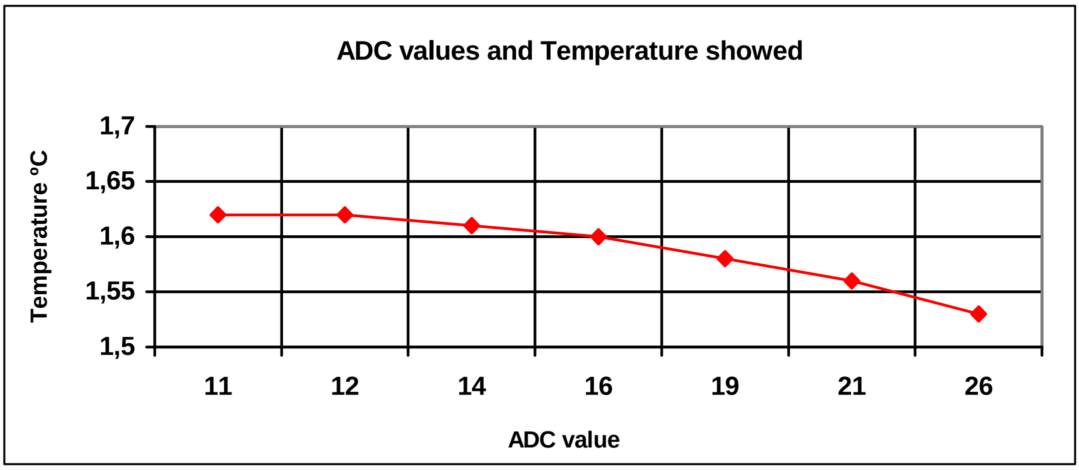


Fig. 5.16 ADC values and Temperature showed

Sensibility in the LM35 is 10.0 mV / ºC, so it means that for 23 ºC the Vout should be 230 mV or 0,23 V. In Fig. 5.5 for Vout equal to 0, 23 temperature showed on the computer screen is 1, 62 ºC. It means something is wrong.

Furthermore if Vout increase the ADC value should increase as well and consequently temperature on screen should increase. But on the experiment it does not happened.

The mistake is in the factor that converts the integer values of the ADC in float values of temperature.

To solve the problem in the conversion factor a new method is studied. The new method takes in account that for each increase of input voltage in port A0, the ADC will increase the output bits.

$$V(mV/bit) = \frac{Vs}{2^N - 1} \times 100 = \frac{5}{2^8 - 1} \times 100 = \frac{5}{255} \times 100 = 1{,}961$$

It means that if the ADC value is multiplied by 1, 961, the result will be the correct temperature in Celsius degrees.

So the function to convert bits in Celsius degrees will be such as in the next figure.

```
const float factor = 1.961;

void current_temp (int valueADC, float &tempOK)
 {
        tempOK=(valueADC*factor)/temp_max;
 }
```

Fig. 5.17 Correct function of calibration

The results of the good calibration in the C code are in the *RESULTS* chapter. Because of the next chapter is focused en how the Project was built and which tests were done it.

6. BUILT & TEST

The aim of this chapter is to show and to explain the construction and tests in the laboratory. It has several contents focused in the different parts of the Project software and hardware. The entire hardware tests have been done it with the laboratory equipment, some Multimeters (MULTI EMP by *BlackStart*) and a digital Oscilloscope (HP 54750A by *Hewlett Packard*).

6.1 Sensor and Conditioning

In order to build the sensor and the conditioning circuit it was followed the circuit diagram below. Note that the entire circuit diagrams are done it with Multisim 8.

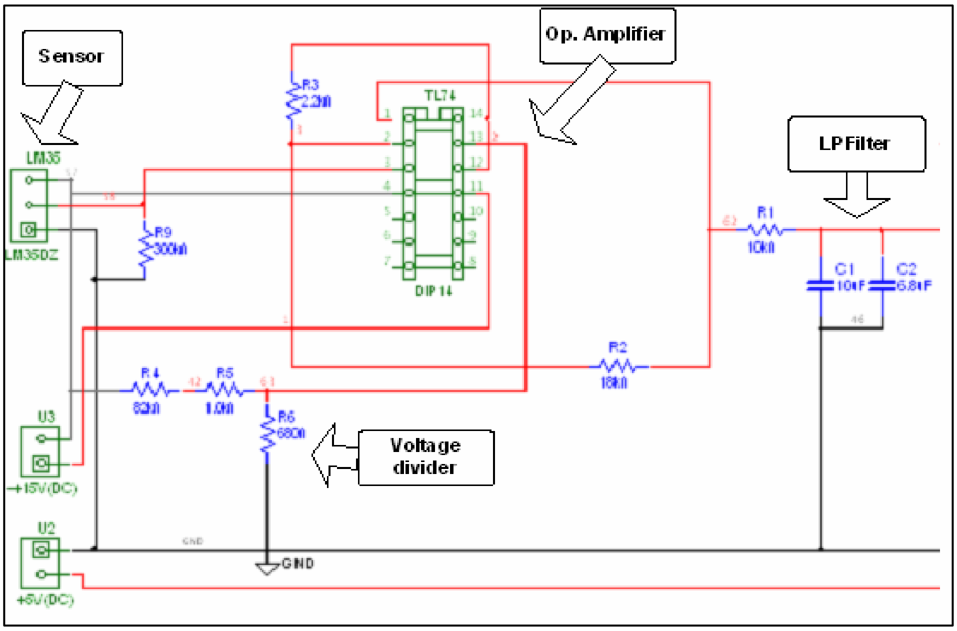


Fig. 6.1 Sensor and Conditioning circuit diagram

Hence the components are placed in a protoboard following the circuit diagram, and testing component by component the signal input and its output signal in order to proof the correct working of the circuitry, before to build other stage of the whole part.

A characterization of the LM35 was achieved to make sure that the transducer is working properly, heating it and measuring the output voltage.

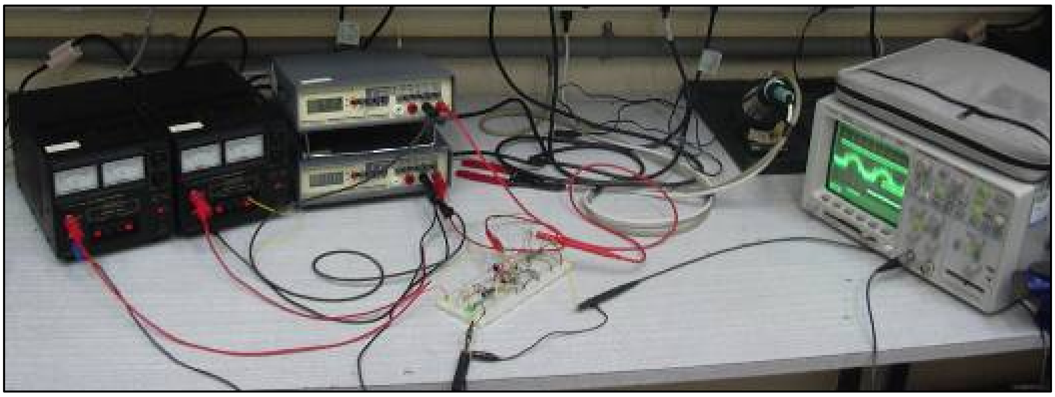


Fig. 6.2 Equipment used to build & test, power supplies, Multimeters and a digital Osc.

6.2 RF Link

The second and third part will be built in this chapter following the specifications of the manufacturers of the transceiver and RF modules in their Datasheets.

Hence the circuit diagrams showed below the connection of the transceiver chips with the RF modules and the antennas.

The first one shows the connections in the transmitter circuit and the next figure shows the connections in the receiver circuit board.

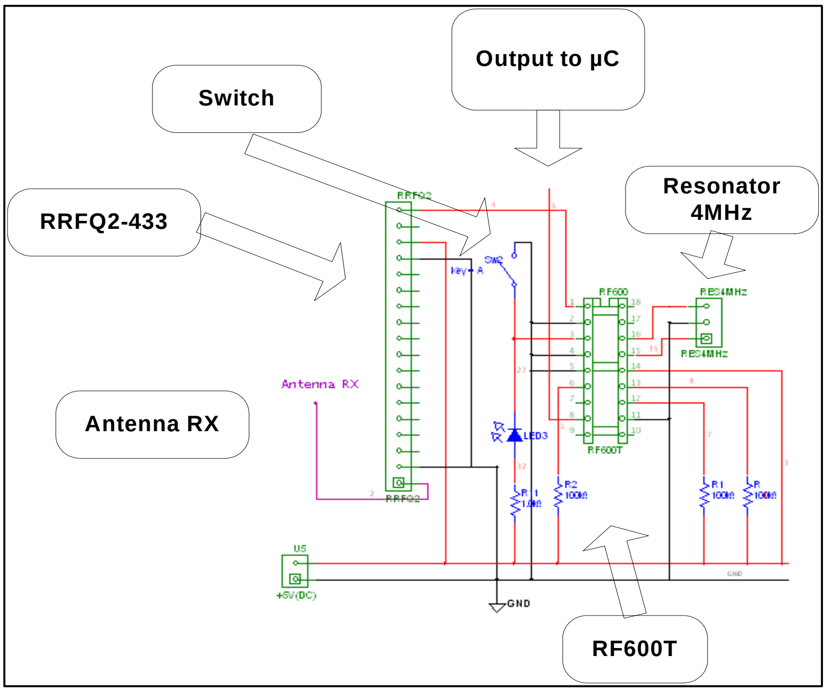


Fig. 6.3 Transmission circuit diagram

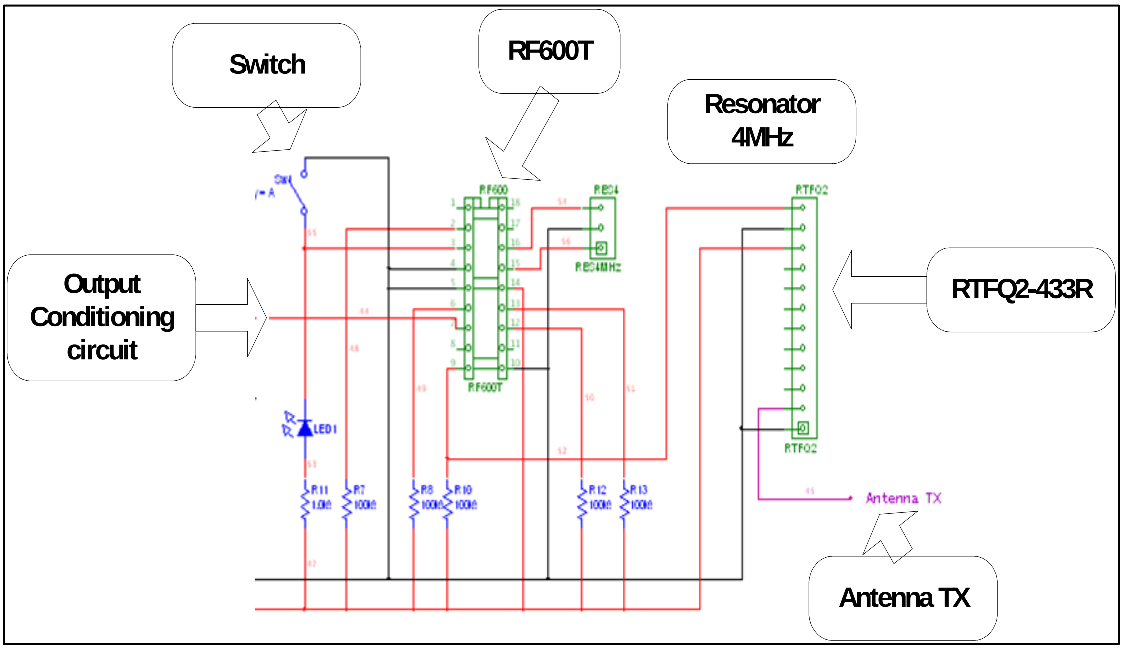


Fig. 6.4 Reception circuit diagram

After the followed the circuit diagrams of the transmitter and the receiver RF link placing the components in two different protoboards. The first one protoboard is for the transmitter, with the first stage (*sensor & conditioning*) implemented and other one is for the receiver.

The tests were done it firstly in the transmitter part. They consists in the measurement of the output signal of the transceiver RF600T, using the scope probe in x1 and the Oscilloscope to see the signal. Then the next measurement was the output signal from the RF module RTFQ2-433R. To finalize the experiments, it was measured the output signal of the transmitter antenna.

Thus the tests were done it into receiver circuit, measuring firstly the signal received into the antenna, followed by the input signal of the RF module RRFQ2-433. Then the measurement followed with output voltage of the RF module and the output signal of the chip RF600T, which goes to the microcontroller.

The antennas of the circuits are made it with a steel bar, cutting two pieces of 15.5 cm.

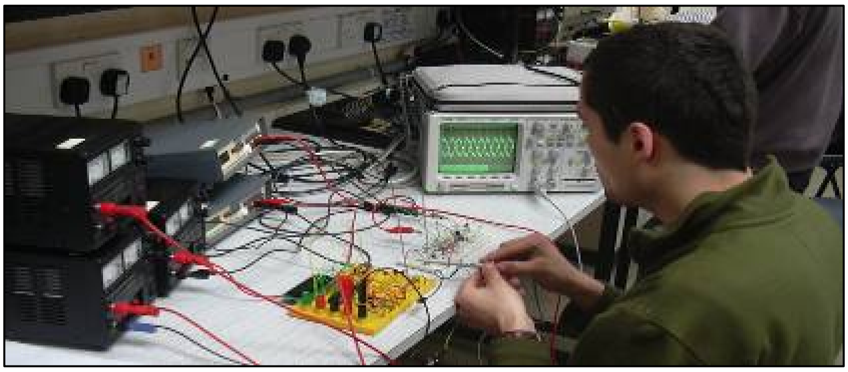


Fig. 6.5 Laboratory measurements in the RF link

6.3 <u>Software and Microcontroller</u>

In order to do a program is necessary to follow five basic rules:

- Specifications of the program
- To make a flow diagram
- To write the code
- Compile and link
- To debug errors, if there are them

Those are developed in the next sub-chapters; the three last rules are together in the same chapter because both can be followed with the same tool, MPLAB IDE.

6.3.1 Specifications of the program

First of all is important to know what the program must do. The purpose of Radio data network is to transmit temperature through the air to a control room.

To achieve that are some parts in the Project and the part in which the program is useful is when the signal of temperature arrives to receiver circuit as a voltage and it goes to the microcontroller that has to be able to detect this voltage signal and send to the zoo control room temperature of Bonobo's habitat.

Voltage signal from the transmitter is an analog signal and the microcontroller need a digital signal to send it to the computer and to treat it. So analog-to-digital converter of the microcontroller will be used.

Another useful feature of the µC for the purpose is the possibility to use serial output, to send data to the control room.

In conclusion the program should be able to receive an analog signal through the embedded device. It should be able to convert this signal into a digital one and send it to a computer or any display legible for the humans.

6.3.2 Flow diagram

The aims of the program are clear above, now is time to the flow diagram. It is the best way to draw the targets of the program in few and clear steps for the developer.

The flow diagram on the next figure (Fig. 6.6) show which are the main parts to take account programming the microcontroller.

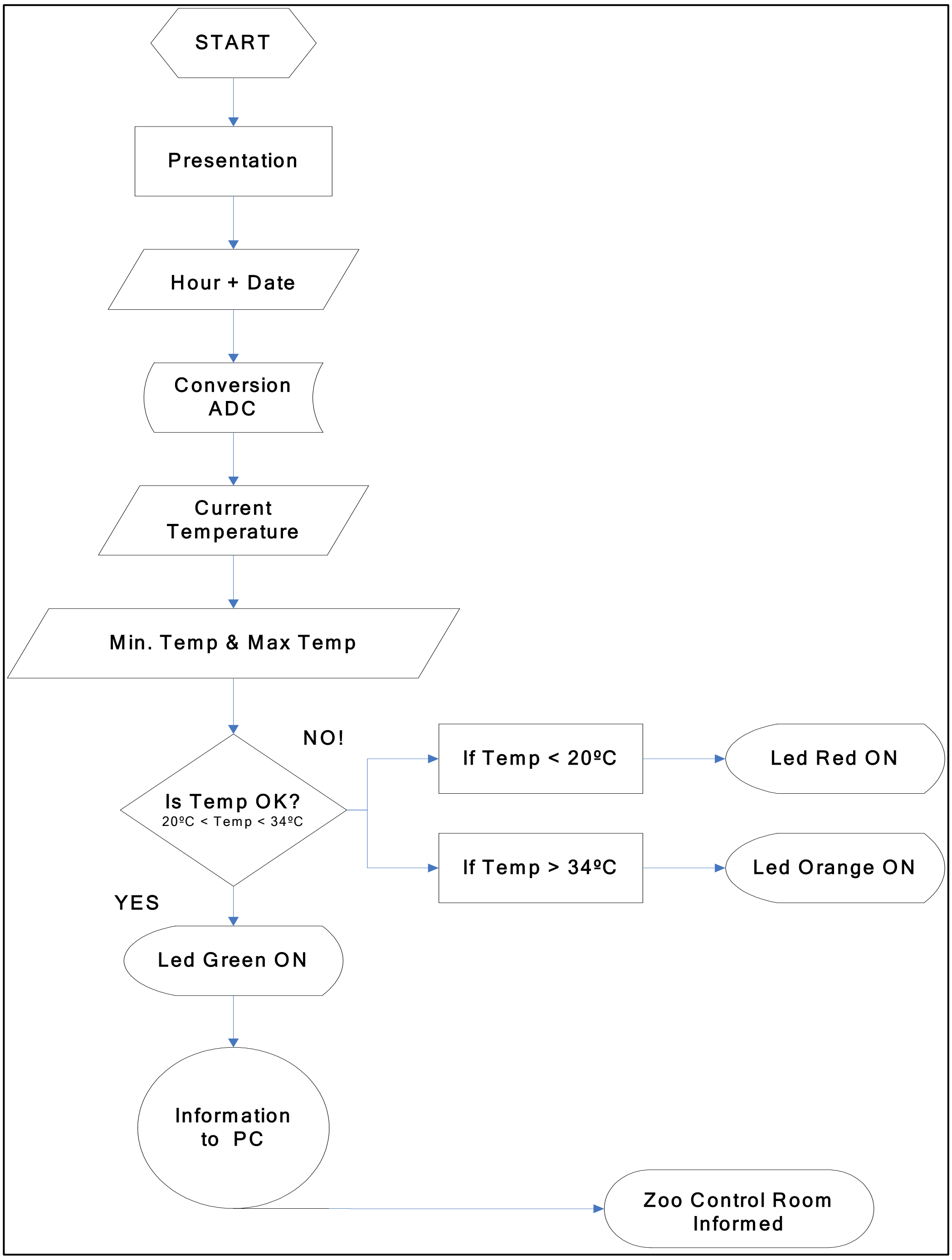


Fig. 6.6 Flow Diagram

6.3.3 The code

To write the code (C language) is necessary a text editor like 'notepad' in Windows. Then the file has to be saved and then change type of the file. Instead of *.txt is necessary *.c to use as a C code file in MPLAB IDE.

MPLAB IDE is a free, integrated toolset for the development of embedded applications employing PICmicrontrollers. The characteristic IDE provides to the developers of software applications the flexibility to edit, to compile, to link, to simulate, to develop and to debug its own software for the families of microcontroller PIC16/17 of Microchip.

In order to start the program, the first block is carried out in C code, and then the first part of the code is tested firstly by MPLAB IDE, and secondly into the training board available in the laboratory.

Once the first part of the flow diagram is accomplished, the next one is carried out and tested as the previous one, but including the new code within the previous code. All this process is followed to all the stages of the program.

The training board as is shown in the picture has some LEDs, an LCD screen, serial port RS-232, so it will be helpful to achieve a correct program for the purpose.

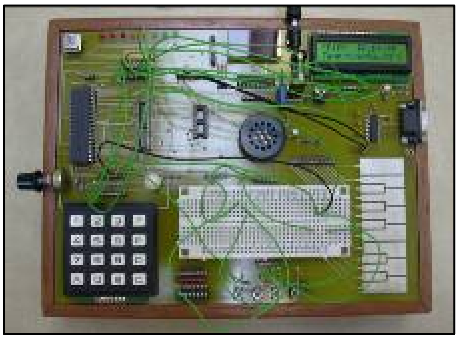


Fig. 6.7 Training Board

6.3.4 Microcontroller circuitry

Since now all the study was focused in the software but an important part of it is how is connected the microcontroller to do it job properly. So in the next circuit diagram is shown how it is connected to the rest of the components in the receiver circuit.

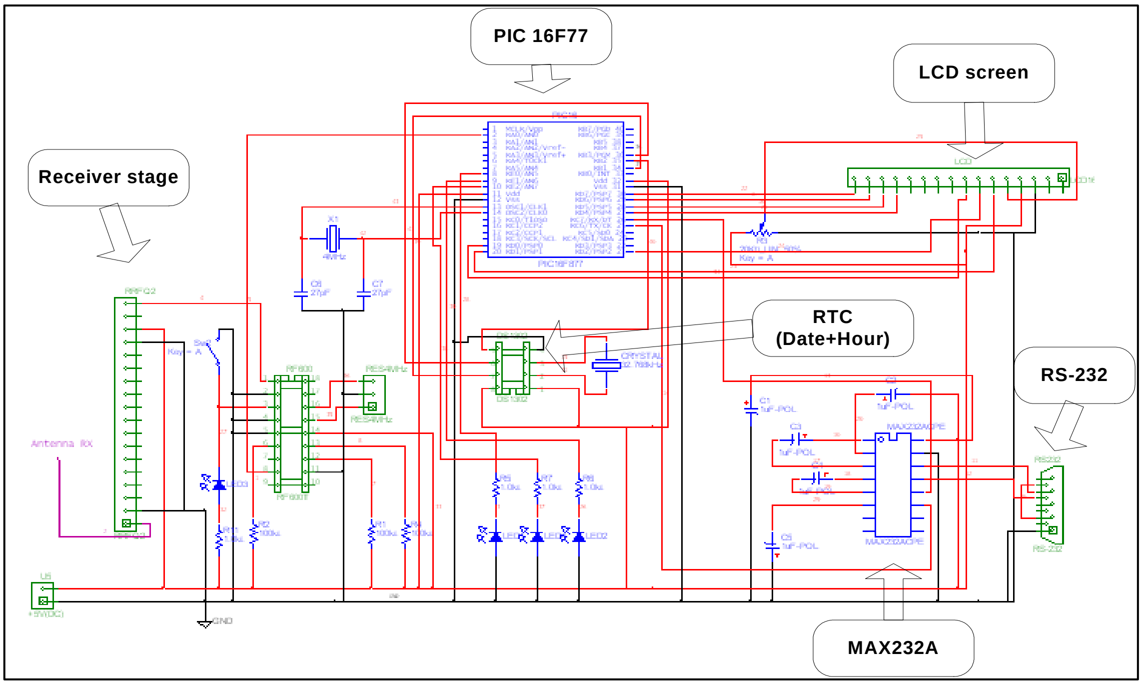


Fig. 6.8 Microcontroller connections

The tests in the microcontroller were the tests that occupied more time in the laboratory, first of all with the program, and then with the connections with it.

So to make sure that all was working properly, the measurements starts with the output signal from the RF600T that contains the data received form the sensor. The next measurements were with the alarm LEDs, to make sure that they were well connected. After the LCD screen was checked with the Multitester, making sure that all the wires were right.

Thus the next part of the measurement is the part that is responsible to show the date and the hour, that part is the Real Time Clock (RTC). It was checked all the wires and after with the program running, in the training board, some modifications were done it, they are explained in the *CORRECTIONS* chapter.

To conclude the measurements of the microcontroller connections, it was measured the MAX232A and afterwards the RS-232 connector with the Oscilloscope as the rest of the output and input signals.

6.4 Control Room

It is impossible to build the zoo control room, but it is possible to simulate it. So the simulation is in a computer, concretely with *Windows* as a S.O. that contains HyperTerminal.

HyperTerminal is a terminal emulation program that allows you to configure a serial port able to receive send into the computer.

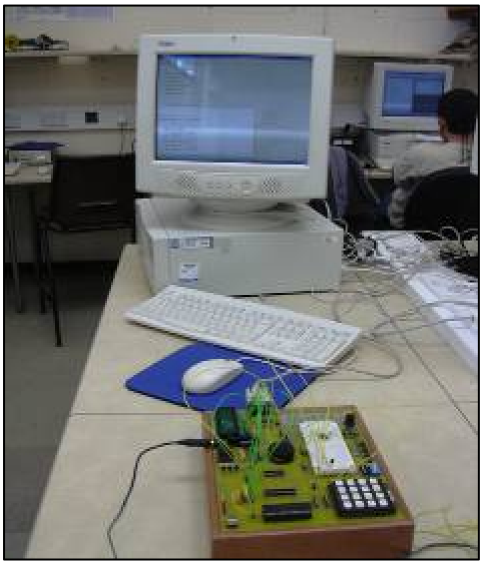
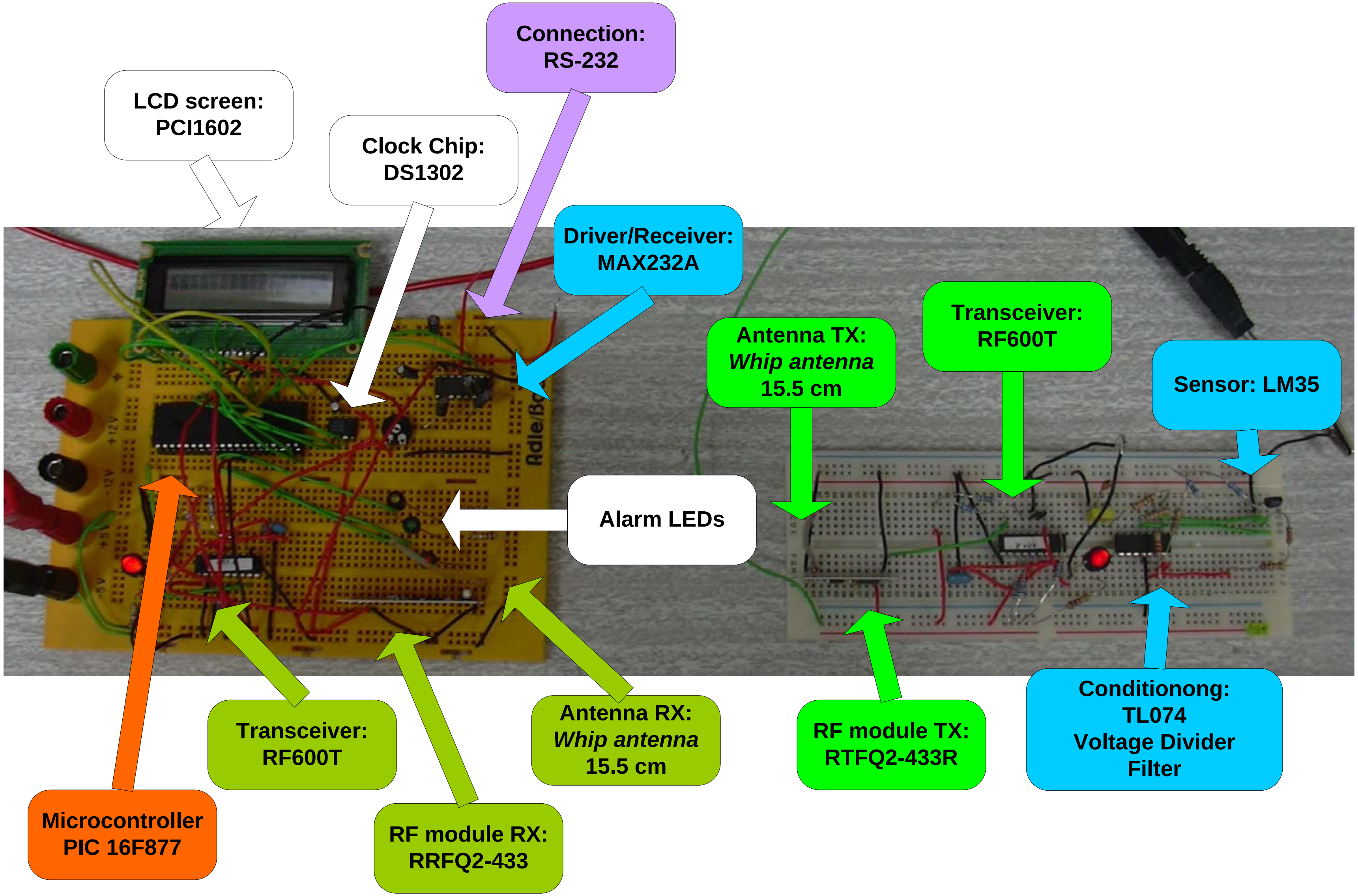


Fig. 6.9 Simulation of the zoo control room

Hence the computer is the best device to test if the Project was working properly and to know in which variables the problems are.

6.5 The whole project built



7. TEST RESULTS

In this chapter the results obtained from the tests and measurements done it in the previous chapter (*BUILT & TEST*) are treated.

7.1 Sensor and Conditioning

The first result obtained is the characterization of the sensor, which is shown in the next table and in the next chart.

Output LM35 [V]	Output Conditioning [V]	Temperature (Thermometer) [ºC]
0.22	3.32	21.57
0.23	3.46	23.52
0.24	3.49	24.05
0.25	3.53	25.23
0.26	3.57	26.15
0.27	3.61	27.45
0.28	3.65	28.04
0.29	3.76	29.41
0.30	3.83	30.50
0.31	3.95	31.37
0.32	4.05	32.14
0.33	4.12	33.30
0.34	4.27	34.04
0.35	4.31	35.29
0.36	4.46	36.14
0.37	4.58	37.25
0.38	4.70	38.22
0.39	4.86	39.04
0.40	5	40.20

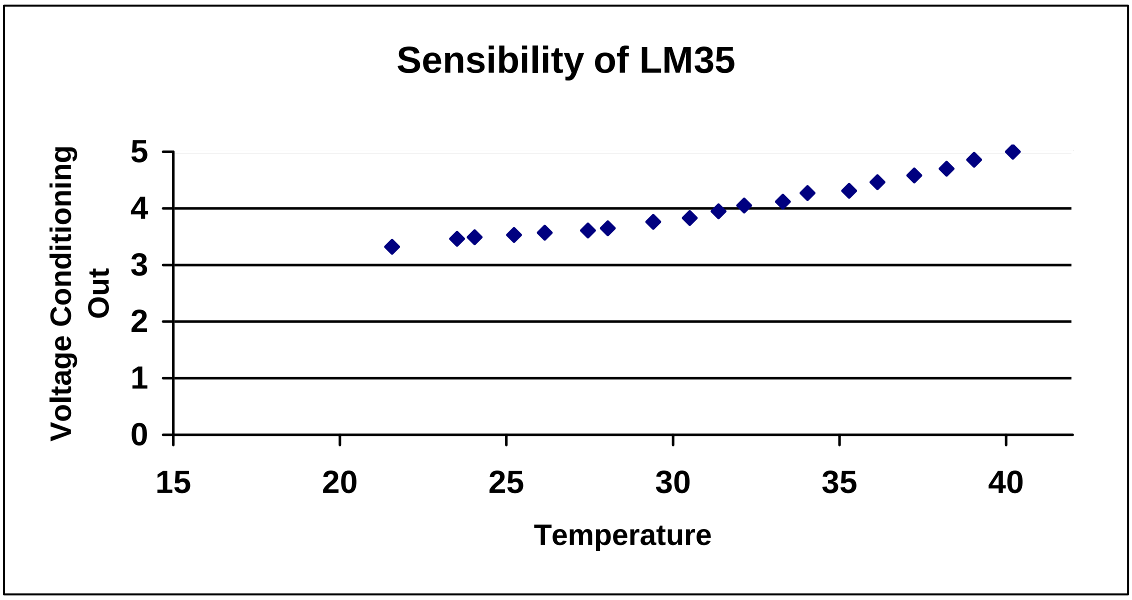


Fig. 7.1 Sensibility of LM35 after the characterization

7.2 RF Link

The results of the tests of the RF link are not too good. They are shown in the table below and in the chart.

Output LM35 [V]	Output RF600T [V]	Amplitude of transmitted signal [mV]	Frequency [Hz]
0	5.01	397	50.28
0.21	5.01	397	50.28
0.50	5.01	397	50.28
1.03	5.01	397	50.28
1.54	5.01	397	50.28
2.01	5.01	397	50.28
2.56	5.01	397	50.28
4.04	5.01	397	50.28
5.51	5.02	397	50.28
6.04	5.12	397	50.28
6.52	5.61	397	50.28
7.09	6.17	397	50.28
7.50	6.58	397	50.28
8.11	7.17	397	50.28
8.46	7.52	397	50.28
9.18	8.23	397	50.28
9.58	8.60	397	50.28
10.05	9.09	397	50.28

As is shown in the table the transceiver RF600T just increase its output voltage when the input voltage signal is from 5.50 Volts.

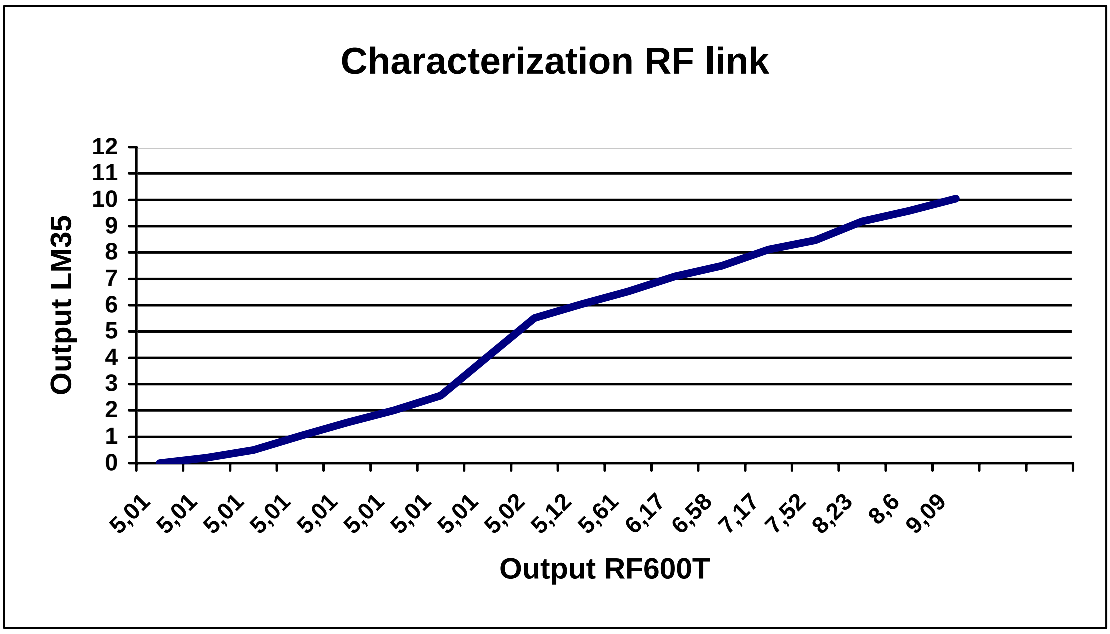


Fig. 7.2 Characterization of the RF link

The usual output of the sensor is 0.23 Volts, and the conditioning circuit has to amplify the output of the transducer till the range detected for the RF600T chip. But in fact is not going in that way.

The chip is not responding to the expected results, because it has to create a signal when it receive an input voltage between 0 and 5 volts, but actually it just responds with signal over 5.01 volts. So that means that the RF link does not work properly.

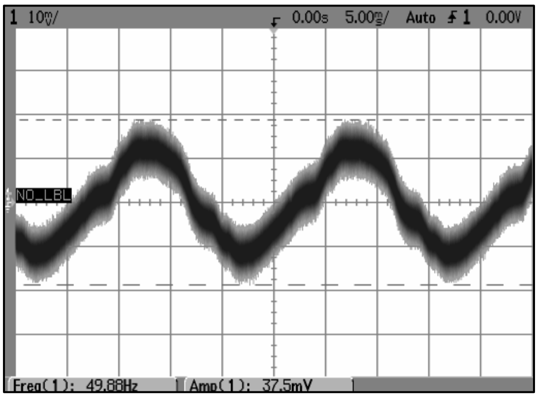


Fig. 7.3 Output of RF600T signal

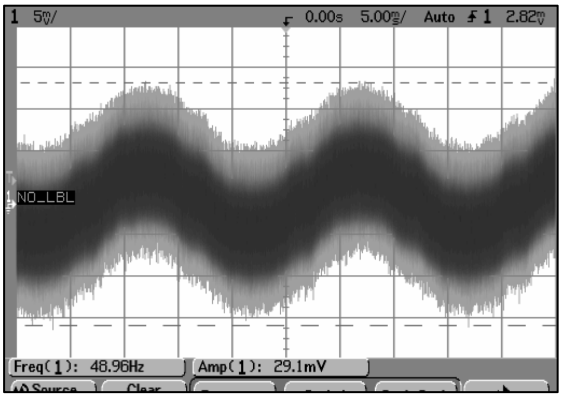


Fig. 7.4 Signal in the Antenna RX

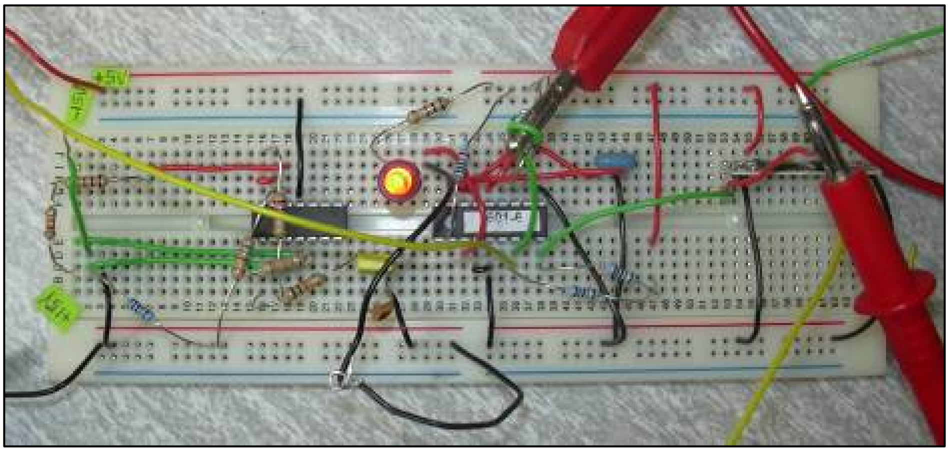


Fig. 7.5 Measurements of the RF600T

7.3 Software

The results of the software are in the LCD screen, as are in the next pictures.

Fig. 7.6 Wrong Temp and hour

Fig. 7.7 Maximum and minimum utility

Until here the wrong tests of the software, and then the right results of the final code.

Fig. 7.8 Program tested

The results with the correct function of calibrations are represented in the follow graphics.

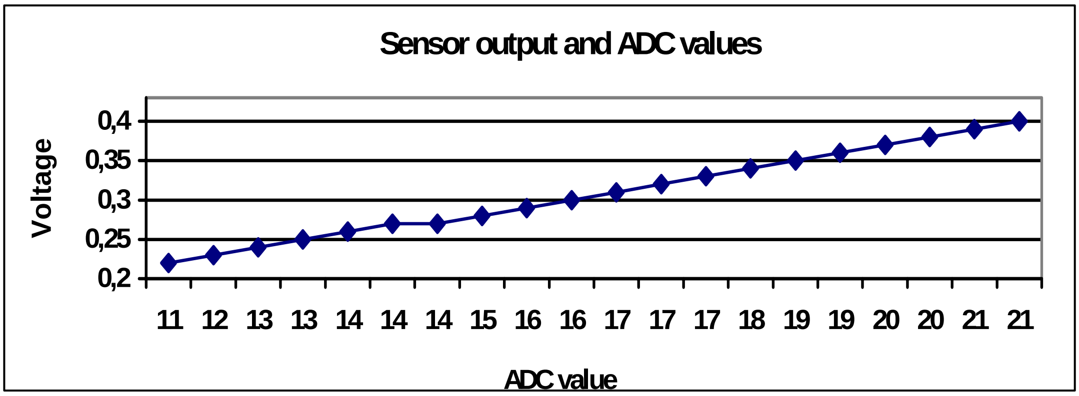


Fig. 7.9 Sensor output and ADC values

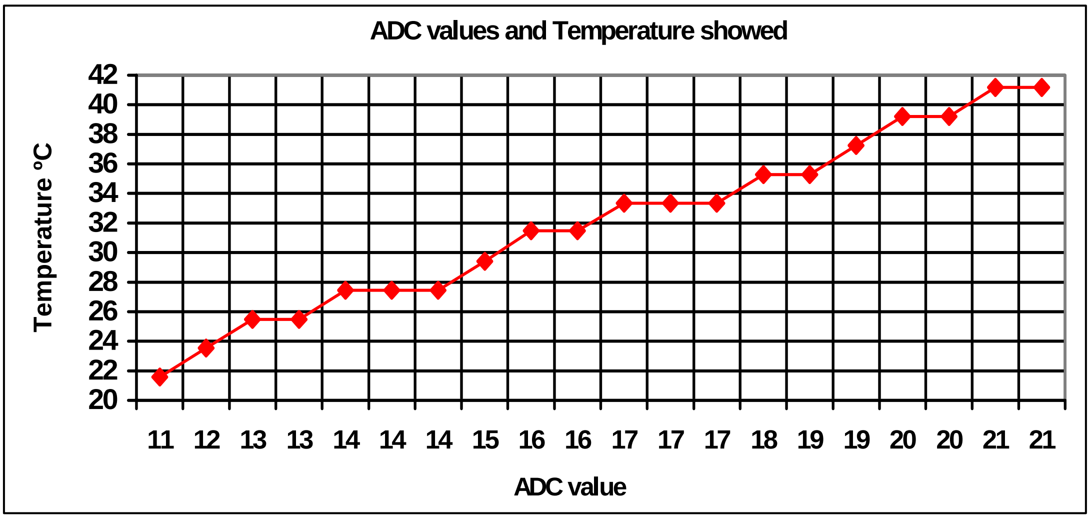


Fig. 7.10 ADC values and Temperature showed

Figure 7.12 indicates the relation between the ADC values and the temperature estimated measured with a thermometer.

7.4 Control room

The results of the last part of the design indicates that the Driver/receiver MAX232A and its connector RS-232 to the computer are right built. All of those tests are done it using HyperTerminal to simulate the real Zoo control room.

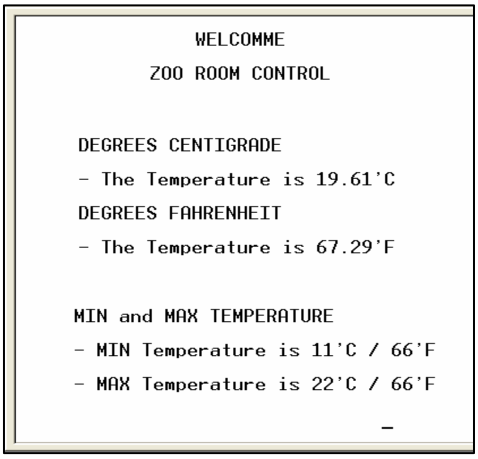


Fig. 7.11 Information

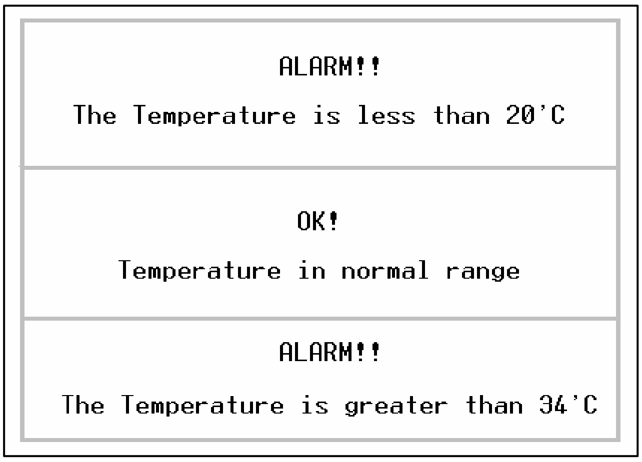


Fig. 7.12 Alarm messages

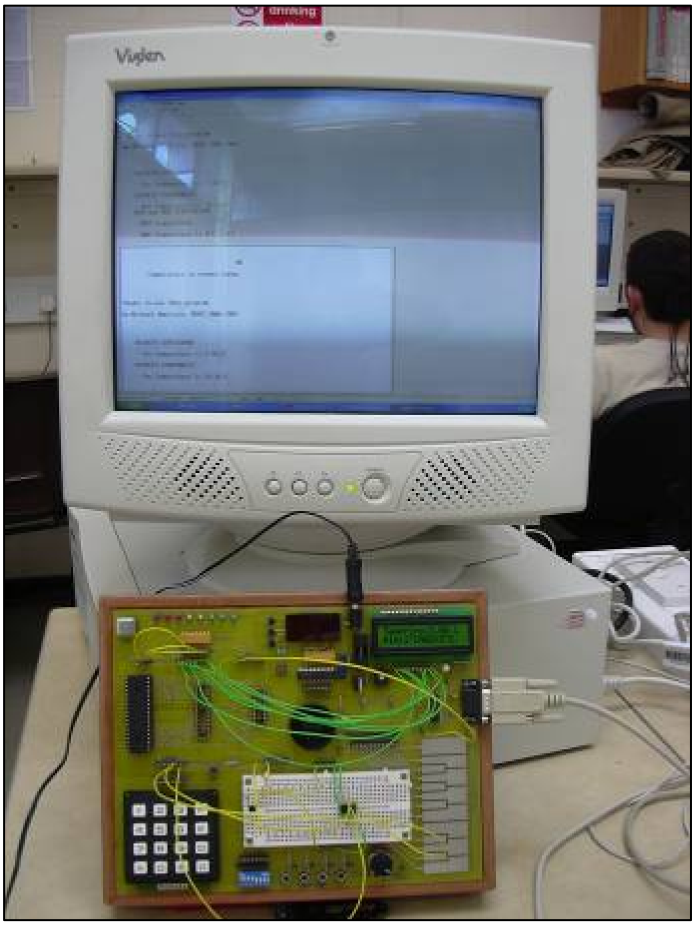


Fig. 7.13 Demonstration that the software works in the simulation as a Zoo room control

8. ENVIROMENTAL IMPACT

There are two kinds of environmental impact of the Project. The first one is referred to the circuit boards and integrated circuits and the influence inside the animal habitat.
Then the second study is about electromagnetic waves emissions that RF modules will produce.

8.1 Environmental impact of circuit boards and integrated circuits

The process of manufacturing integrated circuits has much hazardous elements. Those materials when are exposed in the environment as in the case of the Project, in the animal habitat, have some warning causes.

In the next table there is a summary of the main hazardous elements used in electronic devices, as the created for the purpose.

Element	Use	Harmful effects
Lead	Used primarily in soldering of circuit boards and other device components	Extremely harmful to the human body; damages both the central and peripheral nervous systems; can cause seizures, retardation, high blood pressure, damage to the kidneys and liver; adversely affects child development
Beryllium	Forms significant portions of electrical connectors and battery contacts	Long term exposure can be carcinogenic, especially for the lungs. Extreme exposure can lead to a potentially fatal condition known as Acute Beryllium Disease
Arsenic	Used in some integrated circuits and semiconductors	Arsenic is a notoriously potent poison; causes severe damage to the digestive tract
Mercury	Can be found to a degree in batteries and circuit boards	Attacks the central nervous and endocrine systems; harmful to mouth, teeth and gums; poses risk in the neurological development of unborn foetuses
Antimony	Used in production of diodes and batteries. Pure form used in semiconductor production	Toxic to humans in ways similar to arsenic; fatal in large doses
Cadmium	Used in soldering, semiconductors and chip resistors	Potentially carcinogenic; Repeated exposure can damage the lungs, kidneys and liver

8.2 Environmental impact of EM waves

The electromagnetic spectrum includes all the various forms of electromagnetic energy from extremely low frequency (ELF) energy, with very long wavelengths, to X-rays and gamma rays, which have very high frequencies and correspondingly short wavelengths. In between these extremes are radio waves, microwaves, infrared radiation, visible light, and ultraviolet radiation, in that order [Robert F. Cleveland, Jr. Jerry L. Ulcek, 1999].

The RF part of the electromagnetic spectrum is generally defined as that part of the spectrum where electromagnetic waves have frequencies in the range of about 3 kilohertz to 300 GHz. Note that Project uses the 433 MHz band of Wireless RF.

In the spectrum is possible to differentiate two types of waves, non-ionizing and ionizing waves.

The first type is radiation of insufficient energy to dislodge an orbital electron, but which may be capable of significant energy deposition. The transition between ionizing and non-ionizing radiation occurs at an energy level of about 12 electron volts.

The second radiation is a process in which an atom or molecule loses or gains electrons, acquiring an electric charge or changing an existing charge, capable of damaging cells by removing electrons from atoms or molecules. This damage can lead to cancer or other defects in any form of live, as the Bonobos of the application.

But fortunately the frequency used in the purpose is 433 MHz, and it has the wave's energy of the first type. In the next figure is possible to have an idea of which frequency is damage and which not.

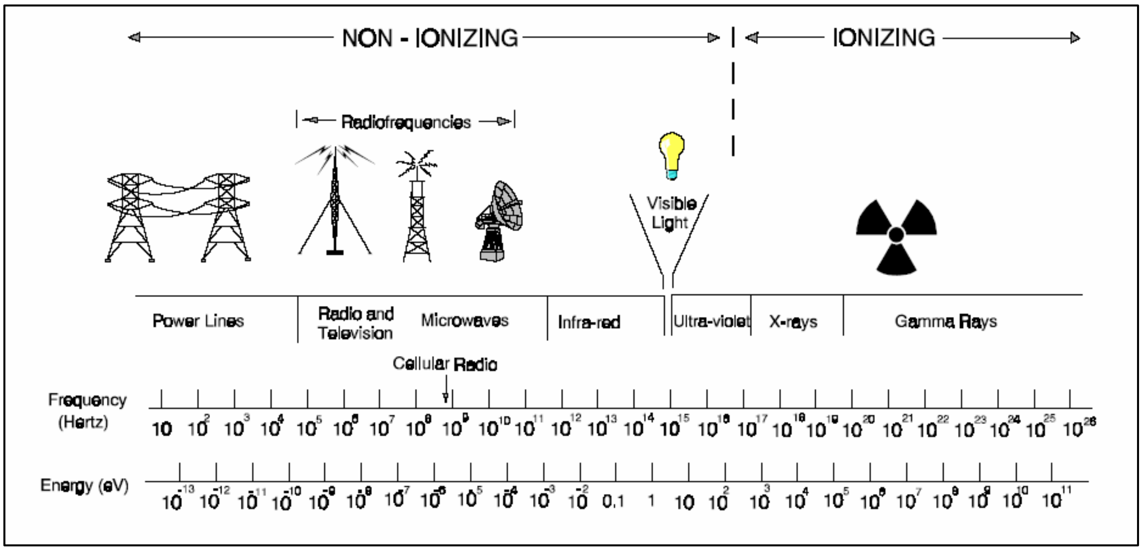


Fig. 8.1 It shows which frequency is non-ionizing and which is ionizing [Robert F. Cleveland, Jr. Jerry L. Ulcek, 1999]

9. CONCLUSIONS

In these eight months I had learned more things than in a whole year studying. But more important is that I learned how to implement in the real world ideas, thoughts, and theories that I studied during my degree. Because of during the degree you receive lots of information, lots of ideas but in fact you do not know really how to develop this knowledge that you have until you are in front of a problem, a trouble. And you are the only person to solve it.

That is one of the main conclusions after the process of the final Project. Another one is the discovery of a huge electronics world; there are many devices, many chips and many components to choose one for your purpose, moreover when you had chosen the component you happened find another better for your application.

To finalize just mention the mystery of electronics field, you can feel this mystery when you at last achieve that some part of your electronic design works, and the next day that part does not work as the day before. But also the mystery has a good side. The good side appears when you are fed up of too much tests, too much devices to find a mistake in your circuit, and suddenly it works when you were thinking to leave it.

9.1 Review

In general the review of the whole Project is successfully. The building of system of control and data transmission for an environmental application had been achieved. But I have to mention that one of the parts of the whole Project did not be accomplished, concretely the radiofrequency link. The radiofrequency link does not work as expected when I design the second and third part of the purpose.

In spite of I accomplished the objectives that I had at the beginning, and more of those, as for example I know how to program a microcontroller using C language, because I programmed before with assembly language. And I know the main differences between those languages in the laboratory, not just in the theory done it in class.

Furthermore I had learned how to use some programs to do circuit diagrams, as for example Multisim 8. It is the program which I used to design the circuit. But I did not learn just engineering programs, else office programs, as *Visio*. This program is a very useful tool to create flow diagrams or to create block diagrams in an easy way.

I have spent all the eight months working in the Project, but to be honest I have to say that the fourth last months were the busiest. Also they are the months in which I learned many things.

9.2 Further work

In order to complete the product it will be necessary to work in the radiofrequency link. Because of it is one of the important parts of the Project. It is necessary spend more time to achieve a correct RF link.
Also could be better to add more transducers in the purpose, but for budget reasons I can not implemented in the Project. There are some interesting sensors to add, as for example humidity sensor, pressure sensor, light sensor, water level sensor. They will help to have a better idea of what is happening inside the animal habitat.
To conclude the further work, mention that a weatherproof body or box could be implemented to keep the circuitry of the transmission circuit in case of rain, hot temperatures or attacks of the animals.

9.3 Applications

The Project has many applications, the most interesting are:

- **Industrial field**: Inside factories controlling the environment, such as temperature, humidity…

- **Agricultural field**: In the greenhouses when a strictly control of the environment is essential to take care of the plants, or whatever is inside.

- **Cattle farming**: This case is very similar to our case, in which the control of animals is the main objective. So to optimize the production in a farm it will be very useful to control from the living room, for example, how are the animals and if they need something.

As we can see the Project has three important applications, but do not forget that it has many more in any environmental control system that t will needed.

APPENDICES

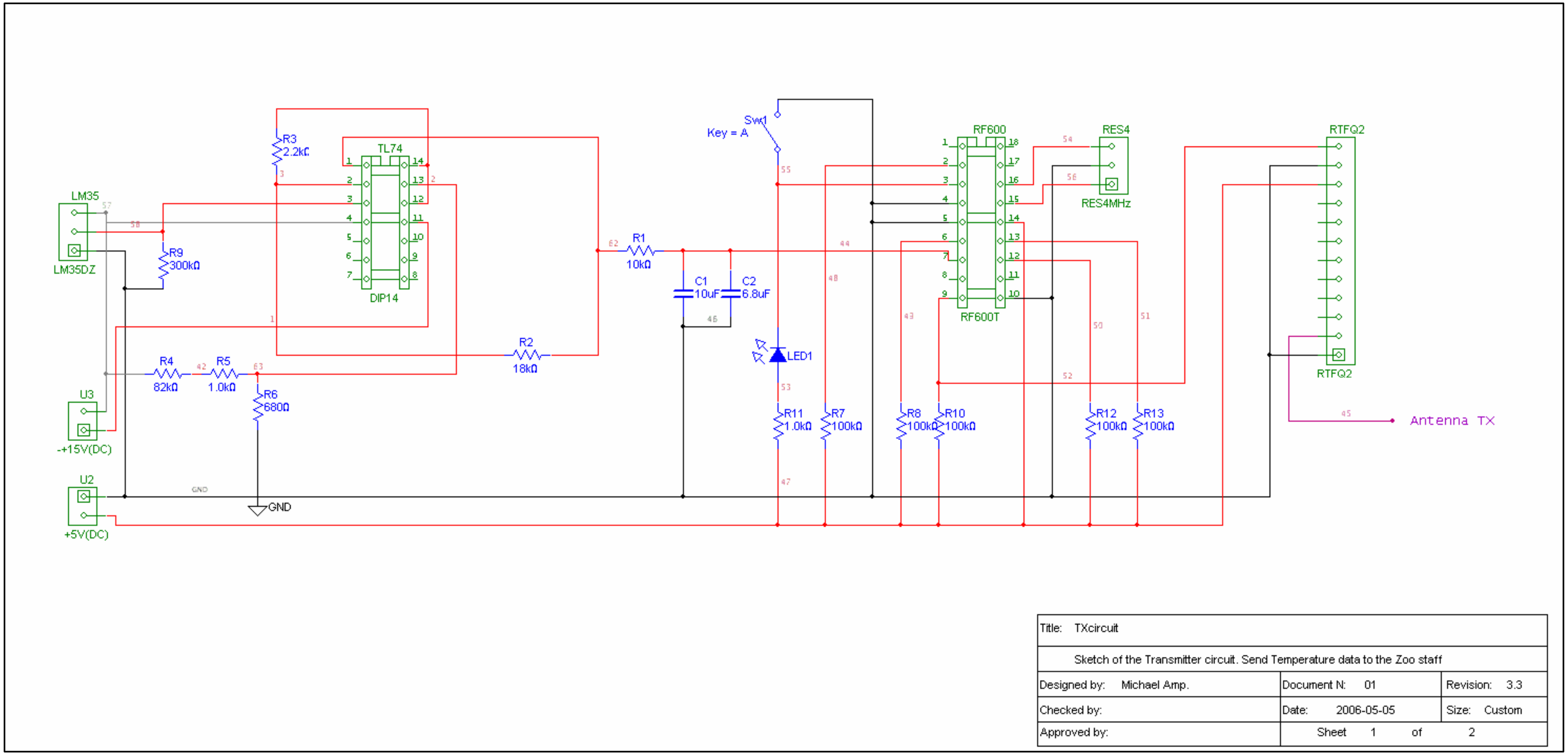
A. The final code

```
#include <16F877.h>
#device adc=8
#fuses HS,NOWDT,NOPROTECT,NOLVP
#use delay(clock=4000000)
#use RS232(BAUD=9600, BITS=8, PARITY=N, XMIT=PIN_C6, RCV=PIN_C7,
RESTART_WDT)

#include <ds1302.c>
#include <lcd.c>

const float factor = 1.961;

void set_clock(){

  byte day,mth,year,dow,hour,min;

  lcd_putc("\nYear 2006 ");
  year=06;
        delay_ms(1000);

  lcd_putc("\f\n\nMonth 4");
  mth=04;
        delay_ms(500);

  lcd_putc("\f\n\nDay 10");
  day=10;//17h=23
        delay_ms(500);

  lcd_putc("\f\n\nWeekday 1");
  dow=1;
        delay_ms(500);

  lcd_putc("\f\n\nHour: 10");
  hour=10;//12h=18
        delay_ms(500);

  lcd_putc("\f\n\nMin: 15");
  min=15;
        delay_ms(500);

  rtc_set_datetime(day,mth,year,dow,hour,min);
}

void current_temp (int valueADC, float &tempOK){
        tempOK=(valueADC*factor);
 }

void main() {
        int valueAD=0, min_temp=100, max_temp=0, min_far=0, max_far=0;              float
inTemp=0.00, farTemp=0.00;
        float lowTemp=20.00, highTemp=34.00;     //Bonobos range of 20-34ºC
```

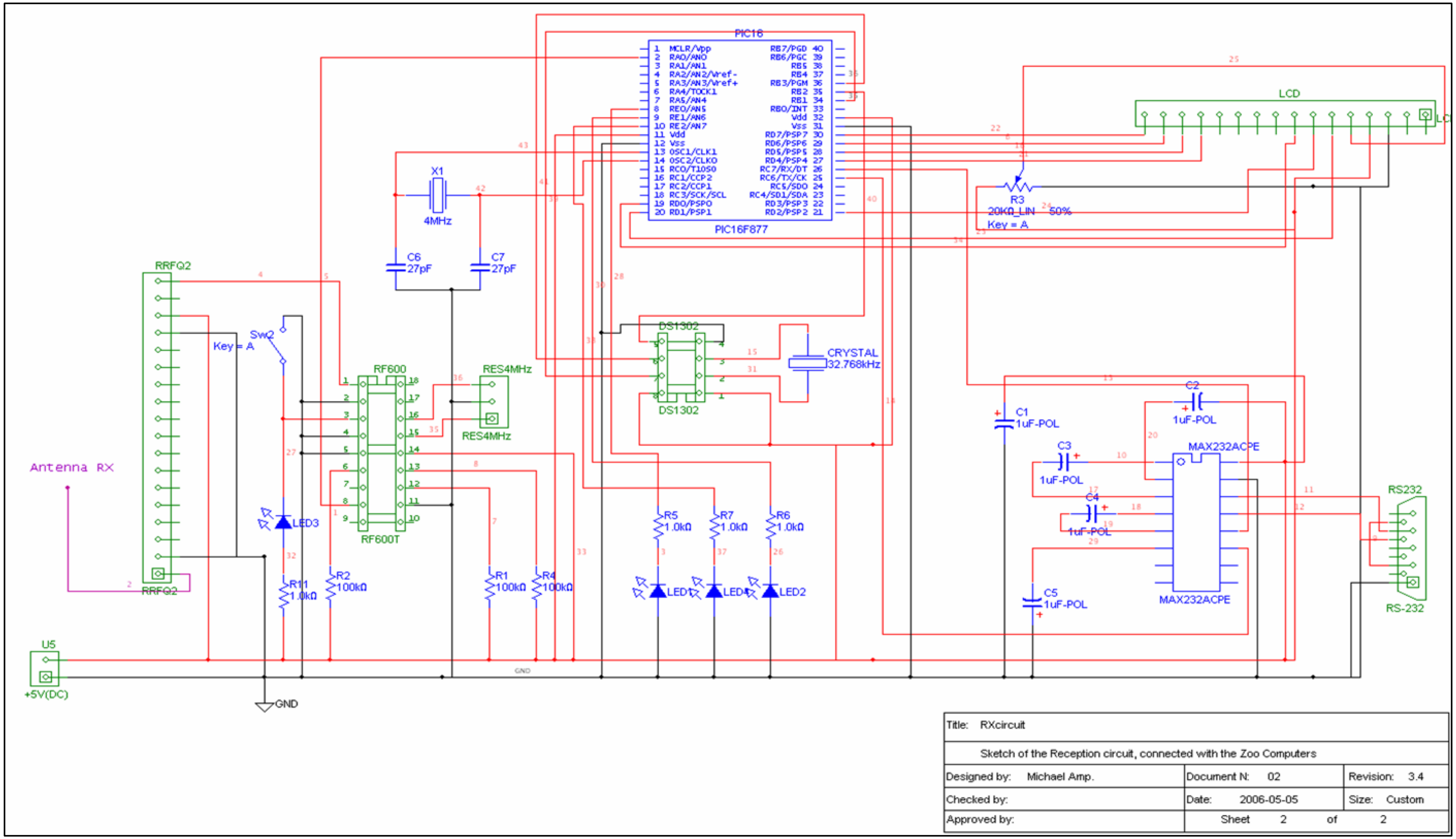
```
        byte day, mth, year, dow, hour, min, sec;

        set_tris_e(0); //PORTE as a output port for LEDs

        puts("\n");                               // HYPERTERMINAL
        puts("\nWELCOMME\n");
        puts("ZOO ROOM CONTROL\n\n\n");

        rtc_init();                       //initialitation function RTC    lcd_init();
                        //initialitation of the LCD
        lcd_putc("\f");                 //erase screen

        lcd_gotoxy(1,1);
        lcd_putc("    WELCOMME    ");               //PRESENTATION IN LCD
        lcd_gotoxy(1,2);
        lcd_putc("ZOO ROOM CONTROL");
        delay_ms(3000);
        lcd_putc("\f");

        set_clock();            //call to the function (date+clock)

while(1)
        {
        rtc_get_time(hour, min, sec);           //DATE + HOUR:MIN
        rtc_get_date(day, mth, year, dow);
        lcd_gotoxy(1,1);
        printf(lcd_putc,"%2U:%2U",hour,min);
        lcd_gotoxy(9,1);
        printf(lcd_putc,"%2U/%2X/%2X",day,mth,year);

        setup_adc(adc_clock_div_32);        //Conversor ON
        setup_adc_ports(AN0);       //select port AN0
        set_adc_channel(0);                 //select channel 0 of ADC
        valueAD=read_adc();         //conversion AD (int)

        current_temp(valueAD, inTemp);
        lcd_gotoxy(1,2);
        printf(lcd_putc,"Temprtre=%1.2Ld'C",inTemp);                   delay_ms(5000);
        lcd_putc("\f");

        puts("\rDEGREES CENTIGRADE\n");
        printf("\r- The Temperature is %1.2Ld'C\n", inTemp);

        farTemp=((inTemp*9)/5)+32;

        puts("\r\nDEGREES FAHRENHEIT\n");
        printf("\r- The Temperature is %1.2Ld'F\n", farTemp);

        if(inTemp>max_temp)
        {
                max_temp=inTemp;
        }
        if(inTemp<min_temp)
        {
                min_temp=inTemp;
```

```
        }

        lcd_gotoxy(1,1);
        printf(lcd_putc,"Temprtre:%1.2Ld'C",inTemp);
        lcd_gotoxy(1,2);
        printf(lcd_putc,"MIN:%D'CMAX:%D'C", min_temp, max_temp);
        delay_ms(5000);
        lcd_putc("\f");

        min_far=((min_temp*9)/5)+32;
        max_far=((max_temp*9)/5)+32;

        puts("\r\n\n\n    MIN and MAX TEMPERATURE\n");
        printf("\r    - MIN Temperature is %D'C / %D'F\n", min_temp, min_far);
        printf("\r\n    - MAX Temperature is %D'C / %D'F\n", max_temp, max_far);

        //ALARM LED TEMP
        if(inTemp>highTemp)                     //Alarm if Temp is greater than 34 ºC
        {
                output_high(PIN_E0);
                        delay_ms(4000);
                output_low(PIN_E0);
        puts("\n\n\nALARM!!\r\n");
        puts("\tThe Temperature is greater than 34'C\n");
        }

        else if(inTemp<lowTemp)                 //Alarm if Temp is less than 20 ºC
        {
                output_high(PIN_E1);
                        delay_ms(4000);
                output_low(PIN_E1);
        puts("\n\n\nALARM!!\r\n");
        puts("\tThe Temperature is less than 20'C\n");
        }

        else
        {
                output_high(PIN_E2);
                        delay_ms(4000);
                output_low(PIN_E2);
        puts("\n\n\nOK!\r\n");
        puts("\tTemperature in normal range\n");
        }

        puts("\n\n\nThank you for use this program\n");
        puts("by Michael Ampliato. NEWI 2005-2006\n\n\n\n");
        }

}
```

B. Transmission circuit diagram



C. Reception circuit diagram



D. List of components

Transmitter

Quantity	Description	Ref. in diagram
1	TL074	TL74
1	SWITCH	Sw1
1	RESONATOR4MHz,	RES4
2	RESISTOR, 1.0kOhm_5%	R11, R5
1	LED red	LED1
5	RESISTOR, 100kOhm_5%	R13, R12, R10, R8, R7
1	RTFQ2-433R	RTFQ2
1	RF600T	RF600
1	Connector, -+15V(DC)	U3
1	RESISTOR, 300kOhm_5%	R9
1	Connector, +5V(DC)	U2
1	RESISTOR, 680Ohm_5%	R6
1	RESISTOR, 82kOhm_5%	R4
1	RESISTOR, 18kOhm_5%	R2
1	RESISTOR, 10kOhm_5%	R1
1	CAPACITOR, 6.8uF	C2
1	CAPACITOR, 10uF	C1
1	LM35DZ	LM35
1	RESISTOR, 2.2kOhm_5%	R3

Receiver

Quantity	Description	Ref. in diagram
1	MAX232A	MAX232A
5	CAP_ELECTROLIT, 1uF-POL	C3, C4, C5, C2, C1
1	Connector, +5V(DC)	U5
1	RRFQ2-433	RRFQ2
1	RF600T	RF600
1	PIC16F877	PIC16
3	RESISTOR, 100kOhm_5%	R2, R1, R4
1	LCD, LCD1602	LCD
1	POTENTIOMETER, 20K_LIN	R3
1	Connector RS232	RS232
1	LED red	LED1
1	LED yellow	LED2
1	LED green	LED3
1	DS1302	DS1302
1	RESONATOR, 32.768kHz	CRYSTAL
4	RESISTOR, 1.0kOhm_5%	R11, R5, R7, R6
1	RESONATOR4MHz	RES4MHz
1	SWITCH	Sw2
1	RESONATOR, 4MHz	X1
2	CAPACITOR, 27pF	C6, C7

E. MPLAB IDE Tutorial

MPLAB IDE is a free, integrated toolset for the development of embedded applications employing PICmicrontrollers. The characteristic IDE provides to the developers of software applications the flexibility to edit, to compile, to simulate, to develop and to debug its own software for the families of microcontroller PIC16/17 of Microchip.

Before to follow with the code this part of the chapter will explain briefly how the software used for the Project works.

Once MPLAB IDE is opened to start programming *Project → Project Wizard*. Select the PIC, in the case of this Project PIC16F877. After the uC is took is turn to choose the language, in this case is C language, so is necessary pick out a compiler, such as CCS compiler.

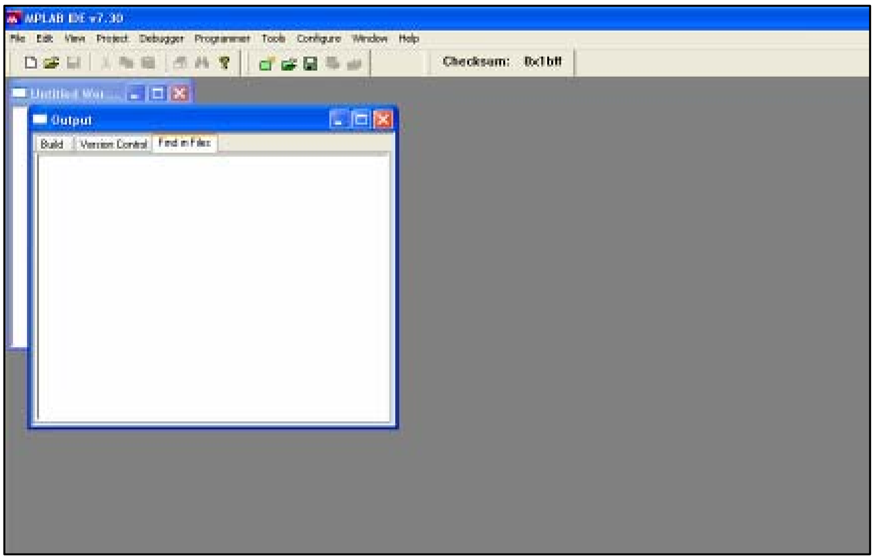
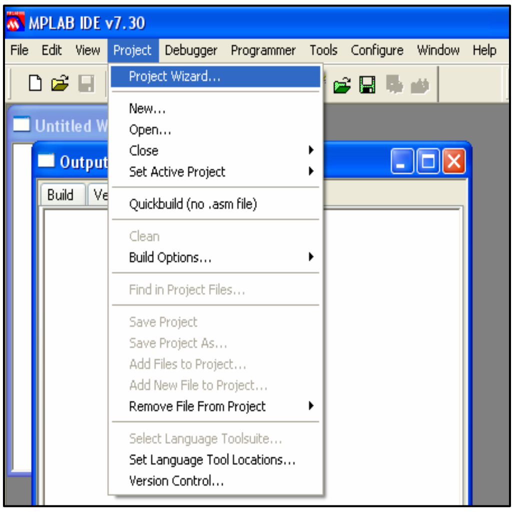


Fig. E.1 MPLAB IDE once opened



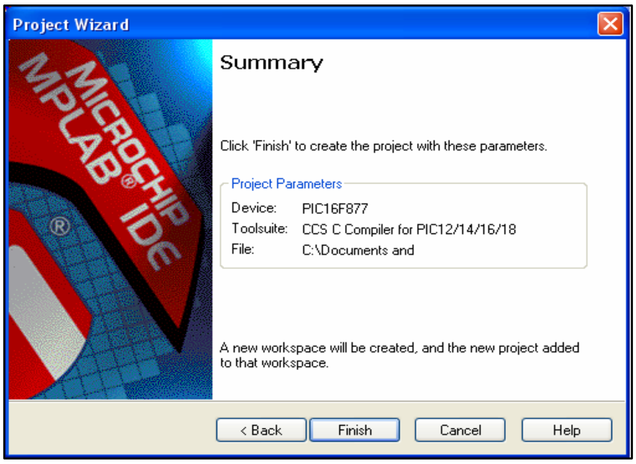
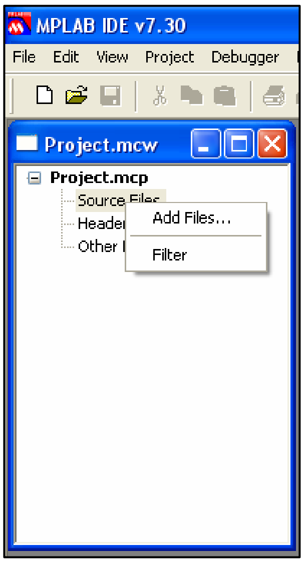


Fig. E.2 To start the configuration

Fig. E.3 Settings required before start to program

After setting steps it must add the program file (*.c) such as in Fig. E.4 and the screen will look like the next picture (Fig. E.5).



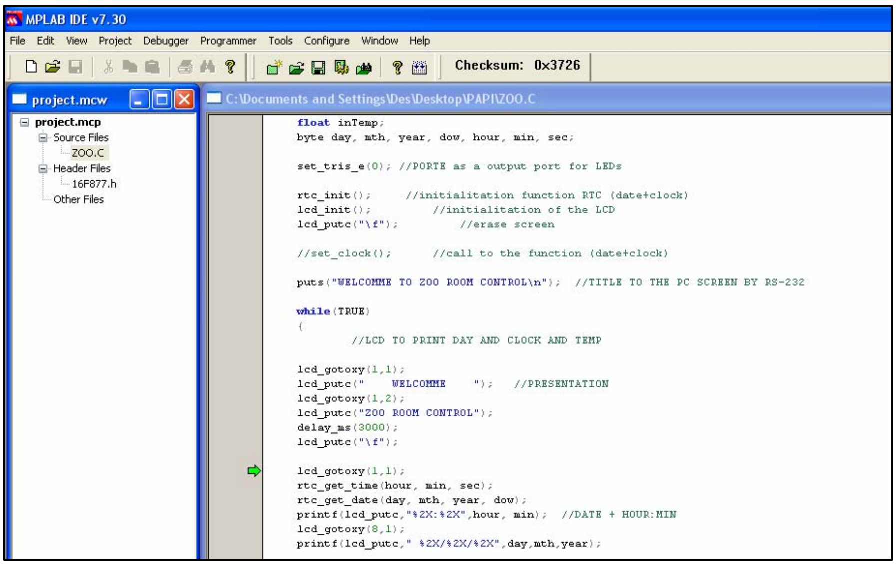


Fig. E.4 Adding files *.c Fig. E.5 MPLAB ready to edit the program

Now it is possible verify if the program is right to compile and to send to the microcontroller. To verify the program is necessary to build it, and if appear a message on screen saying BUILD SUCCEEDED that indicates that is ready to compile, such as Fig. 5.6. If not the program has got some mistakes and appear the message BUILD FAILED.

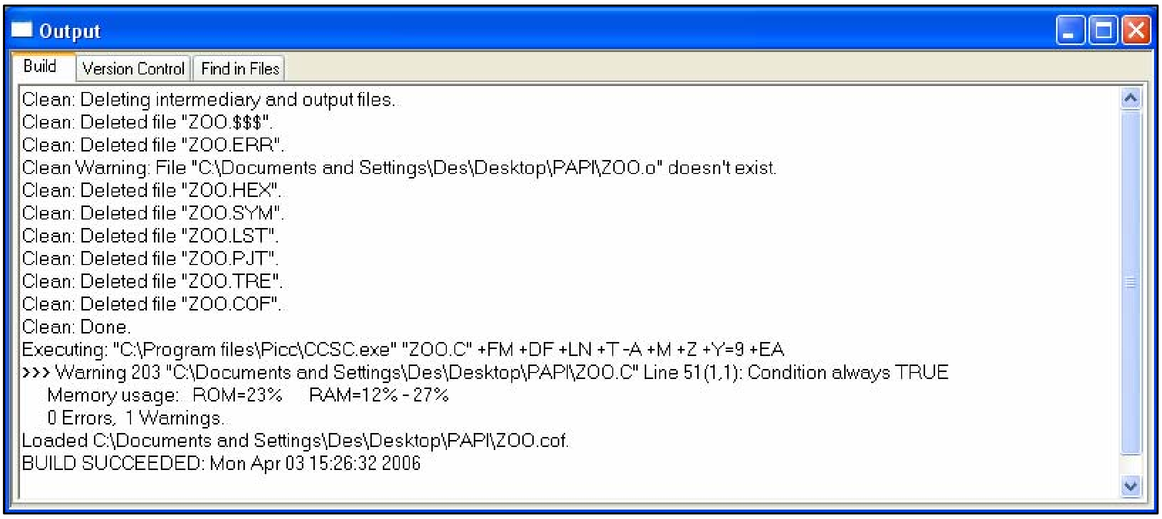


Fig. E.6 Build Succeeded

The next step is to send the program to the embed system through PICSTART Plus programmer (Fig. E.7). But before is necessary to set up *Configure → Configuration Bits* (Fig E.8).

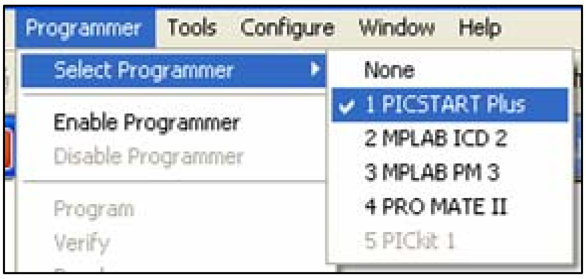


Fig. E.7 Programmer Selection

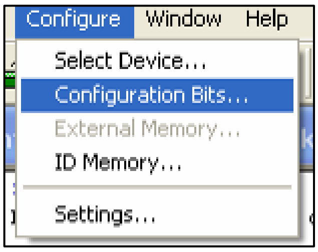
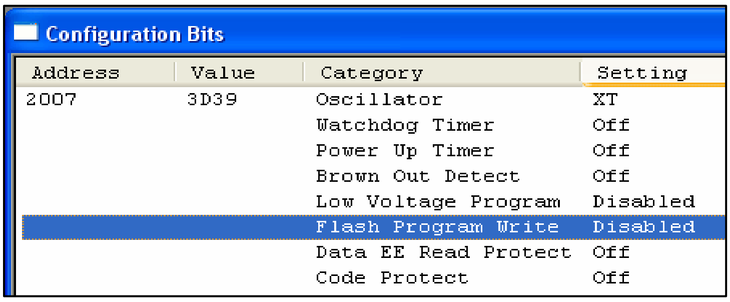


Fig. E.8 Configuration Bits

In this purpose is not necessary to use options of the configure bits, so all will be Off or disabled. And the Oscillator will be XT. As follows in the next picture.


Configuration Bits

Address	Value	Category	Setting
2007	3D39	Oscillator	XT
		Watchdog Timer	Off
		Power Up Timer	Off
		Brown Out Detect	Off
		Low Voltage Program	Disabled
		Flash Program Write	Disabled
		Data EE Read Protect	Off
		Code Protect	Off

Fig. E.9 Configuration settings

The last step is to program the device. To send the program is better erase before the device *Programmer → Erase Flash Device and later Programmer → Program*. Hence the microcontroller is ready to use it.

F. HyperTerminal Tutorial

To start HyperTerminal is necessary to have *Windows* as a S. O. To find the program, go to *Start → Programmes → Accessories → Communications → HyperTerminal.*

Then it will appear a window like the next figure.

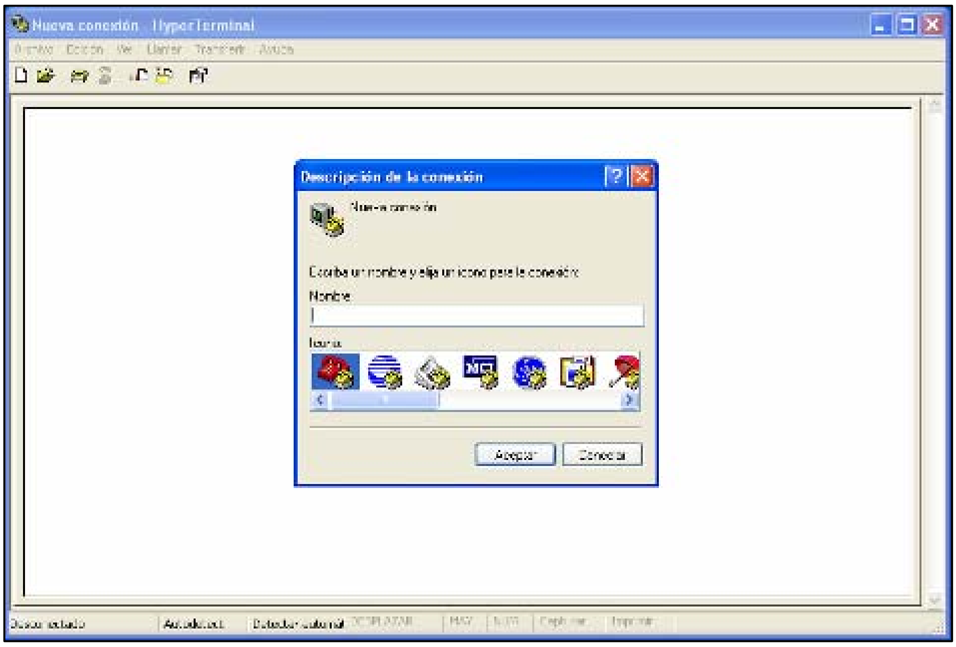


Fig. F.1 Starting the program

Just type a name of the file where it will keep the connection, and press *Accept*.

Then choose the port which you are going to use to communicate. And then configure the communication when a window like the figure below appears.

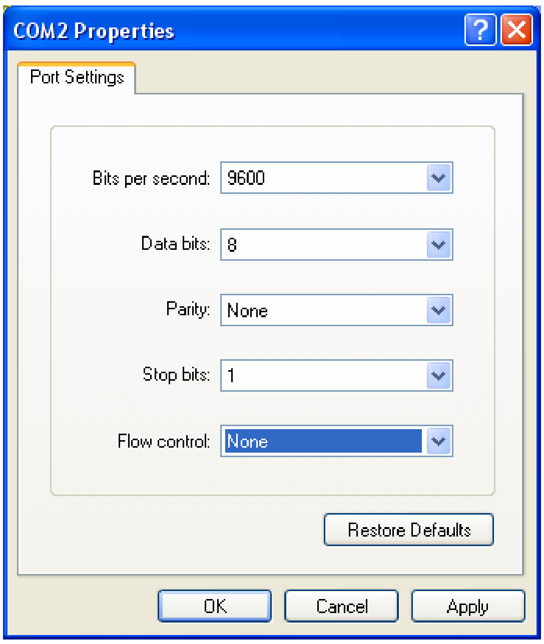


Fig. F.2 How to set up the connection

After those step it will appear a window empty, and after some seconds it will be plenty of the data from the source which you are connecting.

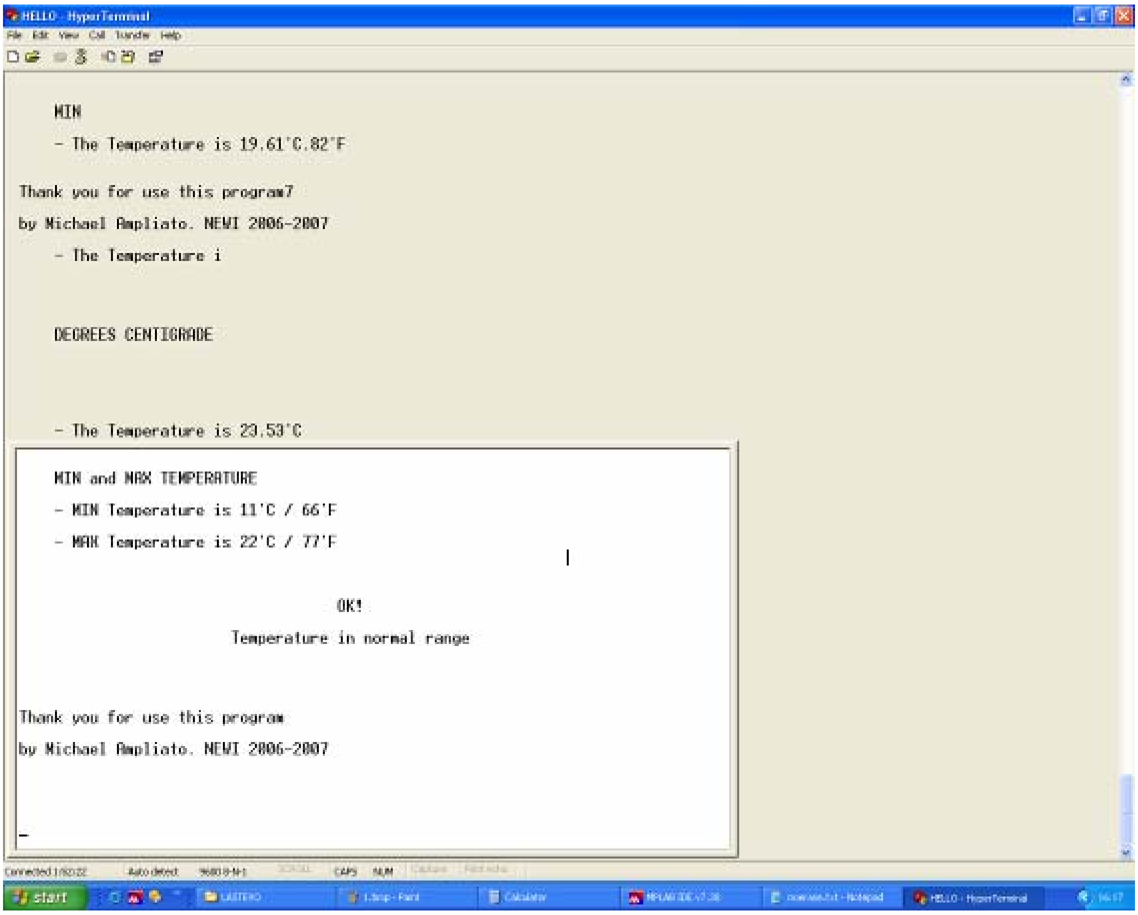


Fig. F.3 Connection realized

National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

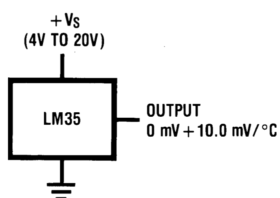
General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼˚C at room temperature and ±¾˚C over a full −55 to +150˚C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1˚C in still air. The LM35 is rated to operate over a −55˚ to +150˚C temperature range, while the LM35C is rated for a −40˚ to +110˚C range (−10˚ with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

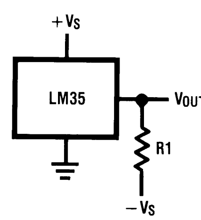
- Calibrated directly in ˚ Celsius (Centigrade)
- Linear + 10.0 mV/˚C scale factor
- 0.5˚C accuracy guaranteeable (at +25˚C)
- Rated for full −55˚ to +150˚C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08˚C in still air
- Nonlinearity only ±¼˚C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications



DS005516-3

FIGURE 1. Basic Centigrade Temperature Sensor (+2˚C to +150˚C)



DS005516-4

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT}=+1,500 mV at +150˚C
= +250 mV at +25˚C
= −550 mV at −55˚C

FIGURE 2. Full-Range Centigrade Temperature Sensor

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	T_A=+25˚C	±0.4	±1.0		±0.4	±1.0		˚C
	T_A=−10˚C	±0.5			±0.5		±1.5	˚C
	$T_A=T_{MAX}$	±0.8	±1.5		±0.8		±1.5	˚C
	$T_A=T_{MIN}$	±0.8		±1.5	±0.8		±2.0	˚C
Accuracy, LM35D (Note 7)	T_A=+25˚C				±0.6	±1.5		˚C
	$T_A=T_{MAX}$				±0.9		±2.0	˚C
	$T_A=T_{MIN}$				±0.9		±2.0	˚C
Nonlinearity (Note 8)	$T_{MIN}≤T_A≤T_{MAX}$	**±0.3**		**±0.5**	**±0.2**		**±0.5**	˚C
Sensor Gain (Average Slope)	$T_{MIN}≤T_A≤T_{MAX}$	**+10.0**	**+9.8, +10.2**		**+10.0**		**+9.8, +10.2**	mV/˚C
Load Regulation (Note 3) 0≤I_L≤1 mA	T_A=+25˚C	±0.4	±2.0		±0.4	±2.0		mV/mA
	$T_{MIN}≤T_A≤T_{MAX}$	**±0.5**		**±5.0**	**±0.5**		**±5.0**	mV/mA
Line Regulation (Note 3)	T_A=+25˚C	±0.01	±0.1		±0.01	±0.1		mV/V
	4V≤V_S≤30V	**±0.02**		**±0.2**	**±0.02**		**±0.2**	mV/V
Quiescent Current (Note 9)	V_S=+5V, +25˚C	56	80		56	80		µA
	V_S=+5V	**105**		**158**	**91**		**138**	µA
	V_S=+30V, +25˚C	56.2	82		56.2	82		µA
	V_S=+30V	**105.5**		**161**	**91.5**		**141**	µA
Change of Quiescent Current (Note 3)	4V≤V_S≤30V, +25˚C	0.2	2.0		0.2	2.0		µA
	4V≤V_S≤30V	**0.5**		**3.0**	**0.5**		**3.0**	µA
Temperature Coefficient of Quiescent Current		**+0.39**		**+0.7**	**+0.39**		**+0.7**	µA/˚C
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1*, I_L=0	+1.5		+2.0	+1.5		+2.0	˚C
Long Term Stability	$T_J=T_{MAX}$, for 1000 hours	±0.08			±0.08			˚C

Note 1: Unless otherwise noted, these specifications apply: −55˚C≤T_J≤+150˚C for the LM35 and LM35A; −40˚≤T_J≤+110˚C for the LM35C and LM35CA; and 0˚≤T_J≤+100˚C for the LM35D. V_S=+5Vdc and I_{LOAD}=50 µA, in the circuit of *Figure 2*. These specifications also apply from +2˚C to T_{MAX} in the circuit of *Figure 1*. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400˚C/W, junction to ambient, and 24˚C/W junction to case. Thermal resistance of the TO-92 package is 180˚C/W junction to ambient. Thermal resistance of the small outline molded package is 220˚C/W junction to ambient. Thermal resistance of the TO-220 package is 90˚C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10mv/˚C times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in ˚C).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

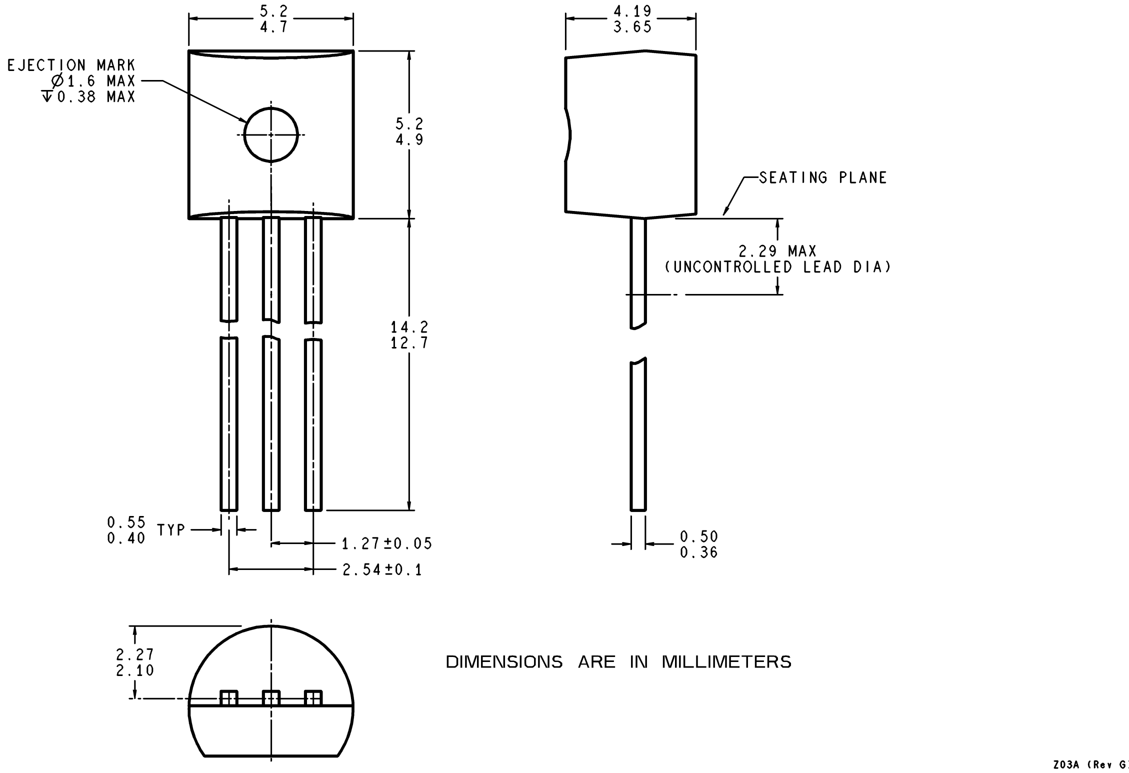
Note 9: Quiescent current is defined in the circuit of *Figure 1*.

Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

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



TO-92 Plastic Package (Z)
Order Number LM35CZ, LM35CAZ or LM35DZ
NS Package Number Z03A

LIFE SUPPORT POLICY

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Email: support@nsc.com
www.national.com

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Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

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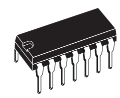
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507

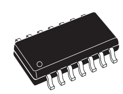
TL074
TL074A - TL074B

LOW NOISE J-FET QUAD OPERATIONAL AMPLIFIERS

- WIDE COMMON-MODE (UP TO V_{CC}^{+}) AND DIFFERENTIAL VOLTAGE RANGE
- LOW INPUT BIAS AND OFFSET CURRENT
- LOW NOISE e_n = 15nV/√Hz (typ)
- OUTPUT SHORT-CIRCUIT PROTECTION
- HIGH INPUT IMPEDANCE J–FET INPUT STAGE
- LOW HARMONIC DISTORTION : 0.01% (typ)
- INTERNAL FREQUENCY COMPENSATION
- LATCH UP FREE OPERATION
- HIGH SLEW RATE : 13V/µs (typ)



N
DIP14
(Plastic Package)



D
SO14
(Plastic Micropackage)

DESCRIPTION

The TL074, TL074A and TL074B are high speed J–FET input quad operational amplifiers incorporating well matched, high voltage J–FET and bipolar transistors in a monolithic integrated circuit.

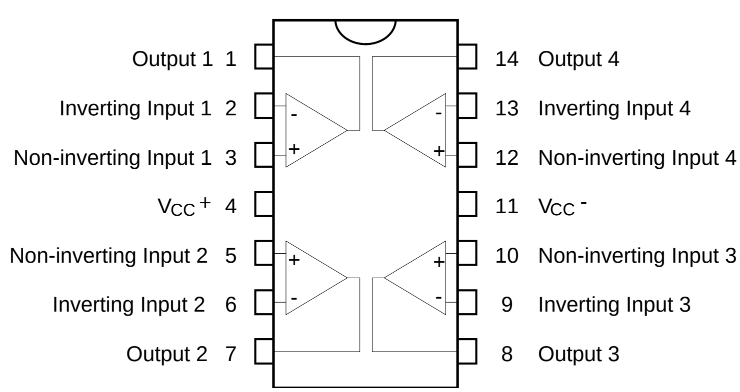
The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient.

ORDER CODE

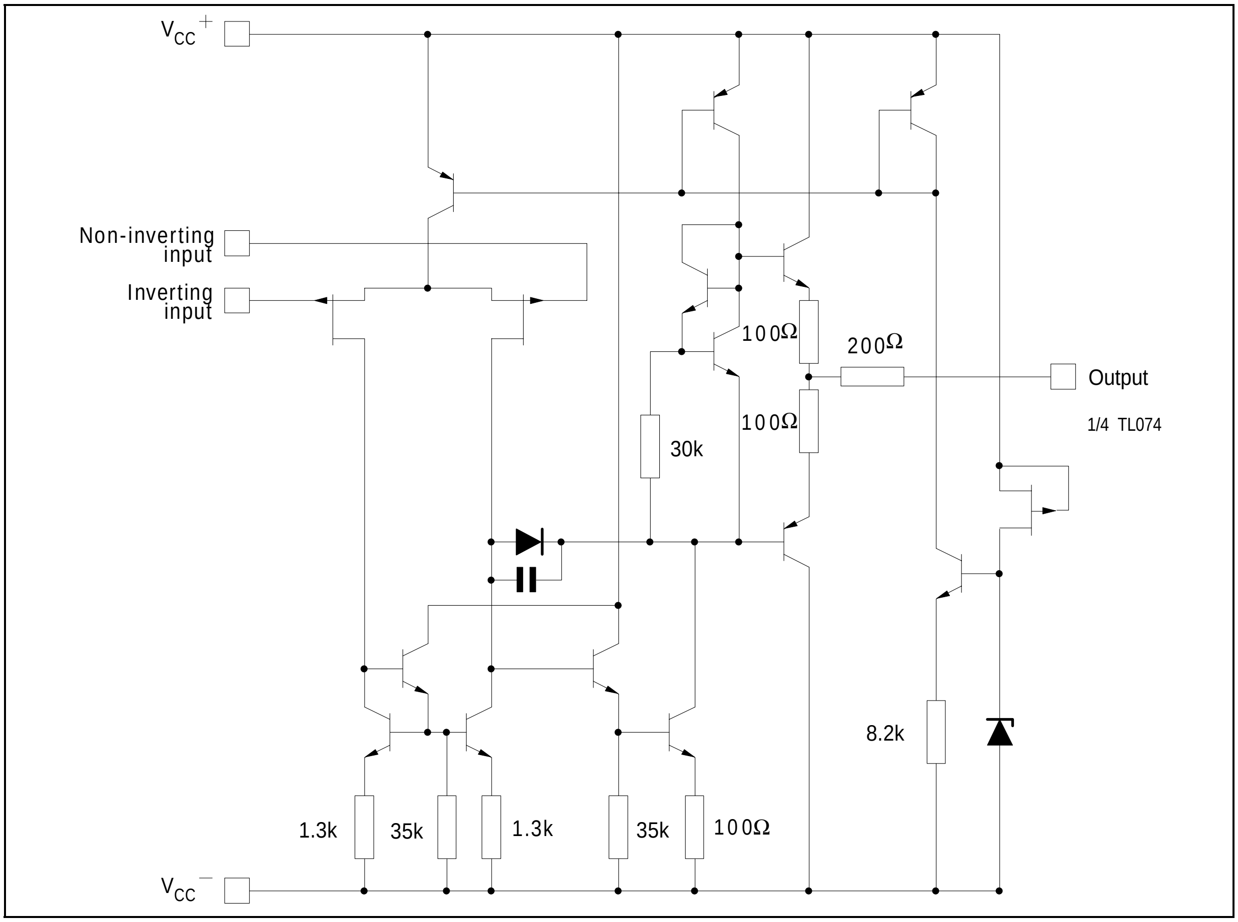
Part Number	Temperature Range	Package	
		N	D
TL074M/AM/BM	-55°C, +125°C	•	•
TL074I/AI/BI	-40°C, +105°C	•	•
TL074C/AC/BC	0°C, +70°C	•	•
Example : TL074IN			

N = Dual in Line Package (DIP)
D = Small Outline Package (SO) - also available in Tape & Reel (DT)

PIN CONNECTIONS (top view)



SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	TL074M, AM, BM	TL074I, AI, BI	TL074C, AC, BC	Unit
V_{CC}	Supply voltage - note 1)	±18			V
V_i	Input Voltage - note 2)	±15			V
V_{id}	Differential Input Voltage - note 3)	±30			V
P_{tot}	Power Dissipation	680			mW
	Output Short-circuit Duration - note 4)	Infinite			
T_{oper}	Operating Free-air Temperature Range	-55 to +125	-40 to +105	0 to +70	°C
T_{stg}	Storage Temperature Range	-65 to +150			°C

1. All voltage values, except differential voltage, are with respect to the zero reference level (ground) of the supply voltages where the zero reference level is the midpoint between V_{CC}^+ and V_{CC}^-.
2. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 volts, whichever is less.
3. Differential voltages are the non-inverting input terminal with respect to the inverting input terminal.
4. The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded

ELECTRICAL CHARACTERISTICS

V_{CC} = ±15V, T_{amb} = +25°C (unless otherwise specified)

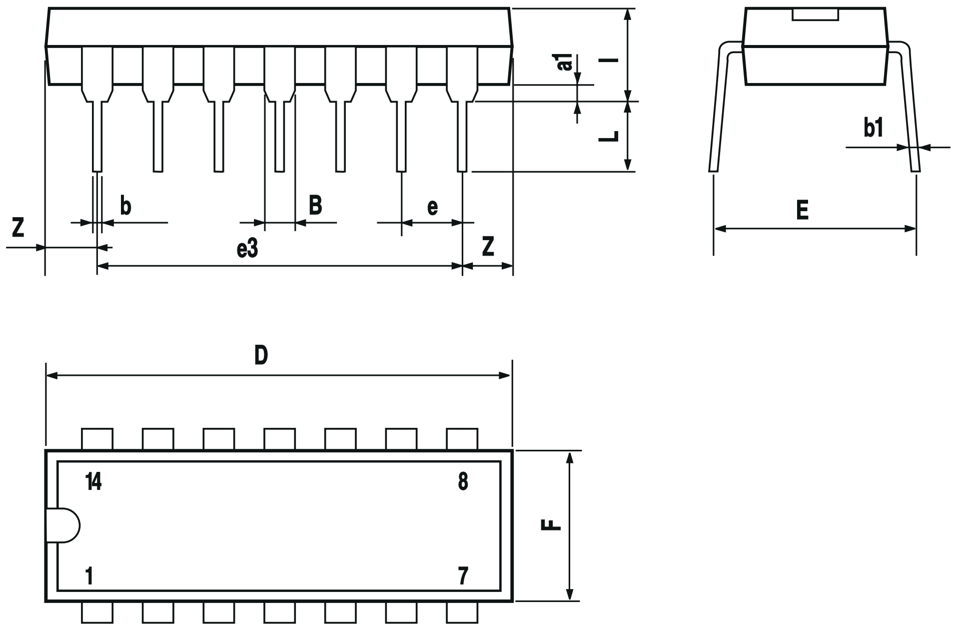
Symbol	Parameter	TL074I,M,AC,AI,AM, BC,BI,BM			TL074C			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input Offset Voltage (R_s = 50Ω) T_{amb} = +25°C TL074 TL074A TL074B $T_{min} \leq T_{amb} \leq T_{max}$ TL074 TL074A TL074B		3 3 1	10 6 3 13 7 5		3	10 13	mV
DV_{io}	Input Offset Voltage Drift		10			10		μV/°C
I_{io}	Input Offset Current - note 1) T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$		5	100 4		5	100 10	pA nA
I_{ib}	Input Bias Current -note 1 T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$		20	200 20		30	200 20	pA nA
A_{vd}	Large Signal Voltage Gain (R_L = 2kΩ, V_o = ±10V) T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	50 25	200		25 15	200		V/mV
SVR	Supply Voltage Rejection Ratio (R_S = 50Ω) T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	80 80	86		70 70	86		dB
I_{CC}	Supply Current, no load, per amplifier T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$		1.4	2.5 2.5		1.4	2.5 2.5	mA
V_{icm}	Input Common Mode Voltage Range	±11	+15 -12		±11	+15 -12		V
CMR	Common Mode Rejection Ratio (R_S = 50Ω) T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	80 80	86		70 70	86		dB
I_{os}	Output Short-circuit Current T_{amb} = +25°C $T_{min} \leq T_{amb} \leq T_{max}$	10 10	40	60 60	10 10	40	60 60	mA
$\pm V_{opp}$	Output Voltage Swing T_{amb} = +25°C RL = 2kΩ RL = 10kΩ $T_{min} \leq T_{amb} \leq T_{max}$ RL = 2kΩ RL = 10kΩ	10 12 10 12	12 13.5		10 12 10 12	12 13.5		V
SR	Slew Rate (T_{amb} = +25°C) V_{in} = 10V, R_L = 2kΩ, C_L = 100pF, unity gain	8	13		8	13		V/μs
t_r	Rise Time (T_{amb} = +25°C) V_{in} = 20mV, R_L = 2kΩ, C_L = 100pF, unity gain		0.1			0.1		μs
K_{ov}	Overshoot (T_{amb} = +25°C) V_{in} = 20mV, R_L = 2kΩ, C_L = 100pF, unity gain		10			10		%
GBP	Gain Bandwidth Product (T_{amb} = +25°C) V_{in} = 10mV, R_L = 2kΩ, C_L = 100pF, f= 100kHz	2	3		2	3		MHz
R_i	Input Resistance		10^{12}			10^{12}		Ω

Symbol	Parameter	TL074I,M,AC,AI,AM, BC,BI,BM			TL074C			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
THD	Total Harmonic Distortion (T_{amb} = +25°C) f= 1kHz, R_L = 2kΩ,C_L = 100pF, A_v = 20dB, V_o = 2V_{pp}		0.01			0.01		%
e_n	Equivalent Input Noise Voltage R_S = 100Ω, f = 1KHz		15			15		$\frac{nV}{\sqrt{Hz}}$
∅m	Phase Margin		45			45		degrees
V_{o1}/V_{o2}	Channel separation A_v = 100		120			120		dB

1. The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature.

PACKAGE MECHANICAL DATA

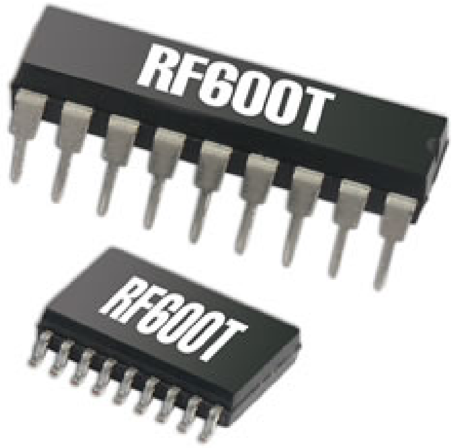
14 PINS - PLASTIC DIP



Dim.	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
a1	0.51			0.020		
B	1.39		1.65	0.055		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		15.24			0.600	
F			7.1			0.280
i			5.1			0.201
L		3.3			0.130	
Z	1.27		2.54	0.050		0.100

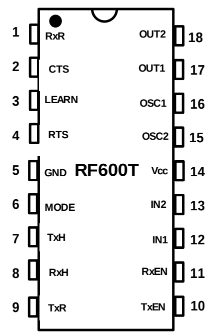
Low-Power-Radio Transceiver IC RF600T

- Addressed Mode With Acknowledge
- Broadcast Mode
- Automatic Retry
- Serial Interface
- Stand Alone Operation
- Achieves Maximum Range From RF Modules
- Flow Control Option
- Two Telemetry I/O Lines (addressed mode only)
- Compatible With Most RF Modules



Typical Applications

- Wireless RS232
- Cable Replacement
- Alarm Systems
- Communications Systems
- Local Area Networking



Hardware Features

- 3.0 – 5.5V Operation. (2.0 – 5.5V optional)
- 190 Byte Internal Buffer
- 'Manchester' Modulation On Radio Link
- CRC Error Checking
- 18 pin DIP/SOIC Package
- 2 Digital Telemetry Lines (addressed mode only)
- Asynchronous Serial Host Interface

The RF600T provides a simple interface between TTL level asynchronous serial data sources and standard RF modules (Transceiver, Transmitter or Receiver). The device allows for either broadcast or addressed point to point modes of operation and is simple to use with minimal interface required. Data packet generation is automatically performed along with 'Manchester' encoding and CRC based error checking. In addition, in addressed mode, automatic retries ensure that the host is informed of successful or failed data packet delivery. The RF600T uses control lines to handle the flow of data to and from the host, and incorporates a 190 byte data buffer.

Part Number	Description	Package
RF600T	Transceiver IC PDIP Package	18pin PDIP
RF600T-SO	Transceiver IC SMT Package	18pin SO

Pin Descriptions

Pin Number	Name	Type	Description
1	**RxR**	In	Received data from RF module.
2	**CTS** **LOOP**	Out In	Dual Function: 1. Clear to send data (to host) when low. 2. Enables loopback mode when low.
3	**LEARN**	In/Out	In addressed mode: Used to initiate 'address learn' and erase functions. Drives indicator LED.
4	**RTS**	In	Request to send data (from host) when low.
5	**GND**	In	Connect to 0 volts.
6	**MODE**	In	Device mode, addressed when high, broadcast when low.
7	**TxH**	In	Serial data from the host, to be sent on the RF path.
8	**RxH**	Out	Serial data from the RF path to be sent to the host.
9	**TxR** **HBAUD**	Out In	Dual Function: 1. Transmit data to the RF module. 2. Host baud rate select. See notes below.
10	**TXEN** **RFBAUD**	Out In	Dual Function: 1. Transmit enable (low) for the RF module. 2. RF baud rate select. See notes below.
11	**RXEN**	In	Receive enable (low) for the RF module.
12	**IN1**	In	Telemetry logic input #1. (addressed mode only)
13	**IN2**	In	Telemetry logic input #2. (addressed mode only)
14	**Vcc**	In	Positive supply voltage connection.
15	**OSC2**	Out	Connect to 4MHz, 3 terminal resonator.
16	**OSC1**	In	Connect to 4MHz, 3 terminal resonator.
17	**OUT1**	Out	Telemetry logic output #1. (addressed mode only)
18	**OUT2**	Out	Telemetry logic output #2. (addressed mode only)

Operating Modes

The device is capable of operation in one of two modes, either broadcast or addressed. The following description describes the features of these mode and assumes two identical system nodes 'A' and 'B' each consisting of an RF600T and its associated radio transceiver module.

Broadcast mode.

This mode allows a host generated data block from node 'A' to be transmitted and received by any number of other nodes. This data is received and verified (for correct Manchester coding and CRC) by the other nodes before being output to their host devices. Alternately, in the same way the other nodes can send data to node 'A'. Note that although any node can initiate a transfer, only one direction of transfer can be active at a given time.

Correct reception of a data packet is not acknowledged and the host nodes have the responsibility of ensuring that data transfers occur as required by operating some form of message protocol over the half duplex data link.

Addressed mode

This mode allows a host generated data block from node 'A' to be transmitted and for the data frame to be addressed to one other network node – in this case we assume node 'B'. When the data is received by node 'B' it is verified for correct Manchester coding, CRC and for address match and then an acknowledge message is transmitted back to node 'A'. Node 'A' then outputs a confirmation to the host in the form of the ASCII character 'C' (Confirmed). Note that confirmation is given when the data block is stored in the buffer of node 'B' and not when it has been delivered to the host at node 'B'.

All message transfers are tagged with the addresses of both the origin and destination, thus ensuring secure data transfer at all times. Either node 'A' or node 'B' can initiate a transfer but only one direction of transfer can be active at a given time. In the event that the originating node does not get confirmation of receipt of the data packet, the software re-tries the transfer five times after which node 'A' will output an error message to the host in the form of the ASCII character 'F' (Failed).

Correct reception (or otherwise) of a data packet is thus acknowledged and the host devices are relieved of most of the workload of ensuring that data transfers occur as required.

The RF600T must be configured before power up for either the broadcast or addressed mode of operation by means of the MODE pin (6). Note that for security, broadcast nodes will not receive data from addressed nodes.

System Operation

Each RF600T is programmed at manufacture with a 24 bit serial number which uniquely identifies the device. In an addressed point to point system, these serial numbers are used as the device address for the nodes in the system and non-volatile eeprom memory in the device stores the address of the 'other' node in the system. If, as at time of manufacture, no address has been stored in the device or if the address has been erased then the device will only operate in the broadcast mode. If however an address has been stored then the device will only operate in the addressed point to point mode.

If operation in the broadcast mode is required then with a new device, no action is necessary. If a device has been used in the point to point addressed mode or if its status is unknown then status erase must be carried out using the following procedure.

The LEARN pin is grounded for a period of 5 seconds and is then allowed to float. The status LED then flashes slowly for 3 seconds to indicate that the device is erased and will now only operate in the broadcast mode.

If operation in the addressed mode is required then the following procedure has to be followed to allow the two nodes in the system to operate together.

The two nodes, 'A' and 'B' are placed within radio range of one another are powered up.

The LEARN pin on one device – say 'B' is briefly taken low, placing the node into learn mode. The LEARN/ERASE status LED on 'B' comes on and remains on for 20 seconds. If within this period, no 'learn' data packet is received (see below) then the LED will be extinguished and the device will operate normally.

At node 'A', the LEARN pin is briefly taken low. The LEARN/ERASE status LED will then come on and node 'A' will transmit its address.

Node 'B' will receive and store the address of 'A'.

Node 'B' sends back to node 'A' both its address and that of node 'A'.

Node 'A' receives and stores the address of 'B' and confirms to 'B' that it has received the information.

Both node 'A' and 'B' LED's flash their status LED's rapidly for 3 seconds to show that they have learned each others addresses.

Note: Other nodes which may be active will ignore this transfer since they have not been placed into learn mode.

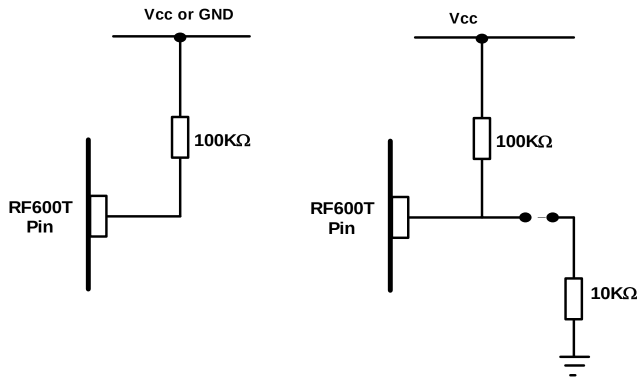
Dual Pin Functions

As shown in the pin function list above, a number of output pins have dual usage. During power up they are briefly configured as inputs to allow the selection of system options as shown below. Note that any load connected to these pins must not bias the RF600T pin such that the option setting network is significantly disturbed.

In order to configure these pins it is recommended that they are connected as shown.

1. Tie the relevant pin to Vcc or GND via a 100K resistor. This is useful if the option is permanently unselected.

2. Tie to Vcc or GND via a 100K resistor and also add a jumper link and 10K resistor to the other rail. This allows the user to select the function of the pin by insertion/removal of the link.



Pin Number	Name	Type	Description
3	**LOOP** **CTS**	In Out	Function during power up: Sets RF600T into 'Loop back' Mode (see below) Disabled if connected to Vcc as shown above. Enabled if connected to GND as shown above. Function after power on: Clear To Send control line to host (when low).
9	**HBAUD** **TxR**	In Out	Function during power up: Host Baud rate Select. 9600baud if connected to Vcc as shown above. 19200baud if connected to GND as shown above. Function after power on: Transmit data to radio module..
10	**RFBAUD** **TXEN**	In Out	Function during power up: Controls the baud rate for the RF link. 400uS if connected to Vcc as shown above. 200uS if connected to GND as shown above. Function after power on: Transmit enable (low) to radio module.

Learn pin (addressed mode only)

The learn pin is used both to sense the learn/erase switch and also to drive the indicator LED and should be connected as shown in the application circuit. The switch, which should be of the normally open type, should be connected from the learn pin to ground. The LED and its series current limiting resistor should be connected from Vcc to the learn pin, ensuring that the maximum current drawn by the LED (as given in this data sheet) is not exceeded.

Data Buffering

The device contains a 190 byte data buffer which is used to either buffer host data prior to transmission over the radio link or alternately to buffer data received over the radio link before it is transmitted to the host. Since this is a shared buffer the device can only operate in a half duplex manner - that is at a given time data can either be received from the host and then transmitted over the radio link or data can be received over the radio link and sent to the host but these functions cannot occur at the same time. Once a character has been received from the host or once the start of a radio data packet has been sensed the device will lock out the ‘other’ function until the first one has been completed.

Host Interface

The interface to the host device consists of the following signal and control lines:

TxH
Serial data from the host which is to be transmitted over the RF link. Idle mark ‘1’.

RxH
Serial data for the host which has been received over the RF link. Idle mark ‘1’.

CTS
Handshake line to the host. When ‘0’ tells the host that it is Clear To Send data to the RF600T for transmission over the RF link.

RTS
Handshake line from the host. When ‘0’ tells the RF600T that the host is making a Request To Send data to the host.

Host Communications

All host communications are carried out using the following asynchronous serial format.

8 data bits.
1 stop bit.
No parity.

The host baud rate is selected using the HBAUD option as described above.

Host Data Flow Control

Serial data from the host which is to be sent over the radio link is input at TTL level on the TxD pin. When the device is ready to receive data, the CTS line from the device will be low and up to 190 data bytes will be accepted and stored in the internal data buffer. When the buffer becomes full the CTS line will be taken high and the host must then stop transmitting. In order to allow for host UART’s which have an output FIFO buffer, a further 4 characters will be accepted after the CTS line has been asserted. In the event that the flow of data characters is not contiguous and an idle period of 20 ms occurs in the data stream then the CTS line will be asserted high to signify that the host should stop sending further data. In this case the current buffer contents will make up the next data packet to be sent over the radio link.

Serial data which has been received over the radio link will be checked for correct Manchester coding and CRC checksum (and address match if in addressed mode) before this data is transmitted at TTL level on the RxH pin. Data flow to the host is controlled by the RTS line from the host. When this line is low, data in the buffer will be transmitted to the host. When the RTS line is taken high then data flow will be inhibited and until the buffer is empty the device will not be able to perform any other operations.

Radio Module Interface

The interface to the radio module(s) consists of the following signal and control lines:

TxR
Serial data output from the RF600T to the radio module.

RxR
Serial Data input to the RF600T from the radio module.

TXEN
When active low the RF Transmitter is enabled

RXEN
When active low the RF Receiver is enabled

Radio Module Communications

All data communications between the radio modules are carried out using an R. F. Solutions proprietary data protocol with Manchester coding. This protocol includes a pre-amble and synchronisation header followed by address and control bytes, data and a CRC check. Element timing is selectable at either 400 us or 200 us using the HBAUD option as described above.

Radio Module Control

The RXEN and TXEN control lines are used to enable or disable the receiver and transmitter modules – or in the case of a transceiver module, to control the direction of operation. The logic of these outputs is such that when the RF600T wishes to transmit, it will take the RXEN line high and the TXEN line low. When the RF600T wishes to receive, it will take the RXEN line low and the TXEN line high.

Digital Telemetry Lines (addressed mode only)

In addressed mode, two input pins have their state monitored at all times and when either changes state the new states will be transmitted and applied to the outputs at the other nodes. In addition each host data packet contains the current status of the inputs.

Some care is required in using the logic pins as shown in the following notes.

1. The acknowledge and retry functions are not applied to these transmissions
2. If host data is being transmitted to the device when the logic input pins change state then the new state will not be transmitted until the current host data packet is sent.

Loop Mode

Loop mode is provided to allow testing of the performance of a system and allows node ‘A’ to transmit a data packet which will be looped back by node ‘B’ and received by node ‘A’. The mode settings of the nodes are ignored in the loop mode and the transfer is carried out in broadcast mode. The mode must only be selected when there are just two nodes in a network.
If we assume that we wish to send a host data packet from node ‘A’ to node ‘B’ and have the packet returned such that host ‘A’ receives back its data packet then the LOOP link in node ‘A’ should be made before that unit is powered up. This unit will now only operate in the loop mode until it is powered down, the loop link removed and then powered up again.
Note that the learn function will not operate when the system is configured for loop mode.

Achieving Optimum Range

Range is dependant on many factors including
1. RF Power output
2. Receiver sensitivity
3. Antenna efficiency
4. Local environmental conditions and any local Interference
5. Data Type which is being transmitted.

Whilst items 1-4 are dependant on the system hardware design, item ‘5’ is equally important and often overlooked. Given that there is a legal maximum power output which can be transmitted, and a limit on the sensitivity of the receiver (usually constrained by cost), and that the antenna can never achieve 0dB loss (100% efficiency), then the data structure and coding is an important aspect of the design.

The RF600T uses a fully balanced Manchester encoded data protocol designed for optimum use of the radio transmission path. Manchester encoding enables the receiver ‘data slicer’ to maintain efficiency for the duration of the data packet, (unlike many other encoder/decoder systems) which results in reduced bit errors and therefore ensures maximum range.

Custom Versions

Customisation of the RF600T is available, please contact our sales department for further information.

Technical Specifications: Absolute Maximum Ratings

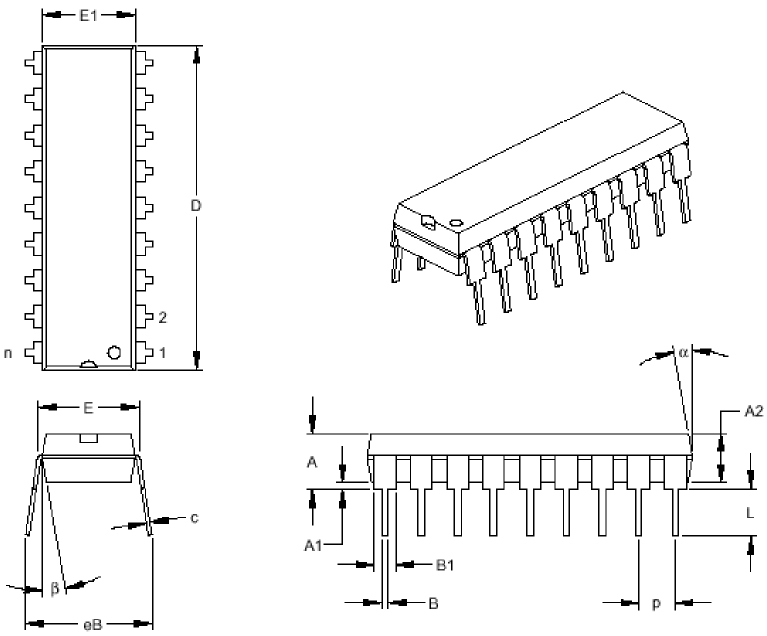
Item	Rating	Units
Supply voltage	-0.3 to 6.9	V
Input voltage	-0.3 to VDD + 0.3	V
Output voltage	-0.3 to VDD+ 0.3	V
Max output current	25	mA
Storage temperature	-55 to +125	°C (Note)
Lead soldering temp	300	°C (Note)
ESD rating	4000	V

Note: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device.

Electrical Characteristics	Min	Typical	Max	Unit
Operating current (average) Vdd = 2 - 3V Vdd = 3 - 6.6V		0.3 0.7	1.2 1.6	mA
High level Input voltage	$0.55V_{DD}$		$V_{DD}+0.3$	V
Low level input voltage	0.3		$0.15V_{DD}$	V
High level output voltage	$0.7V_{DD}$			V
Low level output voltage			$0.08V_{DD}$	V
Output Pin Current rating		-	25	mA
LED sink current		5.0	25	mA

Packaging Diagrams and Parameters

18-Lead Plastic Dual In-line (P) – 300 mil (PDIP)



	Units	INCHES*			MILLIMETERS		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		18			18	
Pitch	p		.100			2.54	
Top to Seating Plane	A	.140	.155	.170	3.56	3.94	4.32
Molded Package Thickness	A2	.115	.130	.145	2.92	3.30	3.68
Base to Seating Plane	A1	.015			0.38		
Shoulder to Shoulder Width	E	.300	.313	.325	7.62	7.94	8.26
Molded Package Width	E1	.240	.250	.260	6.10	6.35	6.60
Overall Length	D	.890	.898	.905	22.61	22.80	22.99
Tip to Seating Plane	L	.125	.130	.135	3.18	3.30	3.43
Lead Thickness	c	.008	.012	.015	0.20	0.29	0.38
Upper Lead Width	B1	.045	.058	.070	1.14	1.46	1.78
Lower Lead Width	B	.014	.018	.022	0.36	0.46	0.56
Overall Row Spacing	eB	.310	.370	.430	7.87	9.40	10.92
Mold Draft Angle Top	α	5	10	15	5	10	15
Mold Draft Angle Bottom	β	5	10	15	5	10	15

*Controlling Parameter

Notes:

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

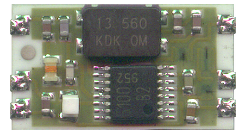
JEDEC Equivalent: MS-001

Drawing No. C04-007

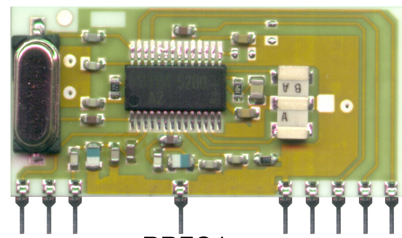
FM TRANSMITTER & RECEIVER HYBRID MODULES.

FM-RTFQ SERIES FM-RRFQ SERIES

- FM Radio Transmitter & Receivers
- Available As 315 or 433 or 868MHz
- Transmit Range Up To 250m
- Miniature Packages
- Data Rate upto 9.6Kbps
- No Adjustable Components
- Very Stable Operating Frequency
- Operates from –20 to +85^{0}C



RTFQ1



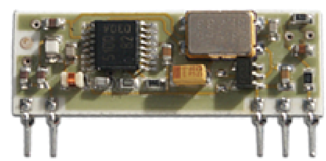
RRFQ1

Transmitter

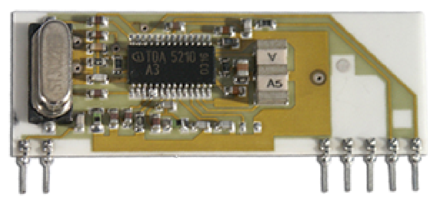
- 3-12 Supply Voltage
- SIL or DIL Package

Receiver

- PLL XTAL Design
- CMOS/TTL Output
- RSSI Output
- **Standby Mode (max 100nA)**
- 5V Supply Voltage



RTFQ2



RRFQ2

Applications

- Wireless Security Systems
- Car Alarms
- Remote Gate Controls
- Remote Sensing
- Data Capture
- Sensor Reporting

Description

These miniature RF modules provide a cost effective high performance FM Radio data link, at either 315, 433.92 or 868MHz. Manufactured using laser trimmed Thick Film ceramic Hybrid the modules exhibits extremely stable electronic characteristics over an Industrial Temperature range. The hybrid technology uses no adjustable components and ensures very reliable operation.

This transmitter and receiver pair enables the simple implementation of a data link at distances upto 75 metres in-building and 250 metres open ground.

These modules will suit one-to-one and multi-node wireless links in applications including car and building security, EPOS and inventory tracking, remote industrial process monitoring and computer networking. Because of their small size and low power requirements, both modules are ideal for use in portable, battery-powered applications such as hand-held terminals.

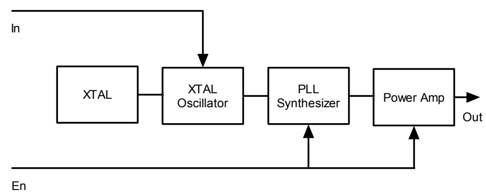
Transmitters

There are two versions of transmitter:

RTFQ1; A Dual in Line Package operating at 3.3V. This provides the most rugged mechanical fixing to the host PCB. Power Down mode is also available.

RTFQ2; A Single in Line Package incorporating a voltage regulator for 3-12V operation. (Compatible with many other RF transmitter modules available)

Transmitter Block Diagram



Part Numbering

Part Number	Description
FM-RTFQ1-315	DIL FM Transmitter Module 315 MHz
FM-RTFQ1-433	DIL FM Transmitter Module 433.92 MHz
FM-RTFQ1-868	DIL FM Transmitter Module 868.35 MHz
FM-RTFQ2-433R	SIL FM Transmitter Module 433.92 MHz 3-12V I/P
FM-RTFQ2-868R	SIL FM Transmitter Module 868.35 MHz 3-12V I/P

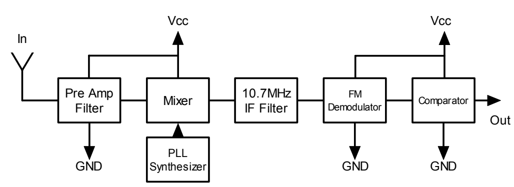
Receivers

There are two versions of receiver:

RRFQ1: A Single in Line Package with sleep / Power down mode.

RRFQ2: A Single in Line Package, pin compatible with many other receivers

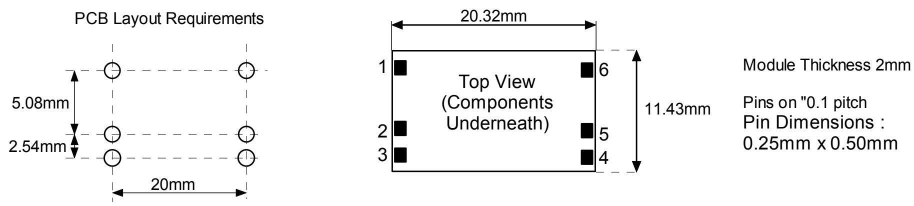
Receiver Block Diagram



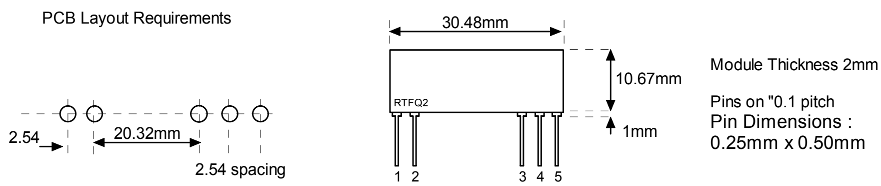
Part Numbering

Part Number	Description
FM-RRFQ1-315	SIL FM Receiver Module 315 MHz
FM-RRFQ1-433	SIL FM Receiver Module 433.92 MHz
FM-RRFQ1-868	SIL FM Receiver Module 868.35 MHz
FM-RRFQ2-433	SIL FM Receiver Module 433.92 MHz
FM-RRFQ2-868	SIL FM Receiver Module 868.35 MHz

RTFQ1 Mechanical Dimensions



RTFQ2 Mechanical Dimensions



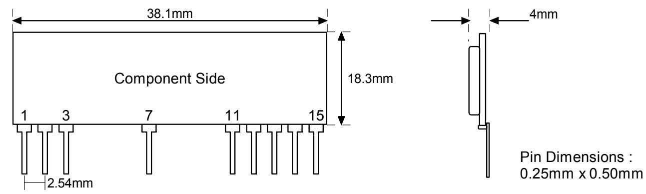
Pin Description

RTFQ1	RTFQ2	Name	Description
1	N/A	En	Enable (active high)
2	5	IN	Data input
3	1	GND	Ground, Connect to RF earth return path
4	3	Vcc	Supply Voltage
5	4	GND	Ground, Connect to RF earth return path
6	2	EA	External Antenna

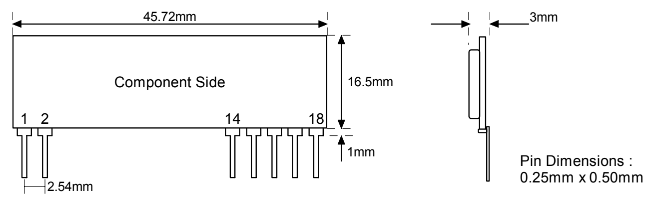
Technical Specifications

Electrical Characteristics	MIN	TYPICAL	MAX	DIMENSION
Supply Voltage RTFQ1	2.1	3.3	4.00	V
Supply Voltage RTFQ2	2.5		12.00	V
Supply Current		7	8	mA
Standby Current (IN = EN = Low)			100	nA
Frequency		315.0 433.92 868.35		MHz
RF Output into 50Ω (Vcc=3.3V)		+5 / +5 / +1		dBm
Initial Frequency Accuracy	-35	0	+35	KHz
FM Deviation	25	30	35	KHz
Harmonic Spurious Emissions		-50		dBc
Input High Voltage RTFQ1	1.5		Vcc	V
Input High Voltage RTFQ2	1.5		5.5	V
Power up Time (En to full RF)			1	mS
Power up Time (Power on to full RF)			5	mS
Max Data Rate			9.6	KHz
Operating Temperature	-25		+80	°C

RRFQ1 Mechanical Details



RRFQ2 Mechanical Details



Pin Description

RRFQ1	RRFQ2	Pin Description
1	16	+Vcc
2, 7,11	2,15	GND
3	1	Data In (Antenna)
12		NC
13	14	Received Signal Strength Output
N/A	17	AF Output
14	18	Data Out
15	N/A	Power Down 0V = Standby 5V = Operating

RSSI Output*

RF In (dBm)	RSSI (V)
-120	1.20
-110	1.32
-100	1.50
-90	1.78
-80	2.06
-70	2.35
-60	2.62
-50	2.72
-40	2.75

RSSI Output

The RSSI provides a DC Voltage proportional to the peak value of the receive data signal. This output can be used as an indicator for the received signal strength to use in wake-up circuits etc.

An RC circuit is normally used to provide the timing for the RSSI signal. The modules have a 10nF capacitor internally connected to GND, therefore a pull down resistor (to GND) connected to the RSSI pin may be used to generate a simple RC network time constant for the RSSI signal output.

Please note that the maximum output current is typically 950µA, the discharge current is lower than 2µA

Technical Specifications

Electrical Characteristics	Min	Typical	Max	Dimension	Notes
Supply Voltage (Vcc)	4.5	5	5.5	V	
Supply Current (Operating)		5.7	6.8	mA	
Supply Current (Standby)			100	nA	
Receiver Frequency		315.00 433.92 868.35		MHz	
R.F Sensitivity (100% AM) 315 ,433MHZ versions 868MHz versions		 -103 -100		dBm	
3dB Bandwidth		+/-150		KHz	
Data Rate	300		9,600	Hz	
Turn on Time			5	mSecs	1
Turn on Time		8		mSecs	2
Level of Emitted Spectrum			-70	dBm	
Low Level Output Voltage			0.8	V	I = 200uA
High Level Output Voltage	Vcc-1			V	I = 200uA
RSSI Output		0.95		mA	
Operating Temperature Range	-25		+80	°C	

Notes
1. Time from PD pin going high to stable data. (RRFQ1 only)
2. Time from Power ON to stable data.

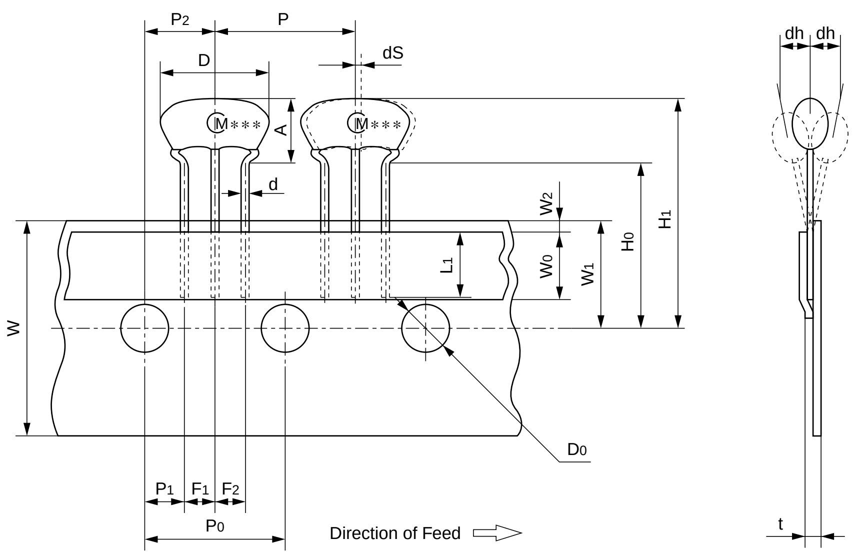
MHz Lead Type CSTLS Series Packaging

■ Minimum Quantity

Part Number	Ammo Pack	Bulk
CSTLS_G (3.40 to 10.0MHz)	2,000	500
CSTLS_X (16.00 to 70.00MHz)	2,000	500

The order quantity should be an integral multiple of the "Minimum Quantity" shown above. (pcs.)

■ Tape Dimensions of CSTLS_G



Item	Code	Dimensions	Tolerance	Remarks
Width of diameter	D	8.0	±1.0	
Height of resonator	A	5.5	±0.5	
Dimensions of terminal	d	ø0.48	±0.05	
Lead length under the hold down tape	L_1	5.0 min.	–	
Pitch of component	P	12.7	±0.5	Tolerance for Pitches 10xP_0=127±1
Pitch of sprocket hole	P_0	12.7	±0.2	
Length from sprocket hole center to lead	P_1	3.85	±0.5	
Length from sprocket hole center to component center	P_2	6.35	±0.5	
Lead spacing (I)	F_1	2.5	±0.2	
Lead spacing (II)	F_2	2.5	±0.2	
Slant to the forward or backward	dh	0	±1.0	1mm max.
Width of carrier tape	W	18.0	±0.5	
Width of hold down tape	W_0	6.0 min.	–	Hold down tape does not exceed the carrier tape.
Position of sprocket hole	W_1	9.0	±0.5	
Gap of hold down tape and carrier tape	W_2	0	$^{+0.5}_{-0}$	
Distance between the center of sprocket hole and lead stopper	H_0	18.0	±0.5	
Total heigth of resonator	H_1	23.5	±1.0	
Diameter of sprocket hole	D_0	ø4.0	±0.2	
Total tape thickness	t	0.6	±0.2	
Body tilt	dS	0	±1.0	

(in mm)

Continued on the following page. ↗

Pin Diagrams – PIC16F884/887, 40-Pin PDIP

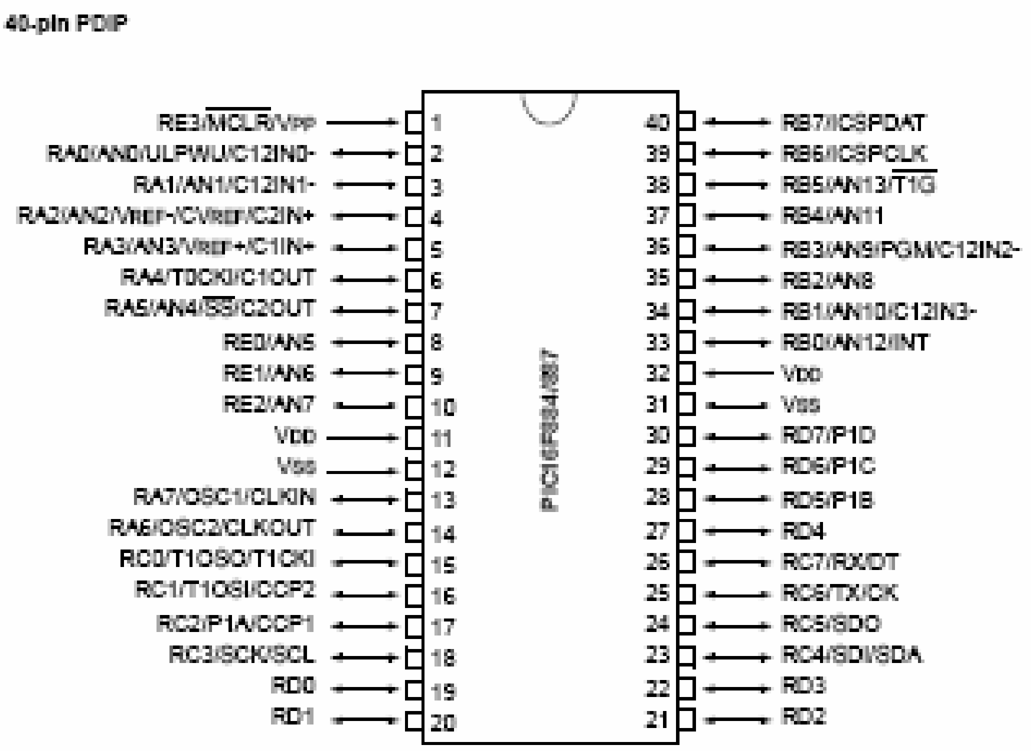


TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	13	14	30	I	ST/CMOS[4]	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	14	15	31	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/V_{PP}/THV	1	2	18	I/P	ST	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1
RA2/AN2/V_{REF}-	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/V_{REF}+	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST[1]	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input
RB4	37	41	14	I/O	TTL	Interrupt on change pin.
RB5	38	42	15	I/O	TTL	Interrupt on change pin.
RB6/PGC	39	43	16	I/O	TTL/ST[2]	Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST[2]	Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.
						PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	15	16	32	I/O	ST	RC0 can also be the Timer1 oscillator output or a Timer1 clock input.
RC1/T1OSI/CCP2	16	18	35	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	17	19	36	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	18	20	37	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I^2C modes.
RC4/SDI/SDA	23	25	42	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	24	26	43	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	25	27	44	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	26	29	1	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as an external interrupt.
2: This buffer is a Schmitt Trigger input when used in serial programming mode.
3: This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
4: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION

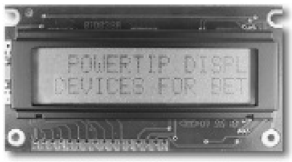
Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	13	14	30	I	ST/CMOS(4)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	14	15	31	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
$\overline{MCLR}$/VPP/THV	1	2	18	I/P	ST	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1
RA2/AN2/VREF-	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/VREF+	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input
RB4	37	41	14	I/O	TTL	Interrupt on change pin.
RB5	38	42	15	I/O	TTL	Interrupt on change pin.
RB6/PGC	39	43	16	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.
						PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	15	16	32	I/O	ST	RC0 can also be the Timer1 oscillator output or a Timer1 clock input.
RC1/T1OSI/CCP2	16	18	35	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	17	19	36	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	18	20	37	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I²C modes.
RC4/SDI/SDA	23	25	42	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I²C mode).
RC5/SDO	24	26	43	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	25	27	44	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	26	29	1	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.

Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

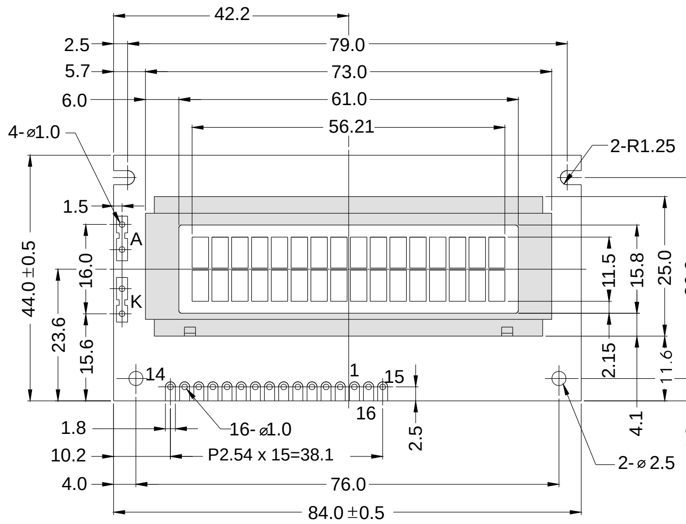
Note 1: This buffer is a Schmitt Trigger input when configured as an external interrupt.
2: This buffer is a Schmitt Trigger input when used in serial programming mode.
3: This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
4: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

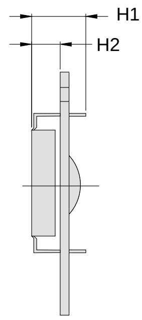
POWERTIP

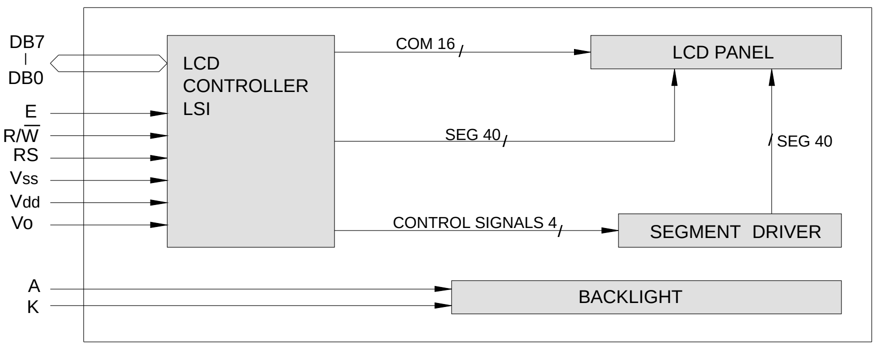
PC 1602-F

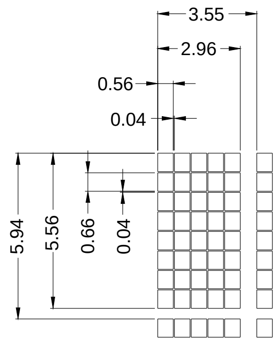


OUTLINE DIMENSION & BLOCK DIAGRAM









The tolerance unless classified ±0.3mm

MECHANICAL SPECIFICATION			
Overall Size	84.0 x 44.0	Module	H2 / H1
View Area	61.0 x 15.8	W /O B/L	5.1 / 9.7
Dot Size	0.56 x 0.66	EL B/L	5.1 / 9.7
Dot Pitch	0.60 x 0.70	LED B/L	9.4 / 14.0

PIN ASSIGNMENT

Pin no.	Symbol	Function
1	Vss	Power supply(GND)
2	Vdd	Power supply(+)
3	Vo	Contrast Adjust
4	RS	Register select signal
5	R/W	Data read / write
6	E	Enable signal
7	DB0	Data bus line
8	DB1	Data bus line
9	DB2	Data bus line
10	DB3	Data bus line
11	DB4	Data bus line
12	DB5	Data bus line
13	DB6	Data bus line
14	DB7	Data bus line
15	A	Power supply for LED B/L (+)
16	K	Power supply for LED B/L (–)

ABSOLUTE MAXIMUM RATING

Item	Symbol	Condition	Min.	Max.	Units
Supply for logic voltage	Vdd-Vss	25°C	-0.3	7	V
LCD driving supply voltage	Vdd-Vee	25°C	-0.3	13	V
Input voltage	Vin	25°C	-0.3	Vdd+0.3	V

ELECTRICAL CHARACTERISTICS

Item	Symbol	Condition	Min.		Typical		Max.		Units
Power supply voltage	Vdd-Vss	25°C	2.7		–		5.5		V
LCD operation voltage	Vop	Top	N	W	N	W	N	W	V
		-20°C	–	7.1	–	7.5	–	7.9	V
		0°C	4.5	–	5.1	–	5.3	–	V
		25°C	4.1	6.1	4.7	6.4	4.9	6.7	V
		50°C	3.8	–	4.4	–	4.6	–	V
		70°C	–	5.7	–	6	–	6.3	V
LCM current consumption (No B/L)	Idd	Vdd=5V	–		2		3		mA
Backlight current consumption	LED/edge	VB/L=4.2V	–		40		–		mA
	LED/array	VB/L=4.2V	–		120		–		mA

REMARK

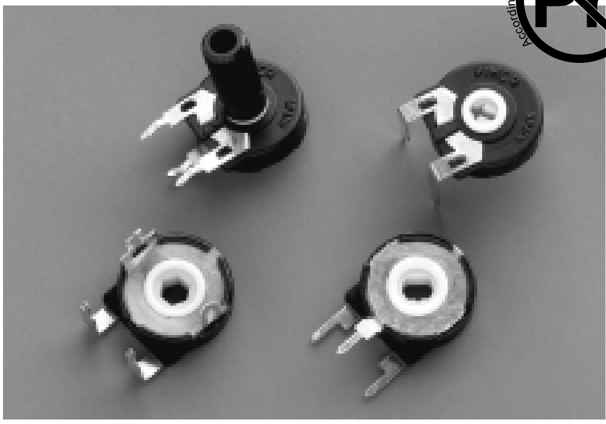
LCD option: STN, TN, FSTN

Backlight Option: LED,EL Backlight feature, other Specs not available on catalog is under request.

PIHER

According to ELV (2000/53/EC) / RoHS (2002/95/EC) Pb

PT-15 15 mm Carbon Potentiometer



FEATURES

- Carbon resistive element.
- Dust proof enclosure.
- Polyester substrate.
- Also upon request:
  - Wiper positioned at 50% or fully clockwise.
  - Long life model for low cost control pot. applications
  - Low torque option
  - Supplied in magazines for automatic insertion.
  - Self extinguishable plastic UL 94V-0
  - Cut track option
  - Special Tapers
  - Mechanical detents

MECHANICAL SPECIFICATIONS

– Mechanical rotation angle: 265° ± 5°
240º ± 5º available under drawing (blue housing only)

– Electrical rotation angle: 250° ± 20°

– Torque: 0.5 to 2.5 Ncm.
(0.7 to 3.4 in-oz)

– Stop torque: > 10 Ncm. (>14 in-oz)

ELECTRICAL SPECIFICATIONS

– Range of values (*)
100Ω ≤ Rn ≤ 5 M (Decad. 1.0 - 2.0 - 2.2 - 2.5 - 4.7 - 5.0)

– Tolerance (*): 100Ω ≤ Rn ≤ 1M Ω ------ ± 20%
1MΩ < Rn ≤ 5M ------ ± 30%

– Max. Voltage: 250 VDC (lin) 125 VDC (no lin)

– Nominal Power 50°C (122°F) (see power rating curve)
0.25 W (lin) 0.12 W (no lin)

– Taper (*) (Log. & Alog. only Rn ≥ 1K) Lin ; Log; Alog.

– Residual resistance: ≤ 5.10^{-3} Rn (2 Ω min.)

– Equivalent Noise Resistance: ≤ 3% Rn (3 Ω min.)

– Operating temperature**: –25°C + 70°C (–13°F + 158°F)

* Others upon request ** Up to 85°C depending on application

HOW TO ORDER

STANDARD: PT-15 | L | H01 | 223 | A | 2020

OPTIONAL EXTRAS: Life | Detent | Flammability | Wiper position | Magazine | Cut track | Shaft Thum. | Shaft/rotor colour | Torque

Series
PT-15

Rotors
C, F, G, L, M, N, R, T, X, W, Y, Z
(See note 1)

Code / Mounting Method

Code	Mounting Method
H01	H2.5
H05	H5
H25	HC5
H06	B
H02	H2.5P
H10	H5P
V02	V12.5
V12	VA
V15	V15
V17	V17.5
V18	D
V24	VD15
V21	V12.5P
V22	VAP
V23	V15P

(See note 2)

Taper
A = Lin.
B = Log.
C = Alog.

Value
101 = 100 Ω
223 = 22 K
504 = 500 K
505 = 5 M
(See note 3)

Tolerance
2020 = ± 20%
3030 = ± 30%
(See note 4)

Life
E= *Long life*
U= *Extra Long life*
(See note 5)

Detent
See PT's with detents data sheet

Cut track
PCI = Initial
PCF= Final

Shaft Thum.
01 – Fig. 1
28 – Fig. 28

Flammability
I= non flammable
(See note 6)

Shaft/rotor colour
RO=Red
NE=Black
VE=Green
AM=Yellow
AZ=Blue
MA=Brown
GR=Grey
NA=Orange
CR=Cream.
(See note 7)

Wiper position
PM = 50%
PF = Final

Torque
– = Standard
L = Low torque
(See note 8)

Magazine
T
(See note 9)

NOTES:

(1) "Z" adjustment only available on "H" versions. Standard colour for the "T" rotor: Orange
(2) Terminal styles: "P" are crimped terminals. V=Vertical adjust; H=Horizontal Adjust
(3) Value Example: Code: 10 1 100 Ω
1 → Numb of zeros
10 → First two digits of the value.
(4) Non standard tolerance, upon request. Example: +7% -5% Code: 07 05
05 → negative tolerance
07 → positive tolerance
(5) Life
- Standard 500 cycles
- Long life 10000 cycles
- Extra Long life 100000 cycles (to be studied case by case)
(6) Non flammable: housing, rotor and shaft.
(7) Colour shaft/rotor: • Potentiometer without shaft: only rotor • Potentiometer with shaft: only shaft
Cream colour only available in standard plastic
(8) Low Torque: ≤1.5Ncm. *No detent option available for low torque models*
(9) Magazines (35 pcs/mag): available for VA (12.5), V (12.5), V (12.5P), V (15), V15 (P) and H models.
For more information please contact your nearest Piher supplier.

NOTE: The information contained here should be used for reference purposes only.

ISO TS 16949 / ISO 14001

MEGGITT

DS1302
Trickle-Charge Timekeeping Chip

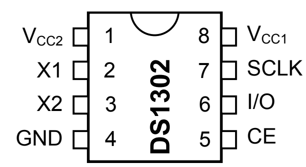
www.maxim-ic.com

FEATURES

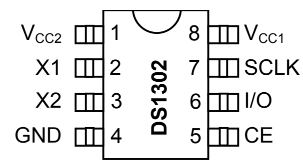
- Real-Time Clock Counts Seconds, Minutes, Hours, Date of the Month, Month, Day of the Week, and Year with Leap-Year Compensation Valid Up to 2100
- 31 x 8 RAM for Scratchpad Data Storage
- Serial I/O for Minimum Pin Count
- 2.0V to 5.5V Full Operation
- Uses Less than 300nA at 2.0V
- Single-Byte or Multiple-Byte (Burst Mode) Data Transfer for Read or Write of Clock or RAM Data
- 8-Pin DIP or Optional 8-Pin SO for Surface Mount
- Simple 3-Wire Interface
- TTL-Compatible (V_{CC} = 5V)
- Optional Industrial Temperature Range: -40°C to +85°C
- DS1202 Compatible
- Underwriters Laboratory (UL) Recognized

PIN CONFIGURATIONS

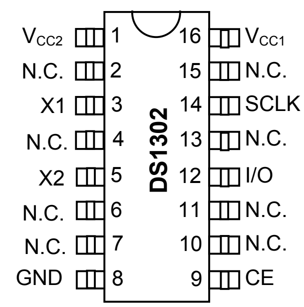
TOP VIEW



DIP (300 mils)



SO (208 mils/150 mils)



SO (300 mils)

ORDERING INFORMATION

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK*
DS1302	0°C to +70°C	8 PDIP (300 mils)	DS1302
DS1302+	0°C to +70°C	8 PDIP (300 mils)	DS1302
DS1302N	-40°C to +85°C	8 PDIP (300 mils)	DS1302
DS1302N+	-40°C to +85°C	8 PDIP (300 mils)	DS1302
DS1302S	0°C to +70°C	8 SO (208 mils)	DS1302S
DS1302S+	0°C to +70°C	8 SO (208 mils)	DS1302S
DS1302SN	-40°C to +85°C	8 SO (208 mils)	DS1302S
DS1302SN+	-40°C to +85°C	8 SO (208 mils)	DS1302S
DS1302Z	0°C to +70°C	8 SO (150 mils)	DS1302Z
DS1302Z+	0°C to +70°C	8 SO (150 mils)	DS1302Z
DS1302ZN	-40°C to +85°C	8 SO (150 mils)	DS1302ZN
DS1302ZN+	-40°C to +85°C	8 SO (150 mils)	DS1302ZN
DS1302S-16	0°C to +70°C	16 SO (300 mils)	DS1302S16
DS1302SN-16	-40°C to +85°C	16 SO (300 mils)	DS1302SN16

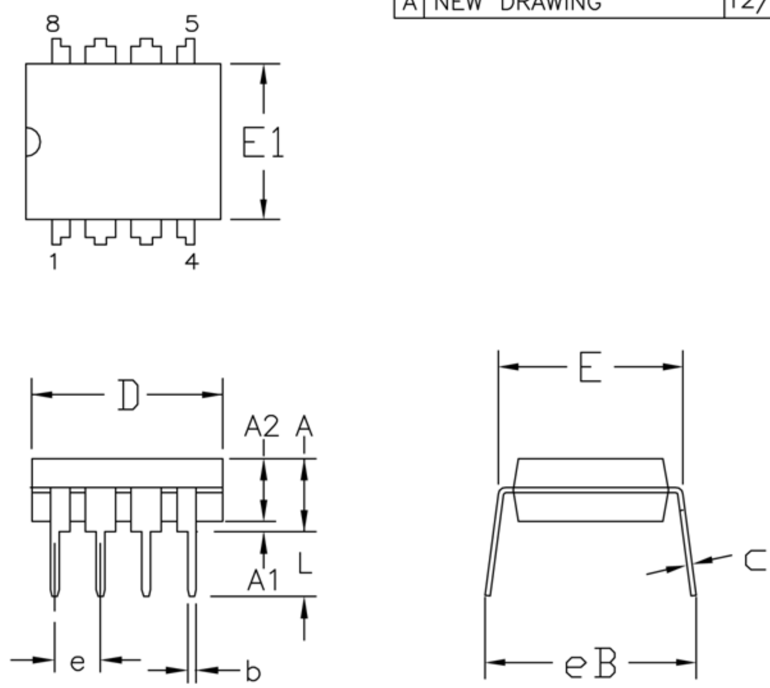
+ Denotes a lead-free/RoHS-compliant device.
**An N anywhere on the top mark indicates an industrial temperature grade device. A + anywhere on the top mark indicates a lead-free device.*

***Note:** Some revisions of this device may incorporate deviations from published specifications known as errata. Multiple revisions of any device may be simultaneously available through various sales channels. For information about device errata, click here: www.maxim-ic.com/errata.*

PACKAGE INFORMATION

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information, go to **www.maxim-ic.com/DallasPackInfo**.)

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	NEW DRAWING	12/01	



	8 PIN	
	MIN	MAX
A	–	0.170
A1	0.015	–
A2	0.115	0.195
b	0.015	0.022
c	0.008	0.012
D	0.360	0.380
E	0.300	0.325
E1	0.240	0.260
e	0.090	0.110
L	0.125	0.135
eB	–	0..430

ALL DIMENSIONS ARE IN INCHES

SIGNATURE		DATE
DOC. CONTROL:		
ENGR. MGR:		
MFG. ENGR:		
CHECKED BY:	TWM	12/01
DRAWN BY:	JFD	12/01
DO NOT SCALE DWG.		

DALLAS SEMICONDUCTOR MAXIM

TITLE MARKETING OUTLINE, 8 LEAD PLASTIC DUAL–IN–LINE PACKAGE (0.300”)

SIZE	FSCM NO	PART NO.	REV
A		56–G5005–000	A
SCALE N/A		SHEET 1 OF 1	

19-4323; Rev 14; 8/04

+5V-Powered, Multichannel RS-232 Drivers/Receivers

General Description

The MAX220–MAX249 family of line drivers/receivers is intended for all EIA/TIA-232E and V.28/V.24 communications interfaces, particularly applications where ±12V is not available.

These parts are especially useful in battery-powered systems, since their low-power shutdown mode reduces power dissipation to less than 5μW. The MAX225, MAX233, MAX235, and MAX245/MAX246/MAX247 use no external components and are recommended for applications where printed circuit board space is critical.

Applications

Portable Computers

Low-Power Modems

Interface Translation

Battery-Powered RS-232 Systems

Multidrop RS-232 Networks

AutoShutdown and UCSP are trademarks of Maxim Integrated Products, Inc.

Next-Generation Device Features

- **For Low-Voltage, Integrated ESD Applications**
  MAX3222E/MAX3232E/MAX3237E/MAX3241E/MAX3246E: +3.0V to +5.5V, Low-Power, Up to 1Mbps, True RS-232 Transceivers Using Four 0.1μF External Capacitors (MAX3246E Available in a UCSP™ Package)
- **For Low-Cost Applications**
  MAX221E: ±15kV ESD-Protected, +5V, 1μA, Single RS-232 Transceiver with AutoShutdown™

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX220CPE	0°C to +70°C	16 Plastic DIP
MAX220CSE	0°C to +70°C	16 Narrow SO
MAX220CWE	0°C to +70°C	16 Wide SO
MAX220C/D	0°C to +70°C	Dice*
MAX220EPE	-40°C to +85°C	16 Plastic DIP
MAX220ESE	-40°C to +85°C	16 Narrow SO
MAX220EWE	-40°C to +85°C	16 Wide SO
MAX220EJE	-40°C to +85°C	16 CERDIP
MAX220MJE	-55°C to +125°C	16 CERDIP

Ordering Information continued at end of data sheet.

**Contact factory for dice specifications.*

Selection Table

Part Number	Power Supply (V)	No. of RS-232 Drivers/Rx	No. of Ext. Caps	Nominal Cap. Value (μF)	SHDN & Three-State	Rx Active in SHDN	Data Rate (kbps)	Features
MAX220	+5	2/2	4	0.047/0.33	No	—	120	Ultra-low-power, industry-standard pinout
MAX222	+5	2/2	4	0.1	Yes	—	200	Low-power shutdown
MAX223 (MAX213)	+5	4/5	4	1.0 (0.1)	Yes	✔	120	MAX241 and receivers active in shutdown
MAX225	+5	5/5	0	—	Yes	✔	120	Available in SO
MAX230 (MAX200)	+5	5/0	4	1.0 (0.1)	Yes	—	120	5 drivers with shutdown
MAX231 (MAX201)	+5 and +7.5 to +13.2	2/2	2	1.0 (0.1)	No	—	120	Standard +5/+12V or battery supplies; same functions as MAX232
MAX232 (MAX202)	+5	2/2	4	1.0 (0.1)	No	—	120 (64)	Industry standard
MAX232A	+5	2/2	4	0.1	No	—	200	Higher slew rate, small caps
MAX233 (MAX203)	+5	2/2	0	—	No	—	120	No external caps
MAX233A	+5	2/2	0	—	No	—	200	No external caps, high slew rate
MAX234 (MAX204)	+5	4/0	4	1.0 (0.1)	No	—	120	Replaces 1488
MAX235 (MAX205)	+5	5/5	0	—	Yes	—	120	No external caps
MAX236 (MAX206)	+5	4/3	4	1.0 (0.1)	Yes	—	120	Shutdown, three state
MAX237 (MAX207)	+5	5/3	4	1.0 (0.1)	No	—	120	Complements IBM PC serial port
MAX238 (MAX208)	+5	4/4	4	1.0 (0.1)	No	—	120	Replaces 1488 and 1489
MAX239 (MAX209)	+5 and +7.5 to +13.2	3/5	2	1.0 (0.1)	No	—	120	Standard +5/+12V or battery supplies; single-package solution for IBM PC serial port
MAX240	+5	5/5	4	1.0	Yes	—	120	DIP or flatpack package
MAX241 (MAX211)	+5	4/5	4	1.0 (0.1)	Yes	—	120	Complete IBM PC serial port
MAX242	+5	2/2	4	0.1	Yes	✔	200	Separate shutdown and enable
MAX243	+5	2/2	4	0.1	No	—	200	Open-line detection simplifies cabling
MAX244	+5	8/10	4	1.0	No	—	120	High slew rate
MAX245	+5	8/10	0	—	Yes	✔	120	High slew rate, int. caps, two shutdown modes
MAX246	+5	8/10	0	—	Yes	✔	120	High slew rate, int. caps, three shutdown modes
MAX247	+5	8/9	0	—	Yes	✔	120	High slew rate, int. caps, nine operating modes
MAX248	+5	8/8	4	1.0	Yes	✔	120	High slew rate, selective half-chip enables
MAX249	+5	6/10	4	1.0	Yes	✔	120	Available in quad flatpack package

ABSOLUTE MAXIMUM RATINGS—MAX220/222/232A/233A/242/243

Supply Voltage (V_{CC}) ....-0.3V to +6V
V+ (Note 1)..(V_{CC} - 0.3V) to +14V
V- (Note 1) ....+0.3V to +14V
Input Voltages
T_{IN}...-0.3V to (V_{CC} - 0.3V)
R_{IN} (Except MAX220) ....±30V
R_{IN} (MAX220)...±25V
T_{OUT} (Except MAX220) (Note 2) ....±15V
T_{OUT} (MAX220)..±13.2V
Output Voltages
T_{OUT}..±15V
R_{OUT}..-0.3V to (V_{CC} + 0.3V)
Driver/Receiver Output Short Circuited to GND.........Continuous
Continuous Power Dissipation (T_A = +70°C)
16-Pin Plastic DIP (derate 10.53mW/°C above +70°C)..842mW
18-Pin Plastic DIP (derate 11.11mW/°C above +70°C)..889mW
20-Pin Plastic DIP (derate 8.00mW/°C above +70°C) ..440mW
16-Pin Narrow SO (derate 8.70mW/°C above +70°C) ...696mW
16-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
18-Pin Wide SO (derate 9.52mW/°C above +70°C)......762mW
20-Pin Wide SO (derate 10.00mW/°C above +70°C)....800mW
20-Pin SSOP (derate 8.00mW/°C above +70°C) 640mW
16-Pin CERDIP (derate 10.00mW/°C above +70°C).....800mW
18-Pin CERDIP (derate 10.53mW/°C above +70°C).....842mW
Operating Temperature Ranges
MAX2_ _AC_ _, MAX2_ _C_ _............................0°C to +70°C
MAX2_ _AE_ _, MAX2_ _E_ _ ....-40°C to +85°C
MAX2_ _AM_ _, MAX2_ _M_ _......................-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10s) (Note 3) ....+300°C

Note 1: For the MAX220, V+ and V- can have a maximum magnitude of 7V, but their absolute difference cannot exceed 13V.
Note 2: Input voltage measured with T_{OUT} in high-impedance state, $\overline{SHDN}$ or V_{CC} = 0V.
Note 3: Maximum reflow temperature for the MAX225_WI and MAX233A_WP is +220°C.

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
RS-232 TRANSMITTERS						
Output Voltage Swing	All transmitter outputs loaded with 3kΩ to GND		±5	±8		V
Input Logic Threshold Low				1.4	0.8	V
Input Logic Threshold High	All devices except MAX220		2	1.4		V
	MAX220: V_{CC} = 5.0V		2.4			
Logic Pullup/Input Current	All except MAX220, normal operation			5	40	µA
	$\overline{SHDN}$ = 0V, MAX222/MAX242, shutdown, MAX220			±0.01	±1	
Output Leakage Current	V_{CC} = 5.5V, $\overline{SHDN}$ = 0V, V_{OUT} = ±15V, MAX222/MAX242			±0.01	±10	µA
	V_{CC} = $\overline{SHDN}$ = 0V	V_{OUT} = ±15V		±0.01	±10	
		MAX220, V_{OUT} = ±12V			±25	
Data Rate				200	116	kbps
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V		300	10M		Ω
Output Short-Circuit Current	V_{OUT} = 0V	V_{OUT} = 0V	±7	±22		mA
		MAX220			±60	
RS-232 RECEIVERS						
RS-232 Input Voltage Operating Range					±30	V
		MAX220			±25	
RS-232 Input Threshold Low	V_{CC} = 5V	All except MAX243 $R2_{IN}$	0.8	1.3		V
		MAX243 R2 $_{IN}$ (Note 4)	-3			
RS-232 Input Threshold High	V_{CC} = 5V	All except MAX243 $R2_{IN}$		1.8	2.4	V
		MAX243 R2 $_{IN}$ (Note 4)		-0.5	-0.1	

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243 (continued)

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
RS-232 Input Hysteresis	All except MAX220/MAX243, V_{CC} = 5V, no hysteresis in SHDN		0.2	0.5	1	V
	MAX220			0.3		
	MAX243			1		
RS-232 Input Resistance	T_A = +25°C (MAX220)		3	5	7	KΩ
			3	5	7	
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA			0.2	0.4	V
	I_{OUT} = 1.6mA (MAX220)				0.4	
TTL/CMOS Output Voltage High	I_{OUT} = -1.0mA		3.5	V_{CC} - 0.2		V
TTL/CMOS Output Short-Circuit Current	Sourcing V_{OUT} = GND		-2	-10		mA
	Shrinking V_{OUT} = V_{CC}		10	30		
TTL/CMOS Output Leakage Current	$\overline{SHDN}$ = V_{CC} or $\overline{EN}$ = V_{CC} ($\overline{SHDN}$ = 0V for MAX222), 0V ≤ V_{OUT} ≤ V_{CC}			±0.05	±10	µA
EN Input Threshold Low	MAX242			1.4	0.8	V
EN Input Threshold High	MAX242		2.0	1.4		V
Operating Supply Voltage			4.5		5.5	V
V_{CC} Supply Current ($\overline{SHDN}$ = V_{CC}), figures 5, 6, 11, 19	No load	MAX220		0.5	2	µA
		MAX222/MAX232A/MAX233A/ MAX242/MAX243		4	10	
	3kΩ load both inputs	MAX220		12		
		MAX222/MAX232A/MAX233A/ MAX242/MAX243		15		
Shutdown Supply Current	MAX222/ MAX242	T_A = +25°C		0.1	10	µA
		T_A = 0°C to +70°C		2	50	
		T_A = -40°C to +85°C		2	50	
		T_A = -55°C to +125°C		35	100	
$\overline{SHDN}$ Input Leakage Current	MAX222/MAX242				±1	µA
$\overline{SHDN}$ Threshold Low	MAX222/MAX242			1.4	0.8	V
$\overline{SHDN}$ Threshold High	MAX222/MAX242		2.0	1.4		V
Transition Slew Rate	C_L = 50pF to 2500pF, R_L = 3kΩ to 7kΩ, V_{CC} = 5V, T_A = +25°C, measured from +3V to -3V or -3V	MAX222/MAX232A/MAX233/ MAX242/MAX243	6	12	30	V/µs
		MAX220	1.5	3	30	
Transmitter Propagation Delay TLL to RS-232 (Normal Operation), Figure 1	t_{PHLT}	MAX222/MAX232A/MAX233/ MAX242/MAX243		1.3	3.5	µs
		MAX220		4	10	
	t_{PLHT}	MAX222/MAX232A/MAX233/ MAX242/MAX243		1.5	3.5	
		MAX220		5	10	

Note 4: MAX243 $R2_{OUT}$ is guaranteed to be low when $R2_{IN}$ is ≥ 0V or is floating.

+5V-Powered, Multichannel RS-232 Drivers/Receivers

ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243 (continued)

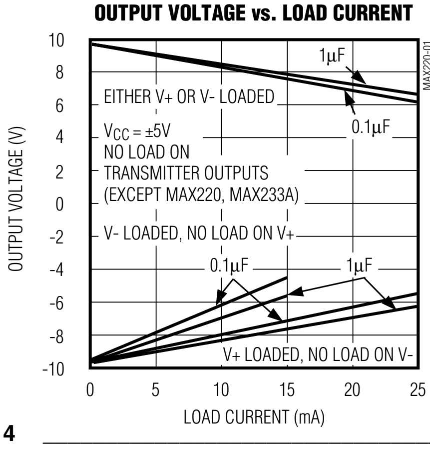
(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Receiver Propagation Delay RS-232 to TLL (Normal Operation), Figure 2	t_{PHLR}	MAX222/MAX232A/MAX233/ MAX242/MAX243		0.5	1	µs
		MAX220		0.6	3	
	t_{PLHR}	MAX222/MAX232A/MAX233/ MAX242/MAX243		0.6	1	
		MAX220		0.8	3	
Receiver Propagation Delay RS-232 to TLL (Shutdown), Figure 2	t_{PHLS}	MAX242		0.5	10	µs
	t_{PHLS}	MAX242		2.5	10	
Receiver-Output Enable Time, Figure 3	t_{ER}	MAX242		125	500	ns
Receiver-Output Disable Time, Figure 3	t_{DR}	MAX242		160	500	ns
Transmitter-Output Enable Time ($\overline{SHDN}$ Goes High), Figure 4	tET	MAX222/MAX242, 0.1µF caps (includes charge-pump start-up)		250		µs
Transmitter-Output Disable Time ($\overline{SHDN}$ Goes Low), Figure 4	tDT	MAX222/MAX242, 0.1µF caps		600		ns
Transmitter + to - Propagation Delay Difference (Normal Operation)	tPHLT - tPLHT	MAX222/MAX232A/MAX233/ MAX242/MAX243		300		ns
		MAX220		2000		
Receiver + to - Propagation Delay Difference (Normal Operation)	tPHLR - tPLHR	MAX222/MAX232A/MAX233/ MAX242/MAX243		100		ns
		MAX220		225		

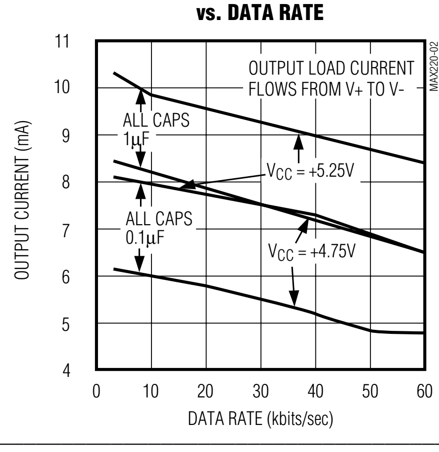
Typical Operating Characteristics

MAX220/MAX222/MAX232A/MAX233A/MAX242/MAX243

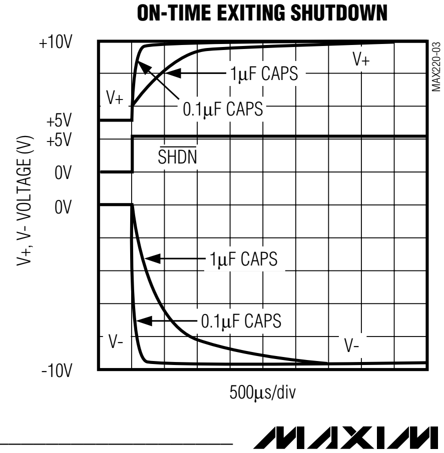
OUTPUT VOLTAGE vs. LOAD CURRENT

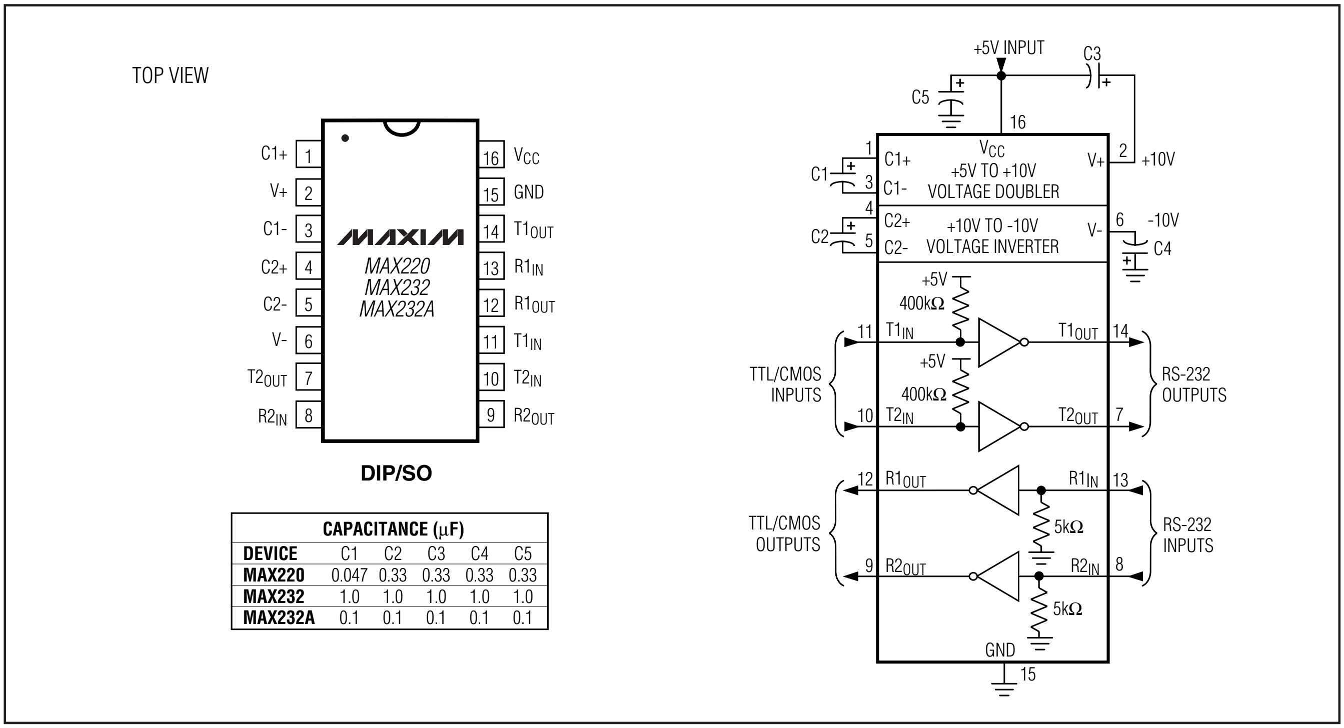


AVAILABLE OUTPUT CURRENT vs. DATA RATE



MAX222/MAX242 ON-TIME EXITING SHUTDOWN





CAPACITANCE (μF)					
DEVICE	C1	C2	C3	C4	C5
MAX220	0.047	0.33	0.33	0.33	0.33
MAX232	1.0	1.0	1.0	1.0	1.0
MAX232A	0.1	0.1	0.1	0.1	0.1

Figure 5. MAX220/MAX232/MAX232A Pin Configuration and Typical Operating Circuit

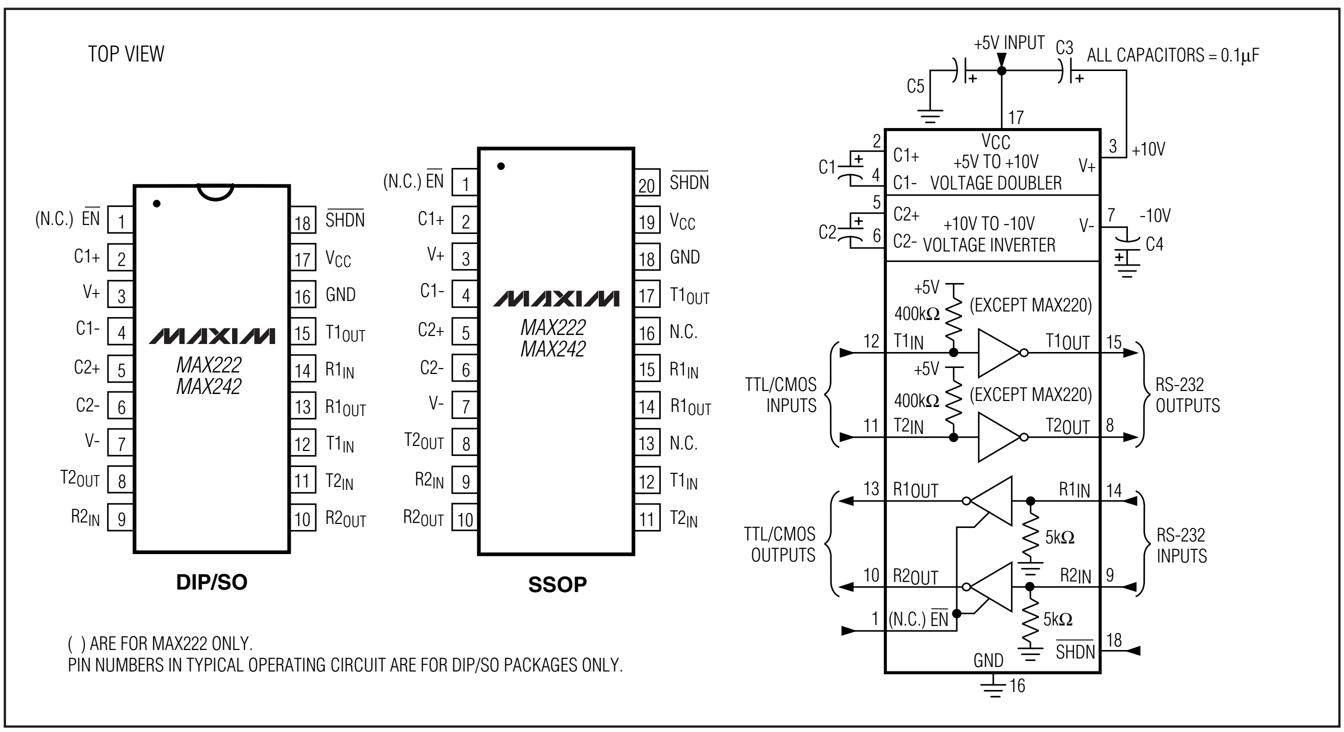


Figure 6. MAX222/MAX242 Pin Configurations and Typical Operating Circuit

REFERENCES

Books

JOHN P. BENTLEY 1995 Principles of Measurement Systems, Longman Group UK Limited.

RON OLEXA 2005 Implementing 802.11, 802.16 and 802.20 Wireless Networks, Elsevier Inc.

AGILIENT TECHNOLOGIES. Digital Modulation in Communications Systems. An Introduction

ARNALDOS, J. [et al.], Medi Ambient I Tecnologia. Guia Ambiental de la UPC,

BERENGUER I SAU, J. Radiofreqüència, una introducció experimental. Barcelona, Edicions UPC

ROBERT F. CLEVELAND, JR. JERRY L. ULCEK, Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields, Federal Communications Commission

Web sites

Fluorescent Interference:
http://www.lrc.rpi.edu/programs/NLPIP/lightinganswers/pdf/view/LAEMI.pdf

Types of sensors:
http://www.profc.udec.cl/~gabriel/tutoriales/rsnote/contents.htm

http://www.answers.com/main/ntquery;jsessionid=5m4ure42qqrpr?tname=dcs&curtab=2222_1&hl=distributed&hl=control&hl=system&sbid=lc04a

Chester Zoo:
http://www.chesterzoo.org/

Cisco Systems:
http://www.cisco.com/web/about/ac123/ac147/archived_issues/ipj_8-1/wireless_networks.html

Network Topology:
http://fcit.usf.edu/network/chap5/

Environmental effects of electronics:
http://www.recyclingforcharities.com/Environmental-Effects-of-E-Waste.php