A Universal Infrared Remote Control

by

Mered Agayev

A project dissertation submitted in partial fulfillment of the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

June 2006

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1) Automation control
2) Remote "

Certification of Approval

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Certification of Originality

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

MERED AGAYEV

Table of Contents

List of Figures

Abstract

This project consists of building a universal remote controller, which can be used to control any kind of device capable of communicating its user interface. The remote device works based on an infrared technology and allows the user to control any of the home appliances. The idea and design of this project are considered as a multi-communication between transmitter and receiver, because the remote control device combines many remotes into one and has an ability to control up to fifteen appliances that are commonly used at homes. The transmitter contains 15 independent inputs and has a carrier wave frequency of 38 kHz, which is the same for almost all infrared remote controls. Similarly, the receiver has 15 independent outputs, each of which can operate separately. The SAA3004 transmitter integrated circuit (IC), which is designed for infrared remote control systems, is used as a main IC on the remote control itself. As for receiver part, PIC16C55-XT/P is used as a microcontroller to control the infrared receiver operations due to the increased number of Input/Output pins. Both ICs are programmed accordingly to provide a multi- communication. A desktop lamp and fan are used as the example appliances to be remotely controlled. The control of these appliances is associated with ON/OFF switching application. Since a remote control has become a part of the everyday life, in this project, an infrared remote control system is designed to prove the universality of it.

Acknowledgment

First and foremost, I would like to thank my supervisor, Mr. Azizuddin Abdul Aziz. Without his guidance, feedback and encouragement, this project would not have been possible. It has been valuable experience to work with Mr. Azizuddin.

I would like to express my gratitude to Mr. Azman B. Zakariya, lecturer at Electrical & Electronics Department of UTP for providing the title and opportunity to work on this project. His advices and support are greatly appreciated.

Special thanks to laboratory technicians at Electrical & Electronics Department of UTP, to Mr. Musa for his help with experiments when the project circuits were tested and to Ms. Siti Hawa for the time she invested in teaching the soldering techniques.

CHAPTER 1

INTRODUCTION

When there are several controllable devices in a certain space, controlling them all in an efficient way requires much thought on the user interface and usability issues. Today's solutions differ from a local mechanical switch to a complex distributed controlling system. One part of these is different remote controllers, which people are using in their everyday life. Another solution is a universal infrared remote control, which can perform all functions of different remotes of various brand appliances that are used at homes [2].

1.1 Background of study

Remote controls have become more sophisticated in recent years. They are able to operate a large indefinite number of home entertainment equipment. However, the "universality" of remote controllers comes into question as entertainment devices add more features and functions to their standard controls [3]. Some remote controllers will not operate certain brands, and many do not come equipped with enough buttons to control all of the features of any given device. This leaves many consumers with no choice but to own a number of remote controls, each for a specific device or task.

A universal remote controller was invented to be able to turn the television on, control the lights, speed of fans, temperature of air conditioners, close the blinds or drapes - in fact, virtually anything electrical. With this device now it is possible to turn off all the lights in the house from the bedside or turn on all the lights with one press to scare away intruders.

The protocol, most commonly used in home entertainment remotes is Infrared (IR). It is line-of-sight only, and the transmission range is usually limited to about 30 meters, however, an IR distribution system can provide virtually unlimited range. IR is not a secure method of communication, as the codes are openly published in an industry standard IR code library. Universal IR remotes have this library built in, which allows them to control most of any manufacturer's devices. For controlling components whose codes are not in the library, learning remotes are available everywhere which can be taught the code of any device. A common feature of universal remotes is the ability to group commands, so as to actuate, with one device, several components simultaneously.

1.2 Problem statement

Nowadays there is usually a unique remote controller for every infrared controllable appliance (See Figure 1.1, where RC stands for Remote Control). Every manufacturer has its own style in their user interfaces and they can be totally unique. So, if a person can use a certain remote controller properly, it does not necessarily mean one can use all the possible remote controllers. Even if the appliances would be from the same manufacturer, the user interface of the remote controllers can differ a lot. Most of the appliances have some kind of special functions and might need some special controls. So, it might be impossible to use the similar user interface to control different appliances. When we try to use the same remote controller to control different kind of appliances (see Figure 1.2, where URC stands for Universal Remote Control) there has to be several functions for one physical controller in different situations. Therefore, a universal remote controller was invented to prove the universal applicability. By universal remote controller the user can control all of the infrared controllable appliances used at home.

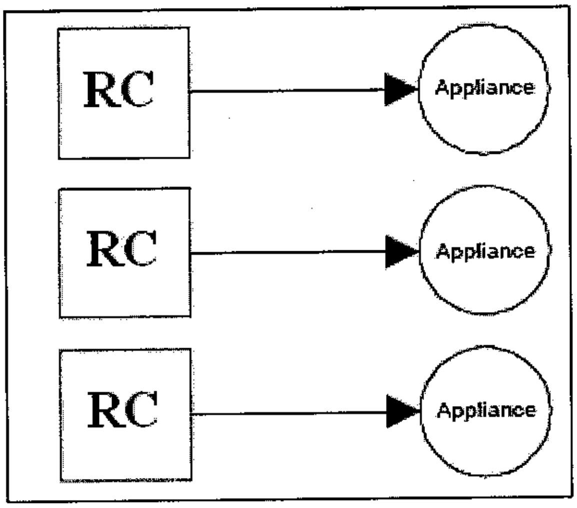


Figure 1.1: ***Traditional way to remotely control***

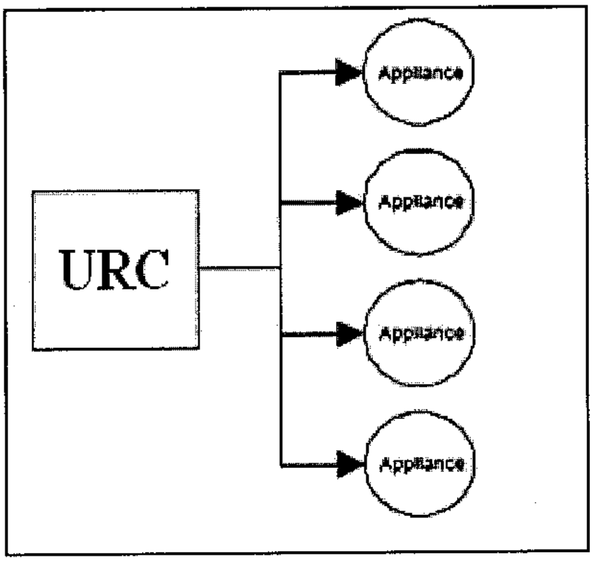


Figure 1.2: Remote controlling using a universal remote controller

1.3 Objective and Scope of study

The main objective of this project is to provide a working prototype of a universal infrared remote control transmitter and receiver on a Printed Circuit Boards (PCB) creating the smallest and simplest set of commands that will provide the greatest flexibility. The control system should perform the operation of remote control for home appliances such as fan and lamp. An additional objective of the project is to create a command code using Microsoft Visual Basic to control these appliances from computer. At the end, the system should be user-friendly and reliable.

Scope of project's work is divided into two parts, FYP1 and FYP2 semesters:

<u>FYP1 semester:</u>

- Research and analysis on materials related to project.
- Project planning.
- Finalize the project's objectives and deliverability.
- Define what are the hardware and software required for the project's implementation.
- Get familiar with PCB design and learn how to work on it.
- Get familiar with PIC microcontroller and learn how to program it.
- Learn how to study the signal codes transmitted from remote control.

- Design, implement, test and prove the viability of an infrared single-channel receiver circuit.

FYP2 semester:

- Define a universal infrared remote control transmitter and receiver circuits.
- Learn how to decode the transmitted signals for remote control input buttons.
- Program the PIC Microcontroller that is being used at the receiver part accordingly by using the obtained signal codes for remote control.
- Implement and test the remote control system, and work on it to prove the universality.
- Additionally, learn about the computer parallel port and create a command code using Microsoft Visual Basic that will give the instructions to the transmitter from computer.
- Complete the project and achieve all the required objectives.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 What is Infrared?

Infrared (IR), just like any light ray, is an electromagnetic radiation of a wavelength longer than visible light, but shorter than microwave radiation. The name means "below red" (from the Latin "infra" - "below"), red being the color of visible light of longest wavelength. A very interesting phenomenon that can be observed is that anything material above absolute zero (-273.15 degrees Celsius or 0 Kelvin), radiates in the infrared, even ice emits infrared radiation. We as a human being cannot see IR, because our eyes are designed for visible light. Even though IR is not visible to the human eye, our skin can sense it [4].

The electromagnetic spectrum classifies electromagnetic energy according to frequency or wavelength.

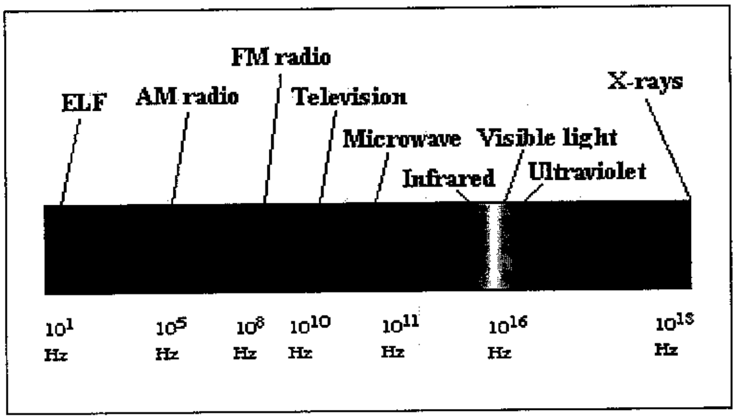


Figure 2.1: Electromagnetic spectrum

Figure 2.1 represents the electromagnetic spectrum, which ranges from energy waves having extremely low frequency (ELF) to energy waves having much higher frequency, such as X-rays. A horizontal bar represents a range of frequencies from 10 Hertz (cycles per second) to 10^{18} Hertz [5]. Some familiar allocated frequency bands are labeled on the spectrum. Approximate locations are as follows.

10^1 Hertz: extremely low frequency or ELF.

10^5 Hertz: AM radio

10^8 Hertz: FM radio

10^{10} Hertz: Television

10^{11} Hertz: Microwave

10^{16} Hertz: Infrared (frequency range is below the visible light spectrum)

10^{16} Hertz: Visible Light

10^{16} Hertz: Ultraviolet (frequency range is above the visible light spectrum)

10^{18} Hertz: X-rays

2.2 How does an infrared system work?

As it was mentioned, an IR radiation is the region of the electromagnetic spectrum between microwaves and visible light. In infrared communication, light emitting diode (LED) transmits the infrared signal as bursts of non-visible light. At the receiving end a photodiode or photoreceptor detects and captures the light pulses, which are then processed to retrieve the information they contain.

Generally, an IR system comprises three sections: the transmitter, the emitter and the receiver [6]. The emitter is sometimes located within its transmitter. It is known, that in any communications system there are transmitter, transmission medium, receiver, and system noise [23]. The transmission medium that provides a means of transporting signals between transmitter and receiver can be as simple as a pair of copper wires or as complex of sophisticated microwave, satellite, or optical fiber communications system. In infrared systems, the transmission medium is a modulated carrier of harmless invisible infrared light.

Infrared is interesting, because it is easily generated and does not suffer electromagnetic interference. It is nicely used in communication and control, but not perfect, because some other light emissions could contain infrared as well, and that can interfere in this communication. The sun is an example of light emission, since it emits a wide spectrum or radiation. IR signal is contained within the room in which it is used, so even adjacent rooms may use identical IR systems without interference among them.

IR products are compact and lightweight. While installing or using IR system, it is essential to consider that the visible components of the transmitter and the receiver must face each other without obstruction.

2.3 Infrared technology

Some common applications of infrared technology are listed below:

Augmentative communication devices:

- Car locking systems
- Computers (Mouse, Keyboards, Printers)
- Emergency response systems
- Environmental control systems (Windows, Doors, Lights, Curtains, Beds, Radios)
- Headphones
- Home security systems
- Navigation systems
- Signage
- Telephones
- TVs, VCRs, CD players, DVDs, stereos
- Toys

Infrared technology offers several important advantages as a form of wireless communication [5]. The advantages and disadvantages of IR technology described as follow:

<u>Advantages of Infrared technology</u>

- Low power requirements
- Low circuitry costs
- Simple circuitry: no special or proprietary hardware is required, can be incorporated into the integrated circuit of a product
- Higher security: directionality of the beam helps to ensure that data is not leaked or spilled to nearby devices as it's transmitted
- Portable
- Few international regulatory constraints: IrDA (Infrared Data Association) functional devices ideally usable by international travelers, no matter where they may be
- High noise immunity: not as likely to have interference from signals from other devices

Disadvantages of Infrared technology

- Line of sight: transmitters and receivers must be almost directly aligned (i.e. able to see each other) to communicate
- Transmission block: people, walls, plants, etc. can block transmission
- Short range: performance drops off with longer distances
- Light, weather sensitive: direct sunlight, rain, fog, dust, pollution can affect transmission
- Lower speed: data rate transmission is lower than typical wired transmission

2.4 How does an infrared remote control work?

An IR remote control sends control information using infrared light. When we touch a key on this device, the circuitry determines what sequence of flashes of infrared light correspond to that key, and then the signal is sent as a sequence of voltages that turn an infrared LED ON and OFF, and the spacing between modulations determines whether the remote is transmitting "1" or "0". The appliance that we are pointing at has an infrared light detector that picks up the infrared light signals, converts the infrared light to electrical signals, and then uses some digital circuitry to determine what function needs to be done in response to that signal sequence.

A remote control has to be flexible enough to be able to encode the commands. By pressing a button in remote control we establish a complete specific connection. The transmitter chip senses that connection and knowing what button we pressed produces a code-line signal specific to that button. The code of bits is modulated with the certain frequency, usually 36 kHz - 40 kHz oscillating signal and the resulting pulses of oscillating signal are amplified through transistors and sent them to the LED, which translates the signal into infrared light and makes it flicker in bursts corresponding to the bits. That frequency oscillation is added to make sure the receiving appliance is not confused by other lights flashing ON and OFF around the home. The receiver can receive the light, filter out the signals that do not include that certain frequency oscillation, and then demodulate the signal to capture the bits from the same frequency modulated signal.

In general, the remote controls use 36 kHz – 40 kHz frequencies to transmit information. Infrared light emitted by IR diodes is pulsated at 36 thousand times per second, when transmitting logic level "1" and silence for "0".

To generate a 36 kHz pulsating infrared is quite easy, more difficult is to receive and identify this frequency. Therefore, most of the times, infrared receivers contain the filters, decoding circuits and the output shaper, that delivers a square wave, meaning the existence or not of the 36 kHz incoming pulsating infrared [7]. This actually means, that an output pin goes high (+5V) when there is a pulsating 36 kHz infrared in front of it, and zero volts when there is not this radiation. A square wave of approximately 27uS (microseconds) injected at the base of a transistor can drive an infrared LED to transmit this pulsating light wave. Upon its presence, the receiver will switch its output to high level (+5V).

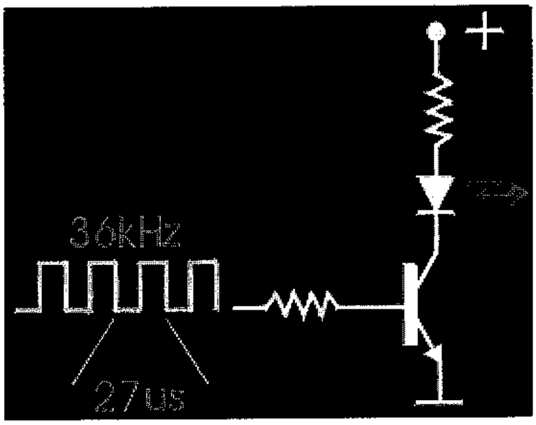


Figure 2.2: *Example of signal translation into IR light*

If we can turn ON and OFF this frequency at the transmitter, the receiver's output will indicate when the transmitter is ON or OFF.

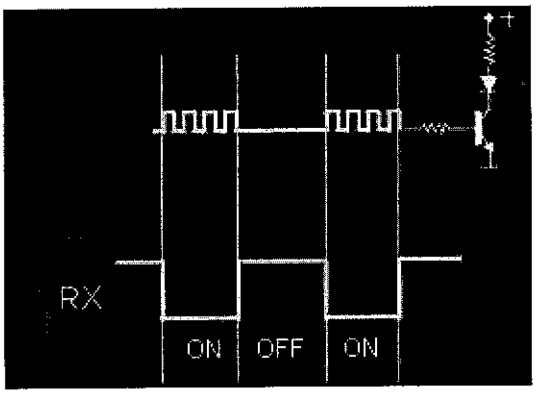


Figure 2.3: *Indication of IR receiver*

Those IR demodulators have inverted logic at its output. When a burst of IR is sensed, it drives its output to low level, meaning logic level = 1.

A universal IR remote control works on the same principle that a normal remote control, on a limited number of codes. The only advantage is that it combines multiple remotes into one to make our life easier.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 General idea of project

A universal infrared remote control that is designed in this project has an ability to combine multiple remotes into one, with some sort of input buttons indicating which device the remote is currently controlling. The main concentration is given on an IR transmitter and receiver, which are required to be as a working prototypes and implemented on a Printed Circuit Boards (PCB). Besides that, to meet the project's complete objectives and expectations there should also be a working program command, which is the code of instructions for remote control transmitter from computer to perform the control operation of its target appliances. The instruction command should be programmed using Microsoft Visual Basic.

A general idea of infrared remote controls is that they usually consist of encoder/decoder parts connected to a transmitter/receiver module, which takes care of the transmission of digital signals by infrared waves. The transmitter has a varying number of buttons and sends the states of these inputs to the receiver. The receiver device decodes the message and sets the outputs accordingly. The information about which key is pressed is encoded and sent. We can press at most one key at a time on the encoder, and only the code for the pressed key is sent to the decoder. This is an efficient method for general remote controls.

Figure 3.1 describes a universal infrared remote control system block diagram, where the signal transmission is clearly shown. In this figure, the input buttons represent function keys and the output appliances match to the input buttons. The signal is being transmitted when any of the input buttons is pressed, and then the appliance responds according to that particular input button. The system uses encoder integrated circuit that is located at the transmitter part and Peripheral Interface Controller (PIC) microcontroller at the receiver. Every signal code transmitted by remote control has to be known and PIC must be programmed before using it in the actual circuit. PIC is pre-programmed to generate 38 kHz carrier frequency by simply pulsing from logic "1" to logic "0" at a rate of approximately 38,000 cycles per second, hence 38 kHz [8]. In general, an encoder IC can be replaced by PIC microcontroller at the transmitter, whereas PIC microcontroller can be also replaced by decoder IC at the receiver.

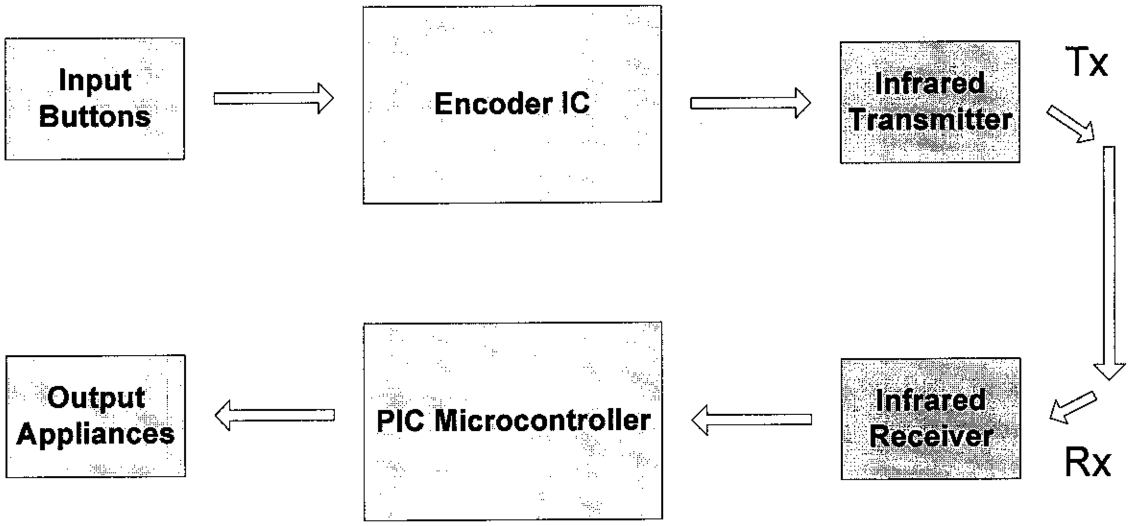


Figure 3.1: System block diagram.

3.2 Software Required

In order to work with the project, there will be several engineering software tools required. These tools are PIC C Compiler and WARP 13, Windows Hyper Terminal and PC Remote Control. The basic functions of required softwares are described below:

PIC C Compiler

PIC C Compiler is software that is used to write the PIC program using C language (see Figure 3.2). When program is written, it should include the header file of the PIC that is being used, its configuration bits, clock speed, which is the oscillator value (e.g. 10MHz), defined inputs and outputs and the main () function. After, when all these requirements are initialized and the program is completely written, it is compiled to generate the HEX file. If the program is written incorrectly or there is an error in the program, PIC C Compiler identifies the error and highlights it in red at the bottom of window [9].

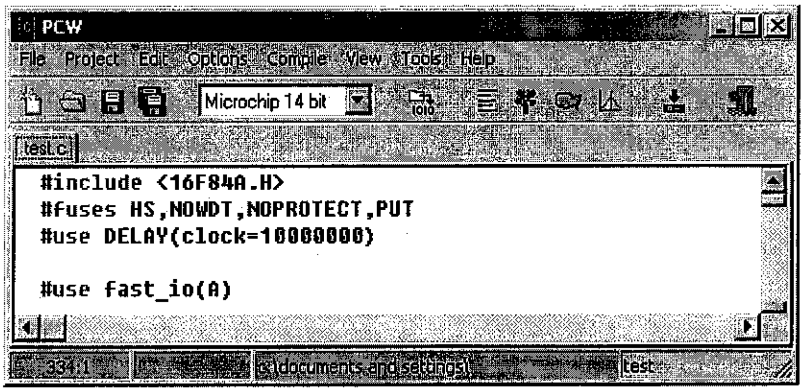


Figure 3.2 PIC C Compiler window

WARP 13

The written C language program is compiled to generate the HEX file/code, which is then used to burn into the PIC microcontroller using chip burner software WARP 13 [10]. Before burning any particular program into microcontroller, PIC device has to be identified (e.g. PIC16F84A) and its EEPROM should be erased and left as an empty blank. After, the new program is written into the PIC memory (see Figure 3.3).

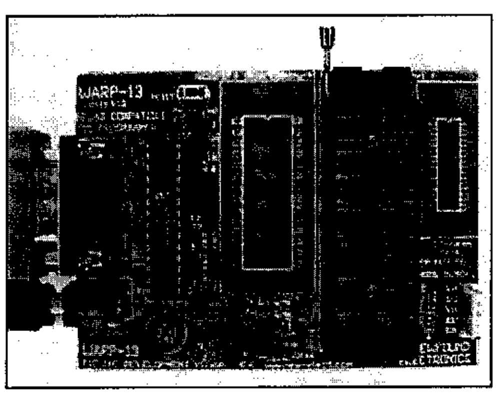


Figure 3.3: WARP13 PIC program burner

Windows HyperTerminal

In general, Windows HyperTerminal is a program that we can to connect to other computers, Telnet sites, bulletin board systems, online services, and host computers, using modem, a null modem cable or Ethernet connection [11]. For this project it is used for other purpose as to check the signal received through serial communication port. The connectivity between infrared receiver circuit and computer allows to read infrared signals transmitted from remote control in ASCII characters form. The HyperTerminal application can be found through the following Windows directive: Start => Programs => Accessories => Communications => HyperTerminal (see Figure 3.4).

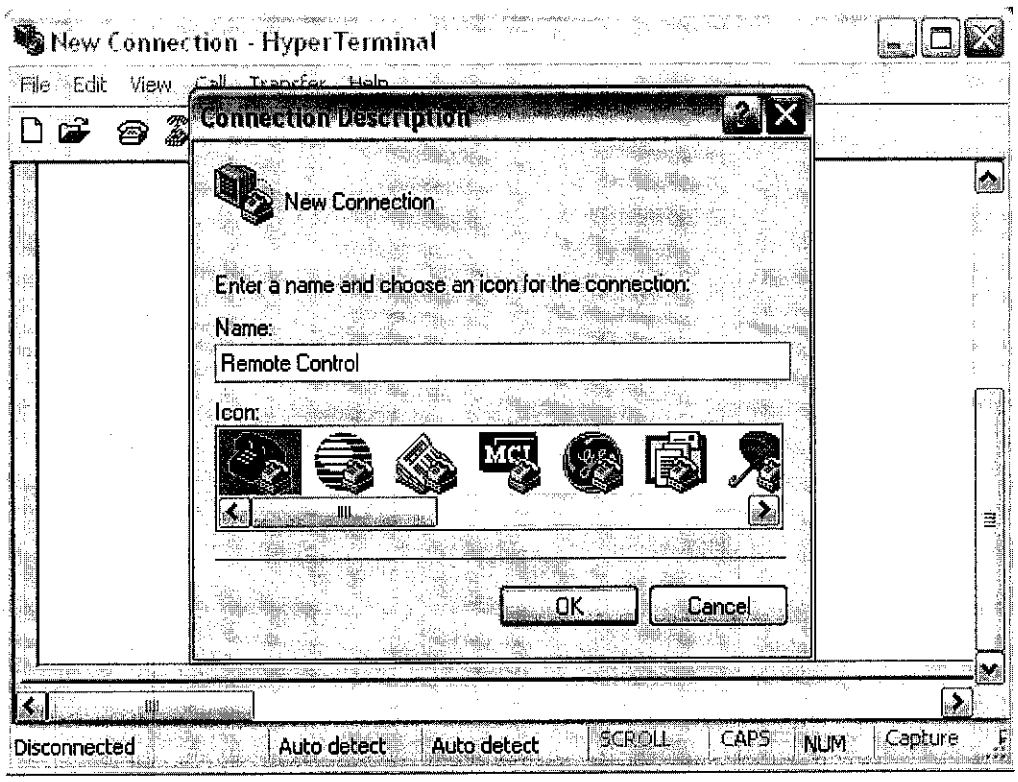


Figure 3.4: Hyper Terminal window

PC Remote Control

PC Remote Control is very useful software that is used to check the ASCII character received through the serial port using its Test Origin feature. Note that the HyperTerminal window can only show the received signals in form of ASCII characters. By using PC Remote Control software it possible to learn the obtained ASCII characters in terms of ASCII codes for the respective number pressed on the remote control (see Figure 3.5). These data are important in defining the conditions to execute the further applications [12].

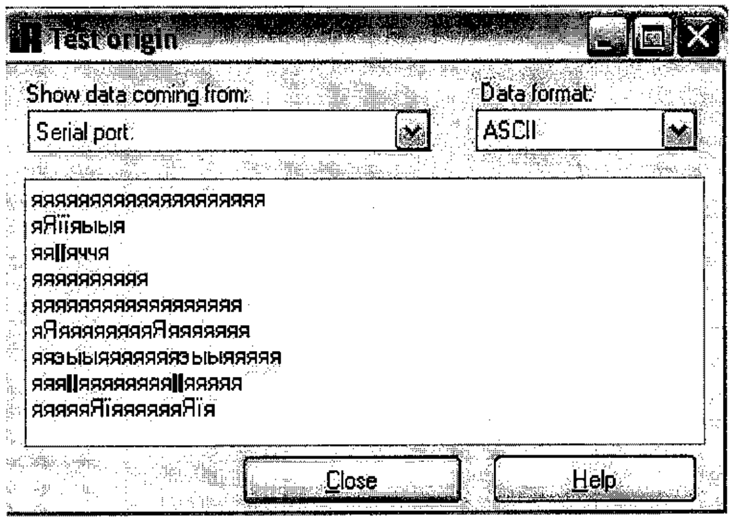


Figure 3.5: Test Origin window for PC Remote Control

3.3 Infrared remote control with a single-channel receiver

Besides research and analysis, during the Final Year Project I semester the idea was to work on a single-channel infrared receiver. It was as a mini-project to clearly understand the transmission and reception of infrared signals. The suitable circuit design was obtained from the early researches and implemented on the breadboard. An infrared receiver circuit (see Figure 3.6) was tested in Electrical & Electronics Laboratory by using a pre-programmed universal infrared remote control as a transmitter. The appliance to be controlled by the remote controller was a desktop lamp that works through 240 Volts AC. The more detailed description of an infrared receiver circuit and its implementation are as follow:

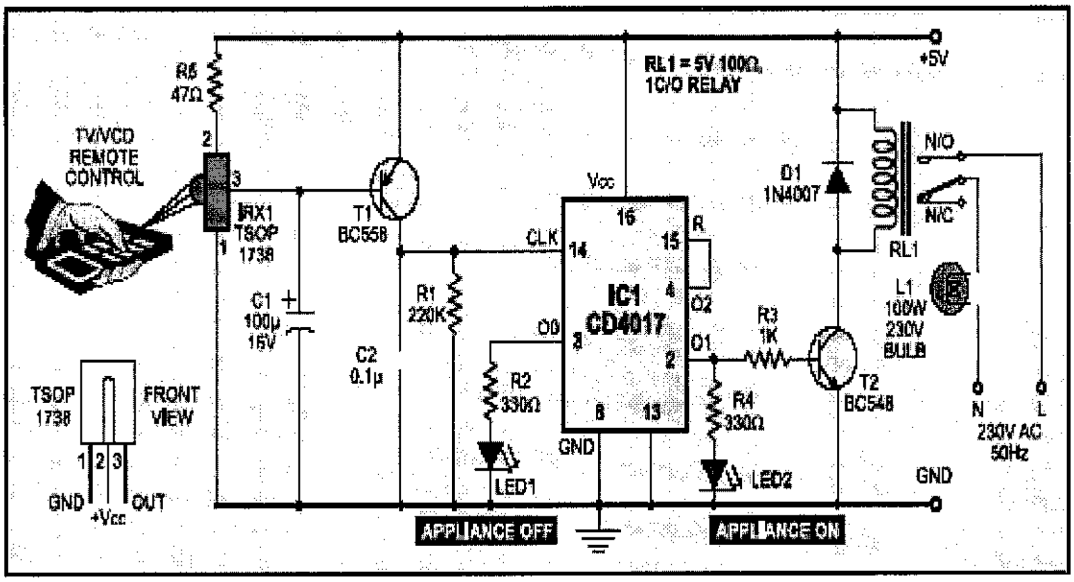


Figure 3.6: Single-channel infrared receiver circuit

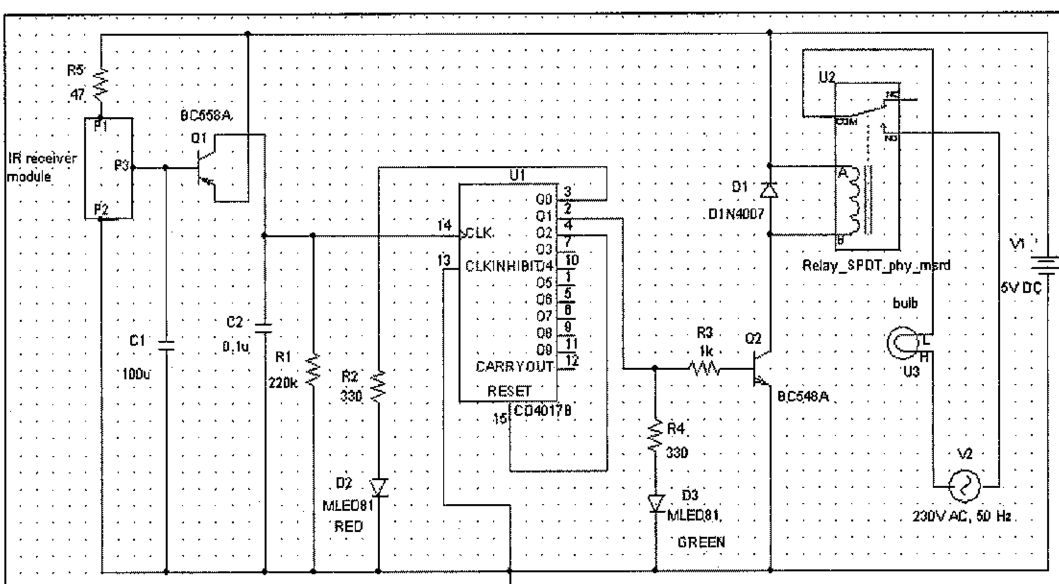


Figure 3.7: Pspice schematic of a single-channel infrared receiver circuit

<u>Required components used for circuit's implementation:</u>

- Breadboard
- 5 Resistors (R1 = 220 kOhms, R2 = 330 Ohms, R3 = 1kOhm, R4 = 330 kOhms and R5 = 47 Ohms)

- 2 Capacitors (C1 = 100 microF, 16V and C2 = 0.1 microF)
- Diode (1N4007)
- 2 LED's (Green & Red)
- 2 Transistors (BC558 PNP and BC548 NPN)
- Counter (CD4017)
- IR receiver module (TSOP 1738)
- Relay (5V, 100 Ohm)
- Appliance to be controlled (i.e.lamp)

Figure 3.6 and Figure 3.7 show the circuitry of an infrared receiver. The circuit works as follow:

Once it has been assembled, it can be connected to any of the home appliances (lamp, fan, radio, etc) to make the appliance turn on/off from a TV/VCD or Universal remote controls. The activation range for the circuit can be for up to 15 meters. The frequency value for the experiment is the most common used in infrared remote control systems, which is 38 kHz. Therefore, the 38 kHz infrared rays generated by the remote control are received by IR receiver module TSOP1738 of the circuit. An IR receiver module TSOP1738 contains 3 pins, where Pin 1 is connected to the ground; pin 2 to the power supply Vcc (+5V) through resistor R5 and the output is taken from pin 3. The output signal is amplified by transistor T1 (BC558) and fed to clock (pin 14) of decade counter IC CD4017 (IC1). Pin 8 of IC1 is grounded, pin 16 is connected to Vcc (+5V) and pin 3 is connected to LED1 (red), which glows to indicate that the appliance is '**off.**' The output of IC1 is taken from its pin 2 and connected to LED2 (green), which is used to indicate the '**on**' state of the appliance. Transistor T2 (BC548) connected to pin 2 of IC1 drives relay RL1. Diode 1N4007 (D1) acts as a freewheeling diode. The appliance to be controlled is connected between the poles of the relay and neutral terminal of mains. It gets connected to live terminal of AC mains via normally opened (N/O) contact when the relay energizes.

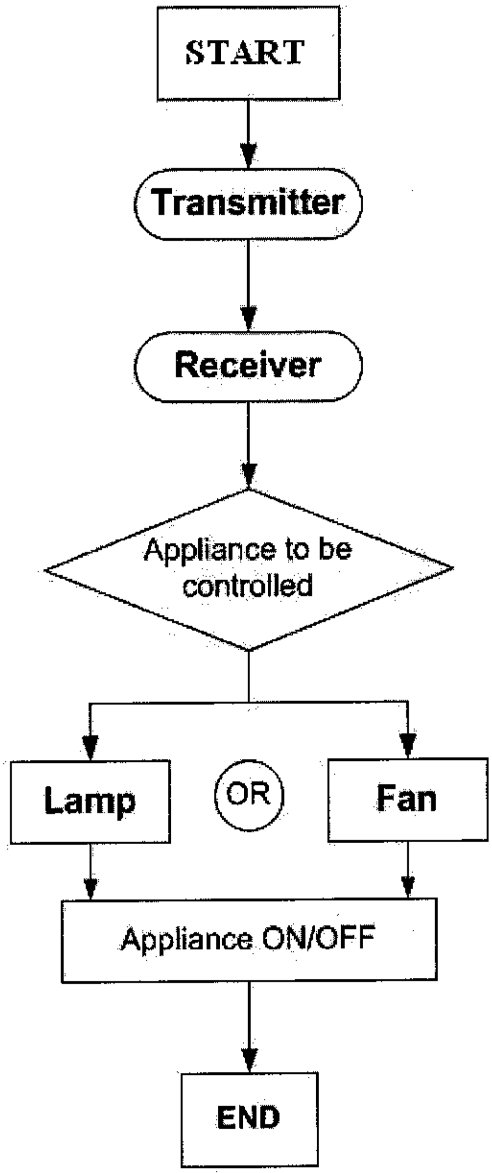
The reason to work on this task was to understand and practically see how an infrared system works. A lamp was connected to the receiver circuit to perform ON and OFF operations and used as an appliance to be controlled by a universal remote control, which is a transmitter with a sending frequency value of 38 kHz that is capable with infrared receiver module. Experimental results have been positively obtained.

3.4 Universal infrared remote control with multi-channel receiver

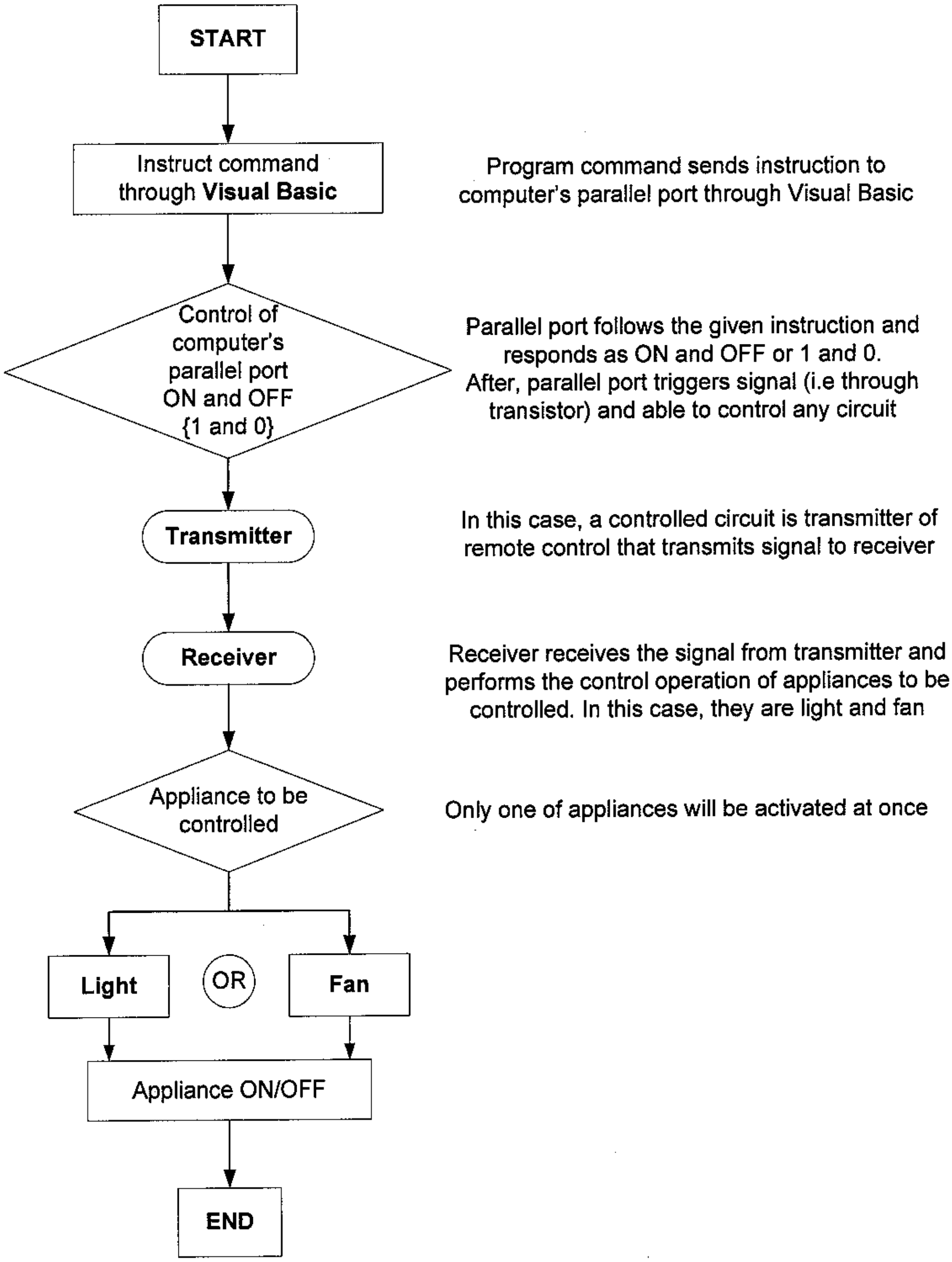
For FYP II semester, the plan was to design the whole infrared system. The idea to continue working on this project was to come up with new transmitter and receiver circuits that have abilities to control multiple appliances. As it was mentioned previously, in this project the control aim is on two appliances that are fan and lamp.

Before starting the procedure, all the gathered information were analyzed. The block diagram (see Figure 3.1) shows how the system looks like. A remote control with several buttons was used as a transmitter, whereas a device with corresponding outputs was used as a receiver.

The following diagrams are the flow charts of the project activities. Flow chart 1 describes the general application of the project, whereas Flow chart 2 shows the additional commands using Microsoft Visual Basic and circuit connection from computer's parallel port to the remote control transmitter.


START
Transmitter
Receiver
Appliance to be controlled
Lamp
OR
Fan
Appliance ON/OFF
END

Flow chart 1


START
Instruct command through **Visual Basic**
Program command sends instruction to computer's parallel port through Visual Basic
Control of computer's parallel port ON and OFF {1 and 0}
Parallel port follows the given instruction and responds as ON and OFF or 1 and 0. After, parallel port triggers signal (i.e through transistor) and able to control any circuit
Transmitter
In this case, a controlled circuit is transmitter of remote control that transmits signal to receiver
Receiver
Receiver receives the signal from transmitter and performs the control operation of appliances to be controlled. In this case, they are light and fan
Appliance to be controlled
Only one of appliances will be activated at once
Light
OR
Fan
Appliance ON/OFF
END

Flow chart 2

A universal infrared remote control transmitter circuit that is used in this project (see Figure 3.11) has the increased number of inputs and it is able to activate the outputs related to those inputs. Together with multi-channel infrared receiver and/or even with single-channel receiver this infrared transmitter can be used to remotely operate our home appliances. The transmitter contains 15 independent inputs and has a carrier wave frequency of 38 kHz, which is the same for almost all infrared remote controls. For the project, only two inputs and outputs are taken into consideration and used to show the communication of the universal infrared remote control with its receiver (see Figure 3.8). As for the remaining channels, normal LEDs are used on the output to indicate the activation. The receiver (see Figure 3.12 for its circuitry) has 15 independent outputs, each of which can operate separately.

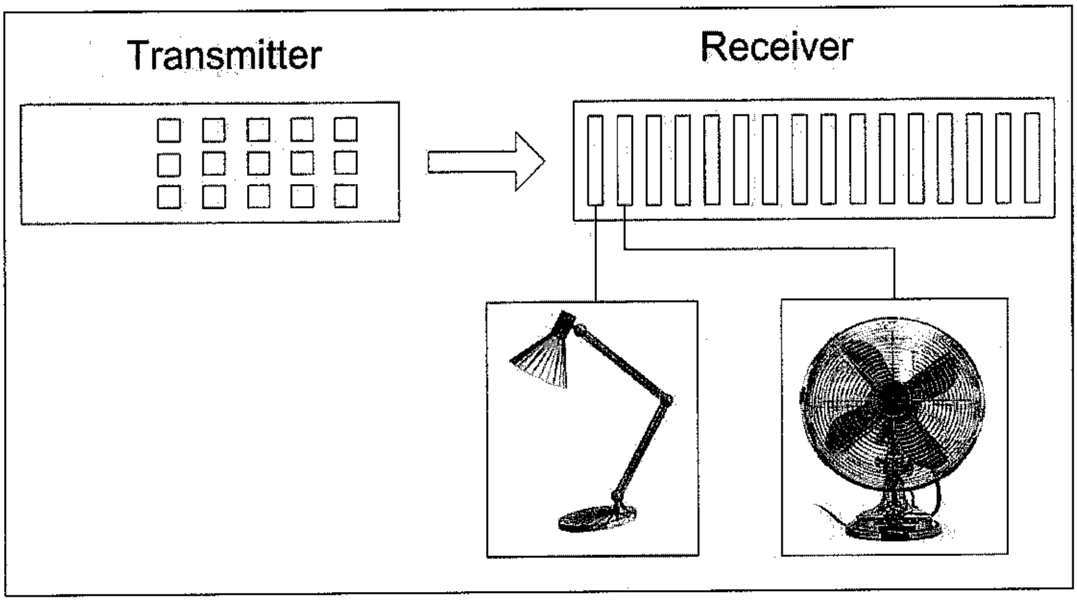
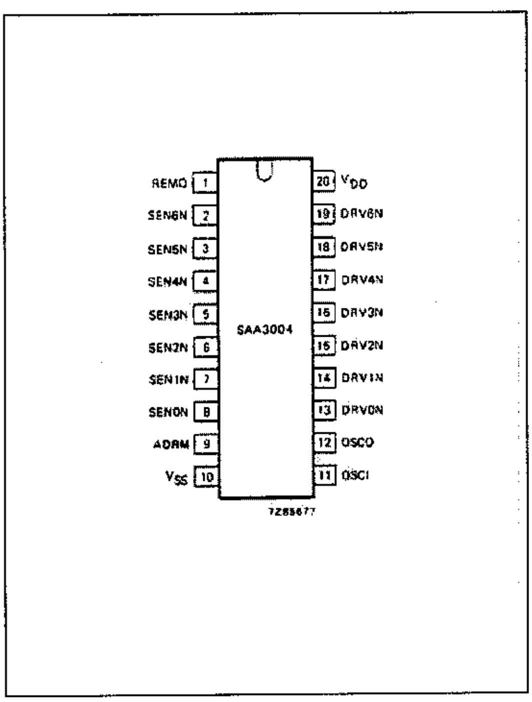


Figure 3.8: *Universal infrared remote control system*

The required components are listed on Appendices (see Appendix A and Appendix B). As it is seen in Figure 3.11, the main device that drives the circuit is IC1. It is a transmitter integrated circuit (SAA3004) designed and used for infrared remote control systems. It has a total of 448 commands which are divided into 7 sub-system groups with 64 commands each. The sub-system code may be selected by a press button, a slider switch or hard wired. The SAA3004 IC generates the pattern for driving the output stage. These patterns are pulse distance coded. The pulses are infrared flashes or modulated pulses. The transmission mode is defined in conjunction with the sub-system address. Modulated pulses allow receivers with narrow-band preamplifiers for improved noise rejection to be used. Flashed pulses require a wide-band preamplifier within the receiver. This chip drives IR LEDs at a 38 kHz modulated output. A standard 455 kHz ceramic resonator, attached across the oscillator input/output pins (pins 11 and 12) of the IC, sets the frequency. The external components must be connected to these pins when using an oscillator with an external resonator. The connections from D3 to D7 are the identification transmitter diodes. As it was mentioned previously, a remote control transmitter can operate for both multi-channel and single-channel receivers. Since in this project, the design requires multi-channel operations, by connecting D4 diode to the circuit we provide the identification of the receiver type for transmitter. LD1 is a red LED that indicates whether remote control is on or off and LD2,3,4 are the infrared LEDs that are used to transmit the signal to receiver. When a key is pressed, a generated signal is amplified and driven by transistors T1 and T2. The supply DC voltage to the circuit is 9 Volts and can be placed by 9V battery.



PINNING

1	REMO	remote data output
2	SEN6N	
3	SEN5N	
4	SEN4N	
5	SEN3N	key matrix sense inputs
6	SEN2N	
7	SEN1N	
8	SEN0N	
9	ADRM	address mode control input
10	V_{SS}	ground
11	OSCI	oscillator input
12	OSCO	oscillator output
13	DRV0N	
14	DRV1N	
15	DRV2N	
16	DRV3N	key matrix drive outputs
17	DRV4N	
18	DRV5N	
19	DRV6N	
20	V_{DD}	positive supply

***Figure 3.9:** Pin diagram for SAA3004*

At the receiver circuit (see Figure 3.12), PIC16C55-XT/P (IC1) is used as a main IC device. It is programmed in order to be able to communicate together with the transmitter IC. Same as for transmitter, it has 15 channels/outputs that are decoded according to the encoded input signals.

Only two of the outputs are used to operate with appliances, as for the rest of the outputs, normal LEDs are placed to indicate the activation.

3.5 What is PIC?

PIC is a name for the microchip microcontroller family, consisting of microprocessor, I/O ports, timer(s) and other internal, integrated hardware. The main advantages of using the PIC are low external part count and wide range of chip sizes (number of pins). Its program memory is initially empty, and needs to be programmed with code to be usable in a circuit [13]. There are three most common ways can be used to program the PIC microcontroller, either using the assembly language, PIC Basic or C language. The assembly language and PIC Basic are considered to be quite messy and complicated to be used in programming. Furthermore, it may take much more time to understand the deliverables of the built-in functions of assembly language compared to C. C language is more straightforward and takes shorter time to be understood. C compiler is made by the third parties to provide viability to the programmer in coding the PICs. If some errors occur while programming, it has a compiler that can define the errors that are occurred. The basic knowledge on C syntax, its built-in functions and pre-processor are essential in pursuing the project to program the microcontroller.

3.6 PIC16C55-XT/P Microcontroller

The PIC16C55XT/P is chosen as the microcontroller to control the infrared receiver operations due to the number of I/O pins available for the entire microcontrollers analyzed. Figure 3.10 shows the pins configuration of the PIC16C55XT/P utilized in the project

Pin Descriptions

PIC16C55XT has a total of 28 pins. Individual I/O pins are programmable as inputs or outputs.

- Sink current: 25 mA per pin, 50 mA per port
- Source current: 20 mA per pin, 40 mA per port

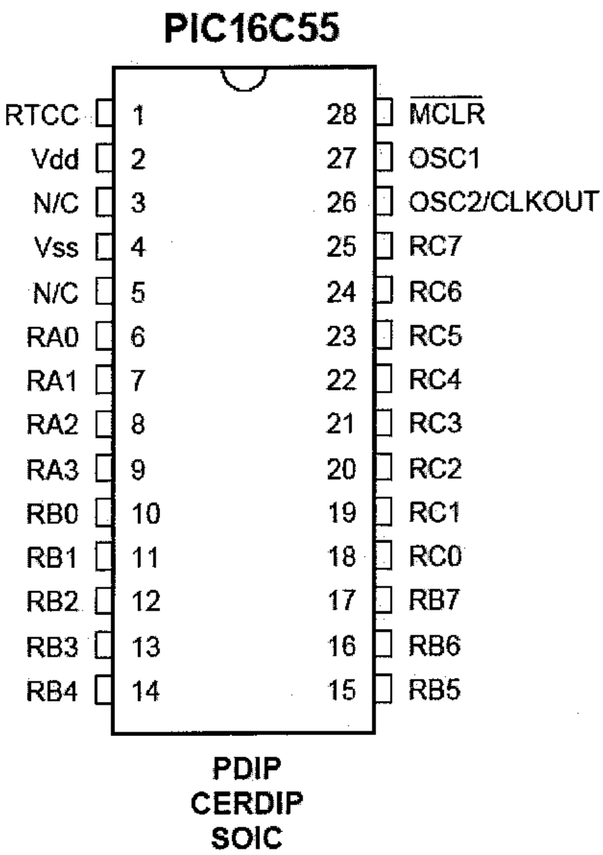


Figure 3.10: *Pin diagram for PIC16C55XT/P*

Pin	Function
RA0 - RA3	I/O Port A
RB0 - RB7	I/O Port B
RC0 - RC7	I/O Port C (only on 28-pin PIC's)
RTCC	Real-time clock/counter input
MCLR	Master clear (reset)
OSC1	Oscillator input
OSC2/CLKOUT	Oscillator output (OSC/4)
Vdd	Power supply
Vss	Ground
N/C	No connection

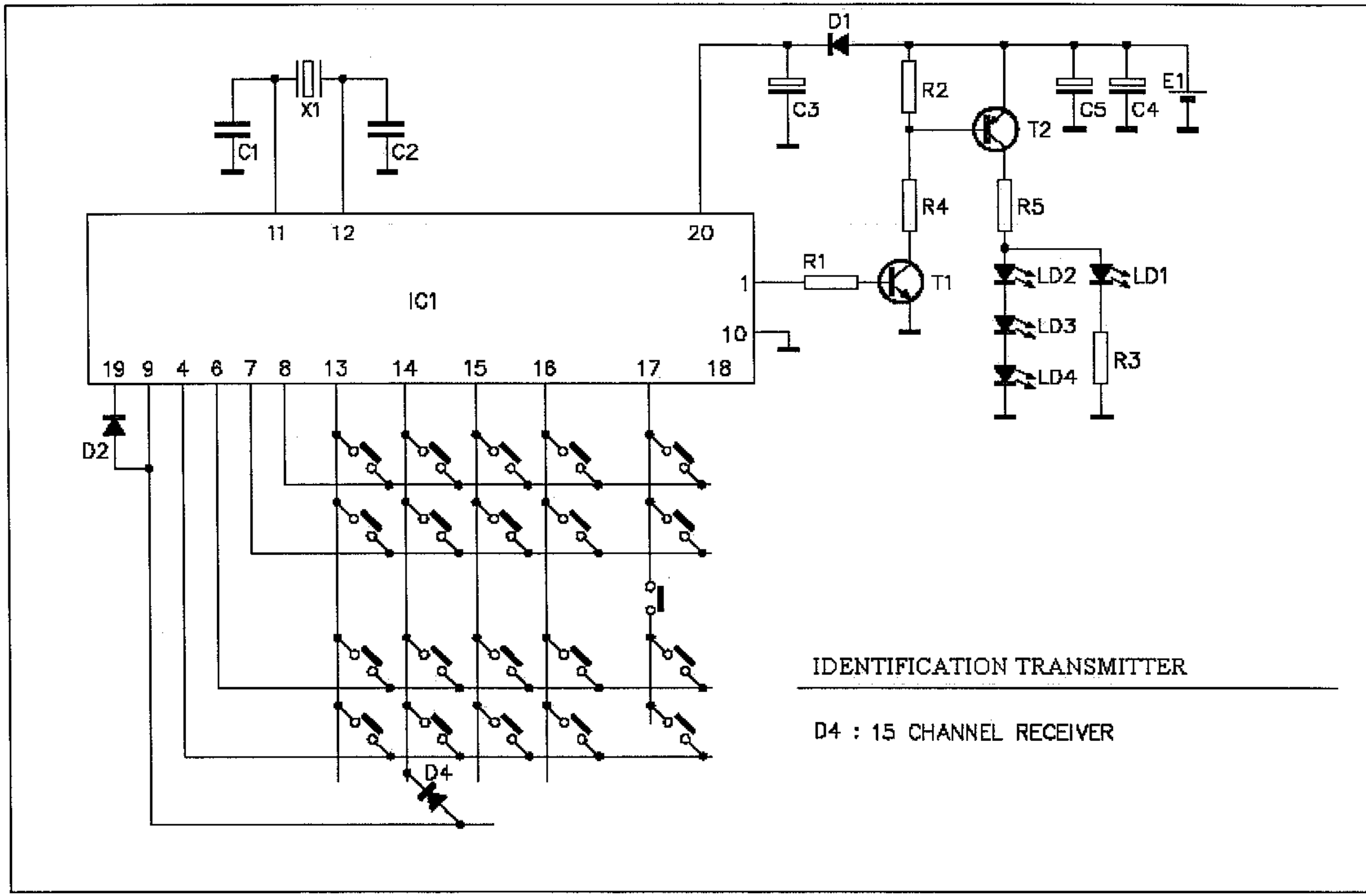


Figure 3.11: *Universal infrared remote control transmitter circuit*

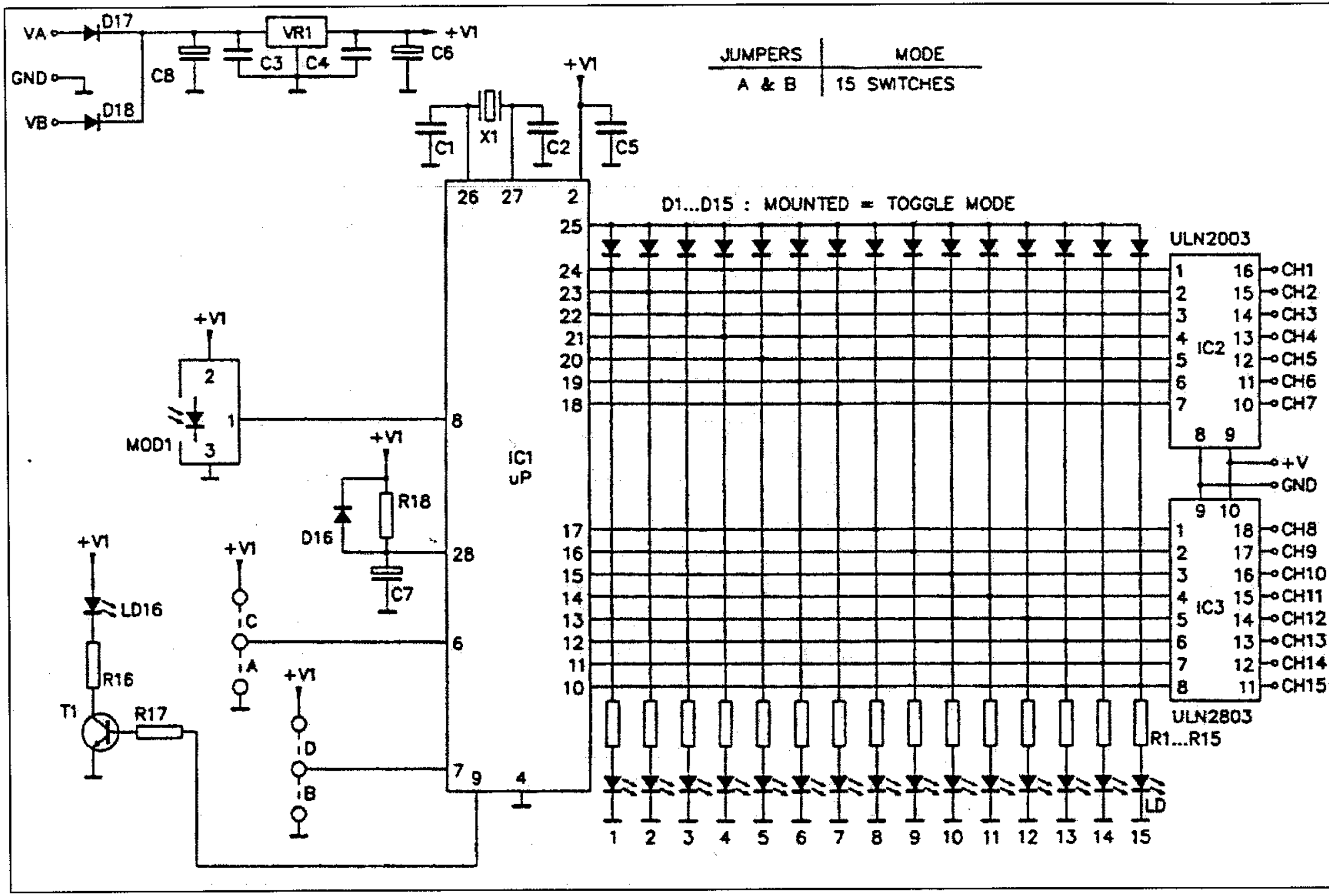


Figure 3.12: Multi-channel infrared receiver circuit

Normally, a universal infrared remote controls are the lesser expensive, and as one of their disadvantage is that they have some drawbacks. In order to avoid the drawbacks of these devices, while working on this project the two criteria must be followed and kept in mind. First, the establishing of communication between the control and any target appliance must be based on a single mechanism and does not require a user to memorize any address or code. Second, the resulting hardware must be as simple as possible to avoid any complicated operations.

In general, for any appliance to be remotely controlled, the code must be known. Therefore, a special identification process is needed to establish a temporary communication link. With this process, the remote control can specify the controlled appliance for subsequent operation. Assigning to each appliance a unique identity code on the receiver fulfills the identification.

The identification process starts with sending out an identity code by the remote control, and if the identity code received by appliance matches, only then it responds. After that, it signals back the remote control immediately before the remote control sends out the next identity code. Once a temporary communication link is accomplished, an appliance alone will interpret further commands from the remote control [21]. Sometimes, it might not be clearly seen that the signal has been received and appliance starts to function immediately. Therefore, to achieve the signal-back and clearly indicate the reception to the user, two LED's (red for OFF state and green for ON state) are added to the receiver hardware. As soon as an identity code is received, the right LED will be on to indicate the performance of an appliance. If it is seen that green LED is ON, then the user stops the remote control from transmitting further identity codes at once. Such an action also indicates to the remote control which appliance it is supposed to control. In Figure 3.13, the summary of linking procedure is described with three advantages. First of all, a single remote control is able to control many appliances. Next, although each appliance is assigned a unique identity code, the code is transparent to users. And finally, since only a unidirectional link is required, involving human action in returning signal reduces the hardware requirement. These advantages will result a convenient size, easy to use and cheap to implement universal remote control system.

Start

↓

Sending an identity code by pressing a button on transmitter

↓

Appliance receives its identity code through receiver

↓

Signal back

↓

Link established

↓

Stop

***Figure 3.13:** Summary of linking procedure*

The identification process works only when the time-lapse between sending two identity codes is long enough for the user to respond. For instance, if the appliance receives another identity code, the communication link will be dropped. It can be also dropped after a time-out period. The ability of remote control to establish communication link with another appliance without worrying that previously established communication link still exists actually requires a time-out period. The time-lapse period can be as short as less than a second. Furthermore, the time-out of about half a minute should be enough to be accepted.

If the system of linking procedure fails to work, the implementation of hardware must be properly checked and some other troubleshooting techniques related to the project must be used.

3.7 Parallel port

In computers, ports are used mainly for two reasons: device control and communication. We can program PC's parallel ports for both. Parallel ports are mainly meant for connecting the printer to the PC, but we can program this port for many more applications beyond that. Parallel ports are easy to program and faster compared to the serial ports [14]. But main disadvantage is it needs more number of transmission lines. Because of this reason parallel ports are not used in long distance communications. PC parallel port can be very useful I/O channel for connecting our own circuits and to perform some very amusing hardware interfacing experiments, as in this project to control appliances from computer using infrared waves as a signal transmission.

PC parallel port is 25 pins D-shaped female connector at the back of the computer. Not all 25 pins are needed always. Usually we can easily do with only 8 output pins (data lines) and signal ground. Those output pins are adequate for many purposes. Those data pins are TTL level output pins. This means that they put out ideally 0V when they are in low logic level (0) and +5V when they are in high logic level (1).

Pin functions

2 D0

3 D1

4 D2

5 D3

6 D4

7 D5

8 D6

9 D7

Pins 18,19,20,21,22,23,24 and 25 are all ground pins (see Figure 3.14 and 3.15).

Initially, before connecting the actual circuit to parallel port, we can make simple circuit for driving small LED's through PC parallel port. The only components needed are 8 software controllable LED's and 470 ohm resistors connected in series. The resistors are needed to limit the current taken from parallel port to a value which light up acceptably normal LED's and is still safe value (not overloading the parallel port chip).

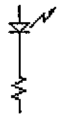


Figure 3.14 shows the connection of LED's to the parallel port, where one end of the LED's goes to data pins and another goes to the ground pins.

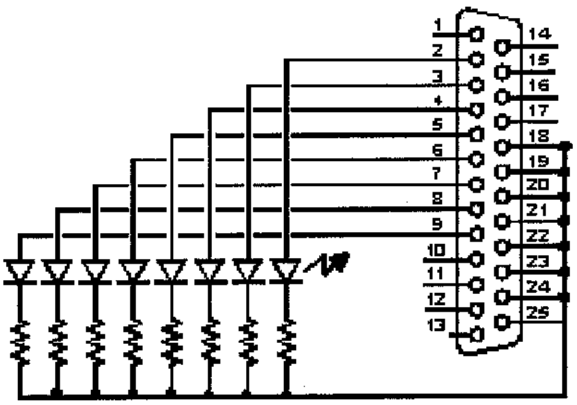


Figure 3.14: Computer parallel port

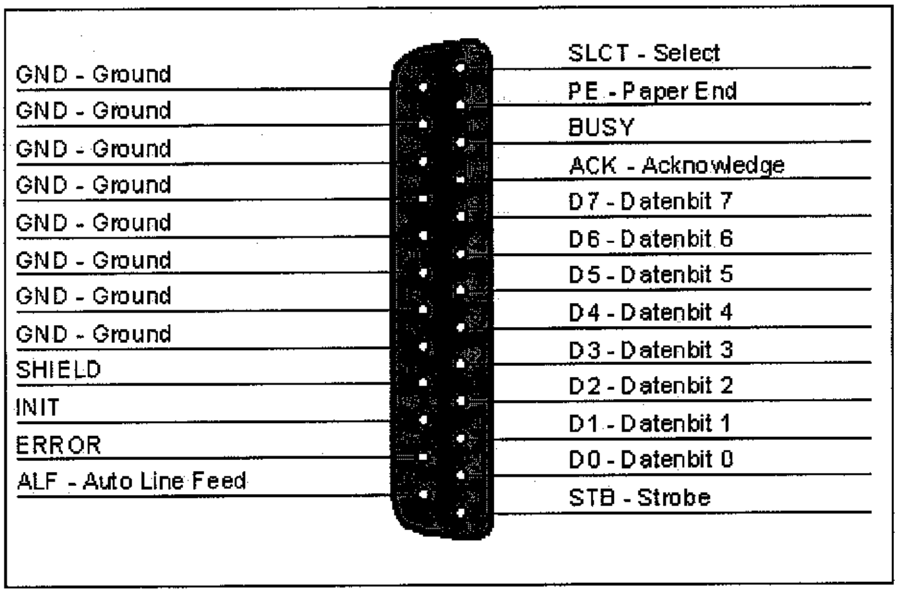


Figure 3.15: Detailed computer parallel port

By using program command code, when high level logic is sent to the data pin where the LED is connected, that LED will light on. When low level logic is sent to that same pin, the LED will no longer light. The command code has to be done through Microsoft Visual Basic software. For the project, only two pins are taken into consideration. The first click of any of these considered two buttons will ON that related appliance and second click on it will make it OFF.

Unfortunately, due to complexity in transmitter circuit, a parallel port can not be connected to transmitter. In order, to make the connection, the project's transmitter has to be redesigned. Because of time constraints this additional objective was not implemented.

CHAPTER 4

RESULTS AND DISCUSSION

The experiment with a single-channel infrared receiver demonstrated in FYP1 semester has shown positive results. Figure 4.1 shows the experimental set-up. By using DC and AC voltages through the circuit implemented on a normal breadboard, it was proven that by universal infrared remote control it is possible to control any of home appliances, by meaning to switch ON and OFF.

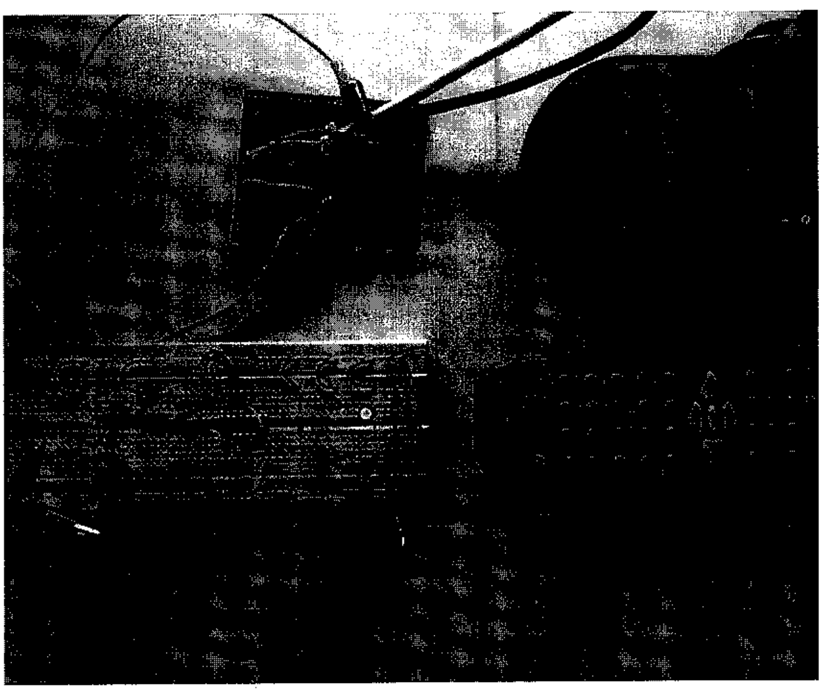


Figure 4.1: Single-channel infrared receiver

4.1 Findings

Before proceeding with the actual project system, it was necessary to decode and list the corresponding codes for each input button on the remote control. To do so, another infrared receiver circuit with the computer serial port connection has been used. Figure 4.2 represents the circuit diagram of the infrared receiver that is uses PIC16F84A microcontroller [20].

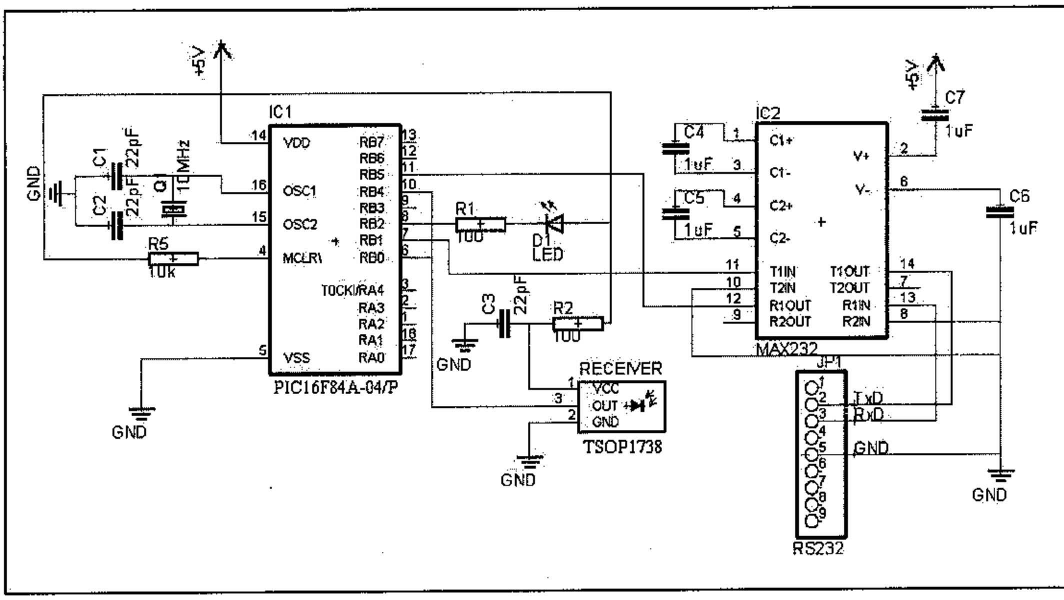


Figure 4.2: Infrared receiver circuit diagram for decoding the signals

Circuit description

An infrared receiver circuit (see Figure 4.2) has helped a lot for decoding and studying the signals that are being transmitted by remote control. The detailed description of circuit is as follow: An infrared receiver module contains three pins, where pin 1 is connected to +5 V power supply thought resistor (R2). This module can generate false IR strings when there is high frequency distortion on the +5V supply. Hence, 22pF capacitor (C3) is connected in between the +5V and ground to filter the noise received. Pin 3 is connected to the ground and pin 2 to pin RB0 of the PIC16F84A microcontroller as an interrupt-on-change input. By using 22pF capacitors (C1 and C2) and oscillator of 10MHz that are connected to the OSC1 and OSC2 pins of the microcontroller; we establish high speed oscillations. A red LED is inversely connected to pin RB2 of the microcontroller through resistor (R1) to indicate when the circuit is powered-up. The following is MAX232, which is used as a level translation IC for serial I/O communication between the receiver circuit and computer. Pin RB1 and RB5 of PIC16F84A are connected to the CMOS input and CMOS output of MAX232. And then, from MAX232, the RS232 output and RS232 input pins are connected to the receive-in and transmit-out pins of 9-pin female connector, respectively. Initially, PIC16F84A was programmed accordingly in order to be able to communicate with computer serial port and send the received data to computer (see Appendix C for PIC coding). The circuit has been implemented on the breadboard (see Figure 4.3) and the communication between infrared receiver circuit and PC serial port has been established.

Figure 4.3: Implementation of infrared receiver circuit

But, actually before constructing the circuit on Figure 4.2, PIC16F84A has been programmed with a simple command just to check that circuit is working. To do that, the circuit was simplified (see Figure 4.4) and only one output LED, which is connected to RB3 was tested. The input was the signal received by infrared receiver module. The programming is quite simple (see Appendix D). When any button on the remote control is pressed, an input RB0 receiver signal and understands it as logic 1(high), and therefore it activates output RB3. When the button is pressed again, the output goes low (logic 0). The implementation of circuit is shown in Figure 4.5.

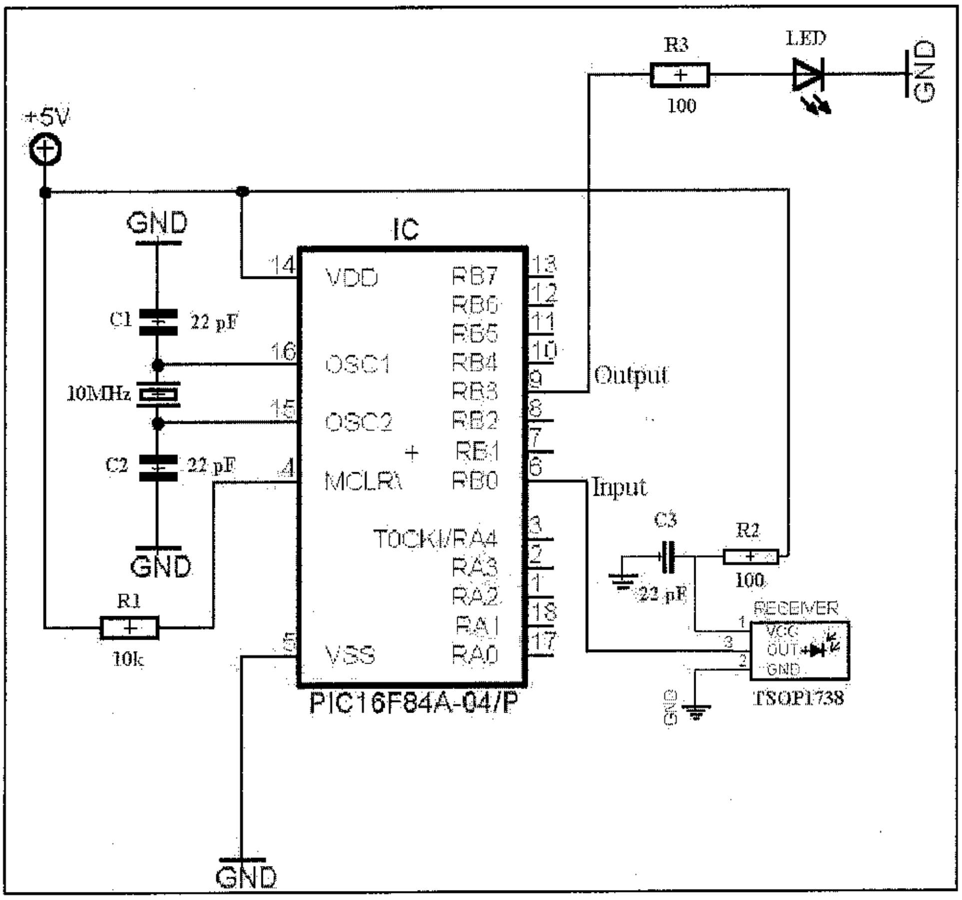


Figure 4.4: Single input-output Infrared receiver circuit

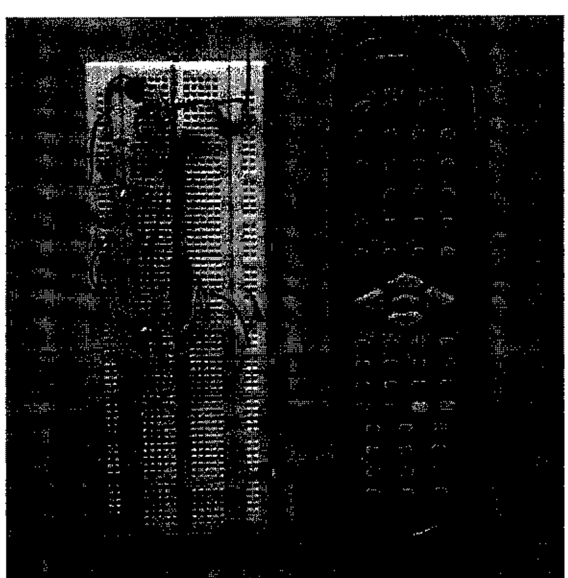


Figure 4.5: Implementation circuit in Figure 4.4

Decoding the signals

An infrared receiver circuit has been implemented on the bread board, and the next step was to decode and study the received signals. As for transmitter, an available universal infrared remote control (Model 'AV10') has been used. In order to check the signal received through serial communication port, the Hyper Terminal program has been used (the location of program: Start => Programs => Accessories => Communications => HyperTerminal). If there is connectivity between receiver circuit and computer, the signal received at the infrared receiver can be read in ASCII code at the Hyper Terminal window. The ASCII code for each input button of remote control has been viewed (see Figure 4.6).

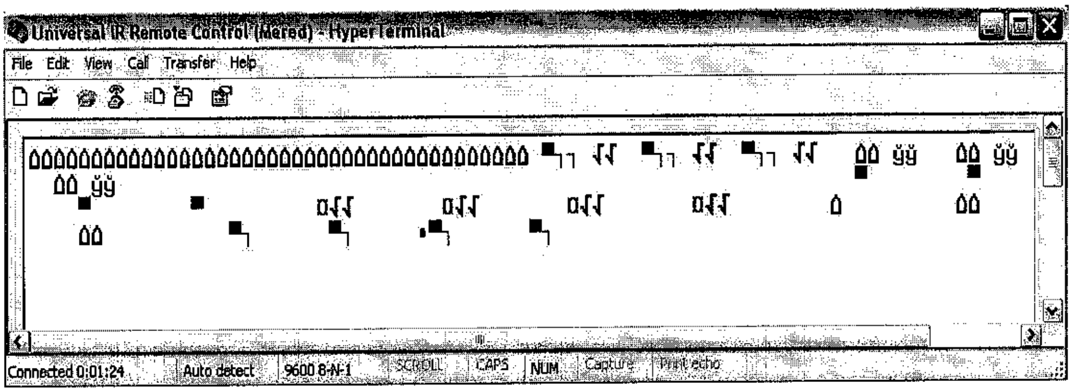


Figure 4.6: HyperTerminal Window

By looking at the long strings of characters received and being displayed on the HyperTerminal Window, it was difficult to recognize the signal. Therefore, as solution, PC remote control software was used to clearly see the ASCII character received through the serial port using its Test Origin feature. The signals obtained for the respective input numbers pressed on the remote control were translated into three data formats: ASCII, decimal and hexadecimal (see Figures 4.7, 4.8 and 4.9).

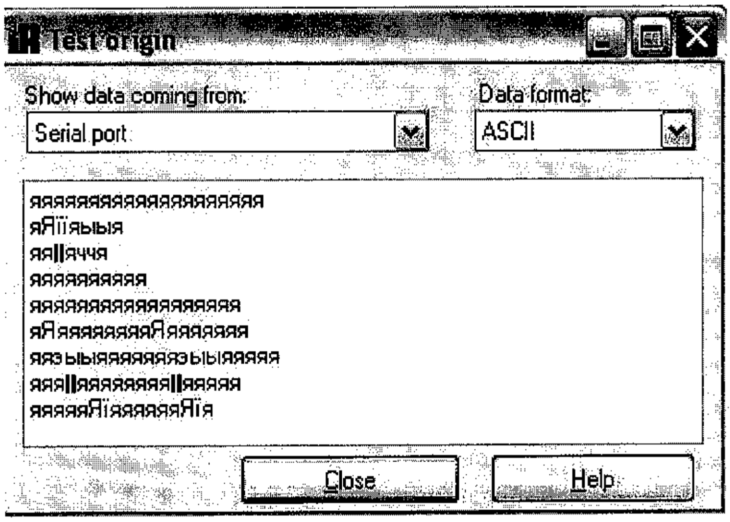


Figure 4.7: Reading ASCII characters for remote control buttons

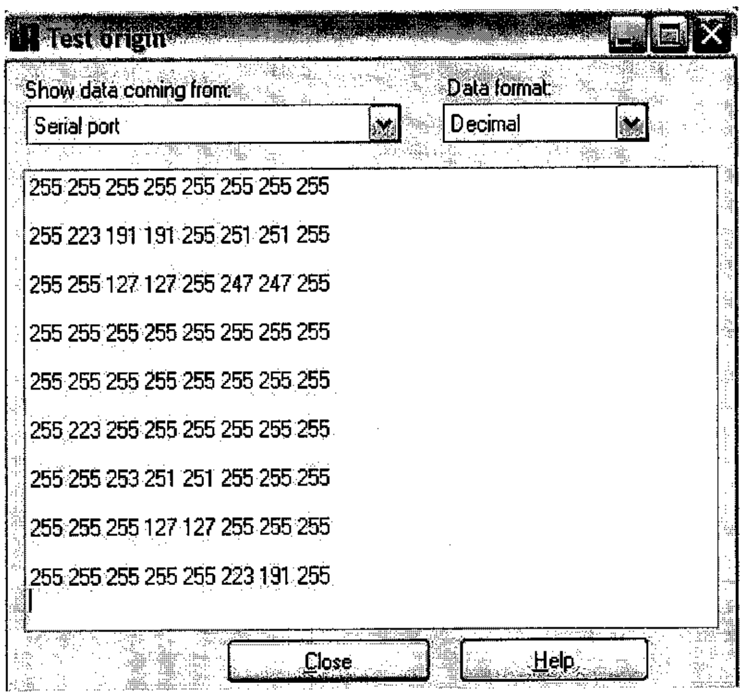


Figure 4.8: Reading decimal values for remote control buttons

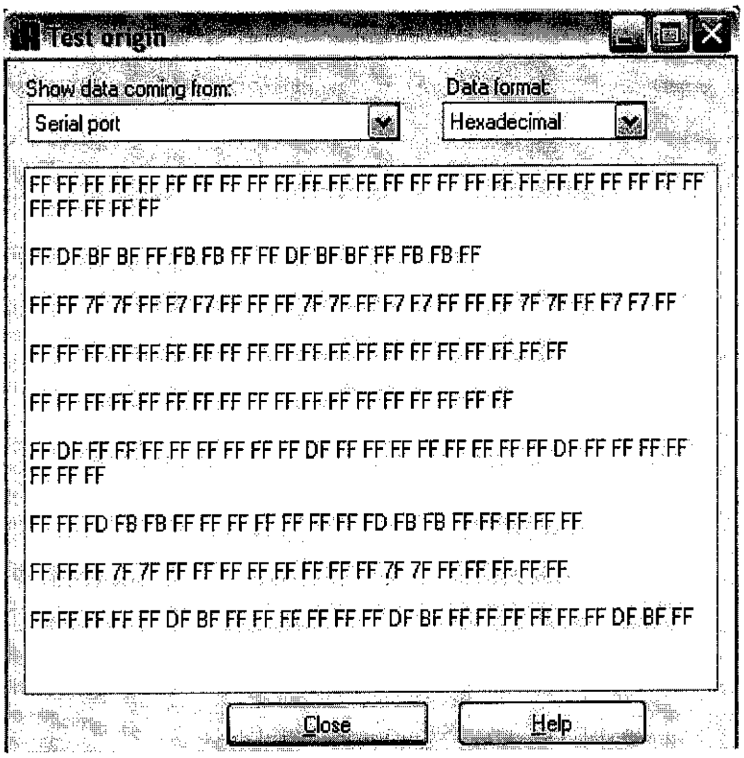


Figure 4.9: Reading hexadecimal values for remote control buttons

The signal codes for each button were obtained as a repetition of strings. The repetition of strings depends on how often and for how long the specific button has been pressed. Therefore, to define the difference between the signal codes of remote control buttons, a single string is enough (see Figure 4.8).

Once the signal codes for each button of remote control are retrieved, they can be used for further applications. One of these applications is to design the Graphical User Interface using Visual Basic and control the Windows applications (e.g. Windows Media player, Winamp, Microsoft Office). The application covers the capability of the receiver to receiver the signals sent from remote control, transmit them to the PC through serial port communication and lastly the interfacing software should start an application if the received ASCII characters match any of the defined characters. Another application is to control the multiple outputs of the receiver. In this case, PIC microcontroller has to be reprogrammed according to the number outputs that has to be controlled. While writing the programming by, for example, C language, any of the data formats (ASCII, decimal, or hexadecimal) can be used. In program these data formats have to be defined as single string.

A universal IR remote control works on the principle that almost all remote control devices work, on a limited number of codes. There may be numerous televisions, stereo and other manufacturers in the world, but they all use the same handful of frequencies and programming codes. By identifying and listing the codes used by individual manufacturers, a universal remote control can duplicate the functions of the original remote. Consumers simply find their make and model of electronic device in the coding list, and then use the universal remote control's function keys to enter the necessary information. Different universal remote control models control different electronic devices, so consumers should choose accordingly. Some models only replace one system, such as television, while others can control almost every electronic or electrical device. If a universal remote control operates more than one system, keypad controls for separate devices should be present. A function key for each system should be depressed first to let the remote know which device to control.

Figure 4.10 shows the set-up of universal infrared remote control system. In these transmitter and receiver models, a total of fifteen inputs and related outputs are specified as communication objects. Both transmitter and receiver boards use 9 VDC supply. The lamp is connected through the relay board to output pin number 1 on the receiver. The transmission range is about 30 meters long.

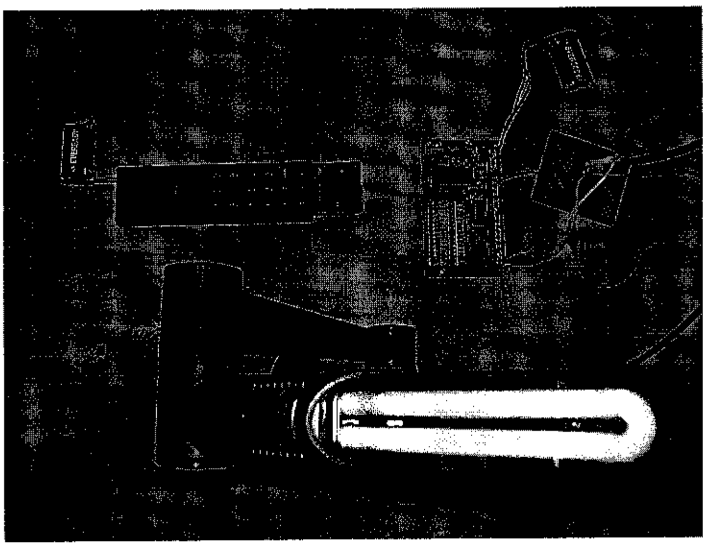


Figure 4.10: Set-up of multi-channel infrared remote control system

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project presents how a universal infrared remote control design is carried out. The main idea of the project is to achieve a simple and cost effective universal infrared remote control system and to control the home appliances such as fan and lamp.

A clear definition on the remote control operation has been acknowledged. Several experiments related to infrared remote control system were conducted and the results were noted. The final outcome of the project is user-friendly and can be extended and applied to various applications with additional features.

It is been a great experience to work on this project. The basic knowledge learned during the early years of study in Electrical and Electronics Engineering was reapplied. Besides, new knowledge have been gained in usage of PIC microcontroller in the circuits, C language programming and burning data into PIC microcontroller. An ability to decode the signals transmitted from remote control is a big part of the project. A new knowledge have been extended also in using the decoded signals for Graphical User Interface through Visual Basic and programming PIC microcontroller to control the outputs.

There are several recommendations based on the completion of the project. An infrared remote control system that is designed in this project can be applied to various applications such as controlling the lights and white board in the new lecture halls of Universiti Teknologi PETRONAS by universal infrared remote control, since they are still controlled by manual switches.

Besides, the system can be upgraded with more operations and easily used at home. The receiver model can be used as a central device and placed somewhere in the corner of the room. All the appliances that are intended to be controlled will require additional relay connections with some extra wires, and accurately arranged without causing any damage to the device.

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APPENDICES

Appendix A: Required component for Universal infrared remote control transmitter's implementation

Components	Quantity
R1, 1K8 (brown, grey, red)	1
R2, 1K (brown, black, red)	1
R3, 33 (orange, orange, black)	1
R4, 68 ½ W (blue, grey, black)	1
R5, 1 ½ W (brown, black, gold)	1
D1,D2, D4 1N4148 diode	3
T1, BC547 NPN transistor	1
T2, BC640 PNP transistor	1
Cl, 100pF ceramic capacitor	1
C2, 220pF ceramic capacitor	1
C3, 10uF electrolytic capacitor	1
C4, C5, 470 uF electrolytic capacitor	2
LD1, LD2, LD3, LD4, LED	4
SAA3004 remote control transmitter, IC1	1
455kHz ceramic resonator	1

Appendix B: Required component for multi-channel remote control receiver's implementation

Components	Quantity
R1...R16, 390 (3-9-1-B)	16
R17, R18, 10K (1-0-3-B)	2
D1...D16, 1N4148 diode	16
D17, D18, 1N4000...4007	2
T1, BC547 NPN transistor	1
Cl, C2 18pF	2
C3, C4, C5 100nF (104, 0.1u)	3
C6, C7, 10uF	2
C8, 1000uF	1
LD1...LD16, LED	16
IC1, PIC16C55 XT/P, IR remote control receiver	1
IC2, ULN2003 High Voltage & Current driver, IC2	1
IC3, ULN2803 Octal High Current & Voltage driver	1
MOD1, IR receiver module, carrier 38kHz	1
X1, X-TAL 4.000000 MC - HC-49/U	1
VR1, UA7805 1A- 5V TO-220	1

Appendix C: PIC16F84A C language coding for Figure 4.2

```
#include <16F84A.H>
#fuses HS,NOWDT,NOPROTECT,PUT
#use DELAY(clock=10000000)

#use fast_io(A)
#use fast_io(B)


#define RS232_XMIT    PIN_B1  // (output) RS232 serial transmit
#define RED_LED       PIN_B2  // (output) Red LED (low true)
#define IR_LED        PIN_B3  // (output) Infrared LED (low true)
#define IR_SENSOR     PIN_B4  // (input) IR sensor (Sharp IS1U30)
#define RS232_RCV     PIN_B5  // (input) RS232 serial receive

// Macros to simplify I/O operations
//
#define RED_LED_ON     output_low(RED_LED)
#define RED_LED_OFF    output_high(RED_LED)
#define IR_LED_ON      output_low(IR_LED)
#define IR_LED_OFF     output_high(IR_LED)
#define  IR_RECEIVED   (!input(IR_SENSOR))

// Default TRIS bits: RS232_RCV and IR_SENSOR are inputs, all
// others are outputs
//
#define IRX_B_TRIS     0b00110000

// =================================================================
// General definitions
//

struct {
  short int RBIF;
  short int INTF;
  short int T0IF;
  short int RBIE;
  short int INTE;
  short int T0IE;
  short int PEIE;
  short int GIE;
} INTCON;
#byte    INTCON         = 0x0B

// general I/O buffer
//
#define BUF_SIZE        32
char gBuf[BUF_SIZE];

// =================================================================
// IRDA constants
//

// Port B0 is also an input (jumpered from IR_RECEIVE port)
#define IRDA_TRIS       (IRX_B_TRIS | 0b00000001)

// Minimum IRDA pulse is 1.63 uSec.  With 400 nSec instruction
```

```
// cycle time (10MHz clock), this requires 4+ cycles, ergo 5.
//
#define IRDA_PULSE_CYCLES  5

// The following assume an RTCC prescaler of 4:1, or 1600 nSec tics
//
#define  IRDA_BIT_TICS              65       // 1/9600 baud
#define  IRDA_STARTBIT_TICS 98      // 1.5 * 1/9600 baud
#define  IRDA_TIMEOUT_TICS  255

// ================================================================
// IR Output
//

// Wait until the *previous* bit period has expired, then
// write a single bit using IrDA 1.0 protocol: a 1.63 uSec
// pulse for a zero bit, no pulse for a one bit.
//
// Reads low order bit in b
//
void putIRDABit(int b) {
 do {} while (!INTCON.T0IF);     // wait for TMR0 to expire
 set_rtcc(256-IRDA_BIT_TICS);  // reset for next bit period
 INTCON.T0IF = 0;
 output_high(PIN_A2);             // for 'scope testing
 if (!(b&1)) {                     // pulse for 0 bit, no pulse for 1
  IR_LED_ON;
  delay_cycles(IRDA_PULSE_CYCLES-1);
  IR_LED_OFF;
 }
 output_low(PIN_A2);              // for 'scope testing
}

// write a start bit, 8 bits of b (LSB first), and a stop
// bit using IrDA 1.0 protocol.
//
void putIRDAByte(char b) {
 output_high(PIN_A1);
 putIRDABit(0);          // start bit
 putIRDABit(b);          // b0: lsb first
 b >>= 1;
 putIRDABit(b);          // b1
 b >>= 1;
 putIRDABit(b);          // b2
 b >>= 1;
 putIRDABit(b);          // b3
 b >>= 1;
 putIRDABit(b);          // b4
 b >>= 1;
 putIRDABit(b);          // b5
 b >>= 1;
 putIRDABit(b);          // b6
 b >>= 1;
 putIRDABit(b);          // b7: msb
 putIRDABit(1);          // stop bit
 output_low(PIN_A1);
}
```

```
// Send all the chars in Buf[] via IrDA
//
void putIRDABuf(int count) {
  int i;

  INTCON.T0IF = 1;                    // makes putIRBit() start immediately
  for (i=0; i<count; i++) {
    putIRDAByte(gBuf[i]);
  }
}

// ==================================================================
// IR Input
//

// Wait for an IR start bit.  If no start bit
// was seen within the timeout interval, return
// 0.  Otherwise set up RTCC to roll over in the
// middle of the next bit cell and return 1.
//
int findIRDAStart() {
  output_high(PIN_A1);
  set_rtcc(256-IRDA_TIMEOUT_TICS);
  INTCON.T0IF = 0;

  while (!INTCON.T0IF) {
    if (INTCON.INTF) {
      output_high(PIN_A2);
      // caught a start bit.  next tic in 1.5 bit cells...
      set_rtcc(256-IRDA_STARTBIT_TICS);
      INTCON.T0IF = 0;
      INTCON.INTF = 0;
      output_low(PIN_A1);
      output_low(PIN_A2);
      return 1;                       // start bit seen
    }
  }
  output_low(PIN_A1);
  return 0;                           // start bit not seen
}

// Wait for TMR0 to indicate the end of a bit cell.  If
// in that time an IR pulse has been received, return a
// zero.  Otherwise return a 1
//
int getIRDABit() {
  int seen;
  output_high(PIN_A3);
  do {
    output_high(PIN_B7);
    seen = INTCON.INTF;
    output_low(PIN_B7);
  } while (!INTCON.T0IF);
  set_rtcc(256-IRDA_BIT_TICS);  // reset for next bit period
  INTCON.T0IF = 0;
  INTCON.INTF = 0;                    // reset "pulse seen" flag
  output_low(PIN_A3);
  return !seen;
```

```
}

// Read a single IrDA byte.  Assumes the start bit has
// already been detected and that RTCC is set to roll
// over in the middle of the first bit cell.
//
int getIRDAByte() {
  char ch;

  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  shift_right(&ch, 1, getIRDABit());
  return ch;
}

// Read bytes from the IrDA input and store them
// in gBuf[].  Upon entry, it's assumed that a
// start pulse has been detected and that RTCC
// is set up to roll over in the middle of the
// first bit period.
//
// Returns when no start bit is detected within
// the given timeout period OR when the buffer
// is full.
//
int getIRDABuf() {
  int count = 0;
  output_high(PIN_A0);
  do {
    gBuf[count++] = getIRDAByte();
    if (count == BUF_SIZE) break;
  } while (findIRDAStart());
  output_low(PIN_A0);
  return count;
}

// ================================================================
// RS232 constants

#use rs232(baud=9600, xmit=RS232_XMIT, rcv=RS232_RCV)

// The following assume an RTCC prescaler of 4:1, or 1600 nSec tics
//
#define  RS232_TIMEOUT_TICS 255

// ================================================================
// RS232 Output
//

// Send all the chars in Buf[] via RS232
//
void putRS232Buf(int count) {
  int i;
```

```
 for (i=0; i<count; i++) {
  putc(gBuf[i]);
 }
}


// ===========================================================================
// RS232 Input
//

// Look for an RS232 start bit, returning 1 if
// a start bit was detected or 0 if no start bit
// was detected in the timeout period.
//
int findRS232Start() {
 set_rtcc(256-RS232_TIMEOUT_TICS);
 INTCON.T0IF = 0;

 while (!INTCON.T0IF) {
  if (kbhit()) return 1;
 }
 return 0;                          // timed out waiting for RS232 data
}

// Read bytes from the RS232 input and store them
// in gBuf[]. Upon entry, it's assumed that an
// RS232 start bit has been detected.
//
// Returns when no start bit is detected within
// the given timeout period OR when the buffer
// is full.
//
int getRS232Buf() {
 int count = 0;
 do {
  gBuf[count++] = getc();
  if (count == BUF_SIZE) break;
 } while (findRS232Start());
 return count;
}


// ===========================================================================
// Main read/write loop
//

#define IRDA_SEEN      1
#define  RS232_SEEN    0

// loop until an IrDA start bit or a serial start bit
// is detected.
//
// If an IrDA bit is seen, set up RTCC to interrupt
// after 1.5 bit cells and return IRDA_SEEN. Otherwise
// if an RS232 start bit is seen, return RS232_SEEN.
//
int waitForStart() {
```

```
  output_high(PIN_B6);
  while (1) {
    if (INTCON.INTF) {
      set_rtcc(256-IRDA_STARTBIT_TICS);
      INTCON.T0IF = 0;
      INTCON.INTF = 0;
      output_low(PIN_B6);
      return IRDA_SEEN;
    } else if (kbhit()) {
      output_low(PIN_B6);
      return RS232_SEEN;
    }
  }
}

void main() {
  set_tris_a(0x00);                // all outputs
  set_tris_b(IRDA_TRIS);

  output_low(PIN_A0);
  output_low(PIN_A1);
  output_low(PIN_A2);
  output_low(PIN_A3);
  output_low(PIN_A4);

  setup_counters(RTCC_INTERNAL, RTCC_DIV_4);

  RED_LED_ON;                      // reality check at startup
  delay_ms(1000);
  RED_LED_OFF;

  ext_int_edge(H_TO_L);            // watch for leading edge of IR pulse

  printf("Decoding the remote control V1.1\r\n");

  while (1) {
    if (waitForStart() == IRDA_SEEN) {
      putRS232Buf(getIRDABuf());
    } else {
      putIRDABuf(getRS232Buf());
    }
  }
}
```

Appendix D: PIC16F84A C language coding for Figure 4.3

```
#include <16F84A.h>
#use delay(clock=10000000)
#fuses hs,nowdt

int a;

void main()
{
  loop1:
  a = input(PIN_B0);

  if(a==1)
  {
    do
    {
      output_high(PIN_B3);
    }
    while(!input(PIN_B0));
    goto loop1;
  }

  if(a!=1)
  {
    output_low(PIN_B3);
    goto loop1;
  }
}
```

Appendix E: Gantt Charts

Gantt chart for the First Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research Work		■	■											
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report	●													
4	Project Work				■	■	■	■							
	-Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report						●								
6	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
7	Submission of Interim Report Final Draft										●				
8	Oral Presentation											●			
9	Submission of Interim Report												●		

● Report submissions

■ Process

Gantt chart for the Second Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work Continue		■	■											
	-Practical/Laboratory Work														
2	Submission of Progress Report 1		●												
3	Project Work Continue				■	■	■	■							
	-Practical/Laboratory Work														
4	Submission of Progress Report 2							●							
5	Project work continue								■	■	■	■			
	-Practical/Laboratory Work														
6	Submission of Dissertation Final Draft											●			
7	Oral Presentation												●		
8	Submission of Project Dissertation													●	

● Report submissions

■ Process

Appendix F: Data sheets

IS1U60/IS1U60L

Sensors with 1-Package Design of Remote Control Detecting Functions owing to OPIC

■ Features

1. 1-package design owing to adoption of OPIC
2. Compact
   (Volume : About 1/8 compared with **GP1U58X**)
3. B.P.F. (Band Pass Frequency) : (TYP. 38kHz)
4. Aspherical lens

■ Applications

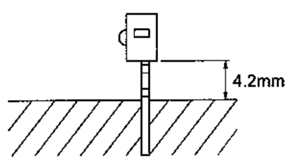
1. Audio equipment
2. Cameras

■ Absolute Maximum Ratings

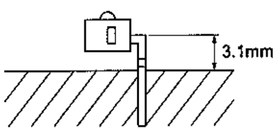
(Ta=25°C)

Parameter	Symbol	Rating	Unit
Supply voltage	V_{CC}	0 to 6.0	V
*1Operating temperature	T_{opr}	- 10 to +60	°C
Storage temperature	T_{stg}	- 20 to +70	°C
*2Soldering temperature	T_{sol}	260	°C

*1 No dew condensation is allowed.
*2 For 5 seconds



Soldering area

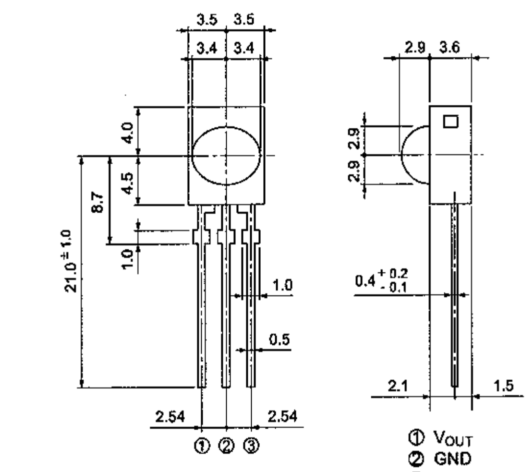


Soldering area

■ Outline Dimensions

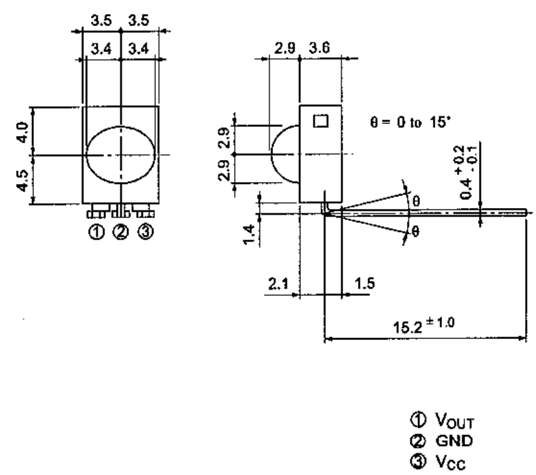
(Unit : mm)

IS1U60



* Tolerance : ± 0.2

IS1U60L



* Tolerance : ± 0.2

* "OPIC" (Optical IC) is a trademark of the SHARP Corporation.
An OPIC consists of a light-detecting element and signal-processing circuit integrated onto a single chip.

■ Recommended Operating Conditions

Parameter	Symbol	Recommended operating conditions	Unit
Operating supply voltage	V_{CC}	4.7 to 5.3	V

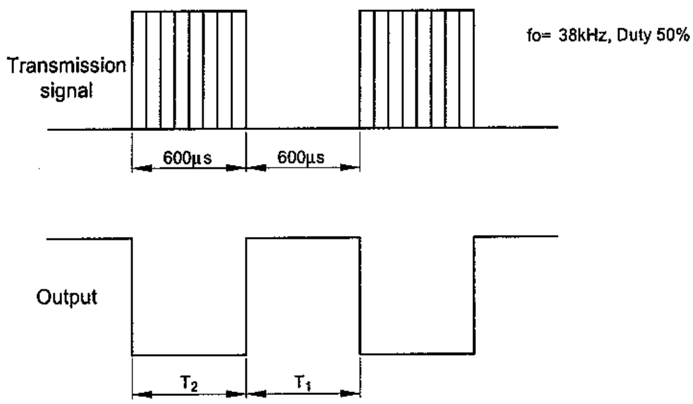
" In the absence of confirmation by device specification sheets, SHARP takes no responsibility for any defects that occur in equipment using any of SHARP's devices, shown in catalogs, data books, etc. Contact SHARP in order to obtain the latest version of the device specification sheets before using any SHARP's device."

■ Electrical Characteristics

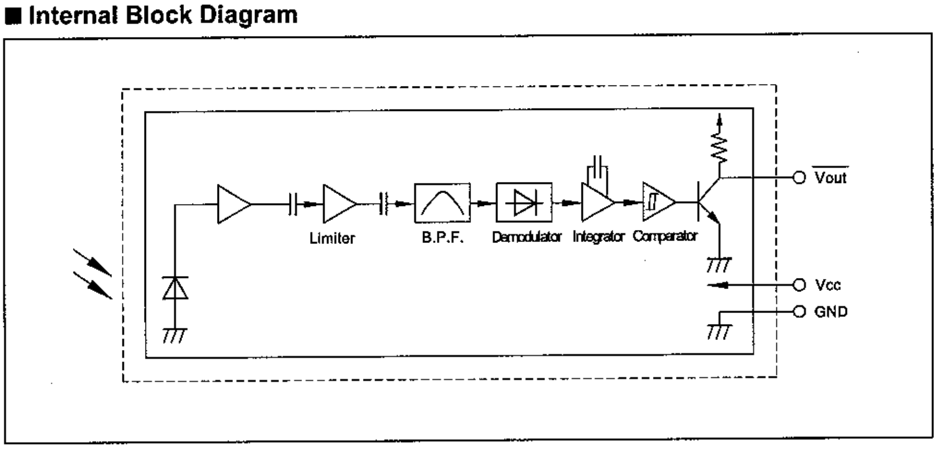
(Ta=25°C, V_{CC} =+5V)

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Dissipation current	I_{CC}	No input light	-	2.8	4.5	mA
High level output voltage	V_{OH}	*3, Output terminal OPEN	V_{CC}- 0.2	-	-	V
Low level output voltage	V_{OL}	*3, *4	-	0.45	0.6	V
High level pulse width	T_1	*3	400	-	800	μs
Low level pulse width	T_2		400	-	800	μs
B.P.F. center frequency	fo		-	38	-	kHz
Linear ultimate distance	L	$\phi, \theta = 0°$, $E_e < 10$ lx	5.0	-	-	m
Linear ultimate distance	L_l	$\phi = \pm 30°$ ($\theta = 0°$) $\theta = \pm 15°$ ($\phi = 0°$) $E_e < 10$ lx	3.0	-	-	m

*3 The burst wave as shown in the following figure shall be transmitted.
*4 Pull-up resistance : 2.2kΩ
*5 By SHARP transmitter



■ Internal Block Diagram



■ Performance

Using the transmitter shown in Fig. 1, the output signal of the light detecting unit is good enough to meet the following items in the standard optical system in Fig. 2.

(1) Linear reception distance characteristics

When L=0.2 to 5 m, Ee < 10 lx (*4) and ϕ =0° in Fig. 2, the output signal shall meet the electrical characteristics in the attached list.

(2) Sensitivity angle reception distance characteristics

When L=0.2 to 3 m, Ee < 10 lx (*4) and ϕ<= 30 ° in the direction X and θ =0° in the direction Y in Fig. 2, the output signal shall meet the electrical characteristics in the attached list Further, the electrical characteristics shall be met when L=0.2 to 5 m, Ee < 10 lx (*4) and ϕ =0° in the direction X and θ<= 15° in the direction Y.

*4 It refers to detector face illuminance.

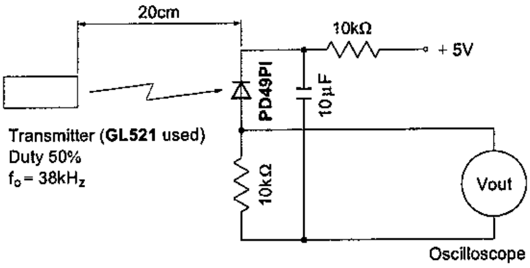


Fig. 1 Transmitter

In the above figure, the transmitter should be set so that the output Vout can be 40mV_{P-P}.
However, the **PD49PI** to be used here should be of the short-circuit current I_{SC}=2.6 μ A at Ev=100 lx.
(Ev is an illuminance by CIE standard light source A (tungsten lamp).)

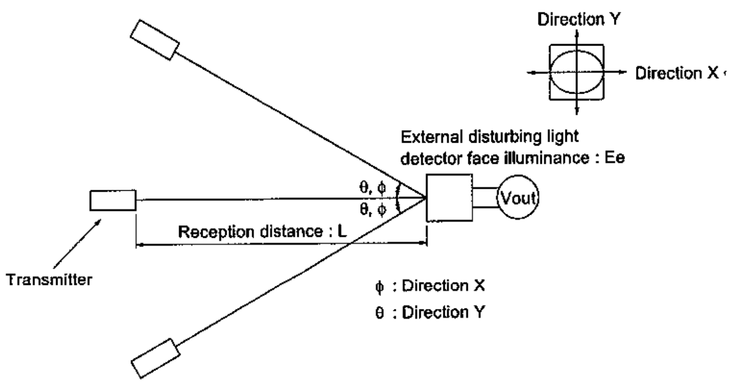


Fig. 2 Standard optical system

Fig. 1 B.P.F. Frequency Characteristics (TYP.)

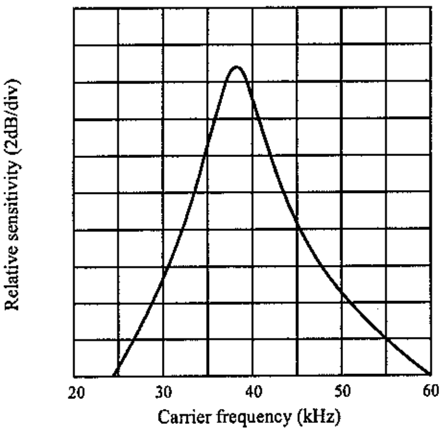


Fig. 2 Sensitivity Angle (Direction X) Characteristics (TYP.) for Reference

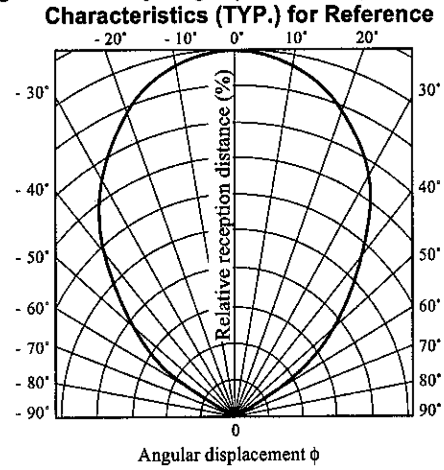


Fig. 3 Sensitivity Angle (Direction Y) Characteristics (TYP.) for Reference

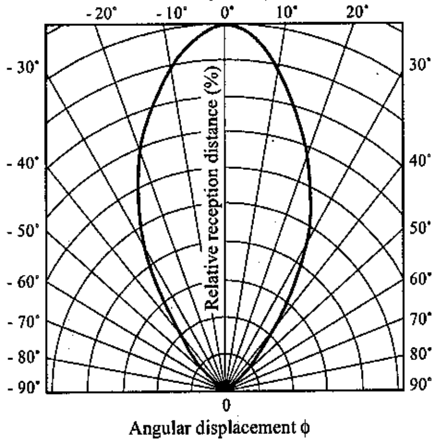


Fig. 4 Relative Reception Distance vs. Ambient Temperature (TYP.) for Reference

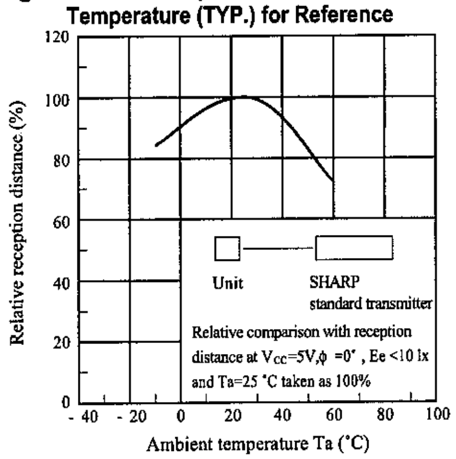
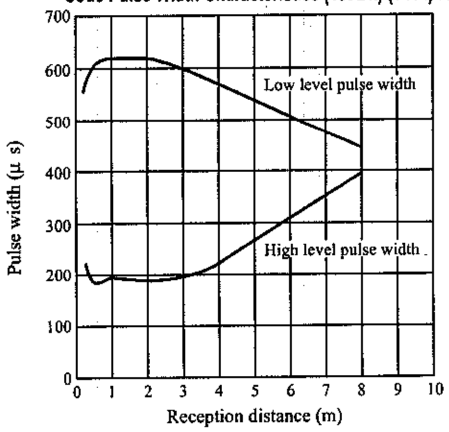
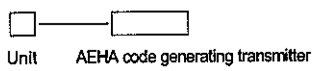


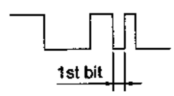
Fig. 5 AEHA (Japan Association of Electrical Home Appliances) Code Pulse Width Characteristics (1st Bit) (TYP.) for Reference



(Conditions)

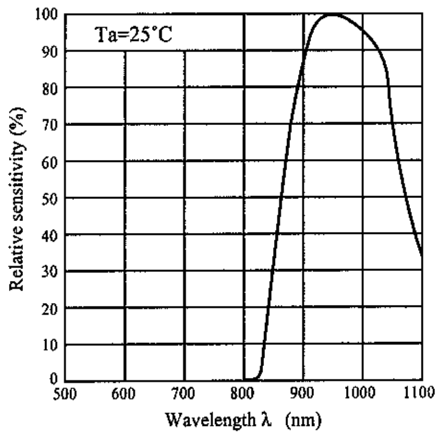


V_{CC}=5V, Ta=RT, φ =0° , Ee < 10 lx



T= 430μ s

Fig. 6 Spectral Sensitivity for Reference



■ Precautions for Operation

(1) Use the light emitting unit (remote control transmitter), in consideration of performance, characteristics, operating conditions of light emitting device and the characteristics of the light detecting unit.

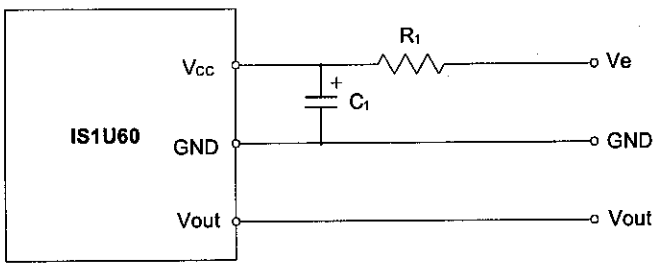
(2) Pay attention to a malfunction of the light detecting unit when the surface is stained with dust and refuse.
Care must be taken not to touch the light detector surface.
• Conduct cleaning as follows.

(3) Cleaning
Solvent dip cleaning : Solvent temperature of 45 °C max., dipping time : Within 3 minutes
Ultrasonic cleaning : Elements are affected differently depending on the size of cleaning bath, ultrasonic output, time, size of PWB and mounting method of elements.
Conduct trial cleaning on actual operating conditions in advance to make sure that no problem results.
• Use the following solvents only.
Solvents : Ethyl alcohol, methyl alcohol or isopropyl alcohol

(4) To avoid the electrostatic breakdown of IC, handle the unit under the condition of grounding with human body, soldering iron, etc.

(5) Do not apply unnecessary force to the terminal.

(6) Example of recommended external circuit (mount outer mounting parts near the sensor as much as possible.)



(Circuit constant)
$R_1 = 47\Omega \pm 5\%$
$C_1 = 47\mu F$

ꞁxial Lead
tandard Recovery Rectifiers

'his data sheet provides information on subminiature size, axial lead unted rectifiers for general–purpose low–power applications.

chanical Characteristics

Case: Epoxy, Molded
Weight: 0.4 gram (approximately)
Finish: All External Surfaces Corrosion Resistant and Terminal Leads are Readily Solderable
Lead and Mounting Surface Temperature for Soldering Purposes: 220°C Max. for 10 Seconds, 1/16″ from case
Shipped in plastic bags, 1000 per bag.
Available Tape and Reeled, 5000 per reel, by adding a "RL" suffix to the part number
Polarity: Cathode Indicated by Polarity Band
Marking: 1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

1N4001 thru 1N4007

1N4004 and 1N4007 are Motorola Preferred Devices

LEAD MOUNTED RECTIFIERS 50–1000 VOLTS DIFFUSED JUNCTION

CASE 59–03
DO–41

ꞁXIMUM RATINGS

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
ᑭeak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Ꞁon–Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
ꞁMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
ꞁverage Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 8, T_A = 75°C)	I_O	1.0							Amp
Ꞁon–Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	30 (for 1 cycle)							Amp
ꞁperating and Storage Junction Temperature Range	T_J T_{stg}	– 65 to +175							°C

ECTRICAL CHARACTERISTICS*

Rating	Symbol	Typ	Max	Unit
ꞁaximum Instantaneous Forward Voltage Drop (i_F = 1.0 Amp, T_J = 25°C) Figure 1	v_F	0.93	1.1	Volts
ꞁaximum Full–Cycle Average Forward Voltage Drop (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$V_{F(AV)}$	—	0.8	Volts
ꞁaximum Reverse Current (rated dc voltage) (T_J = 25°C) (T_J = 100°C)	I_R	 0.05 1.0	 10 50	µA
ꞁaximum Full–Cycle Average Reverse Current (I_O = 1.0 Amp, T_L = 75°C, 1 inch leads)	$I_{R(AV)}$	—	30	µA

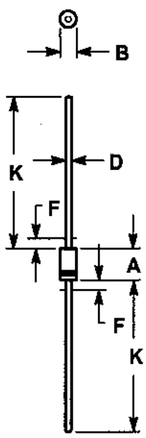
ꞁicates JEDEC Registered Data

ferred devices are Motorola recommended choices for future use and best overall value.

ꞁotorola, Inc. 1996

MOTOROLA

PACKAGE DIMENSIONS



NOTES:
1. ALL RULES AND NOTES ASSOCIATED WITH JEDEC DO–41 OUTLINE SHALL APPLY.
2. POLARITY DENOTED BY CATHODE BAND.
3. LEAD DIAMETER NOT CONTROLLED WITHIN F DIMENSION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	4.07	5.20	0.160	0.205
B	2.04	2.71	0.080	0.107
D	0.71	0.86	0.028	0.034
F	—	1.27	—	0.050
K	27.94	—	1.100	—

CASE 59–03
(DO–41)
ISSUE M

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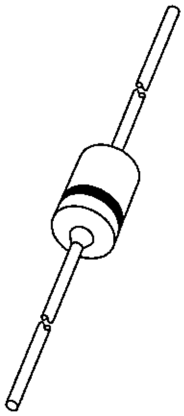
ITERNET: http://motorola.com/sps

DATA SHEET



1N4148; 1N4448
High-speed diodes

Product specification 2002 Jan 23
Supersedes data of 1999 May 25

Philips
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High-speed diodes

1N4148; 1N4448

EATURES

- Hermetically sealed leaded glass SOD27 (DO-35) package
- High switching speed: max. 4 ns
- General application
- Continuous reverse voltage: max. 75 V
- Repetitive peak reverse voltage: max. 100 V
- Repetitive peak forward current: max. 450 mA.

PPLICATIONS

- High-speed switching.

DESCRIPTION

The 1N4148 and 1N4448 are high-speed switching diodes fabricated in planar technology, and encapsulated in hermetically sealed leaded glass SOD27 (DO-35) packages.

The diodes are type branded.

Fig.1 Simplified outline (SOD27; DO-35) and symbol.

IMITING VALUES

ı accordance with the Absolute Maximum Rating System (IEC 60134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
$/_{RRM}$	repetitive peak reverse voltage		–	100	V
$/_{R}$	continuous reverse voltage		–	75	V
$_{F}$	continuous forward current	see Fig.2; note 1	–	200	mA
$_{FRM}$	repetitive peak forward current		–	450	mA
$_{FSM}$	non-repetitive peak forward current	square wave; T_j = 25 °C prior to surge; see Fig.4			
		t = 1 μs	–	4	A
		t = 1 ms	–	1	A
		t = 1 s	–	0.5	A
$_{tot}$	total power dissipation	T_{amb} = 25 °C; note 1	–	500	mW
Γ_{stg}	storage temperature		–65	+200	°C
Γ_{j}	junction temperature		–	200	°C

ote

. Device mounted on an FR4 printed circuit-board; lead length 10 mm.

LECTRICAL CHARACTERISTICS

= 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
$'_F$	forward voltage	see Fig.3			
	1N4148	I_F = 10 mA	–	1	V
	1N4448	I_F = 5 mA	0.62	0.72	V
		I_F = 100 mA	–	1	V
R	reverse current	V_R = 20 V; see Fig.5		25	nA
		V_R = 20 V; T_j = 150 °C; see Fig.5	–	50	μA
R	reverse current; 1N4448	V_R = 20 V; T_j = 100 °C; see Fig.5	–	3	μA
$_d$	diode capacitance	f = 1 MHz; V_R = 0; see Fig.6	–	4	pF
r	reverse recovery time	when switched from I_F = 10 mA to I_R = 60 mA; R_L = 100 Ω; measured at I_R = 1 mA; see Fig.7	–	4	ns
$'_{fr}$	forward recovery voltage	when switched from I_F = 50 mA; t_r = 20 ns; see Fig.8	–	2.5	V

HERMAL CHARACTERISTICS

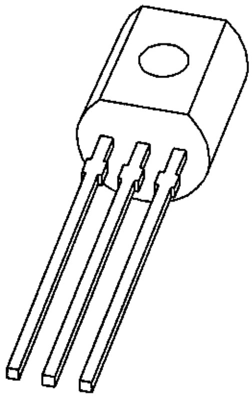
SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}tp}$	thermal resistance from junction to tie-point	lead length 10 mm	240	K/W
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	lead length 10 mm; note 1	350	K/W

ote

Device mounted on a printed circuit-board without metallization pad.

DISCRETE SEMICONDUCTORS

DATA SHEET



BC546; BC547
NPN general purpose transistors

Product specification
Supersedes data of 1997 Mar 04

1999 Apr 15

Philips
Semiconductors

PHILIPS

NPN general purpose transistors | BC546; BC547

EATURES

- Low current (max. 100 mA)
- Low voltage (max. 65 V).

PPLICATIONS

- General purpose switching and amplification.

ESCRIPTION

PN transistor in a TO-92; SOT54 plastic package.
NP complements: BC556 and BC557.

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector

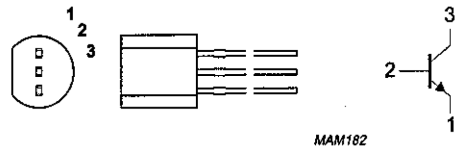


Fig.1 Simplified outline (TO-92; SOT54) and symbol.

IMITING VALUES

accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	BC546		–	80	V
	BC547		–	50	V
V_{CEO}	collector-emitter voltage	open base			
	BC546		–	65	V
	BC547		–	45	V
V_{EBO}	emitter-base voltage	open collector			
	BC546		–	6	V
	BC547		–	6	V
C	collector current (DC)		–	100	mA
CM	peak collector current		–	200	mA
BM	peak base current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C; note 1	–	500	mW
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		–65	+150	°C

ote

1. Transistor mounted on an FR4 printed-circuit board.

HERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	note 1	0.25	K/mW

ote

Transistor mounted on an FR4 printed-circuit board.

HARACTERISTICS

= 25 °C unless otherwise specified.

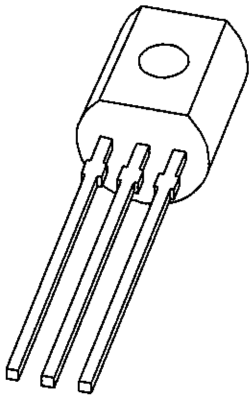
SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$_{CBO}$	collector cut-off current	$I_E = 0$; $V_{CB} = 30$ V	–	–	15	nA
		$I_E = 0$; $V_{CB} = 30$ V; $T_j = 150$ °C	–	–	5	μA
$_{EBO}$	emitter cut-off current	$I_C = 0$; $V_{EB} = 5$ V	–	–	100	nA
h_{FE}	DC current gain	$I_C = 10$ μA; $V_{CE} = 5$ V; see Figs 2, 3 and 4				
	BC546A		–	90	–	
	BC546B; BC547B		–	150	–	
	BC547C		–	270	–	
	DC current gain	$I_C = 2$ mA; $V_{CE} = 5$ V; see Figs 2, 3 and 4				
	BC546A		110	180	220	
	BC546B; BC547B		200	290	450	
	BC547C		420	520	800	
	BC547		110	–	800	
	BC546		110	–	450	
V_{CEsat}	collector-emitter saturation voltage	$I_C = 10$ mA; $I_B = 0.5$ mA	–	90	250	mV
		$I_C = 100$ mA; $I_B = 5$ mA	–	200	600	mV
V_{BEsat}	base-emitter saturation voltage	$I_C = 10$ mA; $I_B = 0.5$ mA; note 1	–	700	–	mV
		$I_C = 100$ mA; $I_B = 5$ mA; note 1	–	900	–	mV
V_{BE}	base-emitter voltage	$I_C = 2$ mA; $V_{CE} = 5$ V; note 2	580	660	700	mV
		$I_C = 10$ mA; $V_{CE} = 5$ V	–	–	770	mV
C_c	collector capacitance	$I_E = i_e = 0$; $V_{CB} = 10$ V; f = 1 MHz	–	1.5	–	pF
C_e	emitter capacitance	$I_C = i_c = 0$; $V_{EB} = 0.5$ V; f = 1 MHz	–	11	–	pF
f_T	transition frequency	$I_C = 10$mA; $V_{CE} = 5$ V; f = 100 MHz	100	–	–	MHz
F	noise figure	$I_C = 200$ μA; $V_{CE} = 5$ V; $R_S = 2$ kΩ; f = 1 kHz; B = 200 Hz	–	2	10	dB

otes

. V_{BEsat} decreases by about 1.7 mV/K with increasing temperature.

. V_{BE} decreases by about 2 mV/K with increasing temperature.

DATA SHEET



BC636; BC638; BC640
PNP medium power transistors

Product specification
Supersedes data of 1999 Apr 23

2001 Oct 10

Philips
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HERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	note 1	150	K/W

lote

. Transistor mounted on an FR4 printed-circuit board.

HARACTERISTICS

$_j$ = 25 °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
$_{CBO}$	collector cut-off current	$I_E = 0$; $V_{CB} = -30$ V	–	–100	nA
		$I_E = 0$; $V_{CB} = -30$ V; $T_j = 150$ °C	–	–10	µA
$_{EBO}$	emitter cut-off current	$I_C = 0$; $V_{EB} = -5$ V	–	–100	nA
h_{FE}	DC current gain	$V_{CE} = -2$ V; see Fig.2			
		$I_C = -5$ mA	63	–	
		$I_C = -150$ mA	63	250	
		$I_C = -500$ mA	40	–	
	DC current gain	$I_C = -150$ mA; $V_{CE} = -2$ V; see Fig.2			
	BC636-10		63	160	
	BC636-16; BC638-16; BC640-16		100	250	
V_{CEsat}	collector-emitter saturation voltage	$I_C = -500$ mA; $I_B = -50$ mA	–	–0.5	V
V_{BE}	base-emitter voltage	$I_C = -500$ mA; $V_{CE} = -2$ V	–	–1	V
f_T	transition frequency	$I_C = -50$ mA; $V_{CE} = -5$ V; f = 100 MHz	100	–	MHz
$\frac{h_{FE1}}{h_{FE2}}$	DC current gain ratio of the complementary pairs	$\lvert I_C \rvert = 150$ mA; $\lvert V_{CE} \rvert = 2$ V	–	1.6	

PNP medium power transistors BC636; BC638; BC640

'EATURES

- High current (max. 1 A)
- Low voltage (max. 80 V).

,PPLICATIONS

- Audio and video amplifiers.

'ESCRIPTION

'NP medium power transistor in a TO-92; SOT54 plastic ackage. NPN complements: BC635, BC637 and BC639.

PINNING

PIN	DESCRIPTION
1	base
2	collector
3	emitter

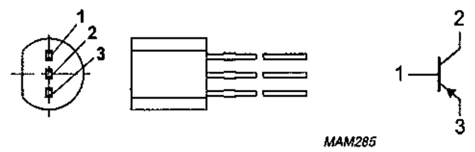


Fig.1 Simplified outline (TO-92; SOT54) and symbol.

IMITING VALUES

ı accordance with the Absolute Maximum Rating System (IEC 60134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	BC636		–	–45	V
	BC638		–	–60	V
	BC640		–	–100	V
V_{CEO}	collector-emitter voltage	open base			
	BC636		–	–45	V
	BC638		–	–60	V
	BC640		–	–80	V
V_{EBO}	emitter-base voltage	open collector	–	–5	V
I_C	collector current (DC)		–	–1	A
I_{CM}	peak collector current		–	–1.5	A
I_{BM}	peak base current		–	–200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C; note 1	–	0.83	W
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		–65	+150	°C

lote

. Transistor mounted on an FR4 printed-circuit board.

PIC16F8X

18-pin Flash/EEPROM 8-Bit Microcontrollers

Devices Included in this Data Sheet:

- PIC16F83
- PIC16F84
- PIC16CR83
- PIC16CR84
- Extended voltage range devices available (PIC16LF8X, PIC16LCR8X)

High Performance RISC CPU Features:

- Only 35 single word instructions to learn
- All instructions single cycle except for program branches which are two-cycle
- Operating speed: DC - 10 MHz clock input
  DC - 400 ns instruction cycle

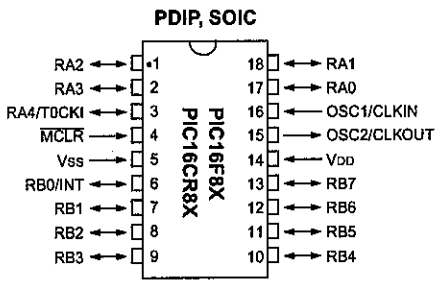
Device	Program Memory (words)	Data RAM (bytes)	Data EEPROM (bytes)	Max. Freq (MHz)
PIC16F83	512 Flash	36	64	10
PIC16F84	1 K Flash	68	64	10
PIC16CR83	512 ROM	36	64	10
PIC16CR84	1 K ROM	68	64	10

- 14-bit wide instructions
- 8-bit wide data path
- 15 special function hardware registers
- Eight-level deep hardware stack
- Direct, indirect and relative addressing modes
- Four interrupt sources:
  - External RB0/INT pin
  - TMR0 timer overflow
  - PORTB<7:4> interrupt on change
  - Data EEPROM write complete
- 1000 erase/write cycles Flash program memory
- 10,000,000 erase/write cycles EEPROM data memory
- EEPROM Data Retention > 40 years

Peripheral Features:

- 13 I/O pins with individual direction control
- High current sink/source for direct LED drive
  - 25 mA sink max. per pin
  - 20 mA source max. per pin
- TMR0: 8-bit timer/counter with 8-bit programmable prescaler

Pin Diagrams



Special Microcontroller Features:

- In-Circuit Serial Programming (ICSP™) - via two pins (ROM devices support only Data EEPROM programming)
- Power-on Reset (POR)
- Power-up Timer (PWRT)
- Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Code-protection
- Power saving SLEEP mode
- Selectable oscillator options

CMOS Flash/EEPROM Technology:

- Low-power, high-speed technology
- Fully static design
- Wide operating voltage range:
  - Commercial: 2.0V to 6.0V
  - Industrial: 2.0V to 6.0V
- Low power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 15 µA typical @ 2V, 32 kHz
  - < 1 µA typical standby current @ 2V

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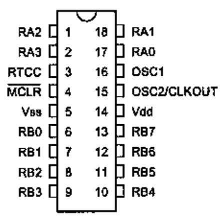
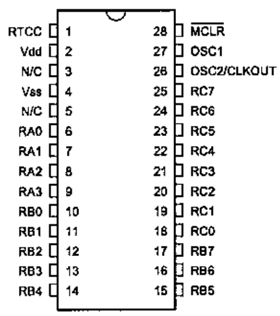
PIC16C5x

PIC16C5x Pin-Outs

The following diagrams show the 18-pin and 28-pin PIC16C5x pin-outs:





Pin	Function
RA0 - RA3	I/O Port A
RB0 - RB7	I/O Port B
RC0 - RC7	I/O Port C (only on 28-pin PIC's)
RTCC	Real-time clock/counter input
MCLR	Master clear (reset)
OSC1	Oscillator input
OSC2/CLKOUT	Oscillator output (OSC/4)
Vdd	Power supply
Vss	Ground
N/C	No connection

DS

ᑭIC16C5x Microcontrollers

'he table below shows the various PIC16C5x devices available:

PART #	ERASE	(E)PROM	RAM	I/O	SUPPLY	OSC.	FREQ.
PIC16C54-RC/P	No	512 x 12	32 x 8	12	3.00 - 6.25 V	RC	DC - 4 MHz
PIC16C54-XT/P	No	512 x 12	32 x 8	12	3.00 - 6.25 V	XTAL	DC - 4 MHz
PIC16C54-HS/P	No	512 x 12	32 x 8	12	4.50 - 5.50 V	XTAL	DC - 20 MHz
PIC16C54-LP/P	No	512 x 12	32 x 8	12	2.50 - 6.25 V	XTAL	DC - 40 kHz
PIC16C54/JW	Yes	512 x 12	32 x 8	12	3.00 - 5.50 V	RC,XTAL	DC - 20 MHz
PIC16C55-RC/P	No	512 x 12	32 x 8	20	3.00 - 6.25 V	RC	DC - 4 MHz
PIC16C55-XT/P	No	512 x 12	32 x 8	20	3.00 - 6.25 V	XTAL	DC - 4 MHz
PIC16C55-HS/P	No	512 x 12	32 x 8	20	4.50 - 5.50 V	XTAL	DC - 20 MHz
PIC16C55-LP/P	No	512 x 12	32 x 8	20	2.50 - 6.25 V	XTAL	DC - 40 kHz
PIC16C55/JW	Yes	512 x 12	32 x 8	20	3.00 - 5.50 V	RC,XTAL	DC - 20 MHz
PIC16C56-RC/P	No	1K x 12	32 x 8	12	3.00 - 6.25 V	RC	DC - 4 MHz
PIC16C56-XT/P	No	1K x 12	32 x 8	12	3.00 - 6.25 V	XTAL	DC - 4 MHz
PIC16C56-HS/P	No	1K x 12	32 x 8	12	4.50 - 5.50 V	XTAL	DC - 20 MHz
PIC16C56-LP/P	No	1K x 12	32 x 8	12	2.50 - 6.25 V	XTAL	DC - 40 kHz
PIC16C56/JW	Yes	1K x 12	32 x 8	12	3.00 - 5.50 V	RC,XTAL	DC - 20 MHz
PIC16C57-RC/P	No	2K x 12	80 x 8	20	3.00 - 6.25 V	RC	DC - 4 MHz
PIC16C57-XT/P	No	2K x 12	80 x 8	20	3.00 - 6.25 V	XTAL	DC - 4 MHz
PIC16C57-HS/P	No	2K x 12	80 x 8	20	4.50 - 5.50 V	XTAL	DC - 20 MHz
PIC16C57-LP/P	No	2K x 12	80 x 8	20	2.50 - 6.25 V	XTAL	DC - 40 kHz
PIC16C57/JW	Yes	2K x 12	80 x 8	20	3.00 - 5.50 V	RC,XTAL	DC - 20 MHz
PIC16LC58A-04/P	No	2K x 12	80 x 8	12	2.50 - 6.25 V	RC,XTAL	DC - 4 MHz
PIC16C58A-04/P	No	2K x 12	80 x 8	12	3.00 - 6.25 V	XTAL	DC - 4 MHz
PIC16C58A-20/P	No	2K x 12	80 x 8	12	3.00 - 6.25 V	XTAL	DC - 20 MHz
PIC16C58A/JW	Yes	2K x 12	80 x 8	12	3.00 - 6.25 V	RC,XTAL	DC - 20 MHz

ᑭeripheral Features

n addition to the obvious features shown above, the PIC's have a ıumber of not-so-obvious features and qualities that are important:

- Fully static operation, allowing you to stop the oscillator and then restart where you left off, with all registers intact. This is useful in applications where power conservation is important.
- Individual I/O pins are programmable as inputs or outputs.
  Sink current: 25 mA per pin, 50 mA per port
  Source current: 20 mA per pin, 40 mA per port
- 2-level hardware stack.

- Real-Time Clock/Counter (RTCC). The RTCC is an 8-bit counter, which can be driven by the RTCC pin or by the PIC's internal instruction clock (OSC/4). If the external pin is used, the counter can be set to increment on low-to-high or high-to-low transitions.

  Normally, the RTCC is driven directly by either source. For higher count values, though, the prescaler can be used to effectively increase the RTCC to 16 bits.

  The RTCC signal source and trigger edge are determined by bits in the Option register (see next section for register descriptions).

  See the Microchip PIC16C5x data sheet for details concerning timing characteristics for the RTCC's external input.

- Watchdog Timer (WDT). When enabled, the watchdog timer is used to reset the PIC if the program has "crashed." Normally, a CLR WDT instruction in the main loop of your program would prevent the watchdog timer from ever timing out and resetting the PIC. However, if the program was not executing properly, the watchdog timer would reset the PIC.

  The watchdog timer works from an internal oscillator, allowing it to run even if the PIC's main oscillator has stopped. The watchdog timer's normal time-out period is 18 ms, but can be increased to several seconds by using the post-scaler.

- Prescaler/Post-scaler. This 8-bit counter can be assigned to the RTCC (as a prescaler) or the watchdog timer (as a post-scaler). For simplicity, this counter is normally referred to as the "prescaler," even when it's used as a post-scaler.

  When assigned to the RTCC, the prescaler is placed between the RTCC and its clock source. The clock signal which would normally increment the RTCC, increments the prescaler. When the prescaler overflows, the RTCC is incremented. Increment ratios from 1:2 - 1:256 can be used, effectively giving you a 16-bit RTCC.

  When assigned to the watchdog timer, the prescaler is placed between the watchdog timer and the PIC's reset circuit. The watchdog timer signal which would normally reset the PIC, increments the prescaler. When the prescaler overflows, the PIC is reset. Delay ratios from 1:1 - 1:128 can be used, allowing the watchdog period to be set from 18 ms to several seconds.

The prescaler setup is determined by bits in the Option register *(see the next section for register descriptions).*

- Code-protect fuse. This is a special fuse that can be blown during programming; once the fuse is blown, the PIC's EPROM cannot be read.

- Power saving sleep mode. For applications where low power consumption is important, the PIC has a sleep mode. This mode is entered by executing a SLEEP instruction, which shuts down the oscillator. I/O pins maintain whatever state they had when the sleep mode was entered.

  To awaken the PIC from sleep mode, a reset must be performed, either from the MCLR pin or from a watchdog timer time-out.

  Once the PIC is running, the "PD" and "TO" bits in the Status register can be read to determine 1) if the PIC was powered up or awakened from sleep, and 2) if the wake-up was caused by an external reset or by the watchdog timer.

- Programmable oscillator type. The PIC can run with any of four oscillator types, as shown below:

LP:	Low power crystal	(DC - 40 KHz)
RC:	Resistor & capacitor	(DC - 4 MHz, ± 13-39 percent)
XT:	Crystal or resonator	(100 KHz - 4 MHz)
HS:	High speed crystal	(4 - 20 MHz)

  The oscillator type is determined by two EPROM bits, which are normally programmed at the factory. The RC and erasable PIC's, however, can be user-programmed for any of the oscillator types. Keep in mind, though, that RC-type PIC's are only tested for use with RC oscillators.

Internal Architecture

Internally, the PIC is based on a register file concept with separate busses and memories for data and instructions (sometimes called "Harvard architecture"). The data bus and memory (RAM) are 8-bits wide, while the program bus and memory (EPROM) are 12-bits wide. All PIC instructions and their operands fit into a single 12-bit word, resulting in smaller code and faster execution. PIC programs are typically 33-50 percent smaller than programs written for 8-bit processors. And most instructions execute in a single instruction cycle (4 clock cycles); instructions that affect the program counter take an extra instruction cycle, for a total of 8 clock cycles. To further increase speed, the PIC uses overlapping instruction fetch and execution cycles; while one instruction is executed, the following instruction is being read from program memory. Because of its efficiency, the PIC can deliver 5 MIPS execution with a clock frequency of 20 MHz.

DS

PIC16C5x Registers

The following table shows the various PIC16C5x registers; the function of each register is described in the following pages.

Register	Function
00h	Indirect addressing register
01h	Real-time clock/counter (RTCC)
02h	Program counter (PC)
-	Stack registers (2)
03h	Status register
04h	File select register (FSR)
05h	I/O Port A
06h	I/O Port B
07h	I/O Port C
-	TRISA
-	TRISB
-	TRISC
-	W register
-	Option register
08h - 0Fh	General purpose registers
10h - 1Fh	General purpose registers (4 banks in PIC16C57)

	BANK 0	BANK 1*	BANK 2*	BANK 3*
	W register	W register	W register	W register
	Stack (2)	Stack (2)	Stack (2)	Stack (2)
	Option register	Option register	Option register	Option register
	TRISA	TRISA	TRISA	TRISA
	TRISB	TRISB	TRISB	TRISB
	TRISC	TRISC	TRISC	TRISC
0h	Indirect addr.	Indirect addr.	Indirect addr.	Indirect addr.
1h	RTCC	RTCC	RTCC	RTCC
2h	PC	PC	PC	PC
3h	STATUS	STATUS	STATUS	STATUS
4h	FSR	FSR	FSR	FSR
5h	PORT A	PORT A	PORT A	PORT A
6h	PORT B	PORT B	PORT B	PORT B
7h	PORT C	PORT C	PORT C	PORT C
8h – Fh	8 general purpose registers (RAM)	reads/writes registers 08h - 0Fh	reads/writes registers 08h - 0Fh	reads/writes registers 08h - 0Fh
0h – Fh	16 general purpose registers (RAM)	30h 16 general purpose registers (RAM)* 3Fh	50h 16 general purpose registers (RAM)* 5Fh	70h 16 general purpose registers (RAM)* 7Fh
	(00h - 1Fh)	(20h - 3Fh)*	(40h - 5Fh)*	(60h - 7Fh)*

* Available on PIC16C57 only.

The following text describes the function of each register. For some of the registers, you'll notice the designation "xxh" following the register name. This indicates the address of the register. Registers with no address cannot be addressed directly.

- Indirect Addressing Register (00h). This register doesn't actually exist. Naming register 00h in an instruction causes the PIC to read the register *pointed to* by register 04h (file select register). For example, the instruction "`ADD 00h,#05`" will *not* add five to register 00h; instead, it will add five to whatever register is *pointed to* by the address in register 04h.

  If register 00h itself is read through register 04h (04h contains "00h"), 00h will be returned. If register 00h is written to through register 04h, the PIC will execute a NOP.

- Real-Time Clock/Counter (01h: RTCC). This is the location of the RTCC (see previous section for a description). Although its contents may change in response to a clock signal, the RTCC register may be read and written just as any other register.

- Program Counter (02h: PC). The program counter holds the address for the instruction currently being executed. The program counter and its associated two-level stack are 9-11 bits wide, depending on the EPROM size of the PIC being used.

  Certain instructions affect the program counter, as shown below:

  GOTO (Microchip) and **JMP** (Parallax) load the lower 9 bits of the program counter. In the PIC16C56 and '57, which have more than 512 words of EPROM, the upper two bits of the program counter are loaded with the page select bits from the status register. The Parallax instruction set includes a convenient instruction, **LJMP**, which sets the page select bits before executing the jump.

  CALL loads the lower 8 bits of the program counter and clears the ninth bit. The program counter + 1 is pushed into the stack. In the '56 and '57, the upper two bits of the program counter are loaded with the page select bits from the status register. The Parallax instruction set includes **LCALL**, which sets the page select bits before executing the jump.

RETLW (Microchip) and **RETW** (Parallax) load the program counter with the address most recently pushed on the stack by a CALL instruction.

Instructions which load a computed value into the program counter, such as **JMP PC+W**, load the value into the lower 8 bits. The ninth bit of the program counter is cleared. In the PIC16C56 and '57, the upper two bits of the program counter are loaded with the page select bits from the status register.

It should be noted that because the ninth bit of the program counter is cleared by CALL instructions and computed value instructions (such as JMP PC+W), all subroutine calls and computed jumps must have their destination in the first 256 locations of any page (each page is 512 words).

As you may have noticed when reading the JMP and CALL paragraphs above, the program counter may not be loaded as expected when using a PIC with more than 512 words of EPROM. This is because the upper two bits of the program counter are loaded with the page select bits from the status register. If your program continues into the second page of memory and executes a JMP without having properly set the page select bits, execution may jump to another page (probably not what you want). To avoid this mistake, make sure to set the page select bits for the correct page. Or, use the Parallax "long" instructions, which do this for you (long instructions are LCALL, LJMP, and LSET).

- Stack. The stack is a pair of registers which are used for calling and returning from subroutines. The stack is affected by two instructions:

  When a **CALL** is executed, the first stack register is copied into the second register, then the program counter + 1 (the return address) is loaded into the first register. The original contents of the second register are lost. Finally, the program counter is loaded with the subroutine address, at which point execution continues.

When a **RETLW** (Microchip) or **RETW** (Parallax) is executed, the first stack register is copied into the program counter, then the second register is copied into the first register. Execution continues at the address loaded from the first stack register.

- Status Register (03h). This register contains the status of the PIC's arithmetic logic unit (ALU), the reset status, and the page select bits for PIC's with more than 512 words of EPROM.

  The function of each bit in the status register is shown below:

Bit	Function
0	Carry bit (C). Set if an addition or subtraction causes an overflow from the most significant bit of the resultant (bit 7). Subtraction is included because it's executed by adding the two's complement. Also used by rotate instructions, which rotate the contents of a register and copy the low or high order bit of the register into the carry bit.
1	Digit carry bit (DC). Set if an addition or subtraction causes an overflow from the 4th low order bit (bit 3). Digit carry indicates that more than one hex digit (4 bits) was necessary to accomodate the result.
2	Zero bit (Z). Set if the result of an arithmetic or logic operation is zero.
3	Power-down bit (PD). Set during power-up or by a CLR WDT (clear watchdog) instruction. Cleared by a SLEEP instruction.
4	Time-out bit (TO). Set during power-up, by CLR WDT, or by SLEEP. Cleared by a watchdog time-out.
5-6	Page select bits (PA0, PA1). In the '54 and '55, these are unused. In the '56, bit 5 selects program page 0 or 1 (bit 6 is unused). In the '57, both bits select page 0, 1, 2, or 3. Each page is 512 words long.

Bit	Function
7	Unused bit (PA2). Reserved by Microchip for future use.

The following table shows how various events affect the power-down and time-out bits:

Event	PD	TO
Power-up	1	1
Watchdog time-out	x	0
SLEEP instruction	0	1
CLR WDT instruction	1	1

Lastly, this table shows the status of the power-down and time-out bits after a reset:

Cause of Reset	PD	TO
Watchdog time-out (not during sleep)	1	0
Watchdog time-out (during sleep)	0	0
External reset (not during sleep)	x	x
External reset (during sleep)	0	1
Normal power-up	1	1

- File Select Register (04h: FSR). This register serves a dual purpose: it selects the register for indirect addressing, and it selects the current register bank in the PIC16C57.

  In all PIC16C5x devices, bits 0-4 select one of 32 registers in the current bank (only the '57 has more than one bank).

  In the PIC16C57, bits 5-6 select one of four register banks. Each bank has 32 registers. However, reading or writing the lower 16 registers in **any** bank will access registers 00h - 0Fh (bank 0). Only the upper 16 registers in each bank are unique. This results in one bank of 32 registers, plus three banks of 16 registers, for a total of 80 registers.

The following table shows the function of each FSR bit:

Bit	Function
0-4	Available in all PIC's; select one of 32 registers in the current bank (only the '57 has more than 1 bank).
5-6	PIC16C57 only; select one of four register banks.
7	Read-only bit; always reads as "1".

DS

This table shows the registers available in the various PIC's:

Registers	Description
00h - 07h	Special registers, bank 0 (RTCC, PC, etc.)
08h - 0Fh	General purpose registers, bank 0
10h - 1Fh	General purpose registers, upper half of bank 0
————	End of register memory in '54, '55, and '56.
20h - 2Fh	Reads/writes registers 00h - 0Fh
30h - 3Fh	General purpose registers, upper half of bank 1
40h - 4Fh	Reads/writes registers 00h - 0Fh
50h - 5Fh	General purpose registers, upper half of bank 2
60h - 6Fh	Reads/writes registers 00h - 0Fh
70h - 7Fh	General purpose registers, upper half of bank 3

The register selected in the FSR can be accessed in the indirect addressing mode *(see description of indirect addressing register, earlier in this section).*

In the PIC16C57, all registers can be accessed through indirect addressing. However, to access registers above 1Fh using direct instructions, you must set the page select bits (5-6) to the appropriate page, then read or write the corresponding register in bank 0. For instance, to load register 30h with #A5h, you would execute the following instructions:

```
MOV  04h,#00100000b    ;Select bank 1

MOV  10h,#A5h          ;Load register 10h in
                       ;bank 1 (register 30h)
                       ;with #A5h
```

- I/O Port A (05h: RA or Port A). 4-bit I/O port. This register is used to read and write I/O Port A. This register can be read and written just as any other register. However, read instructions always read the I/O pins, regardless of whether the pins are programmed as inputs or outputs.

  The upper 4 bits are unused and read as 0's.

- I/O Port B (06h: RB or Port B). 8-bit I/O port.

- I/O Port C (07h: RC or Port C). 8-bit I/O port, only available on 28-pin PIC's. On 18-pin PIC's, this register can be used for storage.

- TRISA (TRI-State A). This is the data direction register for Port A. Bits in this register which are set to "1" cause the corresponding bits in Port A to become inputs (the pins go into high impendence mode, allowing them to be driven by an external source). Bits which are cleared to "0" cause the corresponding bits in Port A to become outputs.

  The data direction registers are not directly addressable; to change their contents, you can use either of these instructions:

`TRIS port_fr`	(Microchip) Copies W into the data direction register for *port_fr*, where *port_fr* is 05h-07h.
`MOV !port_fr,#literal`	(Parallax) Copies *literal* into the data direction register for *port_fr*, where *port_fr* is 05h-07h.

- TRISB. Data direction register for Port B.
- TRISC. Data direction register for Port C.
- W (working register). The W register holds the second operand in two-operand instructions and is used in internal data transfer; much like the "accumulator" in other processors.
- Option Register. This register defines the prescaler ratio, prescaler assignment, RTCC trigger edge, and RTCC signal source. The function of each bit in the option register is shown below:

Bit	Function
0-2	Prescaler ratio. These 3 bits determine the prescaler input-to-output ratio. When using the prescaler with the RTCC, the seven possible ratios are 1:2, 1:4, 1:8, 1:16, 1:32, 1:64, 1:128, 1:256. When using the prescaler with the watchdog timer, the ratios are 1:1, 1:2, 1:4, 1:8, 1:16, 1:32, 1:64, 1:128. For example, let's say that the prescaler is assigned to the watchdog timer. To increase the watchdog time-out period to 64 times its normal length, the prescaler ratio would be set to 110b; this yields a watchdog period of approx. 1 second (64 x 18 ms).
3	Prescaler assignment. This bit determines whether the prescaler is assigned to the RTCC ("0") or to the watchdog timer ("1").
4	RTCC trigger edge. This bit determines whether the RTCC increments on a low-to-high ("0") or high-to-low ("1") transition on the RTCC pin.
5	RTCC signal source. This bit determines whether the RTCC is driven by the PIC's internal instruction clock ("0") or by the RTCC pin ("1").

- General purpose registers. These registers may be used by your program for storage of variables, data, etc.

INTEGRATED CIRCUITS

DATA SHEET

SAA3004
Remote control transmitter

Product specification
File under Integrated Circuits, IC02

August 1982

Philips
Semiconductors

PHILIPS

GENERAL DESCRIPTION

The SAA3004 transmitter IC is designed for infrared remote control systems. It has a total of 448 commands which are divided into 7 sub-system groups with 64 commands each. The sub-system code may be selected by a press button, a slider switch or hard wired.

The SAA3004 generates the pattern for driving the output stage. These patterns are pulse distance coded. The pulses are infrared flashes or modulated. The transmission mode is defined in conjunction with the sub-system address. Modulated pulses allow receivers with narrow-band preamplifiers for improved noise rejection to be used. Flashed pulses require a wide-band preamplifier within the receiver.

The SAA3004 has the following features:

- Flashed or modulated transmission
- 7 sub-system addresses
- Up to 64 commands per sub-system address
- High-current remote output at V_{DD} = 6 V ($-I_{OH}$ = 40 mA)
- Low number of additional components
- Key release detection by toggle bits
- Very low stand–by current (< 2 µA)
- Operational current < 2 mA at 6 V supply
- Wide supply voltage range (4 to 11 V)
- Ceramic resonator controlled frequency (typ. 450 kHz)
- Encapsulation: 20-lead plastic DIL or 20-lead plastic mini-pack (SO-20)

PACKAGE OUTLINES

SAA3004P: 20-lead DIL; plastic (SOT146); SOT146-1; 1996 December 11.

SAA3004T: 20-lead mini-pack; plastic (SO20; SOT163A); SOT163-1; 1996 December 11.

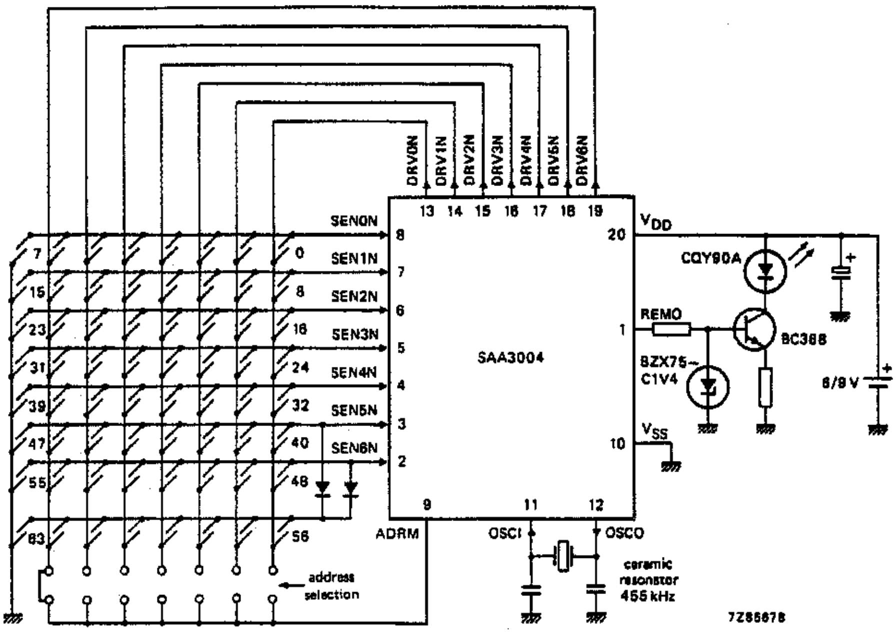


Fig.1 Transmitter with SAA3004.

INPUTS AND OUTPUTS

Key matrix inputs and outputs (DRV0N to DRV6N and SEN0N to SEN6N)

The transmitter keyboard is arranged as a scanned matrix. The matrix consists of 7 driver outputs and 7 sense inputs as shown in Fig.1. The driver outputs DRV0N to DRV6N are open drain N-channel transistors and they are conductive in the stand-by mode. The 7 sense inputs (SEN0N to SEN6N) enable the generation of 56 command codes.
With 2 external diodes all 64 commands are addressable. The sense inputs have P-channel pull-up transistors, so that they are HIGH until they are pulled LOW by connecting them to an output via a key depression to initiate a code transmission.

Address mode input (ADRM)

The sub-system address and the transmission mode are defined by connecting the ADRM input to one or more driver outputs (DRV0N to DRV6N) of the key matrix. If more than one driver is connected to ADRM, they must be decoupled by a diode. This allows the definition of seven sub-system addresses as shown in Table 3. If driver DRV6N is connected to ADRM the data output format of REMO is modulated or if not connected, flashed.

The ADRM input has switched pull-up and pull-down loads. In the stand-by mode only the pull–down device is active. Whether ADRM is open (sub-system address 0, flashed mode) or connected to the driver outputs, this input is LOW and will not cause unwanted dissipation. When the transmitter becomes active by pressing a key, the pull–down device is switched off and the pull-up device is switched on, so that the applied driver signals are sensed for the decoding of the sub-system address and the mode of transmission.

The arrangement of the sub-system address coding is such that only the driver DRVnN with the highest number (n) defines the sub-system address, e.g. if driver DRV2N and DRV4N are connected to ADRM, only DRV4N will define the sub-system address. This option can be used in transmitters for more than one sub-system address. The transmitter may be hard-wired for sub-system address 2 by connecting DRV1N to ADRM. If now DRV3N is added to ADRM by a key or a switch, the transmitted sub-system address changes to 4.

A change of the sub-system address will not start a transmission.

Remote control signal output (REMO)

The REMO signal output stage is a push-pull type. In the HIGH state a bipolar emitter–follower allows a high output current. The timing of the data output format is listed in Tables 1 and 2.

The information is defined by the distance t_b between the leading edges of the flashed pulses or the first edge of the modulated pulses (see Fig.3).

The format of the output data is given in Figs 2 and 3. In the flashed transmission mode the data word starts with two toggle bits T1 and T0, followed by three bits for defining the sub-system address S2, S1 and S0, and six bits F, E, D, C, B and A, which are defined by the selected key.

In the modulated transmission mode the first toggle bit T1 is replaced by a constant reference time bit (REF). This can be used as a reference time for the decoding sequence.

The toggle bits function as an indication for the decoder that the next instruction has to be considered as a new command.

The codes for the sub–system address and the selected key are given in Tables 3 and 4.

Oscillator input/output (OSCI and OSCO)

The external components must be connected to these pins when using an oscillator with a ceramic resonator.
The oscillator frequency may vary between 400 kHz and 500 kHz as defined by the resonator.

FUNCTIONAL DESCRIPTION

Keyboard operation

In the stand-by mode all drivers (DRV0N to DRV6N) are on. Whenever a key is pressed, one or more of the sense inputs (SENnN) are tied to ground. This will start the power-up sequence. First the oscillator is activated and after the debounce time t_{DB} (see Fig.4) the output drivers (DRV0N to DRV6N) become active successively.

Within the first scan cycle the transmission mode, the applied sub-system address and the selected command code are sensed and loaded into an internal data latch. In contradiction to the command code the sub-system address is sensed only within the ***first*** scan cycle. If the applied sub-system address is changed while the command key is pressed, the transmitted sub-system address is not altered.

In a multiple key-stroke sequence (see Fig.5) the command code is always altered in accordance with the sensed key.

Multiple key-stroke protection

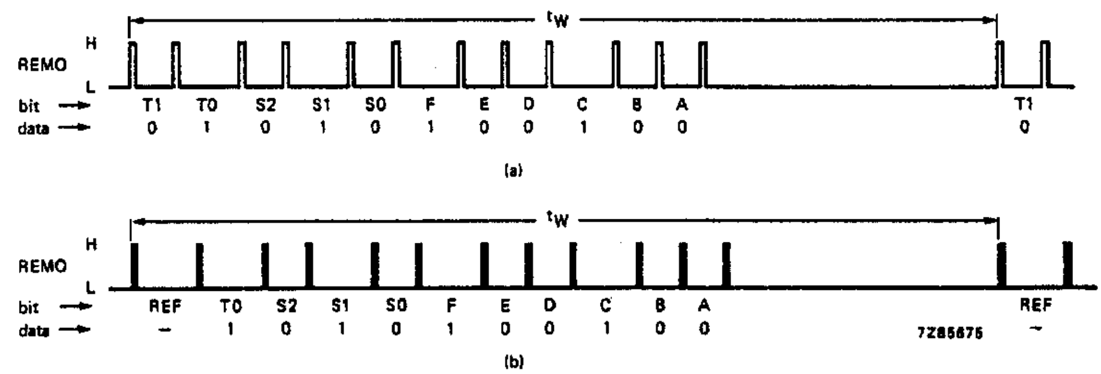
The keyboard is protected against multiple key-strokes. If more than one key is pressed at the same time, the circuit will not generate a new output at REMO (see Fig.5). In case of a multiple key-stroke the scan repetition rate is increased to detect the release of a key as soon as possible.

There are two restrictions caused by the special structure of the keyboard matrix:
- The keys switching to ground (code numbers 7, 15, 23, 31, 39, 47, 55 and 63) and the keys connected to SEN5N and SEN6N are not covered completely by the multiple key protection. If one sense input is switched to ground, further keys on the same sense line are ignored.
- SEN5N and SEN6N are not protected against multiple key-stroke on the same driver line, because this condition has been used for the definition of additional codes (code numbers 56 to 63).

Output sequence (data format)

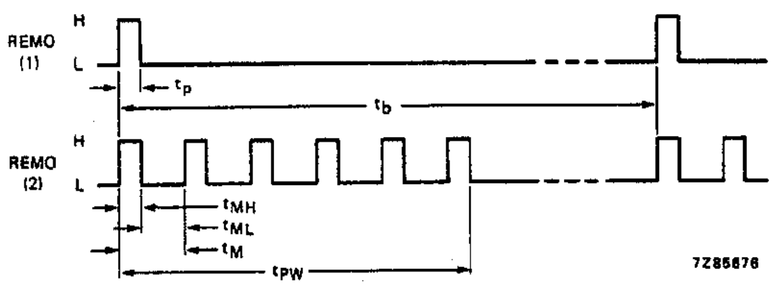
The output operation will start when the selected code is found. A burst of pulses, including the latched address and command codes, is generated at the output REMO as long as a key is pressed. The format of the output pulse train is given in Figs 2 and 3. The operation is terminated by releasing the key or if more than one key is pressed at the same time. Once a sequence is started, the transmitted words will always be completed after the key is released.

The toggle bits T0 and T1 are incremented if the key is released for a minimum time t_{REL} (see Fig.4).
The toggle bits remain unchanged within a multiple key-stroke sequence.



REF = reference time; T0 and T1 = toggle bits; S0, S1 and S2 = system address; A, B, C, D, E and F = command bits
(a) flashed mode: transmission with 2 toggle bits and 3 address bits, followed by 6 command bits (pulses are flashed).
(b) modulated mode: transmission with reference time, 1 toggle bit and 3 address bits, followed by 6 command bits (pulses are modulated).

Fig.2 Data format of REMO output; .



(1) Flashed pulse.
(2) Modulated pulse ($t_{PW} = (5 \times t_M) + t_{MH}$.

Fig.3 REMO output waveform.

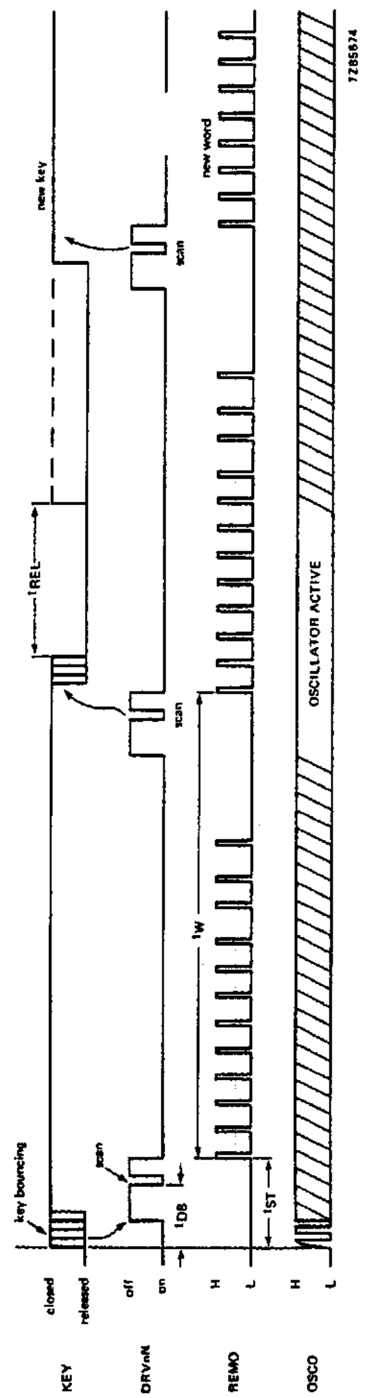


Fig.4 Single key-stroke sequence.
Debounce time: t_{DB} = 4 to 9 × T_O.
Start time: t_{ST} = 5 to 10 × T_o.
Minimum release time: t_{REL} = T_O.
Word distance: t_W.

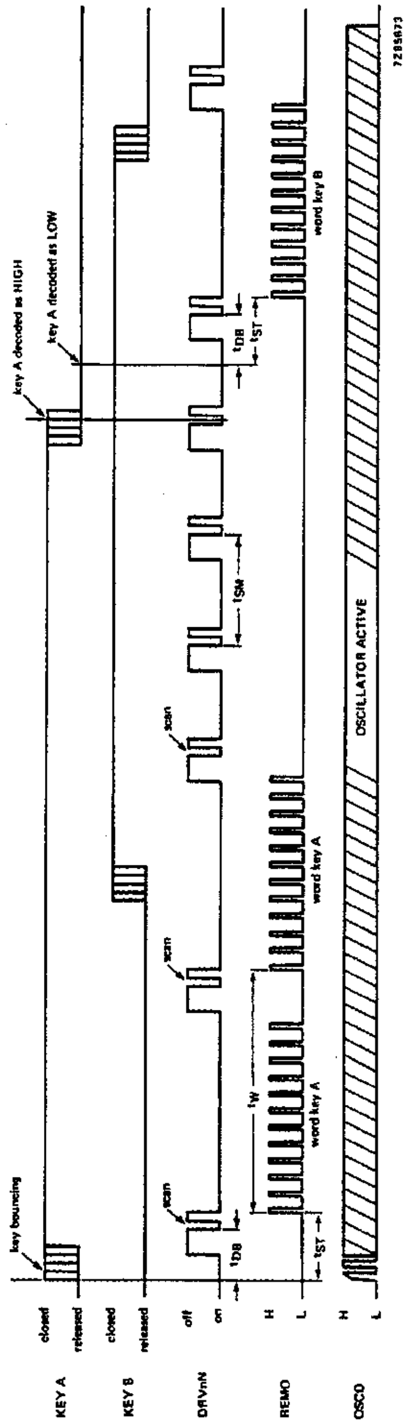


Fig.5 Multiple key-stroke sequence.
Scan rate multiple key-stroke: t_{SM} = 6 to 10 × T_O.
For t_{DB}, t_{ST} and t_W see Fig.4.

Table 1 Pulse train/timing

mode	T_O ms	t_p µs	t_M µs	t_{ML} µs	t_{MH} µs	t_W ms
flashed	2,53	8,8	–	–	–	121
modulated	2,53	–	26,4	17,6	8,8	121

f_{OSC}	455 kHz	t_{OSC} = 2,2 µs
t_P	4 × t_{OSC}	flashed pulse width
t_M	12 × t_{OSC}	modulation period
t_{ML}	8 × t_{OSC}	modulation period LOW
t_{MH}	4 × t_{OSC}	modulation period HIGH
T_O	1152 × t_{OSC}	basic unit of pulse distance
t_W	55 296 × t_{OSC}	word distance

Table 2 Pulse train separation (t_b)

code	t_b
logic "0"	2 × T_o
logic "1"	3 × T_o
reference time	3 × T_o
toggle bit time	2 × T_o or 3 × T_o

Table 3 Transmission mode and sub-system address selection

The sub-system address and the transmission mode are defined by connecting the ADRM input to one or more driver outputs (DRV0N to DRV6N) of the key matrix. If more than one driver is connected to ADRM, they must be decoupled by a diode.

mode	sub-system address				driver DRVnN for n =						
	#	S2	S1	S0	0	1	2	3	4	5	6
F	0	1	1	1							
L	1	0	0	0	o						
A	2	0	0	1	X	o					
S	3	0	1	0	X	X	o				
H	4	0	1	1	X	X	X	o			
E	5	1	0	0	X	X	X	X	o		
D	6	1	0	1	X	X	X	X	X	o	
M											
O	0	1	1	1							o
D	1	0	0	0	o						o
U	2	0	0	1	X	o					o
L	3	0	1	0	X	X	o				o
A	4	0	1	1	X	X	X	o			o
T	5	1	0	0	X	X	X	X	o		o
E	6	1	0	1	X	X	X	X	X	o	o
D											

Notes

1. o = connected to ADRM
2. blank = not connected to ADRM
3. X = don't care

Table 4 Key codes

matrix drive	matrix sense	code F	code E	code D	code C	code B	code A	matrix position
DRV0N	SEN0N	0	0	0	0	0	0	0
DRV1N	SEN0N	0	0	0	0	0	1	1
DRV2N	SEN0N	0	0	0	0	1	0	2
DRV3N	SEN0N	0	0	0	0	1	1	3
DRV4N	SEN0N	0	0	0	1	0	0	4
DRV5N	SEN0N	0	0	0	1	0	1	5
DRV6N	SEN0N	0	0	0	1	1	0	6
V_{SS}	SEN0N	0	0	0	1	1	1	7
note 1	SEN1N	0	0	1	note 2			8 to 15
note 1	SEN2N	0	1	0	note 2			16 to 23
note 1	SEN3N	0	1	1	note 2			24 to 31
note 1	SEN4N	1	0	0	note 2			32 to 39
note 1	SEN5N	1	0	1	note 2			40 to 47
note 1	SEN6N	1	1	0	note 2			48 to 55
note 1	SEN5N and SEN6N	1	1	1	note 2			56 to 63

Notes

1. The complete matrix drive as shown above for SEN0N is also applicable for the matrix sense inputs SEN1N to SEN6N and the combined SEN5N/SEN6N.
2. The C, B and A codes are identical to SEN0N as given above.

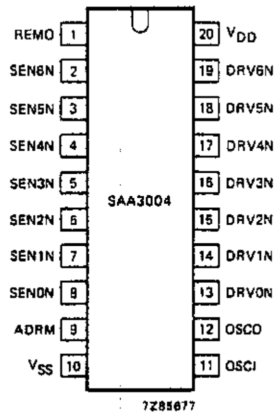


Fig.6 Pinning diagram.

PINNING

1	REMO	remote data output
2	SEN6N	key matrix sense inputs
3	SEN5N	
4	SEN4N	
5	SEN3N	
6	SEN2N	
7	SEN1N	
8	SEN0N	
9	ADRM	address mode control input
10	V_{SS}	ground
11	OSCI	oscillator input
12	OSCO	oscillator output
13	DRV0N	key matrix drive outputs
14	DRV1N	
15	DRV2N	
16	DRV3N	
17	DRV4N	
18	DRV5N	
19	DRV6N	
20	V_{DD}	positive supply

RATINGS

Limiting values in accordance with the Absolute Maximum System (IEC 134)

Supply voltage range	V_{DD}	−0,5 to +15		V
Input voltage range	V_I	−0,5 to V_{DD} +0,5		V
Output voltage range	V_O	−0,5 to V_{DD} +0,5		V
D.C. current into any input or output	± I	max.	10	mA
Peak REMO output current during 10 µs; duty factor = 1%	$-I_{(REMO)M}$	max.	300	mA
Power dissipation per package for T_{amb} = −20 to +70 °C	P_{tot}	max.	200	mW
Storage temperature range	T_{stg}	−55 to +150		°C
Operating ambient temperature range	T_{amb}	−20 to +70		°C

CHARACTERISTICS

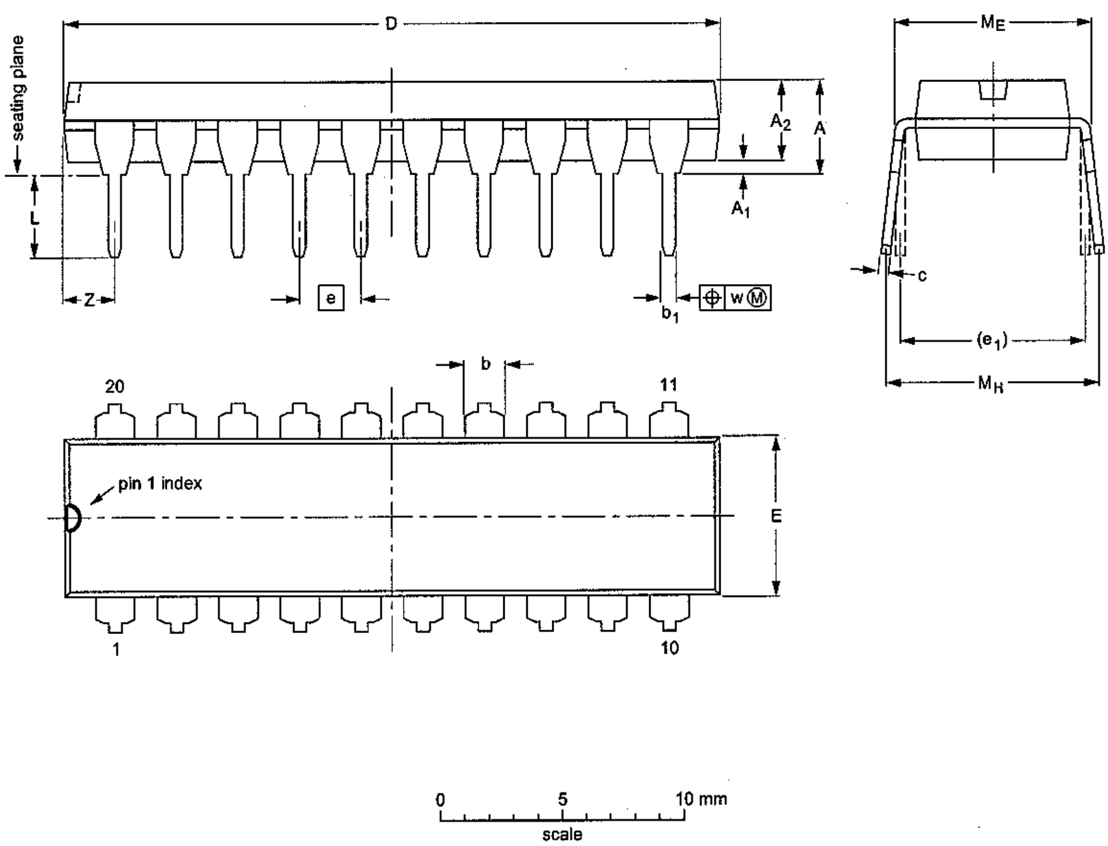
V_{SS} = 0 V; T_{amb} = 25 °C; unless otherwise specified

PARAMETER	V_{DD} (V)	SYMBOL	MIN.	TYP.	MAX.	UNIT
Supply voltage						
T_{amb} = 0 to +70 °C	–	V_{DD}	4	–	11	V
Supply current; active						
f_{OSC} = 455 kHz;	6	I_{DD}	–	1	–	mA
REMO output unloaded	9	I_{DD}	–	3	–	mA
Supply current; inactive						
(stand-by mode)	6	I_{DD}	–	–	2	µA
T_{amb} = 25 °C	9	I_{DD}	–	–	2	µA
Oscillator frequency						
(ceramic resonator)	4 to 11	f_{OSC}	400	–	500	kHz
Keyboard matrix						
Inputs SEN0N to SEN6N						
Input voltage LOW	4 to 11	V_{IL}	–	–	$0,2 \times V_{DD}$	V
Input voltage HIGH	4 to 11	V_{IH}	$0,8 \times V_{DD}$	–	–	V
Input current	4	$-I_I$	10	–	100	µA
V_I = 0 V	11	$-I_I$	30	–	300	µA
Input leakage current						
$V_I = V_{DD}$	11	I_I	–	–	1	µA
Outputs DRV0N to DRV6N						
Output voltage "ON"						
I_O = 0,1 mA	4	V_{OL}	–	–	0,3	V
I_O = 1,0 mA	11	V_{OL}	–	–	0,5	V
Output current "OFF"						
V_O = 11 V	11	I_O	–	–	10	µA
Control input ADRM						
Input voltage LOW	–	V_{IL}	–	–	$0,8 \times V_{DD}$	V
Input voltage HIGH	–	V_{IH}	$0,2 \times V_{DD}$	–	–	V
Input current (switched P- and N-channel pull-up/pull-down)						
Pull-up active	4	I_{IL}	10	–	100	µA
stand-by voltage: 0 V	11	I_{IL}	30	–	300	µA
Pull-down active	4	I_{IH}	10	–	100	µA
stand-by voltage: V_{DD}	11	I_{IH}	30	–	300	µA

PARAMETER	V_{DD} (V)	SYMBOL	MIN.	TYP.	MAX.	UNIT
Data output REMO						
Output voltage HIGH	6	V_{OH}	3	–	–	V
$-I_{OH}$ = 40 mA	9	V_{OH}	6	–	–	V
Output voltage LOW	6	V_{OL}	–	–	0,2	V
I_{OL} = 0,3 mA	9	V_{OL}	–	–	0,1	V
Oscillator						
Input current						
OSCI at V_{DD}	6	I_I	0,8	–	2,7	μA
Output voltage HIGH						
$-I_{OL}$ = 0,1 mA	6	V_{OH}	–	–	V_{DD}–06	V
Output voltage LOW						
I_{OH} = 0,1 mA	6	V_{OL}	–	–	0,6	V

PACKAGE OUTLINE

DIP20: plastic dual in-line package; 20 leads (300 mil) **SOT146-1**

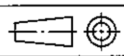


DIMENSIONS (inch dimensions are derived from the original mm dimensions)

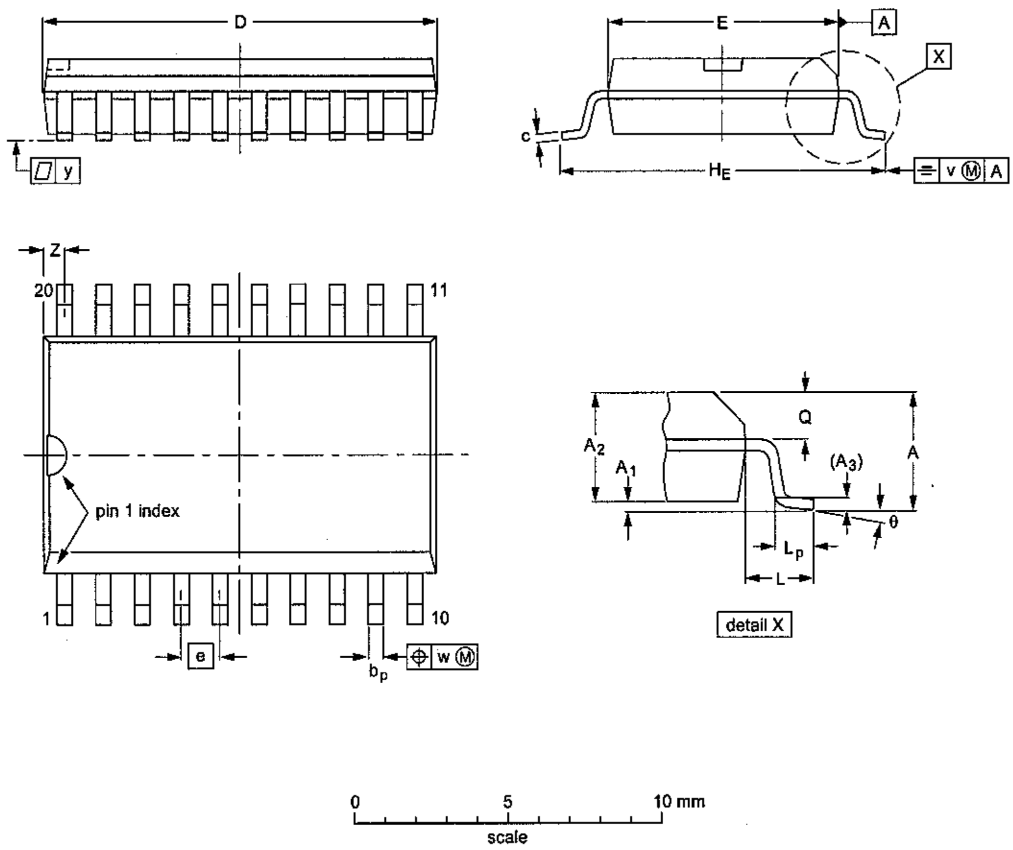
UNIT	A max.	A_1 min.	A_2 max.	b	b_1	c	D (1)	E (1)	e	e_1	L	M_E	M_H	w	Z (1) max.
mm	4.2	0.51	3.2	1.73 1.30	0.53 0.38	0.36 0.23	26.92 26.54	6.40 6.22	2.54	7.62	3.60 3.05	8.25 7.80	10.0 8.3	0.254	2.0
inches	0.17	0.020	0.13	0.068 0.051	0.021 0.015	0.014 0.009	1.060 1.045	0.25 0.24	0.10	0.30	0.14 0.12	0.32 0.31	0.39 0.33	0.01	0.078

Note

1. Plastic or metal protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT146-1			SC603			~~92-11-17~~ 95-05-24

SO20: plastic small outline package; 20 leads; body width 7.5 mm **SOT163-1**



DIMENSIONS (inch dimensions are derived from the original mm dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	D(1)	E(1)	e	H_E	L	L_p	Q	v	w	y	Z(1)	θ
mm	2.65	0.30 0.10	2.45 2.25	0.25	0.49 0.36	0.32 0.23	13.0 12.6	7.6 7.4	1.27	10.65 10.00	1.4	1.1 0.4	1.1 1.0	0.25	0.25	0.1	0.9 0.4	8° 0°
inches	0.10	0.012 0.004	0.096 0.089	0.01	0.019 0.014	0.013 0.009	0.51 0.49	0.30 0.29	0.050	0.419 0.394	0.055	0.043 0.016	0.043 0.039	0.01	0.01	0.004	0.035 0.016	

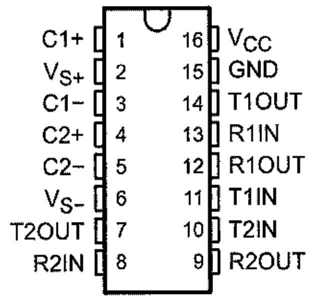
Note

1. Plastic or metal protrusions of 0.15 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT163-1	075E04	MS-013AC				~~95-01-24~~ 97-05-22

- **Meets or Exceeds TIA/EIA-232-F and ITU Recommendation V.28**
- **Operates From a Single 5-V Power Supply With 1.0-μF Charge-Pump Capacitors**
- **Operates Up To 120 kbit/s**
- **Two Drivers and Two Receivers**
- **±30-V Input Levels**
- **Low Supply Current . . . 8 mA Typical**
- **ESD Protection Exceeds JESD 22**
  - **2000-V Human-Body Model (A114-A)**
- **Upgrade With Improved ESD (15-kV HBM) and 0.1-μF Charge-Pump Capacitors is Available With the MAX202**
- **Applications**
  - **TIA/EIA-232-F, Battery-Powered Systems, Terminals, Modems, and Computers**

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



ɜscription/ordering information

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

ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP (N)	Tube of 25	MAX232N	MAX232N
	SOIC (D)	Tube of 40	MAX232D	MAX232
		Reel of 2500	MAX232DR	
	SOIC (DW)	Tube of 40	MAX232DW	MAX232
		Reel of 2000	MAX232DWR	
	SOP (NS)	Reel of 2000	MAX232NSR	MAX232
−40°C to 85°C	PDIP (N)	Tube of 25	MAX232IN	MAX232IN
	SOIC (D)	Tube of 40	MAX232ID	MAX232I
		Reel of 2500	MAX232IDR	
	SOIC (DW)	Tube of 40	MAX232IDW	MAX232I
		Reel of 2000	MAX232IDWR	

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

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Function Tables

EACH DRIVER

INPUT TIN	OUTPUT TOUT
L	H
H	L

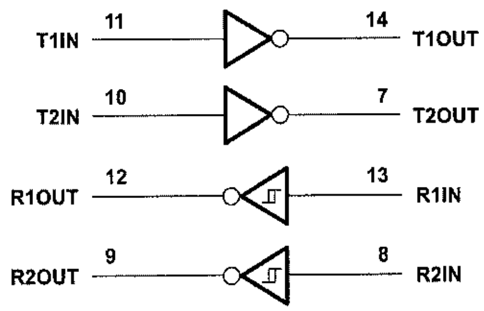
H = high level, L = low level

EACH RECEIVER

INPUT RIN	OUTPUT ROUT
L	H
H	L

H = high level, L = low level

diagram (positive logic)



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

Input supply voltage range, V_{CC} (see Note 1) .... −0.3 V to 6 V
Positive output supply voltage range, V_{S+} .... V_{CC} − 0.3 V to 15 V
Negative output supply voltage range, V_{S-} .... −0.3 V to −15 V
Input voltage range, V_I: Driver .... −0.3 V to V_{CC} + 0.3 V
Receiver .... ±30 V
Output voltage range, V_O: T1OUT, T2OUT .... V_{S-} − 0.3 V to V_{S+} + 0.3 V
R1OUT, R2OUT .... −0.3 V to V_{CC} + 0.3 V
Short-circuit duration: T1OUT, T2OUT .... Unlimited
Package thermal impedance, θ_{JA} (see Notes 2 and 3): D package .... 73°C/W
DW package .... 57°C/W
N package .... 67°C/W
NS package .... 64°C/W
Operating virtual junction temperature, T_J .... 150°C
Storage temperature range, T_{stg} .... −65°C to 150°C

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

ıTES: 1. All voltages are with respect to network GND.
2. Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.
3. The package thermal impedance is calculated in accordance with JESD 51-7.

commended operating conditions

			MIN	NOM	MAX	UNIT
ɔC	Supply voltage		4.5	5	5.5	V
H	High-level input voltage (T1IN,T2IN)		2			V
L	Low-level input voltage (T1IN, T2IN)				0.8	V
1IN, R2IN	Receiver input voltage				±30	V
\	Operating free-air temperature	MAX232	0		70	°C
		MAX232I	−40		85	

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

PARAMETER		TEST CONDITIONS	MIN	TYP‡	MAX	UNIT
ɔC	Supply current	V_{CC} = 5.5 V, All outputs open, T_A = 25°C		8	10	mA

ll typical values are at V_{CC} = 5 V and T_A = 25°C.
ΤE 4: Test conditions are C1−C4 = 1 µF at V_{CC} = 5 V ± 0.5 V.

DRIVER SECTION

cal characteristics over recommended ranges of supply voltage and operating free-air rature range (see Note 4)

PARAMETER		TEST CONDITIONS	MIN	TYP†	MAX	UNIT
High-level output voltage	T1OUT, T2OUT	R_L = 3 kΩ to GND	5	7		V
Low-level output voltage‡	T1OUT, T2OUT	R_L = 3 kΩ to GND		−7	−5	V
Output resistance	T1OUT, T2OUT	$V_{S+} = V_{S-} = 0$, $V_O = \pm 2$ V	300			Ω
Short-circuit output current	T1OUT, T2OUT	V_{CC} = 5.5 V, $V_O = 0$		±10		mA
Short-circuit input current	T1IN, T2IN	$V_I = 0$			200	μA

al values are at V_{CC} = 5 V, T_A = 25°C.
ebraic convention, in which the least-positive (most negative) value is designated minimum, is used in this data sheet for logic voltage nly.
·e than one output should be shorted at a time.
Test conditions are C1−C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

ing characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 4)

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

Test conditions are C1−C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

RECEIVER SECTION

cal characteristics over recommended ranges of supply voltage and operating free-air rature range (see Note 4)

PARAMETER		TEST CONDITIONS	MIN	TYP†	MAX	UNIT
High-level output voltage	R1OUT, R2OUT	I_{OH} = −1 mA	3.5			V
Low-level output voltage‡	R1OUT, R2OUT	I_{OL} = 3.2 mA			0.4	V
Receiver positive-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C		1.7	2.4	V
Receiver negative-going input threshold voltage	R1IN, R2IN	V_{CC} = 5 V, T_A = 25°C	0.8	1.2		V
Input hysteresis voltage	R1IN, R2IN	V_{CC} = 5 V	0.2	0.5	1	V
Receiver input resistance	R1IN, R2IN	V_{CC} = 5, T_A = 25°C	3	5	7	kΩ

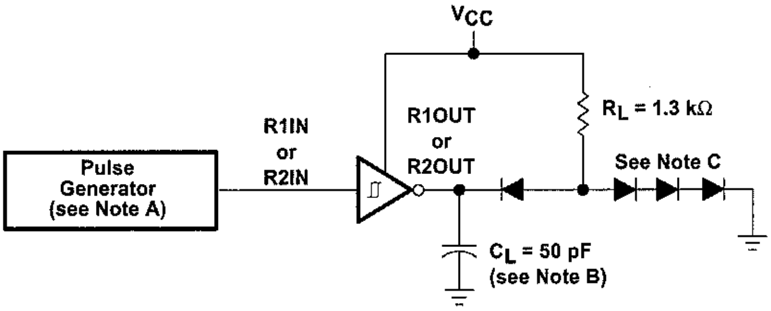
al values are at V_{CC} = 5 V, T_A = 25°C.
ebraic convention, in which the least-positive (most negative) value is designated minimum, is used in this data sheet for logic voltage nly.
Test conditions are C1−C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

ing characteristics, V_{CC} = 5 V, T_A = 25°C (see Note 4 and Figure 1)

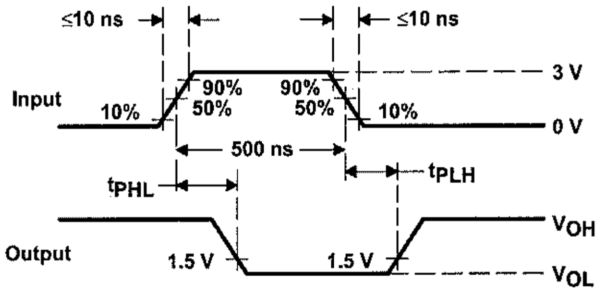
PARAMETER	TYP	UNIT
Receiver propagation delay time, low- to high-level output	500	ns
Receiver propagation delay time, high- to low-level output	500	ns

Test conditions are C1−C4 = 1 μF at V_{CC} = 5 V ± 0.5 V.

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT

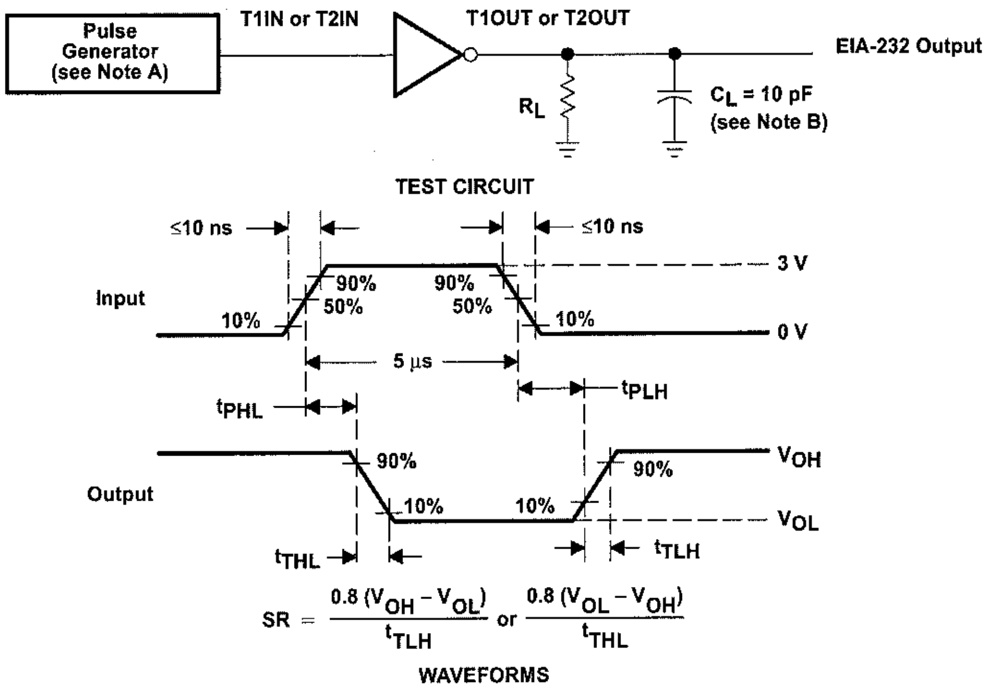


WAVEFORMS

)TES: A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.
C. All diodes are 1N3064 or equivalent.

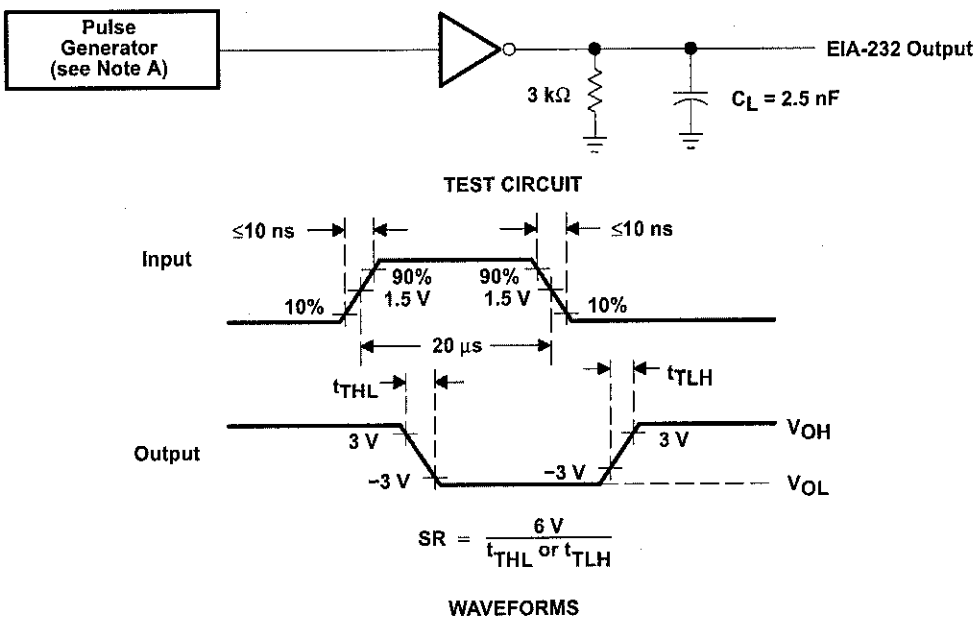
Figure 1. Receiver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements

PARAMETER MEASUREMENT INFORMATION



A. The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.
B. C_L includes probe and jig capacitance.

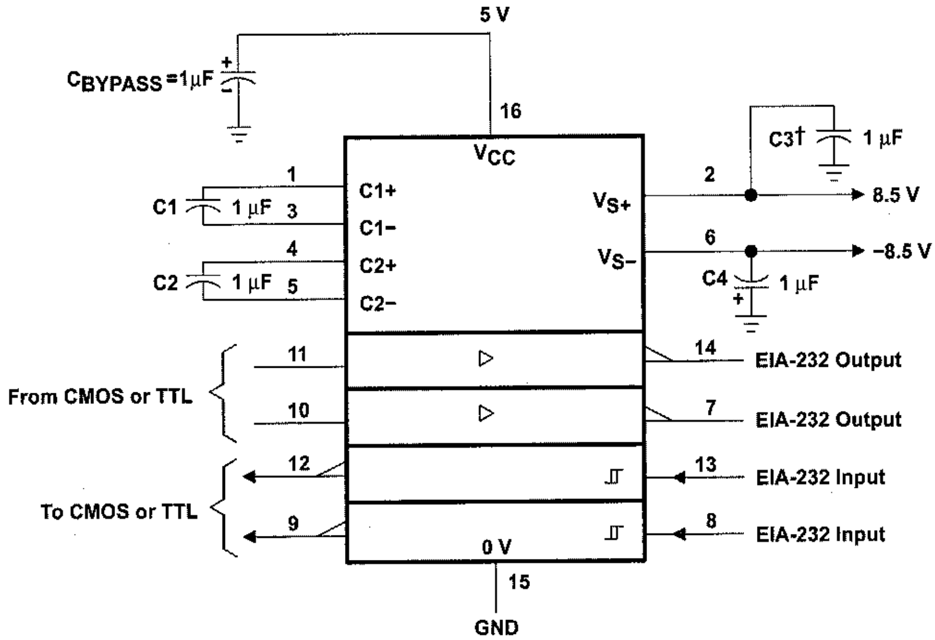
Figure 2. Driver Test Circuit and Waveforms for t_{PHL} and t_{PLH} Measurements (5-µs Input)



.: The pulse generator has the following characteristics: Z_O = 50 Ω, duty cycle ≤ 50%.

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

APPLICATION INFORMATION



† C3 can be connected to V_{CC} or GND.

NOTES: A. Resistor values shown are nominal.

B. Nonpolarized ceramic capacitors are acceptable. If polarized tantalum or electrolytic capacitors are used, they should be connected as shown. In addition to the 1-µF capacitors shown, the MAX202 can operate with 0.1-µF capacitors.

Figure 4. Typical Operating Circuit

CKAGING INFORMATION

Orderable Device	Status [(1)]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [(2)]	Lead/Ball Finish	MSL Peak Temp [(3)]
MAX232D	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DE4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DR	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DRE4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DW	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DWE4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DWR	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232DWRE4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232ID	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDE4	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDR	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDRE4	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDW	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDWE4	ACTIVE	SOIC	DW	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDWR	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IDWRE4	ACTIVE	SOIC	DW	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232IN	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	Level-NC-NC-NC
MAX232INE4	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	Level-NC-NC-NC
MAX232N	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	Level-NC-NC-NC
MAX232NE4	ACTIVE	PDIP	N	16	25	Pb-Free (RoHS)	CU NIPDAU	Level-NC-NC-NC
MAX232NSR	ACTIVE	SO	NS	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
MAX232NSRE4	ACTIVE	SO	NS	16	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM

'he marketing status values are defined as follows:
TIVE: Product device recommended for new designs.
EBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
ND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in ɜw design.
EVIEW: Device has been announced but is not in production. Samples may or may not be available.

;OLETE: TI has discontinued the production of the device.

Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS) or Green (RoHS & no Sb/Br) - please check //www.ti.com/productcontent for the latest availability information and additional product content details.
': The Pb-Free/Green conversion plan has not been defined.
'ree (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements ıll 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered gh temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
ən (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame 'dants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

ISL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder ›erature.

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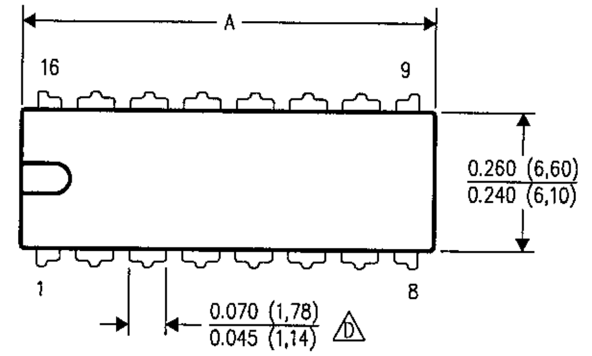
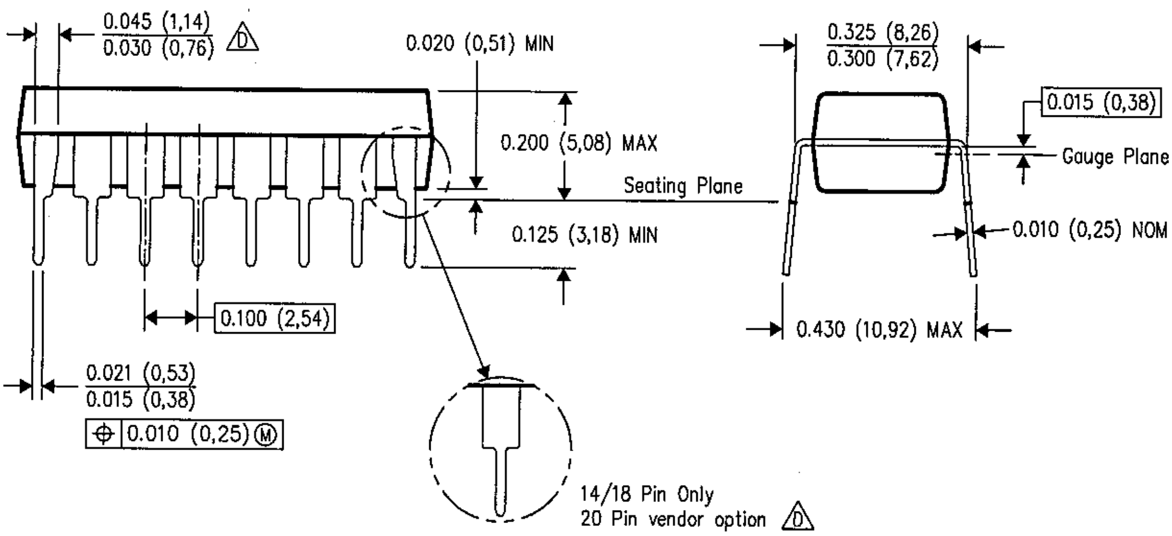
› event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI ustomer on an annual basis.

(R–PDIP–T**) PLASTIC DUAL–IN–LINE PACKAGE

PINS SHOWN



PINS ** / DIM	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23,37)	1.060 (26,92)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21,59)	0.940 (23,88)
△C MS–001 VARIATION	AA	BB	AC	AD

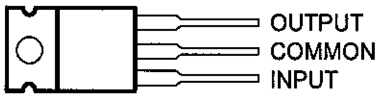


4040049/E 12/2002

ES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
△C Falls within JEDEC MS–001, except 18 and 20 pin minimum body length (Dim A).
△D The 20 pin end lead shoulder width is a vendor option, either half or full width.

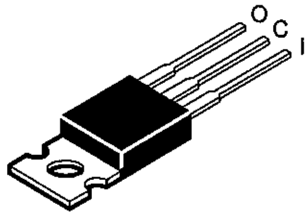
- **3-Terminal Regulators**
- **Output Current up to 1.5 A**
- **Internal Thermal-Overload Protection**
- **High Power-Dissipation Capability**
- **Internal Short-Circuit Current Limiting**
- **Output Transistor Safe-Area Compensation**
- **Direct Replacements for Fairchild µA7800 Series**

KC PACKAGE
(TOP VIEW)

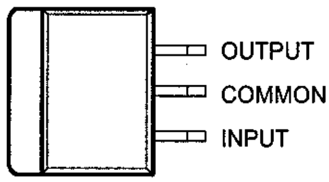


The COMMON terminal is in electrical contact with the mounting base.

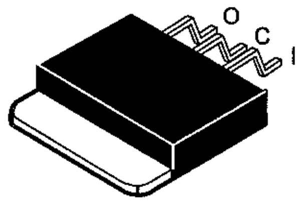
TO-220AB



KTE PACKAGE
(TOP VIEW)



The COMMON terminal is in electrical contact with the mounting base.



escription

This series of fixed-voltage monolithic integrated-circuit voltage regulators is designed for a wide range of applications. These applications include on-card regulation for elimination of noise and distribution problems associated with single-point regulation. Each of these regulators can deliver up to 1.5 A of output current. The internal current-limiting and thermal-shutdown features of these regulators essentially make them immune to overload. In addition to use as fixed-voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents, and also can be used as the power-pass element in precision regulators.

The µA7800C series is characterized for operation over the virtual junction temperature range of 0°C to 125°C.

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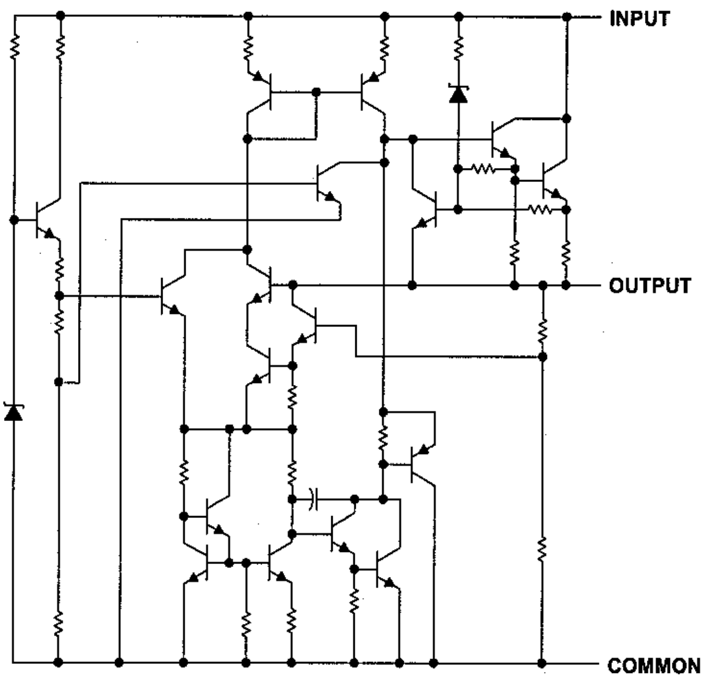
AVAILABLE OPTIONS

T_J	$V_{O(NOM)}$ (V)	PACKAGED DEVICES PLASTIC FLANGE-MOUNT (KC)	PACKAGED DEVICES HEAT-SINK MOUNTED (KTE)	CHIP FORM (Y)
0°C to 125°C	5	µA7805CKC	µA7805CKTE	µA7805Y
	6	µA7806CKC	µA7806CKTE	µA7806Y
	8	µA7808CKC	µA7808CKTE	µA7808Y
	8.5	µA7885CKC	µA7885CKTE	µA7885Y
	10	µA7810CKC	µA7810CKTE	µA7810Y
	12	µA7812CKC	µA7812CKTE	µA7812Y
	15	µA7815CKC	µA7815CKTE	µA7815Y
	18	µA7818CKC	µA7818CKTE	µA7818Y
	24	µA7824CKC	µA7824CKTE	µA7824Y

The KTE package is only available taped and reeled. Add the suffix R to the device type (e.g., µA7805CKTER). Chip forms are tested at 25°C.

natic



bsolute maximum ratings over operating temperature ranges (unless otherwise noted)†

		µA78xx	UNIT
Input voltage, V_I	µA7824C	40	V
	All others	35	
Virtual junction temperature range, T_J		0 to 150	°C
Package thermal impedance, θ_{JA} (see Notes 1 and 2)	KC package	22	°C
	KTE package	23	
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds		260	°C
Storage temperature range, T_{stg}		–65 to 150	°C

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

OTES: 1. Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) – T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can impact reliability. Due to variations in individual device electrical characteristics and thermal resistance, the built-in thermal overload protection may be activated at power levels slightly above or below the rated dissipation.

2. The package thermal impedance is calculated in accordance with JESD 51, except for through-hole packages, which use a trace length of zero.

ecommended operating conditions

		MIN	MAX	UNIT
Input voltage, V_I	µA7805C	7	25	V
	µA7806C	8	25	
	µA7808C	10.5	25	
	µA7885C	10.5	25	
	µA7810C	12.5	28	
	µA7812C	14.5	30	
	µA7815C	17.5	30	
	µA7818C	21	33	
	µA7824C	27	38	
Output current, I_O			1.5	A
Operating virtual junction temperature, T_J	µA7800C series	0	125	°C

rical characteristics at specified virtual junction temperature, V_I = 10 V, I_O = 500 mA (unless wise noted)

PARAMETER	TEST CONDITIONS		T_J†	µA7805C MIN	µA7805C TYP	µA7805C MAX	UNIT
it voltage	I_O = 5 mA to 1 A, $P_D \leq$ 15 W	V_I = 7 V to 20 V,	25°C	4.8	5	5.2	V
			0°C to 125°C	4.75		5.25	
voltage regulation	V_I = 7 V to 25 V		25°C		3	100	mV
	V_I = 8 V to 12 V				1	50	
ɜ rejection	V_I = 8 V to 18 V,	f = 120 Hz	0°C to 125°C	62	78		dB
it voltage regulation	I_O = 5 mA to 1.5 A		25°C		15	100	mV
	I_O = 250 mA to 750 mA				5	50	
it resistance	f = 1 kHz		0°C to 125°C		0.017		Ω
ɜrature coefficient of output voltage	I_O = 5 mA		0°C to 125°C		−1.1		mV/°C
it noise voltage	f = 10 Hz to 100 kHz		25°C		40		µV
ıut voltage	I_O = 1 A		25°C		2		V
urrent			25°C		4.2	8	mA
urrent change	V_I = 7 V to 25 V		0°C to 125°C			1.3	mA
	I_O = 5 mA to 1 A					0.5	
circuit output current			25°C		750		mA
ɔutput current			25°C		2.2		A

testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ıt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

ical characteristics at specified virtual junction temperature, V_I = 11 V, I_O = 500 mA (unless wise noted)

PARAMETER	TEST CONDITIONS		T_J†	µA7806C MIN	µA7806C TYP	µA7806C MAX	UNIT
t voltage	I_O = 5 mA to 1 A, $P_D \leq$ 15 W	V_I = 8 V to 21 V,	25°C	5.75	6	6.25	V
			0°C to 125°C	5.7		6.3	
ɾoltage regulation	V_I = 8 V to 25 V		25°C		5	120	mV
	V_I = 9 V to 13 V				1.5	60	
rejection	V_I = 9 V to 19 V,	f = 120 Hz	0°C to 125°C	59	75		dB
t voltage regulation	I_O = 5 mA to 1.5 A		25°C		14	120	mV
	I_O = 250 mA to 750 mA				4	60	
t resistance	f = 1 kHz		0°C to 125°C		0.019		Ω
ɪrature coefficient of output voltage	I_O = 5 mA		0°C to 125°C		−0.8		mV/°C
t noise voltage	f = 10 Hz to 100 kHz		25°C		45		µV
ɹt voltage	I_O = 1 A		25°C		2		V
ɹrrent			25°C		4.3	8	mA
ɹrrent change	V_I = 8 V to 25 V		0°C to 125°C			1.3	mA
	I_O = 5 mA to 1 A					0.5	
ɔircuit output current			25°C		550		mA
ɔutput current			25°C		2.2		A

:esting techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ıt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

lectrical characteristics at specified virtual junction temperature, V_I = 14 V, I_O = 500 mA (unless therwise noted)

PARAMETER	TEST CONDITIONS	T_J†	μA7808C MIN	μA7808C TYP	μA7808C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, V_I = 10.5 V to 23 V, $P_D \leq$ 15 W	25°C	7.7	8	8.3	V
		0°C to 125°C	7.6		8.4	
Input voltage regulation	V_I = 10.5 V to 25 V	25°C		6	160	mV
	V_I = 11 V to 17 V			2	80	
Ripple rejection	V_I = 11.5 V to 21.5 V, f = 120 Hz	0°C to 125°C	55	72		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	160	mV
	I_O = 250 mA to 750 mA			4	80	
Output resistance	f = 1 kHz	0°C to 125°C		0.016		Ω
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–0.8		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		52		μV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.3	8	mA
Bias current change	V_I = 10.5 V to 25 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		450		mA
Peak output current		25°C		2.2		A

Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

lectrical characteristics at specified virtual junction temperature, V_I = 15 V, I_O = 500 mA (unless therwise noted)

PARAMETER	TEST CONDITIONS	T_J†	μA7885C MIN	μA7885C TYP	μA7885C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, V_I = 11 V to 23.5 V, $P_D \leq$ 15 W	25°C	8.15	8.5	8.85	V
		0°C to 125°C	8.1		8.9	
Input voltage regulation	V_I = 10.5 V to 25 V	25°C		6	170	mV
	V_I = 11 V to 17 V			2	85	
Ripple rejection	V_I = 11.5 V to 21.5 V, f = 120 Hz	0°C to 125°C	54	70		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	170	mV
	I_O = 250 mA to 750 mA			4	85	
Output resistance	f = 1 kHz	0°C to 125°C		0.016		Ω
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–0.8		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		55		μV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.3	8	mA
Bias current change	V_I = 10.5 V to 25 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		450		mA
Peak output current		25°C		2.2		A

Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

rical characteristics at specified virtual junction temperature, V_I = 17 V, I_O = 500 mA (unless 'wise noted)

PARAMETER	TEST CONDITIONS	T_J†	µA7810C MIN	µA7810C TYP	µA7810C MAX	UNIT
ıt voltage	I_O = 5 mA to 1 A, V_I = 12.5 V to 25 V, $P_D \leq$ 15 W	25°C	9.6	10	10.4	V
		0°C to 125°C	9.5	10	10.5	
voltage regulation	V_I = 12.5 V to 28 V	25°C		7	200	mV
	V_I = 14 V to 20 V			2	100	
ə rejection	V_I = 13 V to 23 V, f = 120 Hz	0°C to 125°C	55	71		dB
ıt voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	200	mV
	I_O = 250 mA to 750 mA			4	100	
ıt resistance	f = 1 kHz	0°C to 125°C		0.018		W
erature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–1		mV/°C
ıt noise voltage	f = 10 Hz to 100 kHz	25°C		70		µV
›ut voltage	I_O = 1 A	25°C		2		V
ːurrent		25°C		4.3	8	mA
ːurrent change	V_I = 12.5 V to 28 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
-circuit output current		25°C		400		mA
output current		25°C		2.2		A

-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ınt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

rical characteristics at specified virtual junction temperature, V_I = 19 V, I_O = 500 mA (unless 'wise noted)

PARAMETER	TEST CONDITIONS	T_J†	µA7812C MIN	µA7812C TYP	µA7812C MAX	UNIT
ut voltage	I_O = 5 mA to 1 A, V_I = 14.5 V to 27 V, $P_D \leq$ 15 W	25°C	11.5	12	12.5	V
		0°C to 125°C	11.4		12.6	
voltage regulation	V_I = 14.5 V to 30 V	25°C		10	240	mV
	V_I = 16 V to 22 V			3	120	
e rejection	V_I = 15 V to 25 V, f = 120 Hz	0°C to 125°C	55	71		dB
ut voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	240	mV
	I_O = 250 mA to 750 mA			4	120	
ut resistance	f = 1 kHz	0°C to 125°C		0.018		W
›erature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–1		mV/°C
ut noise voltage	f = 10 Hz to 100 kHz	25°C		75		µV
out voltage	I_O = 1 A	25°C		2		V
current		25°C		4.3	8	mA
current change	V_I = 14.5 V to 30 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
t-circuit output current		25°C		350		mA
output current		25°C		2.2		A

ɜ-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ınt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

lectrical characteristics at specified virtual junction temperature, V_I = 23 V, I_O = 500 mA (unless therwise noted)

PARAMETER	TEST CONDITIONS	T_J†	µA7815C			UNIT
			MIN	TYP	MAX	
Output voltage	I_O = 5 mA to 1 A, V_I = 17.5 V to 30 V, $P_D \leq$ 15 W	25°C	14.4	15	15.6	V
		0°C to 125°C	14.25		15.75	
Input voltage regulation	V_I = 17.5 V to 30 V	25°C		11	300	mV
	V_I = 20 V to 26 V			3	150	
Ripple rejection	V_I = 18.5 V to 28.5 V, f = 120 Hz	0°C to 125°C	54	70		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	300	mV
	I_O = 250 mA to 750 mA			4	150	
Output resistance	f = 1 kHz	0°C to 125°C		0.019		W
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		90		µV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.4	8	mA
Bias current change	V_I = 17.5 V to 30 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		230		mA
Peak output current		25°C		2.1		A

Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

lectrical characteristics at specified virtual junction temperature, V_I = 27 V, I_O = 500 mA (unless therwise noted)

PARAMETER	TEST CONDITIONS	T_J†	µA7818C			UNIT
			MIN	TYP	MAX	
Output voltage	I_O = 5 mA to 1 A, V_I = 21 V to 33 V, $P_D \leq$ 15 W	25°C	17.3	18	18.7	V
		0°C to 125°C	17.1		18.9	
Input voltage regulation	V_I = 21 V to 33 V	25°C		15	360	mV
	V_I = 24 V to 30 V			5	180	
Ripple rejection	V_I = 22 V to 32 V, f = 120 Hz	0°C to 125°C	53	69		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	360	mV
	I_O = 250 mA to 750 mA			4	180	
Output resistance	f = 1 kHz	0°C to 125°C		0.022		W
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		110		µV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.5	8	mA
Bias current change	V_I = 21 V to 33 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		200		mA
Peak output current		25°C		2.1		A

Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

rical characteristics at specified virtual junction temperature, V_I = 33 V, I_O = 500 mA (unless rwise noted)

PARAMETER	TEST CONDITIONS		T_J†	µA7824C			UNIT
				MIN	TYP	MAX	
ut voltage	I_O = 5 mA to 1 A, P_D ≤ 15 W	V_I = 27 V to 38 V,	25°C	23	24	25	V
			0°C to 125°C	22.8		25.2	
voltage regulation	V_I = 27 V to 38 V		25°C		18	480	mV
	V_I = 30 V to 36 V				6	240	
e rejection	V_I = 28 V to 38 V,	f = 120 Hz	0°C to 125°C	50	66		dB
ut voltage regulation	I_O = 5 mA to 1.5 A		25°C		12	480	mV
	I_O = 250 mA to 750 mA				4	240	
ut resistance	f = 1 kHz		0°C to 125°C		0.028		W
›erature coefficient of output voltage	I_O = 5 mA		0°C to 125°C		–1.5		mV/°C
ut noise voltage	f = 10 Hz to 100 kHz		25°C		170		µV
out voltage	I_O = 1 A		25°C		2		V
current			25°C		4.6	8	mA
current change	V_I = 27 V to 38 V		0°C to 125°C			1	mA
	I_O = 5 mA to 1 A					0.5	
t-circuit output current			25°C		150		mA
output current			25°C		2.1		A

›-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ınt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

rical characteristics at specified virtual junction temperature, V_I = 10 V, I_O = 500 mA, T_J = 25°C ›ss otherwise noted)†

PARAMETER	TEST CONDITIONS		µA7805Y			UNIT
			MIN	TYP	MAX	
ut voltage				5		V
voltage regulation	V_I = 7 V to 25 V			3		mV
	V_I = 8 V to 12 V			1		
e rejection	V_I = 8 V to 18 V,	f = 120 Hz		78		dB
ut voltage regulation	I_O = 5 mA to 1.5 A			15		mV
	I_O = 250 mA to 750 mA			5		
ut resistance	f = 1 kHz			0.017		W
›erature coefficient of output voltage	I_O = 5 mA			–1.1		mV/°C
ut noise voltage	f = 10 Hz to 100 kHz			40		µV
out voltage	I_O = 1 A			2		V
current				4.2		mA
t-circuit output current				750		mA
output current				2.2		A

›-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into unt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 11 V, I_O = 500 mA, T_J = 25°C (unless otherwise noted)†

PARAMETER	TEST CONDITIONS	μA7806Y MIN	TYP	MAX	UNIT
Output voltage			6		V
Input voltage regulation	V_I = 8 V to 25 V		5		mV
	V_I = 9 V to 13 V		1.5		
Ripple rejection	V_I = 9 V to 19 V, f = 120 Hz		75		dB
Output voltage regulation	I_O = 5 mA to 1.5 A		14		mV
	I_O = 250 mA to 750 mA		4		
Output resistance	f = 1 kHz		0.019		W
Temperature coefficient of output voltage	I_O = 5 mA		–0.8		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz		45		μV
Dropout voltage	I_O = 1 A		2		V
Bias current			4.3		mA
Short-circuit output current			550		mA
Peak output current			2.2		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 14 V, I_O = 500 mA, T_J = 25°C (unless otherwise noted)†

PARAMETER	TEST CONDITIONS	μA7808Y MIN	TYP	MAX	UNIT
Output voltage			8		V
Input voltage regulation	V_I = 10.5 V to 25 V		6		mV
	V_I = 11 V to 17 V		2		
Ripple rejection	V_I = 11.5 V to 21.5 V, f = 120 Hz		72		dB
Output voltage regulation	I_O = 5 mA to 1.5 A		12		mV
	I_O = 250 mA to 750 mA		4		
Output resistance	f = 1 kHz		0.016		W
Temperature coefficient of output voltage	I_O = 5 mA		–0.8		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz		52		μV
Dropout voltage	I_O = 1 A		2		V
Bias current			4.3		mA
Short-circuit output current			450		mA
Peak output current			2.2		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

rical characteristics at specified virtual junction temperature, $V_I = 15$ V, $I_O = 500$ mA, $T_J = 25°C$ ss otherwise noted)†

PARAMETER	TEST CONDITIONS		µA7885Y MIN	µA7885Y TYP	µA7885Y MAX	UNIT
ıt voltage				8.5		V
voltage regulation	V_I = 10.5 V to 25 V			6		mV
	V_I = 11 V to 17 V			2		mV
e rejection	V_I = 11.5 V to 21.5 V,	f = 120 Hz		70		dB
ıt voltage regulation	I_O = 5 mA to 1.5 A			12		mV
	I_O = 250 mA to 750 mA			4		mV
ıt resistance	f = 1 kHz			0.016		W
erature coefficient of output voltage	I_O = 5 mA			–0.8		mV/°C
ıt noise voltage	f = 10 Hz to 100 kHz			55		µV
ɔut voltage	I_O = 1 A			2		V
current				4.3		mA
-circuit output current				450		mA
output current				2.2		A

-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into nt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

rical characteristics at specified virtual junction temperature, $V_I = 17$ V, $I_O = 500$ mA, $T_J = 25°C$ ss otherwise noted)†

PARAMETER	TEST CONDITIONS		µA7810Y MIN	µA7810Y TYP	µA7810Y MAX	UNIT
ıt voltage				10		V
voltage regulation	V_I = 12.5 V to 28 V			7		mV
	V_I = 14 V to 20 V			2		mV
ɛ rejection	V_I = 13 V to 23 V,	f = 120 Hz		71		dB
ıt voltage regulation	I_O = 5 mA to 1.5 A			12		mV
	I_O = 250 mA to 750 mA			4		mV
ıt resistance	f = 1 kHz			0.018		W
erature coefficient of output voltage	I_O = 5 mA			–1		mV/°C
t noise voltage	f = 10 Hz to 100 kHz			70		µV
ut voltage	I_O = 1 A			2		V
urrent				4.3		mA
circuit output current				400		mA
ɔutput current				2.2		A

testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into nt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

lectrical characteristics at specified virtual junction temperature, V_I = 19 V, I_O = 500 mA, T_J = 25°C unless otherwise noted)†

PARAMETER	TEST CONDITIONS		μA7812Y		UNIT
		MIN	TYP	MAX	
Output voltage			12		V
Input voltage regulation	V_I = 14.5 V to 30 V		10		mV
	V_I = 16 V to 22 V		3		
Ripple rejection	V_I = 15 V to 25 V, f = 120 Hz		71		dB
Output voltage regulation	I_O = 5 mA to 1.5 A		12		mV
	I_O = 250 mA to 750 mA		4		
Output resistance	f = 1 kHz		0.018		W
Temperature coefficient of output voltage	I_O = 5 mA		–1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz		75		μV
Dropout voltage	I_O = 1 A		2		V
Bias current			4.3		mA
Short-circuit output current			350		mA
Peak output current			2.2		A

Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

lectrical characteristics at specified virtual junction temperature, V_I = 23 V, I_O = 500 mA, T_J = 25°C unless otherwise noted)†

PARAMETER	TEST CONDITIONS		μA7815Y		UNIT
		MIN	TYP	MAX	
Output voltage			15		V
Input voltage regulation	V_I = 17.5 V to 30 V		11		mV
	V_I = 20 V to 26 V		3		
Ripple rejection	V_I = 18.5 V to 28.5 V, f = 120 Hz		70		dB
Output voltage regulation	I_O = 5 mA to 1.5 A		12		mV
	I_O = 250 mA to 750 mA		4		
Output resistance	f = 1 kHz		0.019		W
Temperature coefficient of output voltage	I_O = 5 mA		–1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz		90		μV
Dropout voltage	I_O = 1 A		2		V
Bias current			4.4		mA
Short-circuit output current			230		mA
Peak output current			2.1		A

Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

rical characteristics at specified virtual junction temperature, $V_I = 27$ V, $I_O = 500$ mA, $T_J = 25°C$ ss otherwise noted)†

PARAMETER	TEST CONDITIONS		µA7818Y MIN	TYP	MAX	UNIT
ut voltage				18		V
voltage regulation	V_I = 21 V to 33 V			15		mV
	V_I = 24 V to 30 V			5		
e rejection	V_I = 22 V to 32 V,	f = 120 Hz		69		dB
ut voltage regulation	I_O = 5 mA to 1.5 A			12		mV
	I_O = 250 mA to 750 mA			4		
ut resistance	f = 1 kHz			0.022		W
erature coefficient of output voltage	I_O = 5 mA			–1		mV/°C
ut noise voltage	f = 10 Hz to 100 kHz			110		µV
out voltage	I_O = 1 A			2		V
current				4.5		mA
t-circuit output current				200		mA
output current				2.1		A

-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ınt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

rical characteristics at specified virtual junction temperature, $V_I = 33$ V, $I_O = 500$ mA, $T_J = 25°C$ ss otherwise noted)†

PARAMETER	TEST CONDITIONS		µA7824Y MIN	TYP	MAX	UNIT
ut voltage				24		V
voltage regulation	V_I = 27 V to 38 V			18		mV
	V_I = 30 V to 36 V			6		
e rejection	V_I = 28 V to 38 V,	f = 120 Hz		66		dB
ut voltage regulation	I_O = 5 mA to 1.5 A			12		mV
	I_O = 250 mA to 750 mA			4		
ut resistance	f = 1 kHz			0.028		W
erature coefficient of output voltage	I_O = 5 mA			–1.5		mV/°C
ut noise voltage	f = 10 Hz to 100 kHz			170		µV
out voltage	I_O = 1 A			2		V
current				4.6		mA
t-circuit output current				150		mA
output current				2.1		A

-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into ınt separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

APPLICATION INFORMATION

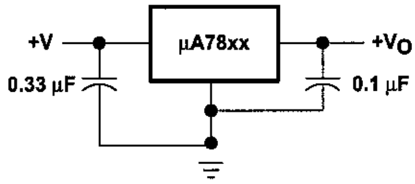


Figure 1. Fixed-Output Regulator

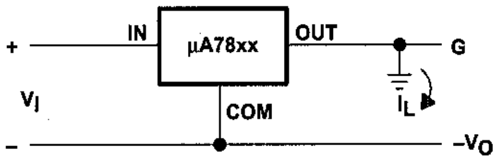
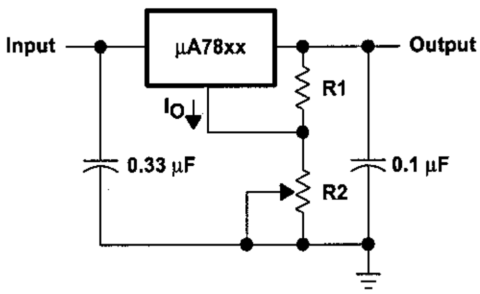


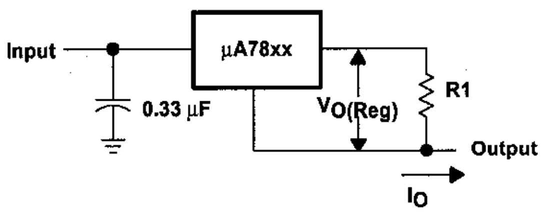
Figure 2. Positive Regulator in Negative Configuration (V_I Must Float)



NOTE A: The following formula is used when V_{XX} is the nominal output voltage (output to common) of the fixed regulator:

$$V_O = V_{xx} + \left(\frac{V_{xx}}{R1} + I_Q\right)R2$$

Figure 3. Adjustable-Output Regulator



$I_O = (V_O/R1) + I_O$ Bias Current

Figure 4. Current Regulator

APPLICATION INFORMATION

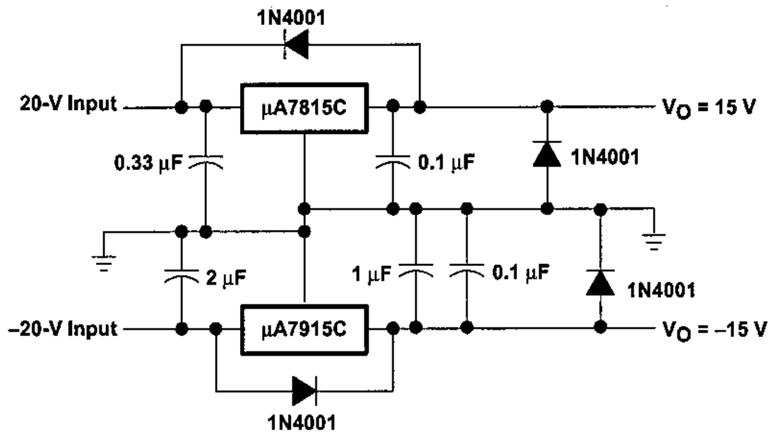


Figure 5. Regulated Dual Supply

ation with a load common to a voltage of opposite polarity

In many cases, a regulator powers a load that is not connected to ground but, instead, is connected to a voltage source of opposite polarity (e.g., operational amplifiers, level-shifting circuits, etc.). In these cases, a clamp diode should be connected to the regulator output as shown in Figure 6. This protects the regulator from output polarity reversals during startup and short-circuit operation.

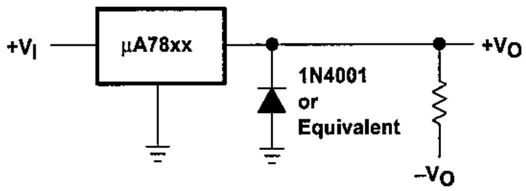


Figure 6. Output Polarity-Reversal-Protection Circuit

rse-bias protection

Occasionally, the input voltage to the regulator can collapse faster than the output voltage. This can occur, for example, when the input supply is crowbarred during an output overvoltage condition. If the output voltage is greater than approximately 7 V, the emitter-base junction of the series-pass element (internal or external) could break down and be damaged. To prevent this, a diode shunt can be used as shown in Figure 7.

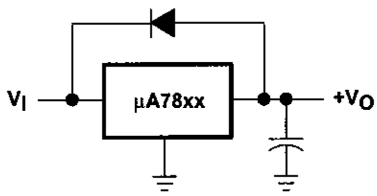
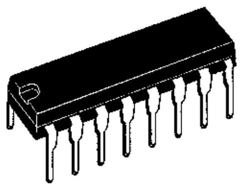


Figure 7. Reverse-Bias-Protection Circuit

ULN2001A-ULN2002A
ULN2003A-ULN2004A

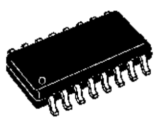
SEVEN DARLINGTON ARRAYS

- SEVEN DARLINGTONS PER PACKAGE
- OUTPUT CURRENT 500mA PER DRIVER (600mA PEAK)
- OUTPUT VOLTAGE 50V
- INTEGRATED SUPPRESSION DIODES FOR INDUCTIVE LOADS
- OUTPUTS CAN BE PARALLELED FOR HIGHER CURRENT
- TTL/CMOS/PMOS/DTL COMPATIBLE INPUTS
- INPUTS PINNED OPPOSITE OUTPUTS TO SIMPLIFY LAYOUT



DIP16

ORDERING NUMBERS: ULN2001A/2A/3A/4A



SO16

ORDERING NUMBERS: ULN2001D/2D/3D/4D

DESCRIPTION

The ULN2001A, ULN2002A, ULN2003 and ULN2004A are high voltage, high current darlington arrays each containing seven open collector darlington pairs with common emitters. Each channel rated at 500mA and can withstand peak currents of 600mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout.

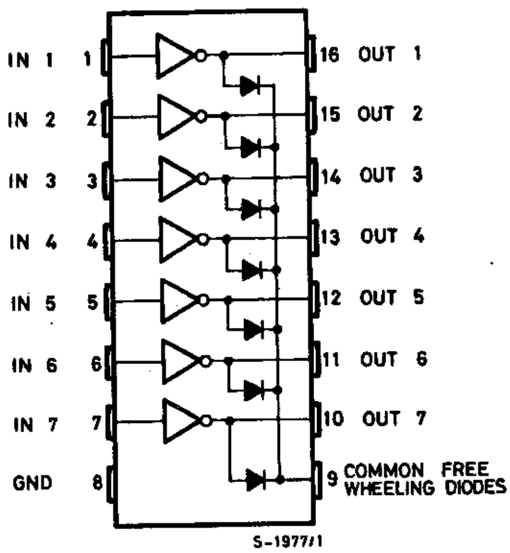
The four versions interface to all common logic families :

ULN2001A	General Purpose, DTL, TTL, PMOS, CMOS
ULN2002A	14-25V PMOS
ULN2003A	5V TTL, CMOS
ULN2004A	6–15V CMOS, PMOS

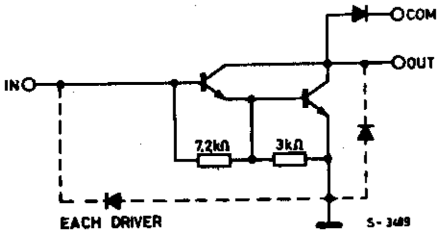
These versatile devices are useful for driving a wide range of loads including solenoids, relays DC motors, LED displays filament lamps, thermal printheads and high power buffers.

The ULN2001A/2002A/2003A and 2004A are supplied in 16 pin plastic DIP packages with a copper leadframe to reduce thermal resistance. They are available also in small outline package (SO-16) as ULN2001D/2002D/2003D/2004D.

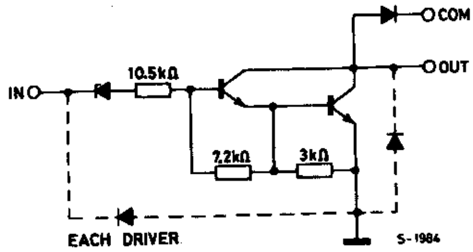
PIN CONNECTION



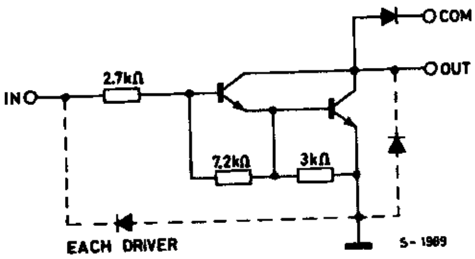
SCHEMATIC DIAGRAM



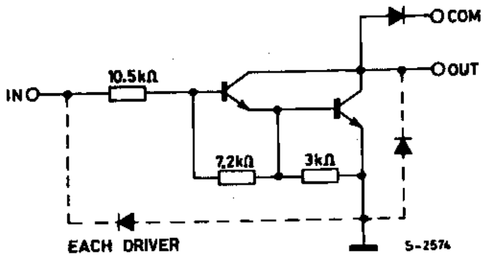
Series ULN-2001A
(each driver)



Series ULN-2002A
(each driver)



Series ULN-2003A
(each driver)



Series ULN-2004A
(each driver)

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_o	Output Voltage	50	V
V_{in}	Input Voltage (for ULN2002A/D - 2003A/D - 2004A/D)	30	V
I_c	Continuous Collector Current	500	mA
I_b	Continuous Base Current	25	mA
T_{amb}	Operating Ambient Temperature Range	– 20 to 85	°C
T_{stg}	Storage Temperature Range	– 55 to 150	°C
T_j	Junction Temperature	150	°C

THERMAL DATA

Symbol	Parameter		DIP16	SO16	Unit
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-ambient	Max.	70	120	°C/W

TEST CIRCUITS

Figure 1a.

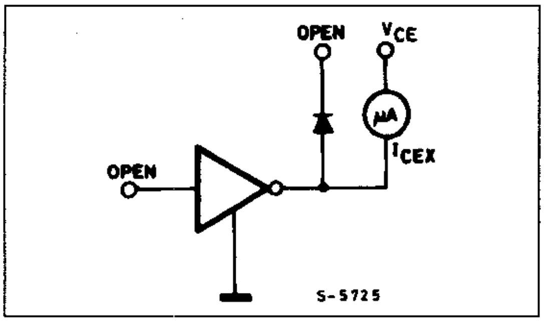


Figure 1b.

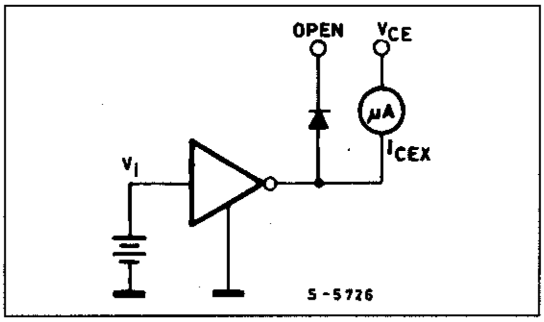


Figure 2.

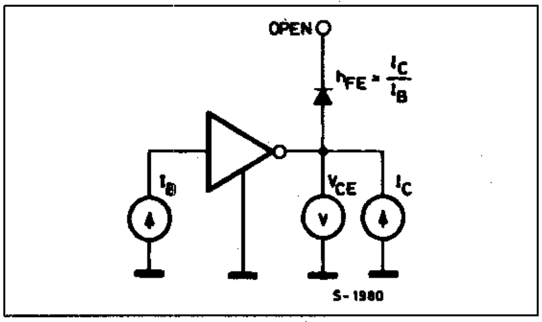


Figure 3.

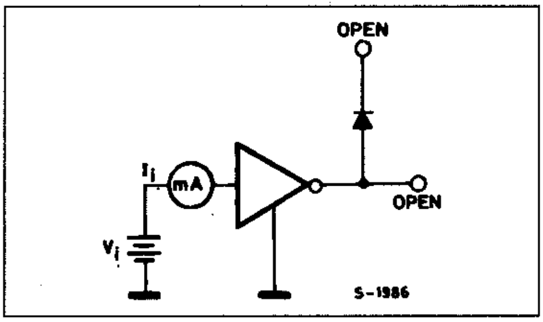


Figure 4.

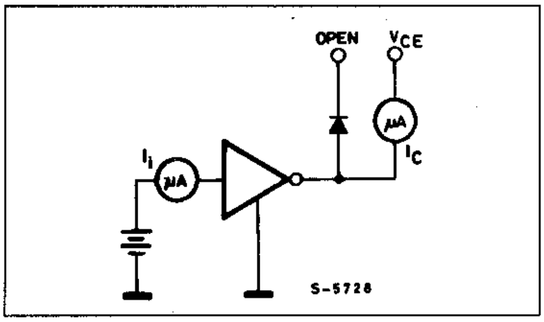


Figure 5.

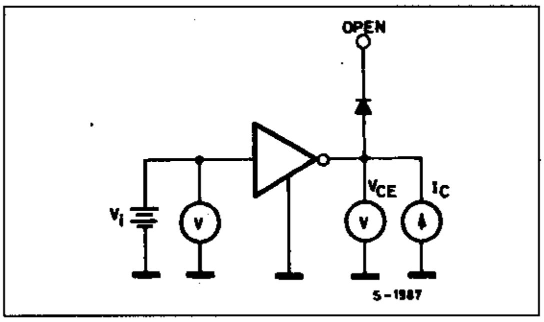


Figure 6.

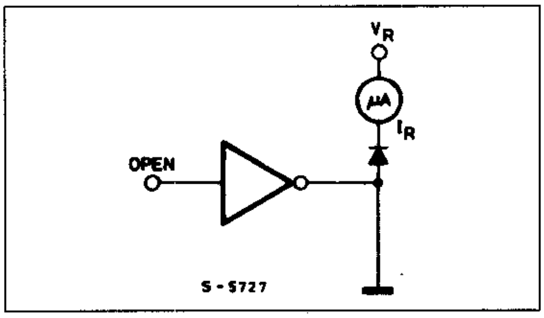
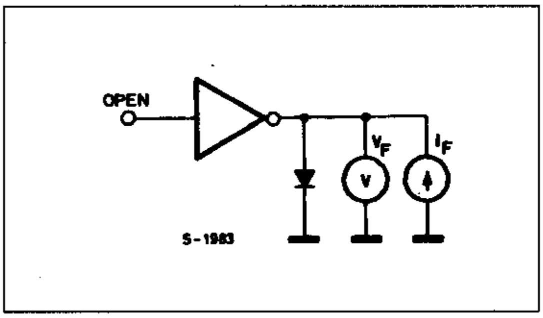


Figure 7.



ELECTRICAL CHARACTERISTICS (T_{amb} = 25°C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit	Fig.
I_{CEX}	Output Leakage Current	V_{CE} = 50V T_{amb} = 70°C, V_{CE} = 50V T_{amb} = 70°C for ULN2002A V_{CE} = 50V, V_i = 6V for ULN2004A V_{CE} = 50V, V_i = 1V			50 100 500 500	µA µA µA µA	1a 1a 1b 1b
$V_{CE(sat)}$	Collector-emitter Saturation Voltage	I_C = 100mA, I_B = 250µA I_C = 200 mA, I_B = 350µA I_C = 350mA, I_B = 500µA		0.9 1.1 1.3	1.1 1.3 1.6	V V V	2 2 2
$I_{i(on)}$	Input Current	for ULN2002A, V_i = 17V for ULN2003A, V_i = 3.85V for ULN2004A, V_i = 5V V_i = 12V		0.82 0.93 0.35 1	1.25 1.35 0.5 1.45	mA mA mA mA	3 3 3 3
$I_{i(off)}$	Input Current	T_{amb} = 70°C, I_C = 500µA	50	65		µA	4
$V_{i(on)}$	Input Voltage	V_{CE} = 2V for ULN2002A I_C = 300mA for ULN2003A I_C = 200mA I_C = 250mA I_C = 300mA for ULN2004A I_C = 125mA I_C = 200mA I_C = 275mA I_C = 350mA			 13 2.4 2.7 3 5 6 7 8	V	5
h_{FE}	DC Forward Current Gain	for ULN2001A V_{CE} = 2V, I_C = 350mA	 1000				 2
C_i	Input Capacitance			15	25	pF	
t_{PLH}	Turn-on Delay Time	0.5 V_i to 0.5 V_o		0.25	1	µs	
t_{PHL}	Turn-off Delay Time	0.5 V_i to 0.5 V_o		0.25	1	µs	
I_R	Clamp Diode Leakage Current	V_R = 50V T_{amb} = 70°C, V_R = 50V			50 100	µA µA	6 6
V_F	Clamp Diode Forward Voltage	I_F = 350mA		1.7	2	V	7

Figure 8: Collector Current versus Input Current

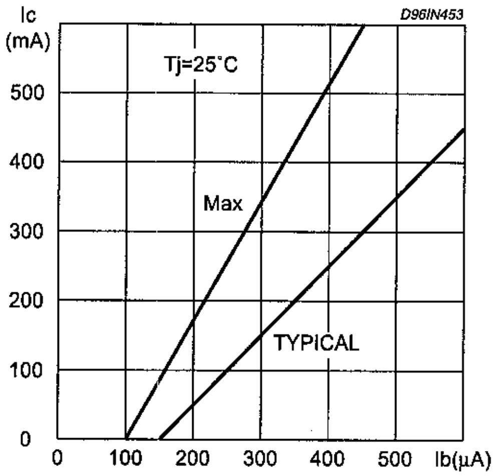


Figure 9: Collector Current versus Saturation Voltage

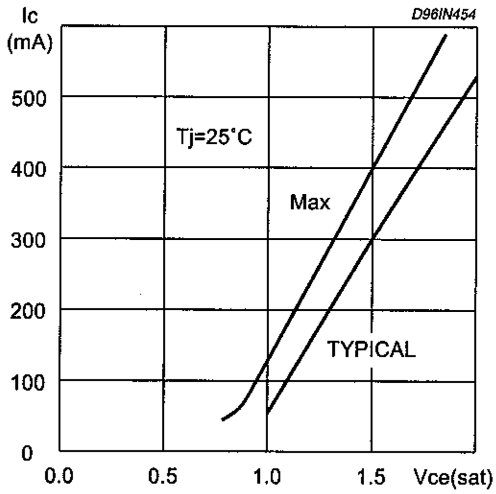


Figure 10: Peak Collector Current versus Duty Cycle

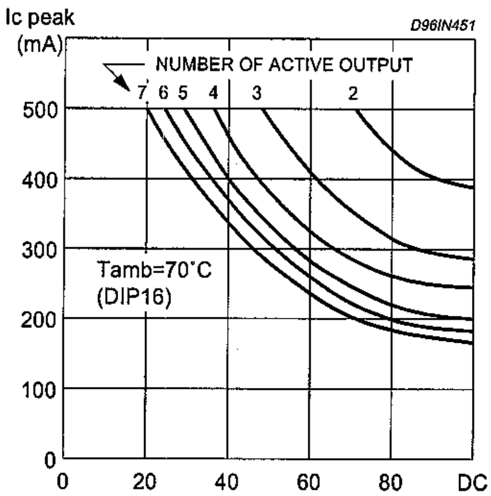
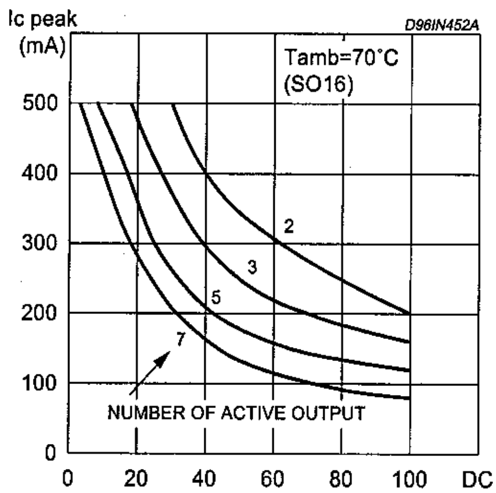
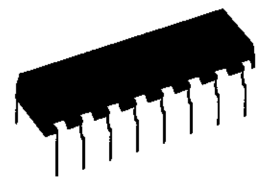


Figure 11: Peak Collector Current versus Duty Cycle

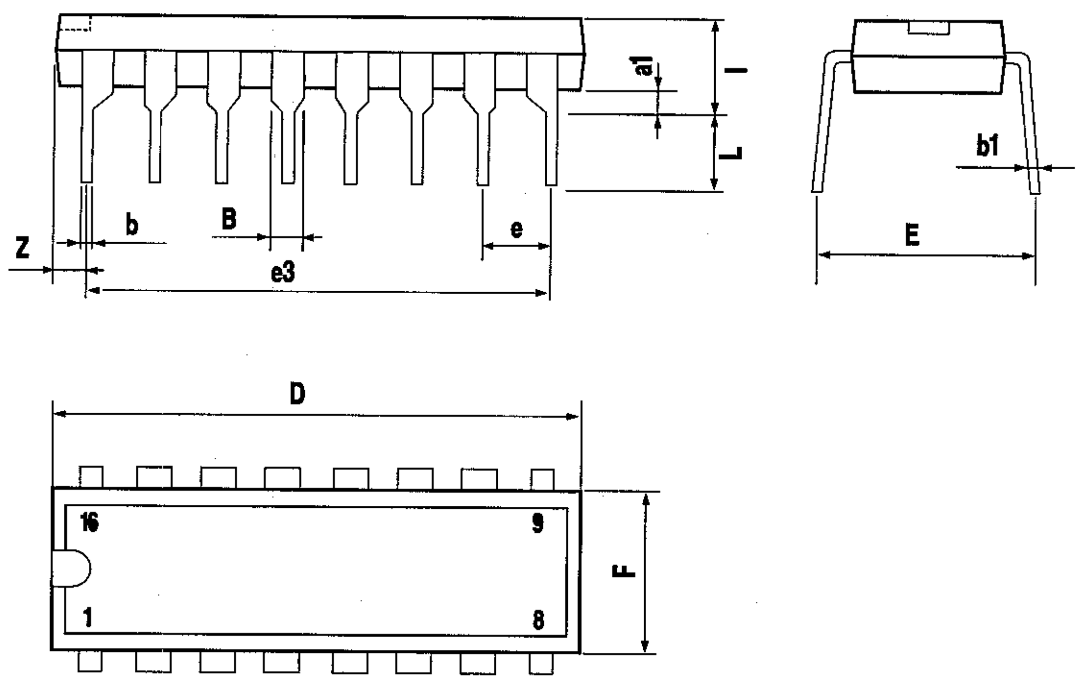


DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
a1	0.51			0.020		
B	0.77		1.65	0.030		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		17.78			0.700	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z			1.27			0.050

OUTLINE AND MECHANICAL DATA

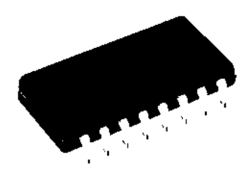


DIP16



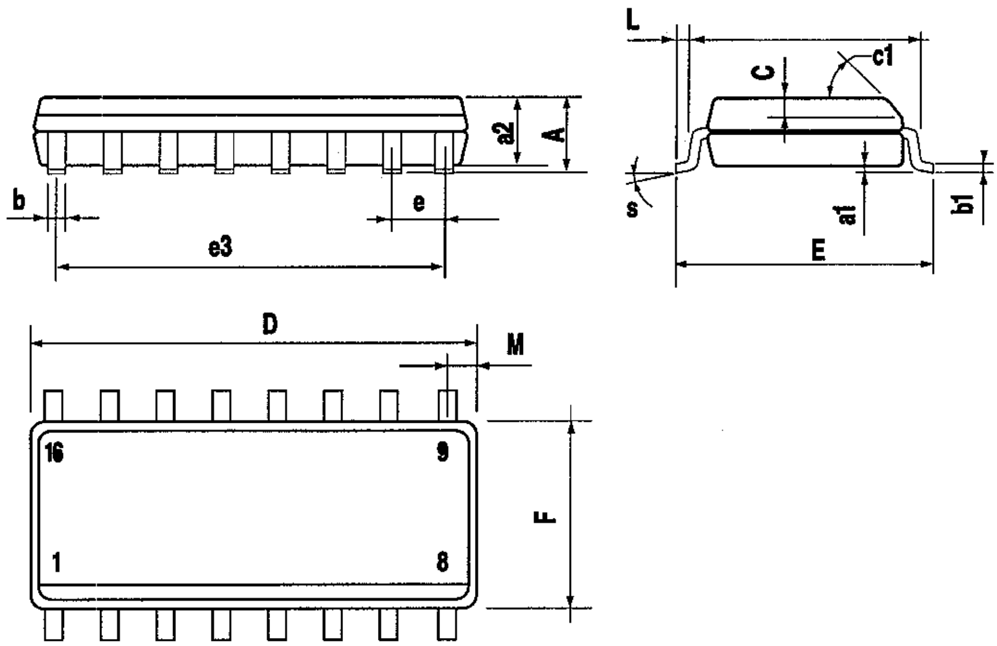
DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			1.75			0.069
a1	0.1		0.25	0.004		0.009
a2			1.6			0.063
b	0.35		0.46	0.014		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.020	
c1	45° (typ.)					
D (1)	9.8		10	0.386		0.394
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		8.89			0.350	
F (1)	3.8		4	0.150		0.157
G	4.6		5.3	0.181		0.209
L	0.4		1.27	0.016		0.050
M			0.62			0.024
S	8°(max.)					

OUTLINE AND MECHANICAL DATA



SO16 Narrow

(1) D and F do not include mold flash or protrusions. Mold flash or potrusions shall not exceed 0.15mm (.006inch).

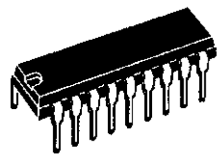


SGS-THOMSON MICROELECTRONICS

ULN2801A
ULN2802A - ULN2803A
ULN2804A - ULN2805A

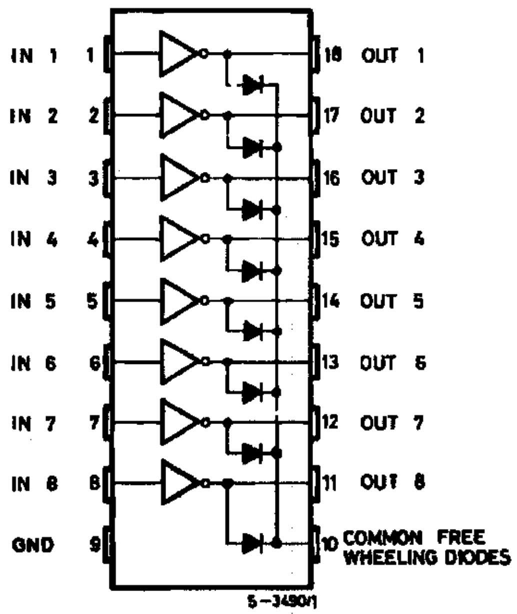
EIGHT DARLINGTON ARRAYS

- EIGHT DARLINGTONS WITH COMMON EMITTERS
- OUTPUT CURRENT TO 500 mA
- OUTPUT VOLTAGE TO 50 V
- INTEGRAL SUPPRESSION DIODES
- VERSIONS FOR ALL POPULAR LOGIC FAMILIES
- OUTPUT CAN BE PARALLELED
- INPUTS PINNED OPPOSITE OUTPUTS TO SIMPLIFY BOARD LAYOUT



DIP18

PIN CONNECTION (top view)



DESCRIPTION

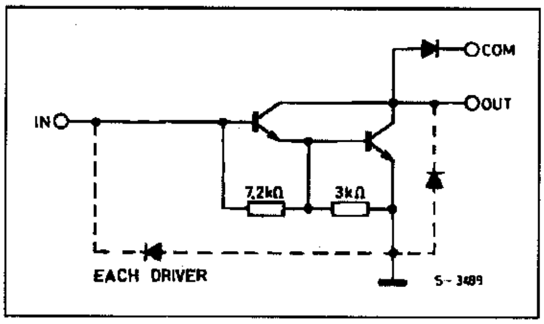
The ULN2801A-ULN2805A each contain eight darlington transistors with common emitters and integral suppression diodes for inductive loads. Each darlington features a peak load current rating of 600mA (500mA continuous) and can withstand at least 50V in the off state. Outputs may be paralleled for higher current capability.

Five versions are available to simplify interfacing to standard logic families : the ULN2801A is designed for general purpose applications with a current limit resistor; the ULN2802A has a 10.5kΩ input resistor and zener for 14-25V PMOS ; the ULN2803A has a 2.7kΩ input resistor for 5V TTL and CMOS ; the ULN2804A has a 10.5kΩ input resistor for 6-15V CMOS and the ULN2805A is designed to sink a minimum of 350mA for standard and Schottky TTL where higher output current is required.

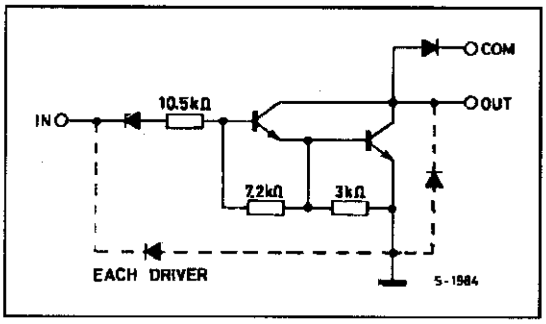
All types are supplied in a 18-lead plastic DIP with a copper lead from and feature the convenient input-opposite-output pinout to simplify board layout.

SCHEMATIC DIAGRAM AND ORDER CODES

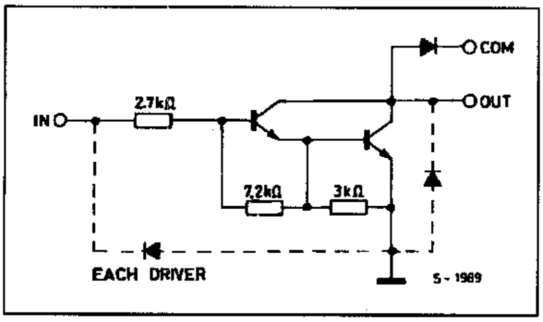
For ULN2801A (each driver for PMOS-CMOS)



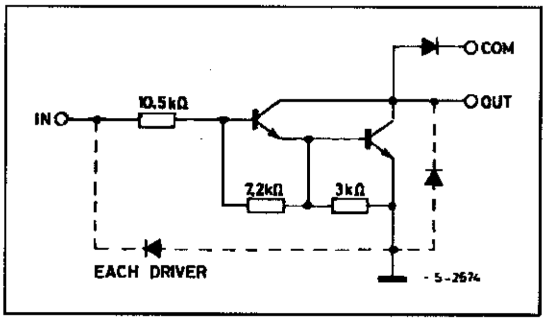
For ULN2802A (each driver for 14-15 V PMOS)



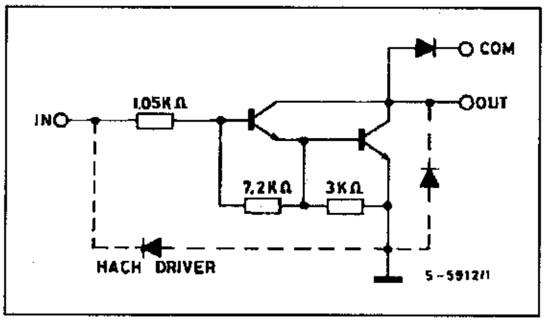
For ULN2803A (each driver for 5 V, TTL/CMOS)



For ULN2804A (each driver for 6-15 V CMOS/PMOS



For ULN2805A (each driver for high out TTL)



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_o	Output Voltage	50	V
V_i	Input Voltage for ULN2802A, UL2803A, ULN2804A for ULN2805A	 30 15	V
I_C	Continuous Collector Current	500	mA
I_B	Continuous Base Current	25	mA
P_{tot}	Power Dissipation (one Darlington pair) (total package)	 1.0 2.25	W
T_{amb}	Operating Ambient Temperature Range	– 20 to 85	°C
T_{stg}	Storage Temperature Range	– 55 to 150	°C
Tj	Junction Temperature Range	– 20 to 150	°C

THERMAL DATA

Symbol	Parameter		Value	Unit
$R_{th\ j-amb}$	Thermal Resistance Junction-ambient	Max.	55	°C/W

ELECTRICAL CHARACTERISTICS (T_{amb} = 25°C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit	Fig.
I_{CEX}	Output Leakage Current	V_{CE} = 50V T_{amb} = 70°C, V_{CE} = 50V T_{amb} = 70°C for ULN2802A V_{CE} = 50V, V_i = 6V for ULN2804A V_{CE} = 50V, V_i = 1V			50 100 500 500	µA µA µA µA	1a 1a 1b 1b
$V_{CE(sat)}$	Collector-emitter Saturation Voltage	I_C = 100mA, I_B = 250µA I_C = 200mA, I_B = 350µA I_C = 350mA, I_B = 500µA		0.9 1.1 1.3	1.1 1.3 1.6	V V V	2
$I_{i(on)}$	Input Current	for ULN2802A V_i = 17V for ULN2803A V_i = 3.85V for ULN2804A V_i = 5V V_i = 12V for ULN2805A V_i = 3V		0.82 0.93 0.35 1 1.5	1.25 1.35 0.5 1.45 2.4	mA mA mA mA mA	3
$I_{i(off)}$	Input Current	T_{amb} = 70°C, I_C = 500µA	50	65		µA	4
$V_{i(on)}$	Input Voltage	V_{CE} = 2 V for ULN2802A I_C = 300mA for ULN2803A I_C = 200mA I_C = 250mA I_C = 300mA for ULN2804A I_C = 125mA I_C = 200mA I_C = 275mA I_C = 350mA for ULN2805A I_C = 350mA			13 2.4 2.7 3 5 6 7 8 2.4	V V V V V V V V V	5
h_{FE}	DC Forward Current Gain	for ULN2801A V_{CE} = 2V, I_C = 350mA	1000			–	2
C_i	Input Capacitance			15	25	pF	–
t_{PLH}	Turn-on Delay Time	0.5 V_i to 0.5 V_o		0.25	1	µs	–
t_{PHL}	Turn-off Delay Time	0.5 V_i to 0.5 V_o		0.25	1	µs	–
I_R	Clamp Diode Leakage Current	V_R = 50V T_{amb} = 70°C, V_R = 50V			50 100	µA µA	6 6
V_F	Clamp Diode Forward Voltage	I_F = 350mA		1.7	2	V	7

TEST CIRCUITS

Figure 1a.

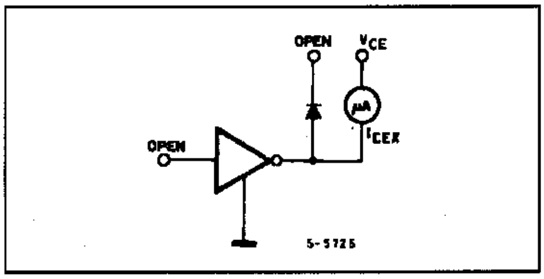


Figure 1b.

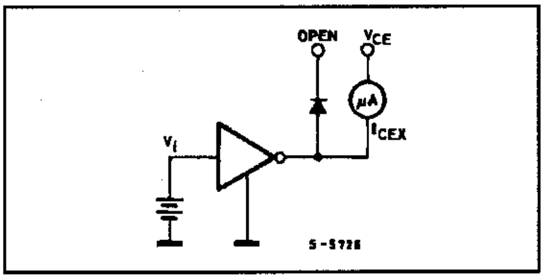


Figure 2.

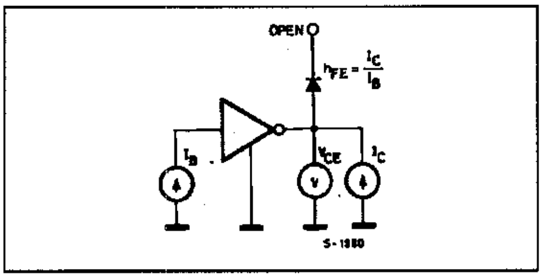


Figure 3.

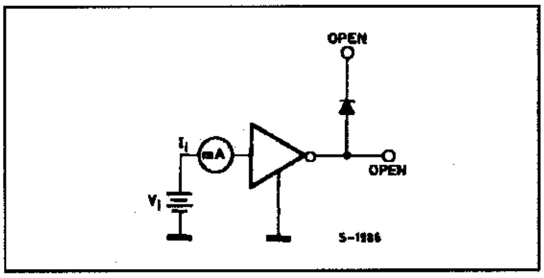


Figure 4.

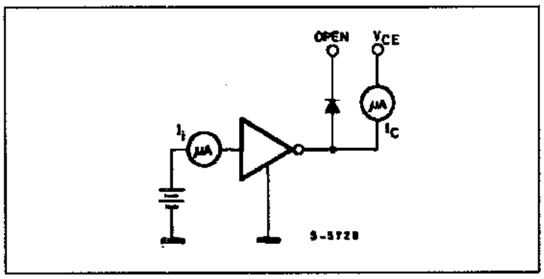


Figure 5.

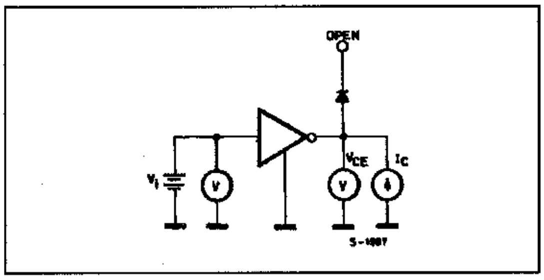


Figure 6.

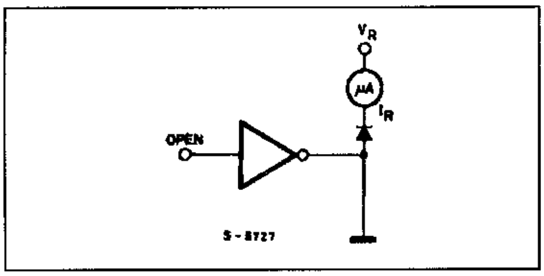


Figure 7.

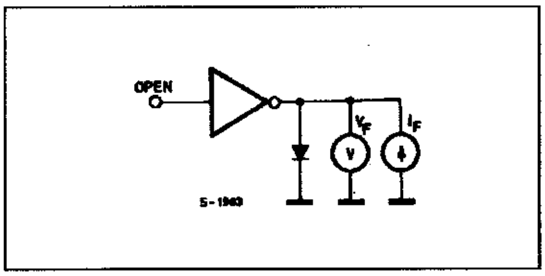


Figure 8 : Collector Current as a Function of Saturation Voltage.

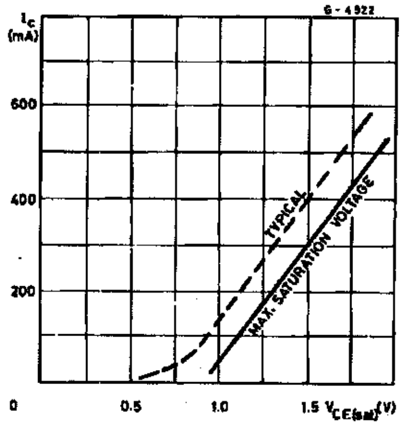


Figure 9 : Collector Current as a Function of Input Current.

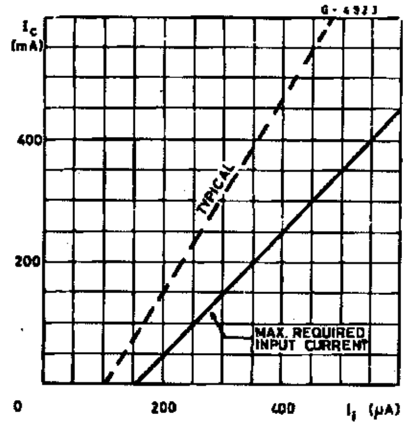


Figure 10 : Allowable Average Power Dissipation as a Function of Ambient Temperature.

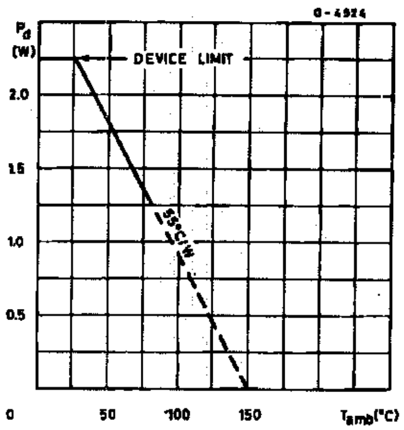


Figure 11 : Peak Collector Current as a Function of Duty Cycle.

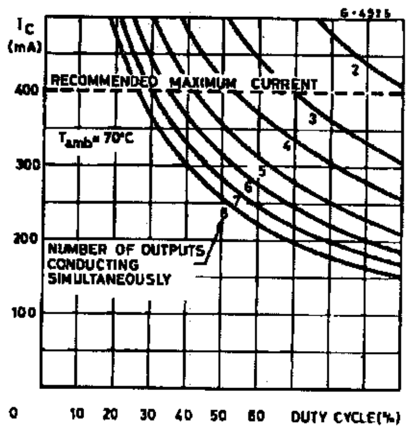


Figure 12 : Peak Collector Current as a Function of Duty.

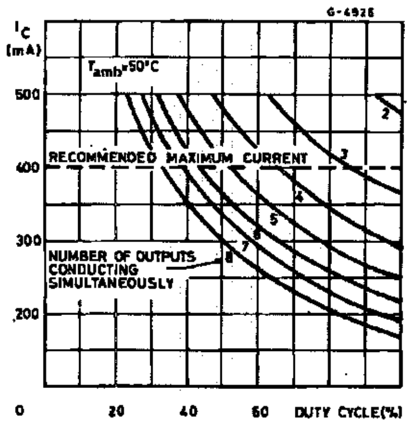


Figure 13 : Input Current as a Function of Input Voltage (for ULN2802A).

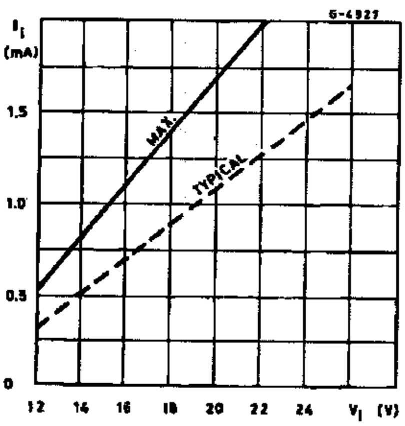


Figure 14 : Input Current as a Function of Input Voltage (for ULN2804A)

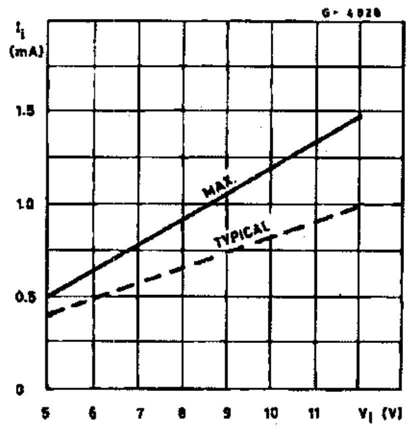


Figure 15 : Input Current as a Function of Input Voltage (for ULN2803A)

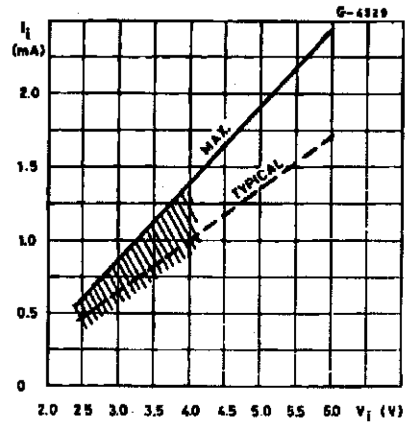
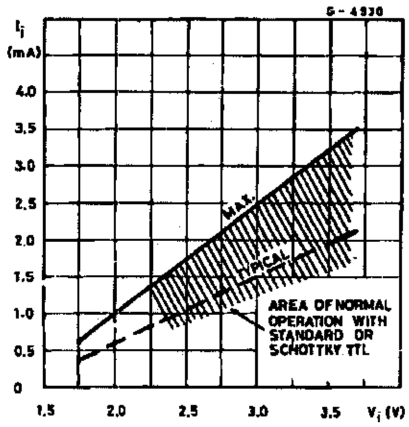


Figure 16 : Input Current as a Function of Input Voltage (for ULN2805A)



DIP18 PACKAGE MECHANICAL DATA

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
a1	0.254			0.010		
B	1.39		1.65	0.055		0.065
b		0.46			0.018	
b1		0.25			0.010	
D			23.24			0.915
E		8.5			0.335	
e		2.54			0.100	
e3		20.32			0.800	
F			7.1			0.280
I			3.93			0.155
L		3.3			0.130	
Z		1.27	1.59		0.050	0.063