RADIO REMOTE CONTROL USING DTMF

Project report submitted in partial fulfillment of the requirement for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

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Certificate

This is to certify that the project report entitled **"RADIO REMOTE CONTROL USING DTMF"**, submitted by Tushar Sinha (061136), Vijitashwa (061141) and Vikash Anand (061142) in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

Date : 19-05-2010

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Certified that this work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

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Acknowledgement

It has been a wonderful and intellectually stimulating experience working on **Radio Remote Control using DTMF** which is used for controlling various appliances using Dual-Tone Multi Frequency Technology.

We gratefully acknowledge the Management and Administration of Jaypee University of Information Technology for providing us the opportunity and hence the environment to initiate and complete our project.

We would like to extend our first thanks to our **HOD, Dr. S.V.Bhooshan** for making us competent in LINUX that today we are able to make our report using the packages of the same.

For providing with the finest details of the subject, we are greatly thankful to our project guide **Ms. Neeru Sharma**. She has provided us the way to get the job done, not providing the exact way to do it, but the concept behind the complexities so that we can make better use of the existing knowledge and build up higher skills to meet the industry needs. Her methodology of making the system strong from inside has taught us that output is not the end of project.

Date: 19-05-2010

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Abstract

The wireless technology is now in its prime and the wealth of knowledge available has enabled wireless technology to play a major role in integrating the various functions associated with it. This needs to tie up the various sources of the department in a closed loop system. With the advent in technology, the existing systems are developed to have an in-built intelligence proposed system.
This system uses DTMF decoder to control the applications. Every key will be having a unique tone, which is decided by combination of keypad's column frequency and row frequency. The DTMF tone is then converted to a BCD code which is given as an input to the transmitter module which controls various electrical appliances through the receiver module. Due to the fully digital nature, the proposed design is less complex and hence the implementation is cost effective. This project greatly reduces the manpower, saves time and operates efficiently.

Chapter 1

Introduction

1.1 Radio Frequency

Radio frequency (RF) radiation is a subset of electromagnetic radiation with a wavelength of 100 km to 1 mm, which is a frequency of 3 kHz to 300 GHz,respectively. This range of electromagnetic radiation constitutes the radio spectrum and corresponds to the frequency of alternating current electrical signals used to produce and detect radio waves. RF can refer to electromagnetic oscillations in either electrical circuits or radiation through air and space. Like other subsets of electromagnetic radiation, RF travels at the speed of light.

1.1.1 Radio Communication

In order to receive radio signals, for instance from AM/FM radio stations, a radio antenna must be used. However, since the antenna will pick up thousands of radio signals at a time, a radio tuner is necessary to tune in to a particular frequency (or frequency range).[2] This is typically done via a resonator (in its simplest form, a circuit with a capacitor and an inductor). The resonator is configured to resonate at a particular frequency (or frequency band), thus amplifying sine waves at that radio frequency, while ignoring other sine waves. Usually, either the inductor or the capacitor of the resonator is adjustable, allowing the user to change the frequency at which it resonates. The resonant frequency of tuned circuit is given by the formula

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where f_0 is the frequency in Hertz, L is inductance in Henries, and C is capacitance in Farads.

1.1.2 Radio Spectrum

Radio spectrum refers to the part of the electromagnetic spectrum corresponding to radio frequencies – that is, frequencies lower than around 300 GHz (or, equivalently, wavelengths longer than about 1 mm). Different parts of the radio spectrum are used for different radio transmission technologies and applications. Radio spectrum is typically government regulated in developed countries, and in some cases is sold or licensed to operators of private radio transmission systems (for example, cellular telephone operators or broadcast television stations). Ranges of allocated frequencies are often referred to by their provisioned use (for example, cellular spectrum or television spectrum).

Frequency Range	Band
3 to 30 MHz	High Frequency
30 to 300 MHz	Very High Frequency
300 to 1000 MHz	Ultra High Frequency
1 to 2 GHz	Long wave
2 to 4 GHz	Short Wave

Table 1.1: RF Band

1.2 DTMF:An Introduction

Dual Tone Multi-Frequency, or DTMF is a method for instructing a telephone switching system of the telephone number to be dialed, or to issue commands to switching systems or related telephony equipment. The DTMF dialing system traces its roots to a technique AT&T developed in the 1950s called MF (Multi-Frequency) which was deployed within the AT&T telephone network to direct calls between switching facilities using in-band signaling. In the early 1960s, a derivative technique was offered by AT&T through its Bell System telephone companies as a "modern" way for network customers to place calls. In AT&Ts Compatibility Bulletin No. 105, AT&T described the product as "a method for pushbutton signaling from customer stations using the voice transmission path".

The consumer product was marketed by AT&T under the registered trade name Touch-Tone. Other vendors of compatible telephone equipment called this same system "Tone" dialing or "DTMF". The DTMF system uses eight different frequency signals transmitted in pairs to represent sixteen different numbers, symbols and letters. The frequencies used were chosen to prevent any harmonics from being incorrectly detected by the receiver as some other DTMF frequency.

The transmitter of a DTMF signal simultaneously sends one frequency from the high-group and one freqency from the low-group. This pair of signals represents the digit or symbol shown at the intersection of row and column in the table. For example, sending 1209Hz and 770Hz indicates that the "4" digit is being sent. At the transmitter, the maximum signal strength of a pair of tones must not exceed +1 dBm, and the minimum strength is -10.5 dBm for the low-group frequencies and -8.5 dBm for the high-group frequencies. When not intentionally sending DTMF tones (including the inter-digit interval), any leakage of these tones must not exceed -55 dBm. The frequencies generated by the transmitter must be nominally within 1.5% of the stated values and the receiver must not accept signals that deviate more than 3.5% from the stated values. The receiver is responsible for performing several checks on the incoming signal

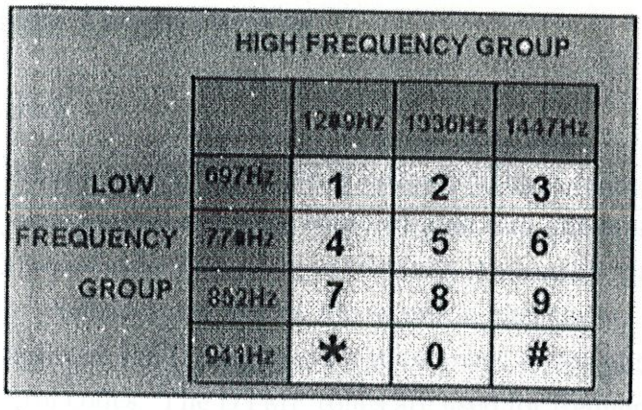


Figure 1.1: DTMF Keypad

before accepting the incoming signal as a DTMF digit:

- Energy from a low-group frequency and a high-group frequency must be detected.

- Energy from all other low-group and all other high-group frequencies must be absent or less than -55dBm.

- The energy from the single low-group and single high-group frequency must persist for at least 40 msec.

- There must have been an inter-digit interval of at least 40 msec in which there is no energy detected at any of the DTMF frequencies. The minimum duty cycle (tone interval and inter-digit interval) is 85 msec.

- The receiver should receive the DTMF digits with a signal strength of at least -25 dBm and no more than 0 dBm.

The energy strength of the high-group frequency must be -8 dB to +4 dB relative to the energy strength of the low-group frequency as measured at the receiver.

This uneven transmission level is known as the "twist", and some receiving equipment may not correctly receive signals where the "twist" is not implemented correctly. Nearly all modern DTMF decoders receive DTMF digits correctly despite twist errors.

The receiver must correctly detect and decode DTMF despite the presence of dial-tone, including the extreme case of dial-tone being sent by the central office at 0 dBm (which may occur in extremely long loops). Above 600Hz, any other signals detected by the receiver must be at least -6 dB below the low-group frequency signal strength for correct digit detection.

1.3 Project Description

1.3.1 Working

Remote control circuits usually make use of infrared light to transmit control signals, their use is thus limited to a very confined area and line-of-sight. However, our circuit makes use of radio frequency to transmit the control signals and hence it can be used for control from almost anywhere in the house. Here we make use of DTMF (dual-tone multi frequency) signals (used in telephones to dial the digits) as the control codes. The DTMF tones are used for frequency modulation of the carrier. At the receiver unit, these frequency modulated signals are intercepted to obtain DTMF tones at the speaker terminals. This DTMF signal is connected to a DTMF-to-BCD converter whose BCD output is used to switch-on and switch-off various electrical applicances (4 in this case).

The remote control transmitter consists of DTMF generator and an RF transmitter circuit.For generating the DTMF frequencies, a dedicated IC UM91214B (which is used as a dialler IC in telephone instruments) is used here. This IC requires 3 volts for its operation. This is provided by a simple zener diode voltage regulator which converts 9 volts into 3 volts for use by this IC. For its time base, it requires a quartz crystal of 3.58 MHz . Pins 1 and 2 are used as chip select and DTMF mode select pins respectively. When the row and column pins (12 and 15) are shorted to each other, DTMF tones corresponding to digit 1 are output from its pin 7. Similarly, pins 13, 16 and 17 are additionally required to dial digits 2, 4 and 8. Rest of the pins of this IC may be left as they are. The output of IC1 is given to the input of this transmitter circuit which effectively ASK modulates the carrier and transmits it in the air. The carrier frequency is around 433MHz operation. An antenna of 10 to 15 cms (4 to 6 inches) length will be sufficient to provide adequate range. Four key switches (DPST push-to-on spring loaded) are required to transmit the desired DTMF tones. The switches when pressed generate the specific tone pairs as well as provide power to the transmitter circuit simultaneously. This way when the transmitter unit is not in use it consumes no power at all and the battery lasts much longer.

The receiver unit consists of an RF receiver,a DTMF-to-BCD converter and a flip-flop toggling latch section. The ASK modulated DTMF signals are received by the ASK receiver and the output (DTMF tones) are fed to the dedicated IC KT3170 which is a DTMF-to-BCD converter. This IC when fed with the DTMF tones gives corresponding BCD output; for example, when digit 1 is pressed, the output is 0001 and when digit 4 is pressed the output is 0100. This IC also requires a 3.58MHz crystal for its operation. The tone input is connected to its pin 2 and the BCD outputs are taken from pins 11 to 14 respectively. These outputs are fed to 4 individual 'D' flip-flop latches which have been converted into toggle flip-flops built around two CD4013B ICs. Whenever a digit is pressed, the receiver decodes it and gives a clock pulse which is used to toggle the corresponding flip-flop to the alternate state. The flip-flop output is used to drive a relay which in turn can latch or unlatch any electrical appliance. We can upgrade the circuit to control as many as 12 channels since IC UM91214B can generates 12 DTMF tones. For this purpose some modification has to be done in receiver unit and also in between IC2 and toggle flip-flop section in the receiver. A 4-to-16 lines demultiplexer (IC 74154) has to be used and the number of toggle flip-flops have also to be increased to 12 from the existing 4.

1.3.2 Features

- We can control up to 12 electrical appliances
- It makes use of DTMF tones as the message signal
- The carrier used is Radio Frequency instead of Infra-red which increases the range of the circuit

1.3.3 Basic Requirements

1. RF Transmitter and Receiver
2. DTMF to BCD converter(IC UM91215B)
3. DTMF Decoder(MT8870)
4. SPDT Relay
5. Crystal Oscillator

6. Voltage Regulator(LM7805)
7. Step-Down Transformer
8. NOT Gate(IC 7408)
9. AND Gate(IC 7404)
10. General PCB

1.4 Structure of report

This report is organized as follows:
Chapter 2 describes the various circuit modules we would be using in our project. Chapter 3 includes the basic hardware requirements. Chapter 4 describes modulation and the types of modulation. Chapter 5 includes the conclusion and the future scope of our project.

Chapter 2

CIRCUIT MODULES

2.1 MODULE 1:DTMF GENERATOR

2.1.1 DTMF: Introduction

The cell phone we are using for this project is based on the GSM technology (uplink frequency of 890-915MHz and downlink frequency of 935-960MHz).

The decoder receives this signal. When you press a button in the telephone set keypad, a connection is made that generates a resultant signal of two tones at the same time. These two tones are taken from a row frequency and a column frequency. The resultant frequency signal is called "Dual Tone Multiple Frequency". These tones are identical and unique. A DTMF signal is the algebraic sum of two different audio frequencies, and can be expressed as follows:

$$f(t) = A_0 Sin(2\pi f_a t) + B_0 Sin(2\pi f_b t) + \dots \tag{2.1}$$

Where f_a and f_b are two different audio frequencies with A and B as their peak amplitudes and f as the resultant DTMF signal. f_a belongs to the low frequency group and f_b belongs to the high frequency group. Each of the low and high frequency groups comprise four frequencies from the various keys present on the telephone keypad; two different frequencies, one from the high frequency group and another from the low frequency group are used to produce a DTMF signal to represent the pressed key. The amplitudes of the two sine waves should be such that $(0.7 < \frac{A}{B} < 0.9$V. The frequencies are chosen such that they are not the harmonics of each other.

When you send these DTMF signals to the telephone exchange through cables, the servers in the telephone exchange identifies these signals and makes the connection to the person you are calling.

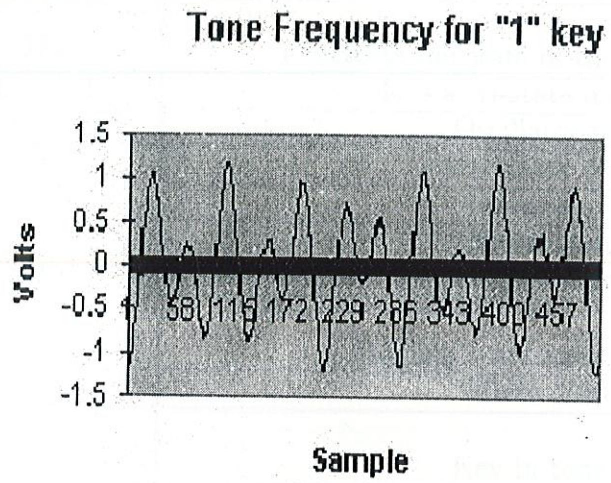


Figure 2.1: DTMF Tone

2.1.2 IC UM91215B

This IC generates the tone corresponding to the key pressed.

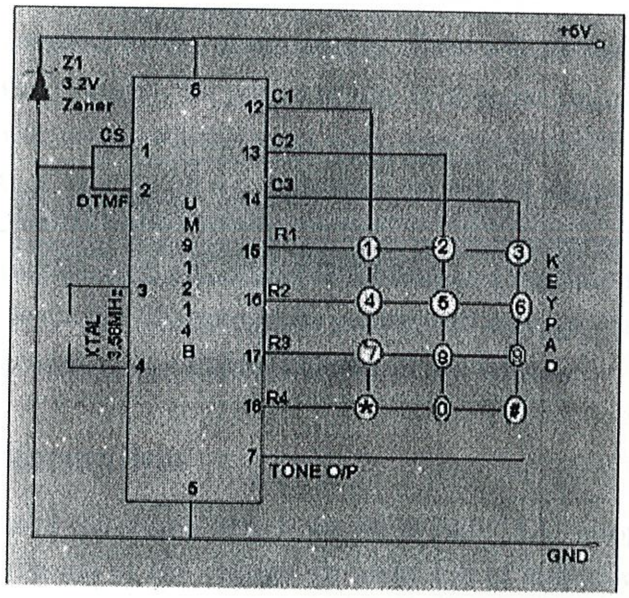


Figure 2.2: IC UM91215B:Pin Out

2.2 MODULE 2:THE POWER SUPPLY

Power supply is used to drive the circuit. Inappropriate voltage will damage the entire circuitry therefore it constitutes a very important part of the circuit. Every electronic circuit requires power for its operation. Every function simple

Pin No.	Pin	Description
1	$\overline{HK}$	It detects the state of the hook switch contact
2	MODE IN	It is a tri-state mode select pin
3	OSCI	Oscillator input pin
4	OSCI	Oscillator output pin
5	V_{SS}	Power supply pin
6	V_{DD}	Power supply pin
7	TONE	Tone dialling output
8	XMIT $\overline{MUTE}$	Dialling transmission mute output
9	MODE OUT	Mode output pin
10	$\overline{KT}$	Key in tone output
11	$\overline{DP}$	Dialling pulse output
12-14	$\overline{C1}$-$\overline{C3}$	Keyboard pins representing the columns of the keypad matrix
15-18	$\overline{R1}$-$\overline{R4}$	Keyboard pins representing the rows of the keypad matrix

Table 2.1: Pin Description for IC UM91215B

or complex is controlled by the power supply. Even a little variation in voltage can damage all the circuitry. So power supply is of prime importance in all the circuits. The power supply which we get is a.c. operating at 220Volts.But as our electronic circuits work only on d.c. therefore; we cannot employ direct usage of supply which we get. In order to overcome this, we require various process namely transformation, rectification, smoothing or filtering and regulation. Power supply is used to drive the circuit. Inappropriate voltage will damage the entire circuitry therefore it constitutes a very important part of the circuit.

2.2.1 Transformation

As already discussed the supply which we get is 220V A.C. supply. In order to decrease the magnitude of the voltage we make use of step down transformer. This transformer has more windings in the primary coil than in the secondary coil. So the voltage output at the secondary is an A.C. supply with magnitude less than 220V as shown below:

2.2.2 Rectification

As all the electronic circuits work on DC therefore this low voltage A.C. cannot be directly fed to our circuit. Thus a process of rectification is required. In this

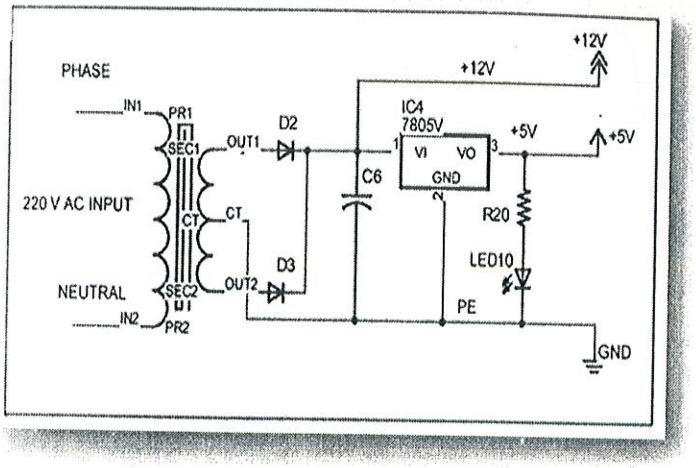


Figure 2.3: Power Supply:Circuit Diagram

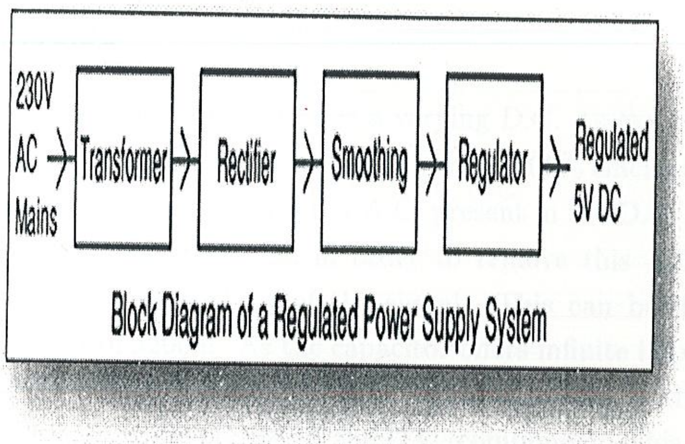


Figure 2.4: Power Supply:Block Diagram

process, A.C. voltage is converted into D.C. voltage using two semiconductor rectifying diodes as shown below:

Now as the two diodes D1 and D2 are connected in the opposite manner. Therefore one of the diode gets forward biased during the positive half of the a.c input and other gets forward biased during the negative half of the a.c. input. Thus during the positive half cycle rectification takes place through diode D1(diode D2 being reverse biased, cannot rectify) and during the negative half cycle, the rectification takes place through the diode D2(diode D1 being reverse biased, cannot rectify). But as at least one of the diode always remain in the conducting mode therefore both the halves of the a.c. input gets rectified and hence the name full wave rectifier.

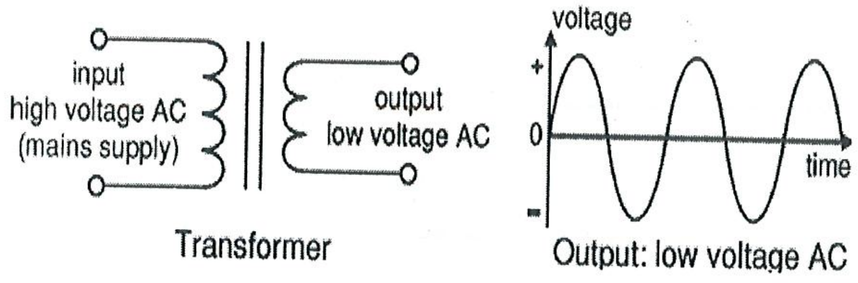


Figure 2.5: Transformation

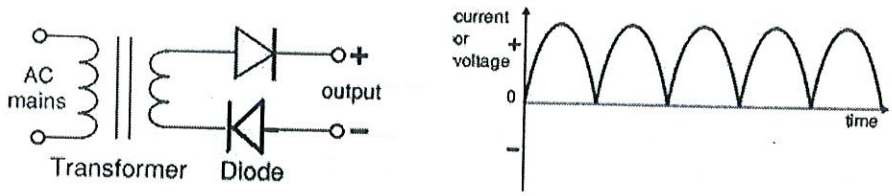


Figure 2.6: Rectification

2.2.2.1 Smoothing

The output of the rectification process is a varying D.C. As the D.C. waveform cannot be varying so it means that rectification is not 100% efficient due to which there is still some component of the input A.C. present in the D.C. voltage which is responsible for the variation. So in order to remove this A.C. component we require filtration or smoothing of the signal. This can be done using an electrolytic capacitor of 2200uf. As the capacitor offers infinite impedance to the D.C. signal and Zero impedance to the A.C. signal therefore, it allows the A.C. component to pass through and blocks the D.C. component. This means it will filter out the D.C. component from the input signal. Thus the output of the process will be a pure D.C. supply as shown below:

Now there is still some variation indicating that output D.C. voltage is not having constant magnitude. This is due to the capacitor used for filtration. Its time of charging and discharging are not equal due to which the filtration is not up to the mark. For making the output voltage assume a constant value we need a voltage regulator.

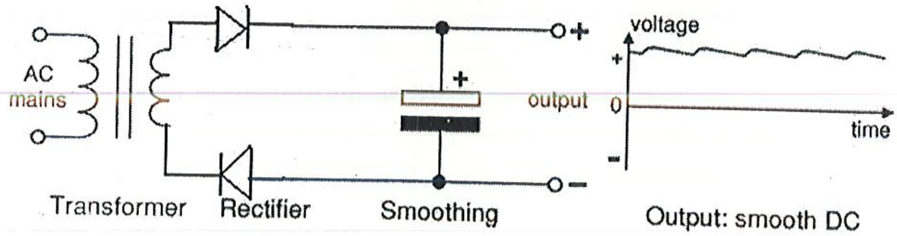


Figure 2.7: Smoothing

2.2.3 Regulation

Voltage regulator is used for this purpose mainly from the series of 78- - of the transistor. For getting the constant output of 5 volts we make use of 7805 voltage regulator. This process takes place as shown below:

This completes all the processes. Now we have a constant D.C. supply with us which can be fed to any electronic circuit without any problem.

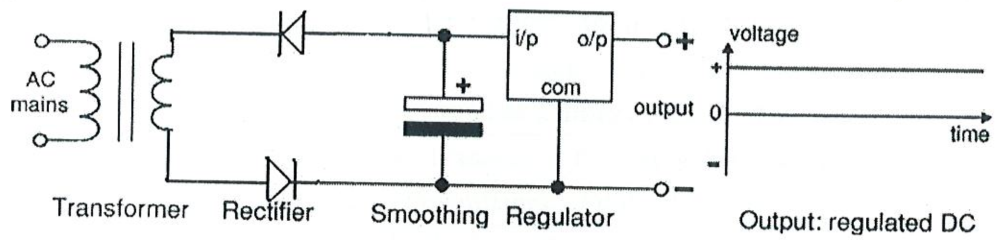


Figure 2.8: Regulation

2.3 MODULE 3:RF TRANSCEIVER

2.3.1 433 MHz Transmitter:Overview

The STT-433 is ideal for remote control applications where low cost and longer range is required. The transmitter operates from a 1.5-12V supply, making it ideal for battery-powered applications. The transmitter employs a SAW-stabilized oscillator, ensuring accurate frequency control for best range performance. Output power and harmonic emissions are easy to control, making FCC and ETSI compliance easy. The manufacturing-friendly SIP style package and low-cost make the STT-433 suitable for high volume applications.

2.3.1.1 Features

- 433.92 MHz Frequency
- Low Cost
- 1.5-12V operation
- 11mA current consumption at 3V
- Small size
- 4 dBm output power at 3V

2.3.1.2 Operation

Theory

OOK(On Off Keying) modulation is a binary form of amplitude modulation. When a logical 0 (data line low) is being sent, the transmitter is off, fully suppressing the carrier. In this state, the transmitter current is very low, less than 1mA. When a logical 1 is being sent, the carrier is fully on. In this state, the module current consumption is at its highest, about 11mA with a 3V power supply. OOK is the modulation method of choice for remote control applications where power consumption and cost are the primary factors. Because OOK transmitters draw no power when they transmit a 0, they exhibit significantly better power consumption than FSK transmitters. OOK data rate is limited by the start-up time of the oscillator. High-Q oscillators which have very stable center frequencies take longer to start-up than low-Q oscillators. The start-up time of the oscillator determines the maximum data rate that the transmitter can send.

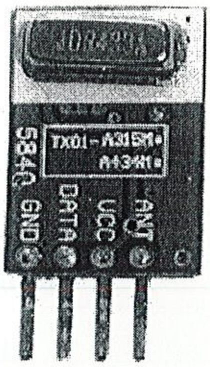


Figure 2.9: 433 MHz RF Transmitter

Data Rate

The oscillator start-up time is on the order of 40uSec, which limits the maximum data rate to 4.8 kbit/sec.

SAW Stabilized Oscillator

The transmitter is basically a negative resistance LC oscillator whose center frequency is tightly controlled by a SAW resonator. SAW (Surface Acoustic Wave) resonators are fundamental frequency devices that resonate at frequencies much higher than crystals.

2.3.2 433 MHz Receiver:Overview

The STR-433 is ideal for short-range remote control applications where cost is a primary concern. The receiver module requires no external RF components except for the antenna. It generates virtually no emissions, making FCC and ETSI approvals easy. The super-regenerative design exhibits exceptional sensitivity at a very low cost. The manufacturing-friendly SIP style package and low-cost make the STR-433 suitable for high volume applications.

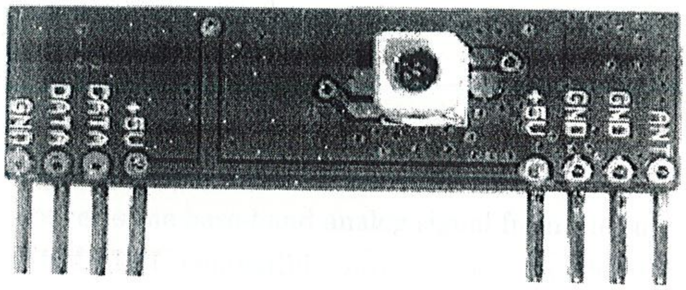


Figure 2.10: 433 MHz RF Receiver

- 5V Operation
- Low Cost
- 3.5 mA current drain
- No External Parts are required
- Receiver frequency 433 MHz
- IF frequency 1 MHz

2.3.2.1 Operation

Super Regenerative AM Detection

The STR-433 uses a super-regenerative AM detector to demodulate the incoming AM carrier. A super- regenerative detector is a gain stage with positive feedback greater than unity so that it oscillates. An RC-time constant is included in the gain stage so that when the gain stage oscillates, the gain will be lowered over time proportional to the RC time constant until the oscillation eventually dies. When the oscillation dies, the current draw of the gain stage decreases, charging the RC circuit, increasing the gain, and ultimately the oscillation starts again. In this way, the oscillation of the gain stage is turned on and off at a rate set by the RC time constant. This rate is chosen to be super-audible but much lower than the main oscillation rate. Detection is accomplished by measuring the emitter current of the gain stage. Any RF input signal at the frequency of the main oscillation will aid the main oscillation in restarting. If the amplitude of the RF input increases, the main oscillation will stay on for a longer period of time, and the emitter current will be higher. Therefore, we can detect the original base-band signal by simply low-pass filtering the emitter current. The average emitter current is not very linear as a function of the RF input level. It exhibits a 1/ln response because of the exponentially rising nature of oscillator start-up. The steep slope of a logarithm near zero results in high sensitivity to small input signals.

Data Slicer

The data slicer converts the base-band analog signal from the super-regenerative detector to a CMOS/TTL compatible output. Because the data slicer is AC coupled to the audio output, there is a minimum data rate. AC coupling also limits the minimum and maximum pulse width. Typically, data is encoded on the transmit side using pulse-width modulation (PWM) or non-return-to-zero (NRZ). The most common source for NRZ data is from a UART embedded in a micro-controller. Applications that use NRZ data encoding typically involve microcontrollers. The most common source for PWM data is from a remote control IC such as the HC-12E from Holtek or ST14 CODEC from Sunrom Technologies. Data is sent as a constant rate square-wave. The duty cycle of that square wave will generally be either 33% (a zero) or 66% (a one). The data slicer on the STR-433 is optimized for use with PWM encoded data, though it will work with NRZ data if certain encoding rules are followed.

Power Supply

The STR-433 is designed to operate from a 5V power supply. It is crucial that this power supply be very quiet. The power supply should be bypassed using a 0.1uF low-ESR ceramic capacitor and a 4.7uF tantalum capacitor. These capacitors should be placed as close to the power pins as possible. The STR-433 is designed for continuous duty operation. From the time power is applied, it can take up to 750mSec for the data output to become valid.

Antenna Input

It will support most antenna types, including printed antennas integrated directly onto the PCB and simple single core wire of about 17cm. The performance of the different antennas varies. Any time a trace is longer than 1/8th the wavelength of the frequency it is carrying, it should be a 50 ohm microstrip.

2.4 MODULE 4:DTMF DECODER

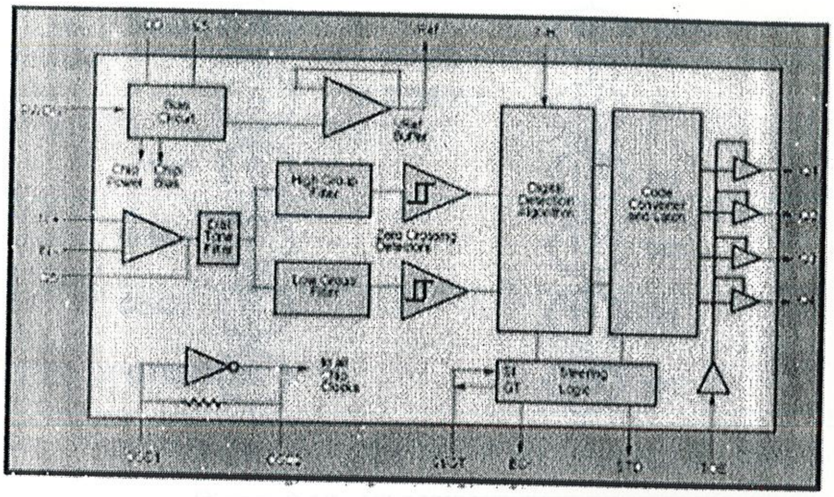


Figure 2.11: IC MT8870:Block Diagram

IC MT8870/KT3170 serves as DTMF decoder. This IC takes DTMF signal coming via telephone line and converts that signal into respective BCD number. It uses same oscillator frequency used in the remote section so same crystal oscillator with frequency of 3.85M Hz is used in this IC.

The MT-8870 is a full DTMF Receiver that integrates both band split filter and decoder functions into a single 18-pin DIP. Its filter section uses switched capacitor technology for both the high and low group filters and for dial tone rejection. Its decoder uses digital counting techniques to detect and decode all 16 DTMF tone pairs into a 4-bit code. External component count is minimized by provision of an on-chip differential input amplifier, clock generator, and latched tri-state interface bus. Minimal external components required include a low-cost 3.579545 MHz crystal, a timing resistor, and a timing capacitor. The MT-8870-02 can also inhibit the decoding of fourth column digits.

The filter also incorporates notches at 350 and 440 Hz, providing excellent dial tone rejection. Each filter output is followed by a single-order switched capacitor section that smoothes the signals prior to limiting. Signal limiting is performed by high gain comparators provided with hysteresis to prevent detection of unwanted low-level signals and noise. The MT-8870 decoder uses a digital counting technique to determine the frequencies of the limited tones and to verify that they correspond to standard DTMF frequencies. When the detector recog-

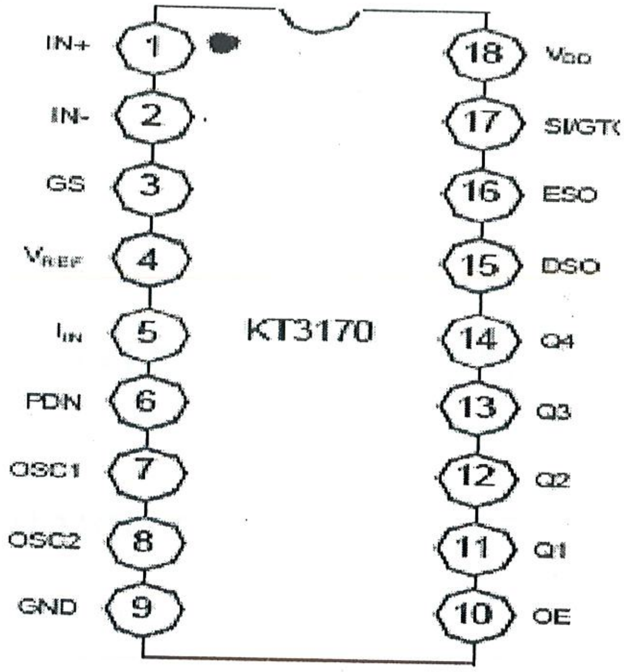


Figure 2.12: IC MT8870:Pin Out

nizes the simultaneous presence of two valid tones (known as signal condition), it raises the Early Steering flag (ESt). Any subsequent loss of signal condition will cause ESt to fall. Before a decoded tone pair is registered, the receiver checks for valid signal duration (referred to as character- recognition-condition). This check is performed by an external RC time constant driven by ESt. A short delay to allow the output latch to settle, the delayed steering output flag (StD) goes high, signaling that a received tone pair has been registered. The contents of the output latch are made available on the 4-bit output bus by raising the three state control input (OE) to logic high. Inhibit mode is enabled by a logic high input to pin 5 (INH). It inhibits the detection of 1633 Hz.

The output code will remain the same as the previous detected code. On the M- 8870 models, this pin is tied to ground (logic low).

The input arrangement of the MT-8870 provides a differential input operational amplifier as well as a bias source (VREF) to bias the inputs at mid-rail. Provision is made for connection of a feedback resistor to the op-amp output (GS) for gain adjustment.

The internal clock circuit is completed with the addition of a standard 3.579545 MHz crystal.

Chapter 3

HARDWARE REQUIREMENTS

3.1 THE BASIC COMPONENTS

3.1.1 The Resistor

The resistor's function is to reduce the flow of electric current. This symbol is used to indicate a resistor in a circuit diagram, known as a schematic. Resistance value is designated in units called the "**Ohm**". A 1000 Ohm resistor is typically shown as 1K-Ohm (kilo Ohm), and 1000 K-Ohms is written as 1M-Ohm (megohm). There are two classes of resistors:

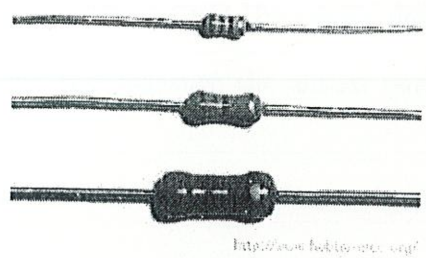


Figure 3.1: Different Resistors

- Fixed resistors
- Variable resistors

They are also classified according to the material from which they are made. The typical resistor is made of either carbon film or metal film. There are other types as well, but these are the most common. The resistance value of the resistor is not the only thing to consider when selecting a resistor for use in a circuit. The "tolerance" and the electric power ratings of the resistor are also important. The tolerance of a resistor denotes how close it is to the actual rated resistence value.

For example, a ±5% tolerance would indicate a resistor that is within ±5% of the specified resistance value. The power rating indicates how much power the resistor can safely tolerate. Just like we wouldn't use a 6 volt flashlight lamp to replace a burned out light in your house, you wouldn't use a 1/8 watt resistor when you should be using a 1/2 watt resistor.

The maximum rated power of the resistor is specified in **Watts**. Power is calculated using the square of the current (I^2) x the resistance value (R) of the resistor. If the maximum rating of the resistor is exceeded, it will become extremely hot, and even burn.

$$P = I^2R$$

Resistors in electronic circuits are typicaly rated 1/8W, 1/4W, and 1/2W. 1/8W is almost always used in signal circuit applications. When powering a light emitting diode, a comparatively large current flows through the resistor, so you need to consider the power rating of the resistor you choose

Rating Electric Power

If we try to drop the voltage from 12V to 5V using only a resistor, then we need to calculate the power rating of the resistor as well as the resistance value. At this time, the current consumed by the 5V circuit needs to be known. Here are a few ways to find out how much current the circuit demands.

- Assemble the circuit and measure the actual current used with a multimeter.
- Check the component's current use against a standard table.

Resistance Value

As for the standard resistance value, the values used can be divided like a logarithm. For example, in the case of E3, The values [1], [2.2], [4.7] and [10] are used. They divide 10 into three, like a logarithm. It is because of this that the resistance value is seen at a glance to be a discrete value. The resistance value is displayed using the color code(the colored bars/the colored stripes), because the average resistor is too small to have the value printed on it with numbers.

Resistance types

Following are the types of resistances which we could have used depending upon the application involved:

1. **Fixed Resistors:**
   - **Carbon film resistors:**This is the most general purpose, cheap resistor. Usually the tolerance of the resistance value is ±5%. Power ratings of 1/8W, 1/4W and 1/2W are frequently used. Carbon film resistors have a disadvantage; they tend to be electrically noisy. Metal film resistors are recommended for use in analog circuits. However, I have never experienced any problems with this noise.
   - **Metal film resistors:**Metal film resistors are used when a higher tolerance (more accurate value) is needed. They are much more accurate in value than carbon film resistors. They have about ±0.05% tolerance. They have about ±0.05% tolerance. I don't use any high tolerance resistors in my circuits. Resistors that are about ±1% are more than sufficient. Ni-Cr (Nichrome) seems to be used for the material of resistor. The metal film resistor is used for bridge circuits, filter circuits, and low-noise analog signal circuits.

2. **Variable Resistors:**There are two general ways in which variable resistors are used. One is the variable resistor which value is easily changed, like the volume adjustment of Radio. The other is semi-fixed resistor that is not meant to be adjusted by anyone but a technician. It is used to adjust the operating condition of the circuit by the technician. Semi-fixed resistors are used to compensate for the inaccuracies of the resistors, and to fine-tune a circuit. The rotation angle of the variable resistor is usually about 300 degrees. Some variable resistors must be turned many times to use the whole range of resistance they offer. This allows for very precise adjustments of their value. These are called "Potentiometers" or "Trimmer Potentiometers."

   When type "A" rotates clockwise, at first, the resistance value changes slowly and then in the second half of its axis, it changes very quickly. The "A" type variable resistor is typically used for the volume control of a radio, for example. It is well suited to adjust a low sound subtly. It suits the characteristics of the ear. The ear hears low sound changes well, but isn't as sensitive to small changes in loud sounds. A larger change is needed as the volume is increased. These "A" type variable resistors are sometimes called "audio taper" potentiometers. As for type "B", the rotation of the axis and the change of the resistance value are directly related. The rate of change is the same, or linear, throughout the sweep of the axis. This type suits a resistance value adjustment in a circuit, a balance circuit and so on. They are sometimes called "linear taper" potentiometers. Type "C" changes exactly the opposite way to type "A". In the early stages of the rotation of the axis, the resistance value changes rapidly, and in the second half, the change occurs more slowly. This type isn't too much used. It is a special use. As for the variable resistor, most are type "A" or type "B".

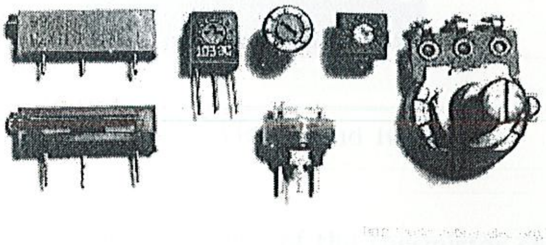


Figure 3.2: Different Types of Variable Resistors

3. **CDS Element**:Some components can change resistance value by changes in the amount of light hitting them. One type is the Cadmium Sulfide Photocell. (Cd) The more light that hits it, the smaller its resistance value becomes. There are many types of these devices. They vary according to light sensitivity, size, resistance value etc.

Figure 3.3: CDS Photocell

4. **Wire Wound Resistor**:A wirewound resistor is made of metal resistance wire, and because of this, they can be manufactured to precise values. Also, high-wattage resistors can be made by using a thick wire material. Wire-wound resistors cannot be used for high-frequency circuits. Coils are used in high frequency circuits. Since a wirewound resistor is a wire wrapped

around an insulator, it is also a coil, in a manner of speaking. Using one could change the behavior of the circuit. Still another type of resistor is the Ceramic resistor. These are wirewound resistors in a ceramic case, strengthened with a special cement. They have very high power ratings, from 1 or 2 watts to dozens of watts. These resistors can become extremely hot when used for high power applications, and this must be taken into account when designing the circuit.

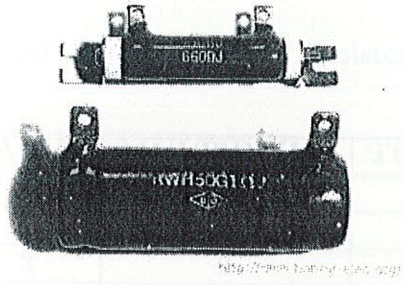


Figure 3.4: Wire-wound Resistors

5. **Thermistor**:The resistance value of the thermistor changes according to temperature. This part is used as a temperature sensor.There are mainly three types of thermistor:

   - **NTC(Negative Temperature Coefficient Thermistor)**: With this type, the resistance value decreases continuously as the temperature rises.
   - **PTC(Positive Temperature Coefficient Thermistor)** : With this type, the resistance value increases suddenly when the temperature rises above a specific point.
   - **CTR(Critical Temperature Resister Thermistor)** : With this type, the resistance value decreases suddenly when the temperature rises above a specific point. The NTC type is used for the temperature control.

   The relation between the temperature and the resistance value of the NTC type can be calculated using the following formula:

$$R = R_0 exp\, B\left(\frac{1}{T} - \frac{1}{T_0}\right)$$

Resistor Color Code

The color coding is shown in figure 3.5 and in the scheme is shown in table 3.1

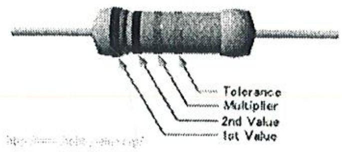


Figure 3.5: Wire-wound Resistors

COLOR	VALUE	MULTIPLIER	TOLERANCE
Black	0	0	-
Brown	1	1	±1
Red	2	2	±2
Orange	3	3	±0.05
Yellow	4	4	-
Green	5	5	±0.5
Blue	6	6	±0.25
Violet	7	7	±0.1
Gray	8	8	-
White	9	9	-
Gold	-	-1	±5
Silver	-	-2	±10
None	-	-	±20

Table 3.1: Color Codes

3.1.2 The Capacitor

The capacitor's function is to **store electricity**, or electrical energy. The capacitor also functions as a **filter passing, alternating, curren AC** and **blocking direct current** (**DC**).The capacitor is constructed with two electrode plates facing eachother, but separated by an insulator.

When DC voltage is applied to the capacitor, an electric charge is stored on each electrode. While the capacitor is charging up, current flows. The current will stop flowing when the capacitor has fully charged. When a circuit tester, such as an analog meter set to measure resistance, is connected to a 10 microfarad (μF) electrolytic capacitor, a current will flow, but only for a moment. You can confirm that the meter's needle moves off of zero, but returns to zero right away. When you connect the meter's probes to the capacitor in reverse, you will note that current once again flows for a moment. Once again, when the capacitor has fully charged, the current stops flowing. So the capacitor can be used as a filter that blocks DC current. (A "DC cut" filter.) However, in the case of alternating current, the current will be allowed to pass. Alternating current is similar to repeatedly switching the test meter's probes back and forth on the capacitor. Current flows every time the probes are switched. The value of a capacitor (the capacitance), is designated in units called the **Farad (F)**. The capacitance of a capacitor is generally very small, so units such as the microfarad ($10^{-6}F$), nanofarad ($10^{-9}F$), and picofarad ($10^{-12}F$) are used. Recently, an new capacitor with very high capacitance has been developed. The Electric Double Layer capacitor has capacitance designated in Farad units. These are known as "**Super Capacitors**".

There are two ways in which the capacitance can be written. One uses letters and numbers, the other uses only numbers. In either case, there are only three characters used. [10n] and [103] denote the same value of capacitance. The method used differs depending on the capacitor supplier. In the case that the value is displayed with the three-digit code, the 1st and 2nd digits from the left show the 1st figure and the 2nd figure, and the 3rd digit is a multiplier which determines how many zeros are to be added to the capacitance. Picofarad (pF) units are written this way.

The capacitor has an insulator(the dielectric) between 2 sheets of electrodes. Different kinds of capacitors use different materials for the dielectric.

Breakdown Voltage

The breakdown voltage is the voltage that when exceeded will cause the dielectric (insulator) inside the capacitor to break down and conduct. When this happens, the failure can be catastrophic.

When using a capacitor, you must pay attention to the maximum voltage which can be used. This is the "breakdown voltage." The breakdown voltage depends on the kind of capacitor being used. You must be especially careful with electrolytic capacitors because the breakdown voltage is comparatively low. The breakdown voltage of electrolytic capacitors is displayed as Working Voltage.

Capacitor Types

Following are the types of various capacitors which are used according to the application involved and rating values required:

1. **Electrolytic Capacitor**:Aluminum is used for the electrodes by using a

thin oxidization membrane. Large values of capacitance can be obtained in comparison with the size of the capacitor, because the dielectric used is very thin. The most important characteristic of electrolytic capacitors is that they have **polarity**. They have a positive and a negative electrode.[Polarised] This means that it is very important which way round they are connected. If the capacitor is subjected to voltage exceeding its working voltage, or if it is connected with incorrect polarity, it may burst. It is extremely dangerous, because it can quite literally explode.

Generally, in the circuit diagram, the **positive side** is indicated by a "+" (plus) symbol. Electrolytic capacitors range in value from about 1μF to thousands of μF. Mainly this type of capacitor is used as a ripple filter in a power supply circuit, or as a filter to bypass low frequency signals.

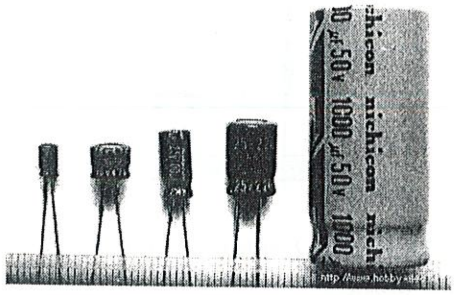


Figure 3.6: Electrolytic Capacitors

2. **Tantalum Capacitor**:Tantalum Capacitors are **electrolytic capacitors** that is use a material called tantalum for the electrodes. Large values of capacitance similar to aluminum electrolytic capacitors can be obtained. Also, tantalum capacitors are superior to aluminum electrolytic capacitors in **temperature and frequency** characteristics. When tantalum powder is baked in order to solidify it, a crack forms inside. An electric charge can be stored on this crack.

   Tantalum capacitors are a little bit more expensive than aluminum electrolytic capacitors. Capacitance can change with temperature as well as frequency, and these types are very stable. Therefore, tantalum capacitors are used for circuits which demand high stability in the capacitance values. Also, it is said to be common sense to use tantalum capacitors for analog signal systems, because the current-spike noise that occurs with aluminum electrolytic capacitors does not appear. Aluminum electrolytic capacitors are fine if you don't use them for circuits which need the high stability characteristics of tantalum capacitors.

3. **Ceramic Capacitor**:Ceramic capacitors are constructed with materials

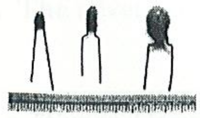


Figure 3.7: Tantalum Capacitors

such as **titanium acid barium** used as the dielectric. Internally, these capacitors are not constructed as a coil, so they can be used in high frequency applications. Typically, they are used in circuits which bypass high frequency signals to ground. These capacitors have the shape of a disk. Their capacitance is comparatively small. Ceramic capacitors should not be used for analog circuits, because they can distort the signal.

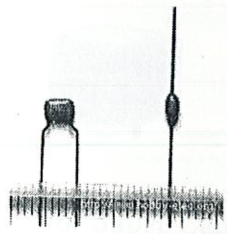


Figure 3.8: Ceramic Capacitors

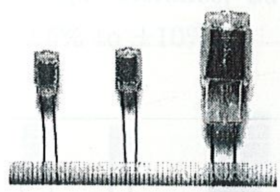


Figure 3.9: Multilayer Ceramic Capacitors

4. **Multilayer Ceramic Capacitor**:The multilayer ceramic capacitor has a **many −layered** dielectric. These capacitors are small in size, and have good temperature and frequency characteristics. Square wave signals used in digital circuits can have a comparatively high frequency component included. This capacitor is used to bypass the high frequency to ground. These capacitors are not polarized. That is, they have no polarity.

5. **Polystyrene Film Capacitor**:In these devices, polystyrene film is used as the dielectric. This type of capacitor is not for use in high frequency circuits, because they are constructed like a coil inside. They are used well in filter circuits or timing circuits which run at several hundred KHz or less. The component shown on the left has a red color due to the copper

leaf used for the electrode. The silver color is due to the use of aluminum foil as the electrode.

6. **Super Capacitor**:This is a "Super Capacitor," which is quite a wonder. The capacitance is 0.47 F (470,000 μF).Care must be taken when using a capacitor with such a large capacitance in power supply circuits, etc.The rectifier in the circuit can be destroyed by a huge rush of current when the capacitor is empty. For a brief moment, the capacitor is more like a short circuit. A protection circuit needs to be set up. The size is small in spite of capacitance. Physically, the diameter is 21 mm, the height is 11 mm. Care is necessary, because these devices do have **polarity**.

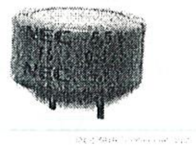


Figure 3.10: Super Capacitor

7. **Polyester Film Capacitor**:This capacitor uses thin polyester film as the dielectric. They are not high tolerance, but they are cheap and handy. Their tolerance is about ±5% to ±10%.

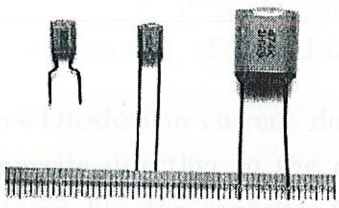


Figure 3.11: Polyester Film Capacitor

3.1.3 The Diode

A diode is a semiconductor device which allows current to flow through it in only one direction. Although a transistor is also a semiconductor device, it does not operate the way a diode does. A diode is specifically made to allow current to flow through it in only one direction.

Some ways in which the diode can be used are listed here:

- A diode can be used as a rectifier that converts AC (Alternating Current) to DC (Direct Current) for a power supply device.

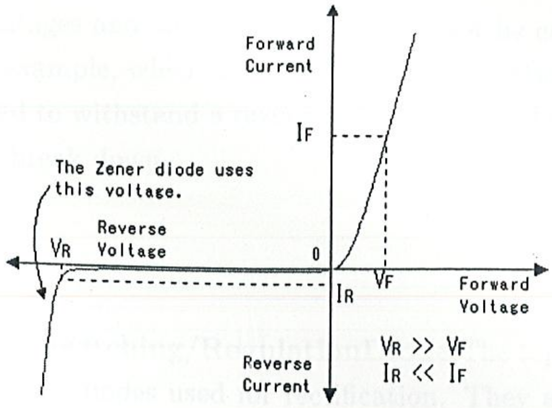


Figure 3.12: Typical Characteristics Of a Diode

- Diodes can be used to separate the signal from radio frequencies.
- Diodes can be used as an on/off switch that controls current.

Current flows from the anode side to the cathode side.Although all diodes operate with the same general principle, there are different types suited to different applications:

1. **Voltage Regulation Diode (Zener Diode)**:It is used to regulate voltage, by taking advantage of the fact that Zener diodes tend to stabilize at a certain voltage when that voltage is applied in the opposite direction.
2. **Light Emitting Diode**:This type of diode emits light when current flows through it in the forward direction. (Forward biased).
3. **Variable Capacitance Diode**:The current doesnot flow when applying the voltage of the opposite direction to the diode.In this condition,the diode has the capacitance like the capacitor.It is a very small capacitnace.The capacitance changes when changing voltage.With the change of this capacitance,the frequency of the oscillator can be changed.

When a small voltage is applied to the diode in the forward direction, current flows easily. Because the diode has a certain amount of resistance, the voltage will drop slightly as current flows through the diode. A typical diode causes a voltage drop of about 0.6 - 1V (VF) (In the case of silicon diode, almost 0.6V). When voltage is applied in the reverse direction through a diode, the diode will have a great resistance to current flow. Different diodes have different characteristics when reverse-biased. A given diode should be selected depending on how it will be used in the circuit. The current that will flow through a diode biased in the reverse direction will vary from several mA to just μA, which is very small.

The limiting voltages and currents permissible must be considered on a case by case basis. For example, when using diodes for rectification, part of the time they will be required to withstand a reverse voltage. If the diodes are not chosen carefully, they will break down.

Diode Types

1. **Rectification/Switching/RegulationDiode:**The top two devices shown in the picture are diodes used for rectification. They are made to handle relatively high currents. The device on top can handle as high as 6A, and the one below it can safely handle up to 1A. However, it is best used at

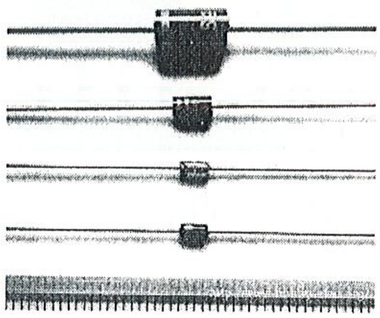


Figure 3.13: Rectification Diodes

about 70% of its rating because this current value is a maximum rating. The third device from the top (red color) has a part number of 1S1588. This diode is used for switching, because it can switch on and off at very high speed. However, the maximum current it can handle is 120 mA. This makes it well suited to use within digital circuits. The maximum reverse voltage (reverse bias) this diode can handle is 30V. The device at the bottom of the picture is a voltage regulation diode with a rating of 6V. When this type of diode is reverse biased, it will resist changes in voltage. If the input voltage is increased, the output voltage will not change. (Or any change will be an insignificant amount.) While the output voltage does not increase with an increase in input voltage, the output current will. This requires some thought for a protection circuit so that too much current does not flow. The rated current limit for the device is 30 mA. Generally, a 3-terminal voltage regulator is used for the stabilization of a power supply. Therefore, this diode is typically used to protect the circuit from momentary voltage spikes. 3 terminal regulators use voltage regulation diodes inside.

2. **Diode Bridge**:Rectification diodes are used to make DC from AC. It is possible to do only 'half wave rectification' using 1 diode. When 4 diodes are combined, 'full wave rectification' occurrs. Devices that combine 4 diodes in one package are called diode bridges. They are used for full-wave rectification. The cylindrical device on the right in the photograph has a current limit of 1A. Physically, it is 7 mm high, and 10 mm in diameter.The flat device on the left has a current limit of 4A. It is has a thickness of 6 mm, is 16 mm in height, and 19 mm in width.It has a current capacity of 15A. The peak reverse-bias voltage is 400V. Diode bridges with large

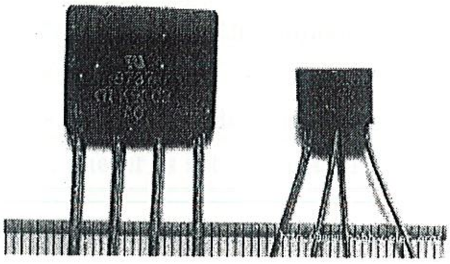


Figure 3.14: Diode Bridge

current capacities like this one, require a heat sink. Typically, they are screwed to a piece of metal, or the chasis of device in which they are used. The heat sink allows the device to radiate excess heat. As for size, this one is 26 mm wide on each side, and the height of the module part is 10 mm.

3. **Light Emitting Diode (LED)**:Light emitting diodes must be choosen according to how they will be used, because there are various kinds. The

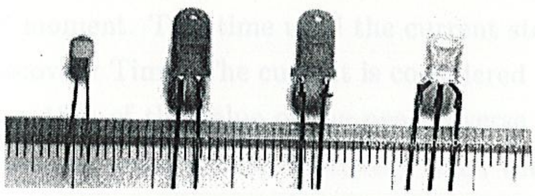


Figure 3.15: Light Emitting Diodes

diodes are available in several colors. The most common colors are red and green, but there are even blue ones.

The device on the far right in the photograph combines a red LED and green LED in one package. The component lead in the middle is common to both LEDs. As for the remaing two leads, one side is for the green, the other for the red LED. When both are turned on simultaneously, it becomes orange.

When an LED is new out of the package, the polarity of the device can be determined by looking at the leads. The longer lead is the Anode side, and the short one is the Cathode side.

The polarity of an LED can also be determined using a resistance meter, or even a 1.5 V battery.

When using a test meter to determine polarity, set the meter to a low resistance measurement range. Connect the probes of the meter to the LED. If the polarity is correct, the LED will glow. If the LED does not glow, switch the meter probes to the opposite leads on the LED. In either case, the side of the diode which is connected to the black meter probe when the LED glows, is the Anode side. Positive voltage flows out of the black probe when the meter is set to measure resistance.

4. **Schottky Barrier Diode**:Diodes are used to rectify alternating current into direct current. However, rectification will not occur when the frequency of the alternating current is too high. This is due to what is known as the "reverse recovery characteristic." The reverse recovery characteristic

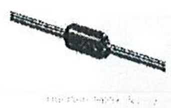


Figure 3.16: Schottky Barrier Diode

can be explained as follows: IF the opposite voltage is suddenly applied to a forward-biased diode, current will continue to flow in the forward direction for a brief moment. This time until the current stops flowing is called the Reverse Recovery Time. The current is considered to be stopped when it falls to about 10% of the value of the peak reverse current. The Shottky barrier diode has a short reverse recovery time, which makes it ideally suited to use in high frequency rectification. The shottky barrier diode has the following characteristics:

- The voltage drop in the forward direction is low.
- The reverse recovery time is short.

3.1.4 The Transistor

The transistor's finction is to amplify an electric current. Many different kinds of transistors are used in analog circuits, for different reasons. This is not the case for digital circuits. In a digital circuit, only two values matter; on or off. The amplification abilitiy of a transistor is not relevant in a digital circuit. In many cases, a circuit is built with integrated circuits(ICs). Transistors are often used in digital circuits as buffers to protect ICs. For example, when powering an electromagnetic switch (called a 'relay'), or when controlling a light emitting diode.

Two different symbols are used for the transistor.

Figure 3.17: Transistor Types:PNP And NPN

Appearance of Transistor

The outward appearance of the transistor varies. Here, two kinds are shown. On

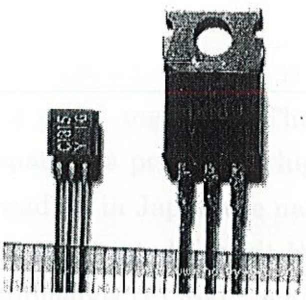


Figure 3.18: Transistor Appearance

the left in the photograph is a 2SC1815 transistor, which is good for use in a digital circuit. On the right is a device which is used when a large current is to be handled. Its part number is 2SD880.

The name (standard part number) of the transistor, as well as the type and the way it is used is shown below.

2SAXXXX PNP type high frequency
2SBXXXX PNP type low frequency
2SCXXXX NPN type high frequency
2SDXXXX NPN type low frequency

The direction of the current flow differs between the PNP and NPN type. When the power supply is the side of the positive (plus), the NPN type is easy to use.

Component Lead Of The Transistor

Because the component leads differ between kinds of transistors, you need to confirm the leads with a datasheet, etc.

- $\underline{Example\,of\,2SC1815\,transistor}$Part number is printed on the flat face of the transistor, and indicates the front.
  Right side : Base
  Center : Collector
  Left side : Emitter

- $\underline{Example\,of\,2SD880\,transistor}$Part number is printed on the flat face of the transistor, and indicates the front.
  Right side : Emitter
  Center : Collector
  Left side : Base
  2SC1815 is opposite.

3.1.5 The Ring Boards

When assembling an electronic circuit, a board is needed on which the components can be mounted and wired together. This board is called a Printed Wiring Board (PWB). In Japan, the printed wiring board used to be called a "Printed Circuit Board." Nowadays in Japan the name "Printed Circuit Board" is not used because the initials of "Printed Circuit Board" are "PCB." PCB also stands for "Polychlorinated Biphenyls (PCBs)," which is a poison. So in Japan, we refer to the boards as "Printed Wiring Boards." In other countries, they are still refered to as "Printed Circuit Boards," or PCBs.

To use the board, the parts are mounted on the face of the board, and the component leads are passed through the nearest holes, to project through the bottom of the board, where the wires can be soldered together. The interval between the holes is 0.1 inches (2.54 mm), so DIP or SIP ICs can be easily mounted. The photograph shows a PWB made of glass epoxy. The color is green. Paper epoxy boards have a beige color. In case of bakelite, the color is thin brown. As for the size of the board, there are several kinds by the number of the holes.
55 x 40 holes (size 160 x 115 mm)

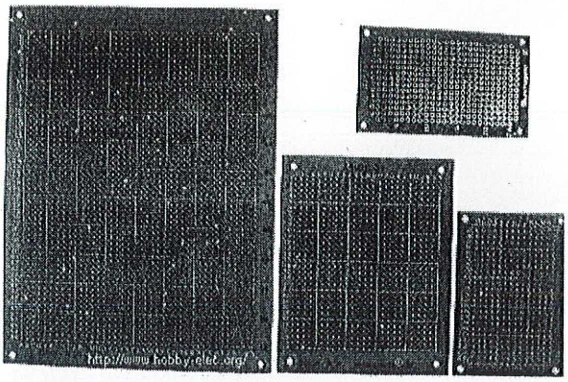


Figure 3.19: Ring Boards

30 x 25 holes (size 95 x 72 mm)
25 x 15 holes (size 72 x 47 mm)
There are various sizes in addition to what I have shown, so you can select a board according to your needs. The boards can also be cut to size.

3.1.6 PCB Etching

Etching is where the excess copper is removed to leave the individual tracks or traces as they are sometimes called. Buckets, bubble tanks, and spray machines lots of different ways to etch, but most firms currently use high pressure con-veyerised spray equipment. Spray etching is fast, ammoniacal etching solutions when sprayed can etch 55 microns of copper a minute. Less than 40 seconds to etch a standard 1 oz, 35 micron circuit board.

Many different chemical solutions can be used to etch circuit boards. Ranging from slow controlled speed etches used for surface preparation to the faster etches used for etching the tracks. Some are best used in horizontal spray process equipment while others are best used in tanks. Etchents for PTH work have to be selective and be non aggressive to tin / tin lead plating, which is used as the etch resist. Copper etching is normally exothermic, where high speed etching is carried out solution cooling is normally required. This is normally done by placing titanium water cooling coil into the etchent. Almost all etching solutions liberate toxic corrosive fumes, extraction is highly recommended. All etchents are corrosive and toxic, mainly due to the high metal content.

1. **PCB Layout**:The PCB layout is a mirrored positive one - black on white. Mirrored as viewed from the silkscreen top (component) side. The PCB layout is printed 1:1 on paper by means of a laser printer or copier machine. The laser printer or copier toner will not run out when it gets wet or

oily. The ink of an inkjet paper print does run out and inkjet printers are therefore useless with the described method.

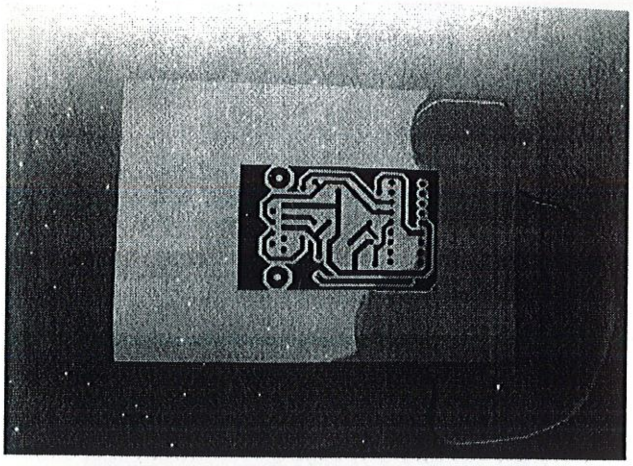


Figure 3.20: Drench Layout with sunflower-seed oil

2. **PCB Preparation:** The PCB layout paper is drenched with sunflower-seed oil. Sunflower-seed oil is common available from your local grocery or wall market. Superfluous oil should be removed carefully with tissue paper. The sunflower-seed oil is used to make the white part of the layout paper transparent for light. If you prefer to use the PCB layout more than once let the drenched PCB layout paper dry at least 48 hours. The layout paper should be carefully dried on forehand as much as possible with tissue paper. Sunflower-seed oil is a 'drying' oil. Exposed to the air over a number of hours, the layout paper becomes rigid again. A kind of polymerization takes place.

3. **PCB UV Exposure:** The protective plastic layer is removed - peeled back - from the photosensitive PCB. The toner side of the greased layout is placed on the copper of the PCB. Captured air-bubbles are gently pressed away from underneath the layout. The PCB with the layout is now covered with an appropriate sized windowpane and placed on a piece of plain polished tile or marble. The tile or marble absorbs the heat coming from the UV bulb, which is significant. Three to four minutes 300W bulb UV exposure from a distance of 30-40 cm will do the photo process. Take care when finished and removing the PCB, it gets hot.

4. **PCB Developmen:** The PCB is developed with a 1% solution of sodium hydroxide NaOH. You can make this solvent by adding 10 gram of sodium hydroxide pellets to 1 liter of water and mix it until everything is dissolved.

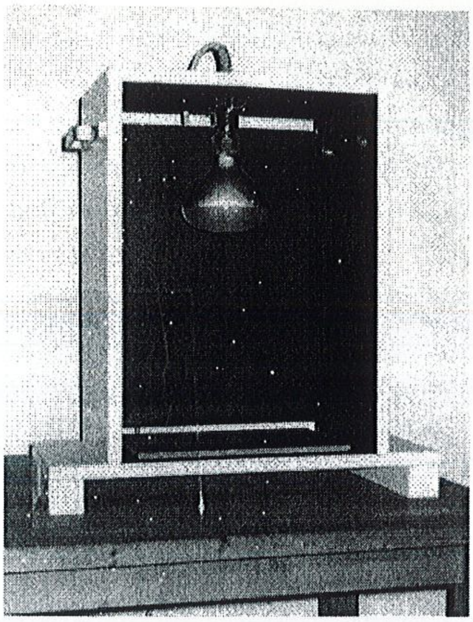
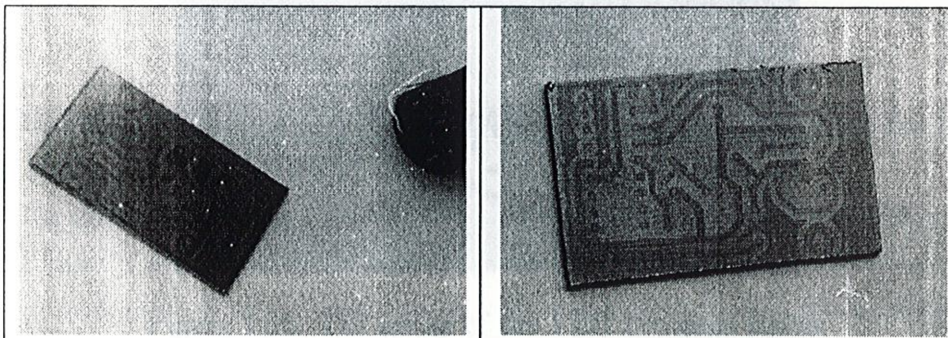


Figure 3.21: Home-built UV exposure box with 300W UV bulb, polished tile and window pane

Use a brush to speed up the developing and clean the PCB during this process if the PCB is still greasy due to the applied sunflower-seed oil. The developing process takes about 1 minute. It is sometimes difficult to guess when the developing is finished. The traces should become clear and the exposed photosensitive layer has dissolved (during the brushing you see darker 'cloud' coming off the PCB surface).



(a) Gently brush the PCB

(b) Almost developed, some traces are not clear yet

Figure 3.22: PCB development

5. **PCB Etching:**The developed PCB is etched with a 220 g/l solution of ammonium peroxydisulfate $(NH_4)_2S_2O_8$ a.k.a. ammonium persulfate, 220 gram added to 1 liter of water and mix it until everything is dissolved.

Theoretically it should be possible to etch slightly more than 60 grams of copper with 1 liter etching solution. Assume an 50% efficiency, about 30 grams of copper.Etching at ambient temperature might take over an hour, it is better to heat up the etching solvent to about 35-45 degrees Celcius. The etching solution heating up could be done in a magnetron, this takes about 40 to 60 seconds in a 850W magnetron. The etching - rocking the

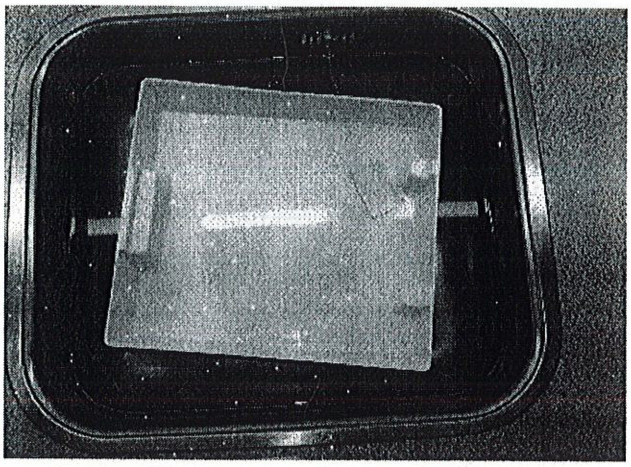


Figure 3.23: Rock the etching tray

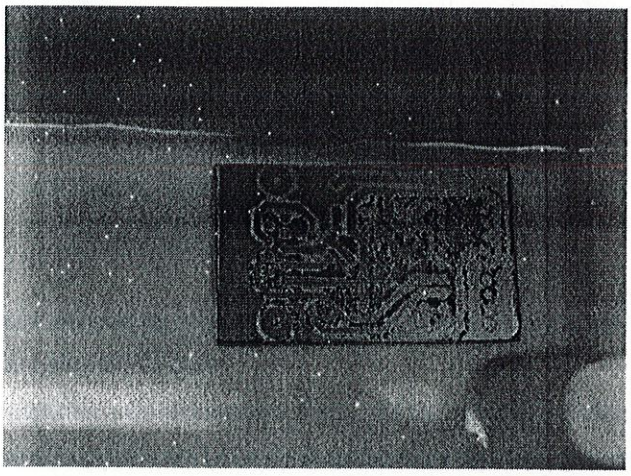


Figure 3.24: The epoxy of the PCB becomes visible

etching tray - takes about 15-30 minutes at this temperature. If you have a heated, air-bubble circulated etching fluid tank available, this is probably the fastest way to etch. At higher temperatures the etching performance decreases. The etching process is an exothermic reaction, it generates heat. When the ammonium peroxydisulfate is dissolved it is a clear liquid. After an etching procedure it gradually becomes blue and more deeper blue - the chemical reaction creates dissolved copper sulfate $CuSO_4$.

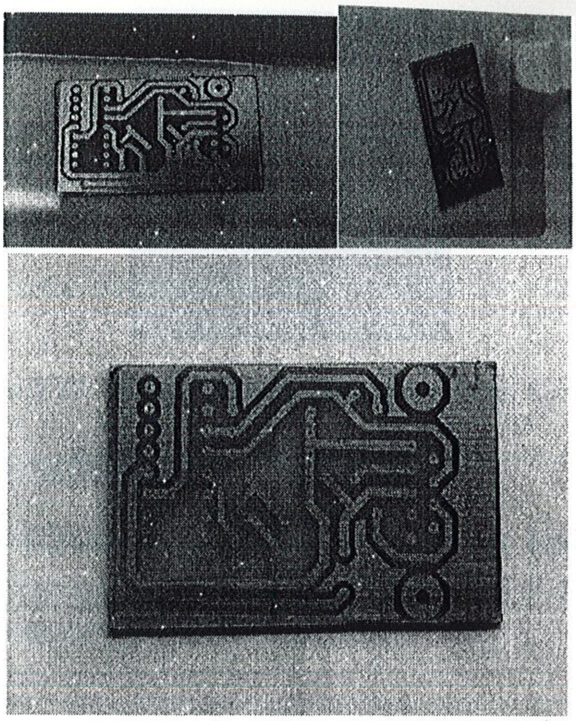


Figure 3.25: Etched PCB

3.1.7 The Relay

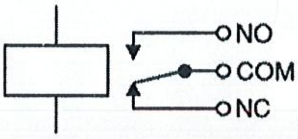


Figure 3.26: Circuit Diagram of a Relay

The relay takes advantage of the fact that when electricity flows through a coil, it becomes an electromagnet.

The electromagnetic coil attracts a steel plate, which is attached to a switch. So the switch's motion (ON and OFF) is controled by the current flowing to the coil, or not, respectively. A very useful feature of a relay is that it can be used to electrically isolate different parts of a circuit. It will allow a low voltage circuit (e.g. 5VDC) to switch the power in a high voltage circuit (e.g. 100 VAC or more). The relay operates mechanically, so it can not operate at high speed. There are many kind of relays. You can select one according to your needs. The various things to consider when selecting a relay are its size, voltage and current capacity of the contact points, drive voltage, impedance, number of contacts, resistance of the contacts, etc. The resistance voltage of the contacts is the maximum voltage that can be conducted at the point of contact in the switch.

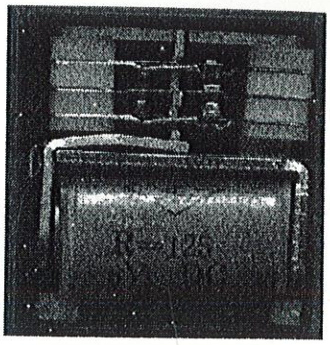
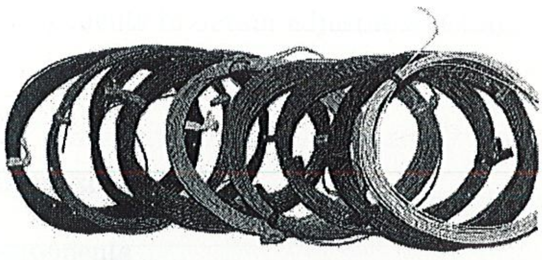


Figure 3.27: Relay Showing Coil and Switch Contacts

3.1.8 Wiring Material

Wire is used to electrically connect circuit parts, devices, equipment etc. There are various kinds of wiring materials. The different types of wire can be divided largely into two categories:

- Single wire
- Twisted strand wire



http://www.hobby-elec.org/

Figure 3.28: Wiring Materials

Usually, single wire is used to connect devices (resistors, capacitors etc.) together on the PWB. (Parts that don't move) It is also used for jumper wiring. Twisted strand wire can bend freely, so it can be used for wiring on the PWB, and also to connect discrete pieces of equipment.If single wire is used to connnect separate equipment, it will break soon, as it is not very flexible.

It is convenient to use the single tin coated wire of the diameter 0.32 mm for the wiring of PWB. If the diameter is larger, soldering becomes a little bit difficult. And if the diameter is too thin, it becomes difficult to bend the wire. Twisted wire covered with soft insulation material is most convenient for wiring. It's convenient to wire the circuit using different color wires for different purposes. Otherwise, wiring the circuit with many wires the same color gets confusing. There are several kinds of coated wires. Tin coated wire colored silver, polyurethane enameled copper wire(UEW) which has a thin brown color, polyester enameled copper wire (PEW) which is also thin brown, and enameled wire with a burnt brown color.Coated wire is used for making coil components like a transformers. The PEW can not be soldered, because the polyester coating will not melt at the soldering temperature. In case of the UEW, you do not need to scrape the insulation off the wire, because the polyurethane will melt at the soldering temperature.

3.2 LM7805 Voltage Regulator

3.2.1 General Description

The LM78XX series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

3.2.2 Features

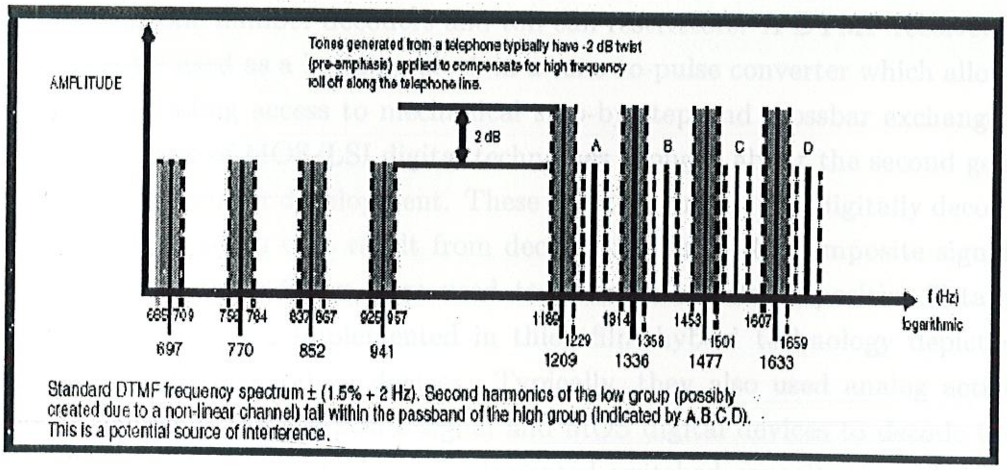
- Output current in excess of 0.5A
- No external components
- Internal thermal overload protection
- Internal short circuit current-limiting
- Output transistor safe-area compensation
- Available in TO-220, TO-39, and TO-252 D-PAK packages
- Output voltages of 5V, 12V, and 15V

Voltage Range

- LM7805C 5V
- LM7812C 12V

3.3 MT8870 Integrated DTMF Receiver

The purpose of this Application Note is to provide information on the operation and application of DTMF Receivers. The MT8870 Integrated DTMF Receiver will be discussed in detail and its use illustrated in the application examples which follow.More than 25 years ago the need for an improved method for transferring dialling information through the telephone network was recognized.The traditional method, Dial pulse signalling, was not only slow, suffering severe distortion over long wire loops, but required a DC path through the communications channel.A signalling scheme was developed utilizing voice frequency tones and implemented as a very reliable alternative to pulse dialling.This scheme is known as DTMF (Dual Tone Multi-Frequency), Touch-ToneTM or simply, tone dialling. As its acronym suggests, a valid DTMF signal is the sum of two tones, one from a low group (697-941Hz) and one from a high group (1209-1633Hz) with each group containing four individual tones. The tone frequencies were carefully chosen such that they are not harmonically related and that their intermodulation products result in minimal signalling impairment. This scheme allows for 16 unique combinations. Ten of these codes represent the numerals zero through nine, the remaining six $(*, \#, A, B, C, D)$ being reserved for special signalling. Most telephone keypads contain ten numeric push buttons plus the asterisk (*) and octothorp (#). The buttons are arranged in a matrix, each selecting its low group tone from its respective row and its high group tone from its respective column. The DTMF coding scheme ensures that each signal contains one and



Standard DTMF frequency spectrum ± (1.5% + 2 Hz). Second harmonics of the low group (possibly created due to a non-linear channel) fall within the passband of the high group (Indicated by A,B,C,D). This is a potential source of interference.

Figure 3.29: DTMF Spectrum

only one component from each of the high and low groups. This significantly simplifies decoding because the composite DTMF signal may be separated with bandpass filters, into its two single frequency components each of which may be handled individually. As a result DTMF coding has proven to provide a flex-

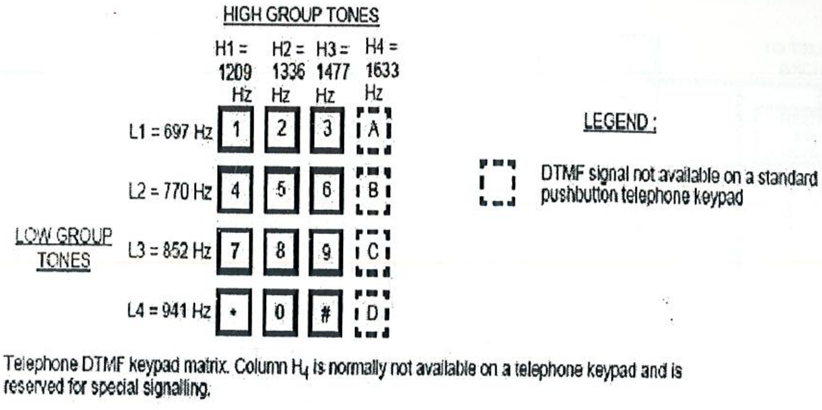


Figure 3.30: DTMF Keypad

ible signalling scheme of excellent reliability, hence motivating innovative and competitive decoder design.

3.3.1 Development

Early DTMF decoders (receivers) utilized banks of bandpass filters making them somewhat cumbersome and expensive to implement. This generally restricted their application to central offices (telephone exchanges).
The first generation receiver typically used LC filters, active filters and/or phase locked loop techniques to receive and decode DTMF tones. Initial functions were, commonly, phone number decoders and toll call restrictors. A DTMF receiver is also frequently used as a building block in a tone-to-pulse converter which allows Touch-Tone dialling access to mechanical step-by-step and crossbar exchanges. The introduction of MOS/LSI digital techniques brought about the second generation of tone receiver development. These devices were used to digitally decode the two discrete tones that result from decomposition of the composite signal. Two analog bandpass filters were used to perform the decomposition.Totally self-contained receivers implemented in thick film hybrid technology depicted the start of third generation devices. Typically, they also used analog active filters to bandsplit the composite signal and MOS digital devices to decode the tones. The development of silicon-implemented switched capacitor sampled filters marked the birth of the fourth and current generation of DTMF receiver technology. Initially single chip bandpass filters were combined with currently available decoders enabling a two chip receiver design. A further advance in integration has merged both functions onto a single chip allowing DTMF receivers to be realized in minimal space at low cost. The second and third generation

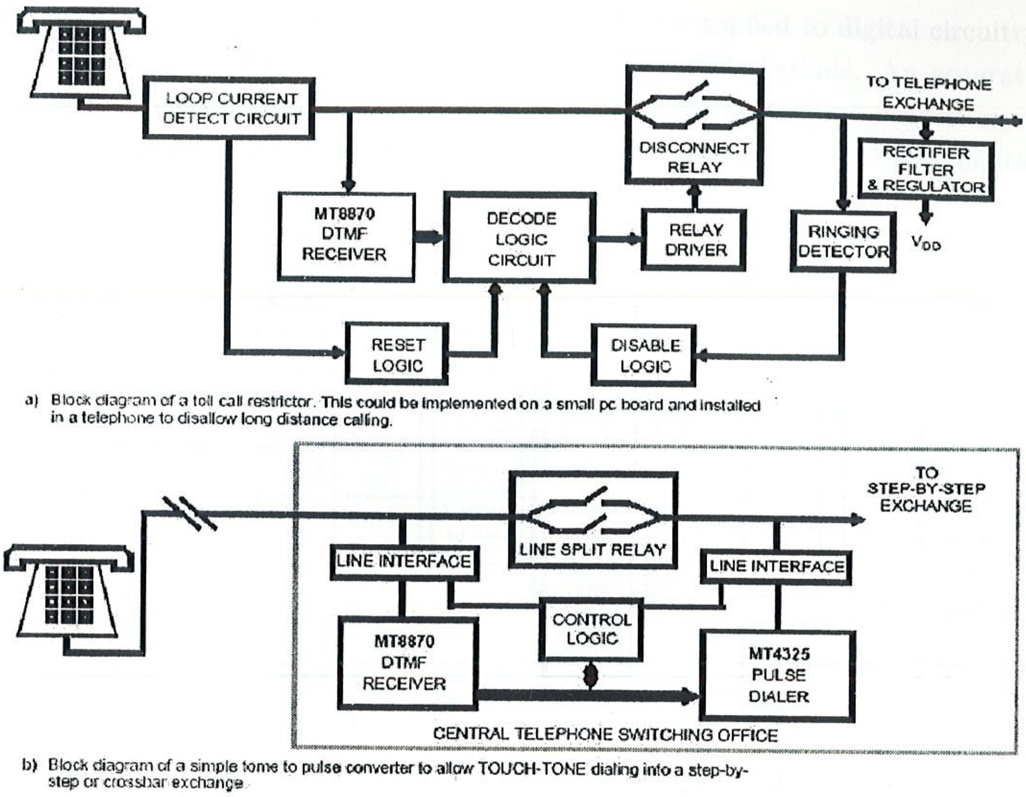


Figure 3.31: Typical DTMF Receiver Application

technologies saw a tendency to shift complexity away from the analog circuitry towards the digital LSI circuitry in order to reduce the complexity of analog filters and their inherent problems. Now that the filters themselves can be implemented in silicon, the distribution of complexity becomes more a function of performance and silicon real estate.

3.3.2 Inside The MT8870

The MT8870 is a state of the art single chip DTMF receiver incorporating switched capacitor filter technology and an advanced digital counting/averaging algorithm for period measurement.The block diagram illustrates the internal workings of this device. To aid design flexibility, the DTMF input signal is first buffered by an input op-amp which allows adjustment of gain and choice of input configuration. The input stage is followed by a low pass continuous RC active filter which performs an antialiasing function. Dial tone at 350 and 440Hz is then rejected by a third order switched capacitor notch filter. The signal, still in its composite form, is then split into its individual high and low frequency components by two sixth order switched capacitor and pass filters. Each component tone is then smoothed by an output filter and squared up by a hard limiting comparator. The two resulting rectangular waves are applied to digital circuitry where a counting algorithm measures and averages their periods. An accurate reference clock is derived from an inexpensive external 3.58MHz colourburst crystal. The timing diagram illustrates the sequence of events which follow digital

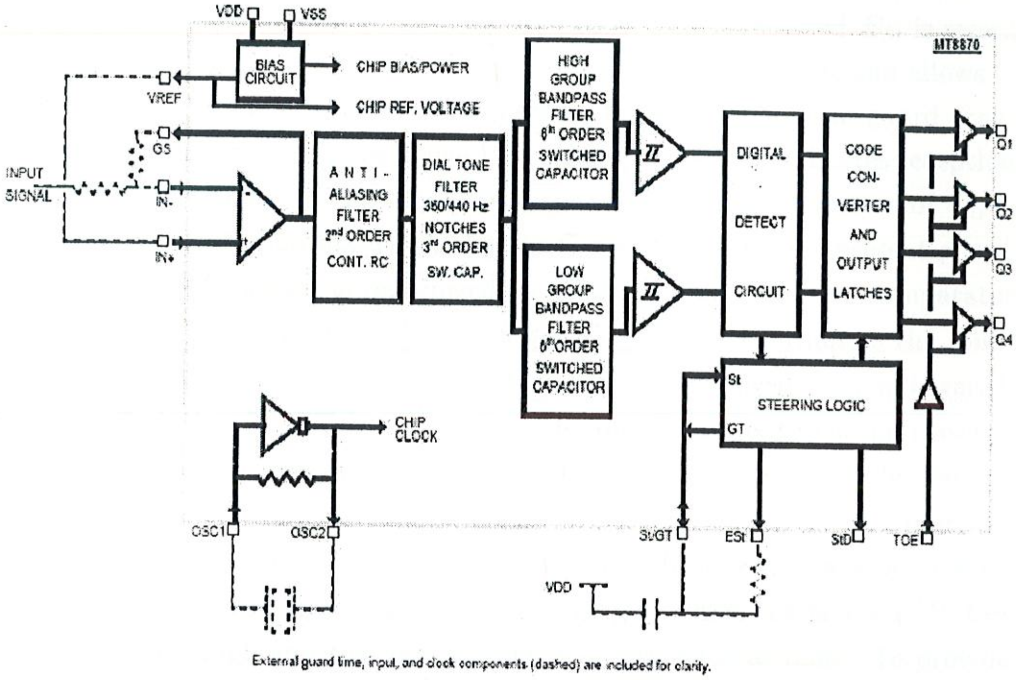


Figure 3.32: Functional Block Diagram Of MT8870

detection of a DTMF tone pair. Upon recognition of a valid frequency from each tone group the Early Steering (E_{St}) output is raised. The time required to detect the presence of two valid tones, t_{DP}, is a function of the decode algorithm, the tone frequency and the previous state of the decode logic. E_{St} indicates that two tones of proper frequency have been detected and initiates an RC timing circuit. If both tones are present for the minimum guard time, t_{GTP}, which is determined by the external RC network, the DTMF signal is decoded and the resulting data is latched in the output register. The Delayed Steering (St_D) output is raised and indicates that new data is available. The time required to receive a valid DTMF signal,t_{REC},is equal to the sum of t_{DP} and t_{GTP}.A simplified circuit diagram illustrates how the chip's steering circuit drives the external RC network to generate guard times. Pin 17, St/GT (Steering/Guard Time), is a bidirectional signal pin which controls St_D, the output latches, and resets the timing circuit. When St/GT is in its input mode (St function) both Q1and Q2 are turned off and the voltage level at St/GT is compared to the steering threshold voltage V_{TSt}. A transition from below to above V_{TSt} will switch the comparator's output from low to high strobing new data into the output latches, and raising the St_D output. As long as an input level above V_{TSt} is maintained St_D will remain high indicating the presence of a valid DTMF signal. Initially, when no valid tone-pairs are present, capacitor C is fully charged applying a low voltage to St/GT. This causes a low at the comparator's output and since E_{St} is also low, Q2 turns on ensuring that C is completely charged. In this condition St/GT is in its output mode (GT function). When a valid tone- pair is received E_{St} is raised turning off Q2 which puts St/GT in its high impedance input mode and allows C to discharge through R. If this condition persists for the tone-present guard time, t_{GTP}, the voltage at St/GT rises above V_{TSt} raising S_{tD} which indicates reception of a valid DTMF signal. If the tone pair drops out before the duration of t_{GTP}, E_{St} is lowered turning on Q2 which charges C resetting the tone-present guard time.Once a DTMF signal is recognized as valid both E_{St} and the comparator output are high. This turns on Q1 which discharges C and initializes the tone-absent guard time, t_{GTA}. After the DTMF signal is removed, E_{St} is lowered, Q1 turns off placing St/GT in its input mode and C begins to charge through R. If the same valid tone-pair does not reappear before t_{GTA} then the voltage at St/GT falls below V_{TSt} which resets the timing circuit via Q2 and prepares the device to receive another signal. If the same valid tone-pair reappears before t_{GTA}, ESt is raised turning on Q1 and discharging C which resets t_{GTA}. In this case St_D remains high and the tone dropout is disregarded as noise. To provide good reliability in a typical telephony environment, a DTMF receiver should be designed to recognize a valid tone-pair greater than 40mS in duration and, to accept as successive digits, tone- pairs that are greater than 40mS apart. However in other environments, such as two-way radio, the optimum tone duration and intra-digit times may differ due to noise considerations. By adding an extra resistor and steering diode t_{GTP} and t_{GTA} can be set to different values. Guard time adjustment allows tailoring of noise immunity and talk-off performance to meet specific system needs. Talk-off is a measure of errors that occur when the receiver falsely detects a tone pair due to speech or background noise simulating a DTMF signal. Increasing t_{GTP} improves talk off performance since it reduces the probability that speech will maintain DTMF simulation long enough to be considered valid. The trade-off here is decreased noise immunity because dropout (longer than tDA) due to noise pulses will restart tGTP. Therefore, for noisy environments, t_{GTP} should be decreased. The signal absent guard time, t_{GTA}, determines the minimum time allowed between successive DTMF signals. A dropout shorter than t_{GTA} will be considered noise and will not register as a successive valid tone detection. This guards against multiple reception of a single character. Therefore, lengthening t_{GTA} will Many considerations must be taken into account in evaluating criteria for noise rejection. In the telephony environment two sources of noise are predominant. These are, third tone interference, which generally comes from dial tone harmonics, and band-limited white noise . In the MT8870 a complex digital averaging algorithm provides excellent immunity to voice, third tone and noise signals which prevail in a typical voice bandwidth channel. The algorithm used in the MT8870 combines the increase

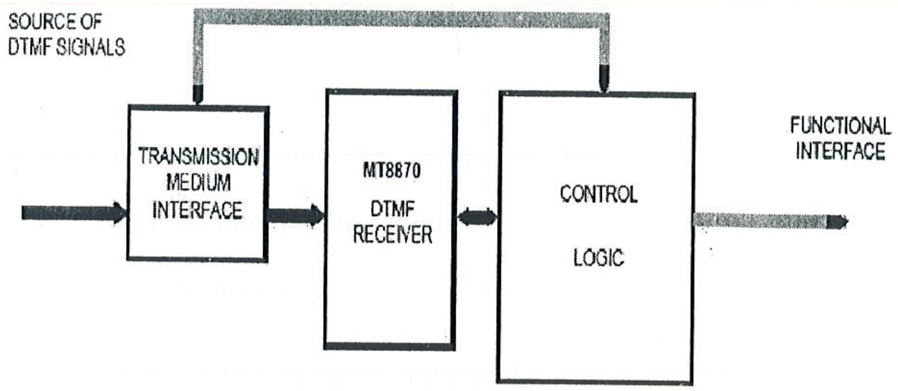


Figure 3.33: Modular Approach to DTMF Receiver System

noise immunity and tolerance to the presence of an unwanted third tone at the expense of decreasing the maximum signalling rate. The intricacies of the digital detection algorithm have a significant impact on the overall receiver performance. It is here that the initial decision is made to accept the signal as valid or reject it as speech or noise. Trade-offs must be made between eliminating talk of errors and eliminating the effects of unwanted third tone signals and noise. These are mutually conflicting events. On one hand valid DTMF signals present in noise must be recognized which requires relaxation of the detection criteria. On the other hand, relaxing the detection criteria increases the probability of receiving "hits" due to talk off errors. Many considerations must be taken into account in evaluating criteria for noise rejection. In the telephony environment two sources of noise are predominant. These are, third tone interference, which generally comes from dial tone harmonics, and band-limited white noise . In the MT8870 a complex digital averaging algorithm provides excellent immunity to voice, third tone and noise signals which prevail in a typical voice bandwidth channel. The algorithm used in the MT8870 combines the best features from two previous generations of Zarlink digital decoders with improvements resulting from years of practical use within the telephone environment. The algorithm has evolved through a combination of statistical calculations and empirical "tweaks" to result in the realization of an extremely reliable decoder.

3.3.3 Data Communication Usinf DTMF

There is a vast array of potential applications for DTMF signalling using the existing telephone network. Considering that there are millions of ready-made data sets installed in convenient locations (i.e. the Touch Tone telephone) remote control and data entry may be performed by users without requiring them to carry around bulky data modems.

Potential applications include:

- Home Remote Control
- Remote Data Entry from any Touch-Tone keypad
- Credit Card Verification and inquiry
- Salesman Order Entry
- Catalogue Store (stock/price returned via voice synthesis)
- Stock Broker buy/sell/inquire -using stock exchange listing mnemonics
- Answering Machine Message Retrieval
- Automatic Switchboard Extension Forwarding

optional data port can boast a variety of conveniences. Remote ON/OFF control may be given to electric appliances such as a slow cooker, exterior lighting and garage heater. An electro-mechanical solenoid operated valve allows remote control of a garden sprinkler. Video buffs could interface to their VCR remote control inputs and record T.V. shows with a few keystrokes of their friend's telephone. This would enhance the function of timers which are currently available on most VCR's.Schedule changes or unexpected broadcasts could be captured from any remote location featuring a Touch-Tone phone.Security systems could be controlled and a microphone could be switched in for remote audio monitoring. Interfacing a home computer to the data port makes an excellent family message center. At the remote end messages are entered from a telephone keypad. The computer responds with voice messages generated by a speech synthesizer.In the home, messages to be left are entered via the computer keyboard. Messages to be read may be displayed on the computer monitor or "played back" through the speech synthesizer.A scheme for coding ASCII characters using one and two digit DTMF signals is outlined in the appendix. Notice that on a telephone keypad keys 2 through 9 are represented by three alpha-characters as well as a numeral. To send an alpha-character, using this scheme, first press the key on which the character appears then press the key corresponding to the position in which the character appears on its key (1, 2 or 3). Numerals are sent by touching the desired number followed by a zero. The asterisk (*) and octothorp (#) have been reserved for "space" and "return" respectively. A plastic overlay the size of a credit card expands the number of useable "positions" on each button. This serves as a guide for sending other ASCII codes and fits snug into a credit card wallet. ASCII control characters that are not commonly used could be listed at the bottom of the card. This user-friendly algorithm eliminates the need to memorize conversion codes and allows significant functionality even without the overlay reference.A simple block diagram shows how this scheme may be implemented for a home DTMF control system. A ringing voltage detector signals the microprocessor of an incoming call. The microprocessor, after the prescribed number of rings, closes the answer relay engaging the proper terminating impedance. A two-to-four wire converter splits bidirectional audio from the balanced telephone line into separate single ended transmit and receive paths. Receive audio is then switched to the DTMF receiver through the

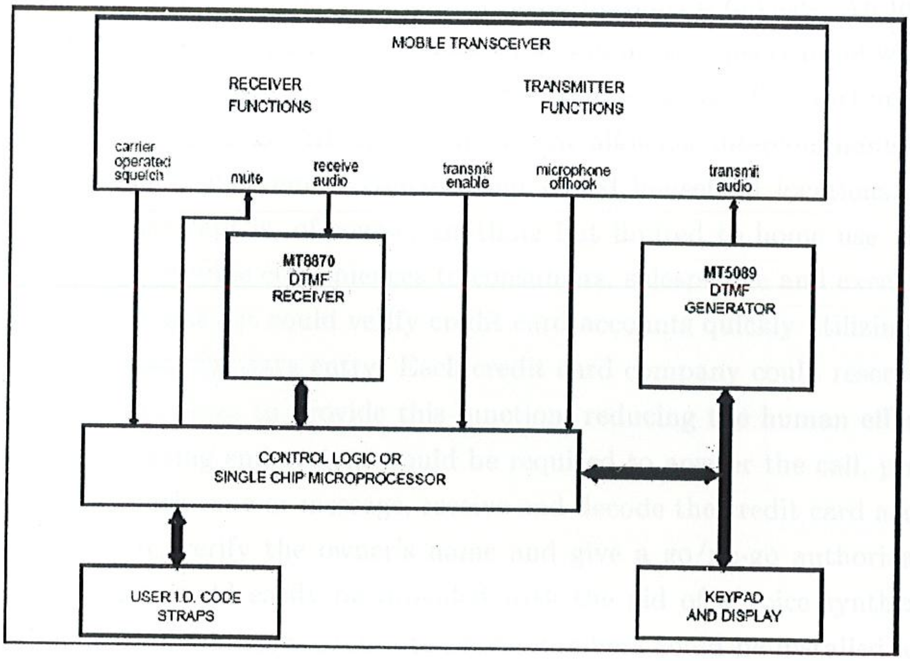


Figure 3.34: Block Diagram Of Mobile Radio Communication System

crosspoint switch. Upon receiving a valid DTMF signal, the microprocessor is alerted by the rising edge of St_D. The microprocessor then checks for a valid password sequence and decodes subsequent commands. A command can be entered to put the system into remote-control mode. In this case the crosspoint switch is configured to route DTMF signals into the FM-over-mains transmitter as well as the system tone receiver. Forwarding of control signals is accomplished by applying an FM carrier to the power line. This eliminates the need to string control wires haphazardly about the house. The appropriate device is selected by its unique DTMF I.D. code. The microcomputer keeps track of all device locations and their I.D. codes since it must decide when to supply function outputs to the "nearby" devices and when to let the "remote" receivers handle the data. Subsequent data is transmitted to a selected device until a 'reset' command is entered. Upon receiving any DTMF signal, answer back tones are returned by the microprocessor to acknowledge valid or invalid operations and to indicate the state of an interrogated device. For example, a low to high tone transition could indicate that a particular device is on, a high to low transition indicating the off state. A command could be entered to put the system in an 'external' mode which would allow communications through the data port. A host computer could be connected to this port to broaden the scope of the system. The resident microprocessor unit contains the software and hardware to control ringing verification, password and command decoding, answer back tone generation, audio routing, output function latches and an optional data port. Output drivers buffer the latches and switch relays or SCRs to control peripheral devices. An infinite variety of devices could be controlled by such a system, the spectrum of which is limited only by the ability to provide appropriate interfacing. This system could also be the heart of a DTMF intercom system allowing intercommunication, "phone- patching", and remote control from varied household locations. This type of system concept is, of course, anything but limited to home use. Many applications can provide conveniences to consumers, salespeople and executives. For example, a merchant could verify credit card accounts quickly utilizing only a telephone keypad for data entry. Each credit card company could reserve one or more telephone lines to provide this function, reducing the human effort required. The receiving end system would be required to answer the call, provide a short answer back tone or message, receive and decode the credit card account number, verify it, verify the owner's name and give a go/no-go authorization. This return data could easily be provided with the aid of a voice synthesizer. An auto-dialler containing appropriate phone numbers could be installed at the merchant end as an added time saver. With a similar arrangement, a travelling salesman could access price, delivery and customer status, enter or delete merchandise orders and retrieve messages all from the comfort of the customer's office. A department store could provide shop-by-phone service to its customers using telephone keypad data entry. Brokerage firms, utilizing the stock exchange mnemonic listings could provide trading price information and buy/sell service via telephone keypad entry. A voice synthesizer could provide opening and current trading price, volume of transactions and other pertinent data. A telephone answering system manufacturer could apply this technique, allowing users to access and change outgoing and incoming messages from a Touch-Tone phone. A PBX manufacturer could offer a feature that relieves the switchboard attendant from unneccesary interaction. A call could be answered automatically and a recording may reply "Thank you for calling XYZ. Please dial the extension you wish to contact or zero for the switchboard".If the caller knows the called party's extension in advance it is not neccesary to wait for the switchboard attendant to forward the call. The attendant could be notified to intervene if there is no action by the caller say, ten seconds after the recording ends. This provides a similar function to a "Direct Inward Dialling" (DID) trunk but without the additional overhead incurred with renting a block of phone numbers as in the DID case. Now that a DTMF receiver is so easy and inexpensive to implement there are many simple dedicated uses that become attractive. A useful home and office application for DTMF receivers is in a self-contained telephone-line-powered toll call restrictor similar to the block diagram. This could be installed in an individual telephone or at the incoming main termination depending on which phone or phones are to be restricted. While disallowing visitors from making unauthorized long distance calls, the owner may still desire access to toll dialling. This could be provided by adding a logic circuit that disables the toll restrictor upon receiving a predetermined sequence of DTMF characters. In this case, the user must enter his password before dialling a long distance number.

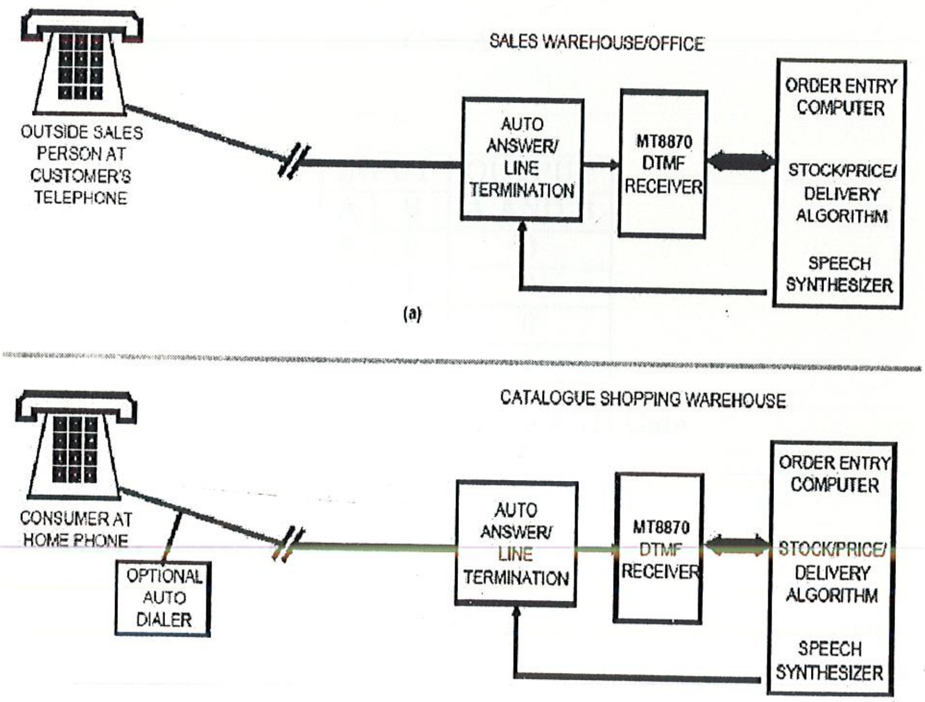


Figure 3.35: Two Applications of DTMF data communication

3.4 Logic Gates

A logic gate performs a logical operation on one or more logic inputs and produces a single logic output. The logic normally performed is Boolean logic and is most commonly found in digital circuits. Logic gates are primarily implemented electronically using diodes or transistors, but can also be constructed using electromagnetic relays (relay logic), fluidic logic, pneumatic logic, optics, molecules, or even mechanical elements. In electronic logic, a logic level is represented by a voltage or current, (which depends on the type of electronic logic in use). Each logic gate requires power so that it can source and sink currents to achieve the correct output voltage. In logic circuit diagrams the power is not shown, but in a full electronic schematic, power connections are required.

3.4.1 AND Gate:IC 7408

The AND gate is a digital logic gate that implements logical conjunction - it behaves according to the truth table to the right. A HIGH output (1) results only if both the inputs to the AND gate are HIGH (1). If neither or only one input to the AND gate is HIGH, a LOW output results. In another sense, the function of AND effectively finds the minimum between two binary digits, just as the OR function finds the maximum.
The AND gate with inputs A and B and output C implements the logical expression:

$$C = A \cdot B$$

INPUT		OUTPUT
A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

Table 3.2: Truth Table:AND Gate

3.4.2 NOT Gate:IC 7404

In digital logic, an inverter or NOT gate is a logic gate which implements logical negation. The truth table is shown on the right.This represents perfect switching behavior, which is the defining assumption in Digital electronics. In practice, actual devices have electrical characteristics that must be carefully considered

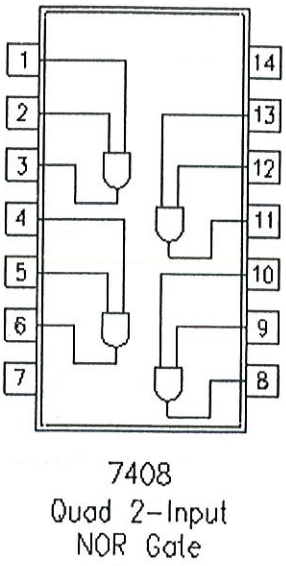


Figure 3.36: AND Gate IC 7408

when designing inverters. In fact, the non-ideal transition region behavior of a CMOS inverter makes it useful in analog electronics as a class A amplifier.Digital electronics circuits operate at fixed voltage levels corresponding to a logical 0 or 1 . An inverter circuit serves as the basic logic gate to swap between those two voltage levels. Implementation determines the actual voltage, but common levels include (0, +5V) for TTL circuits.

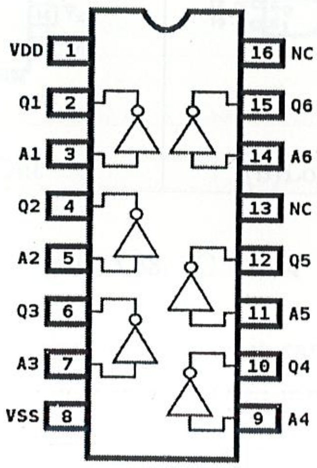


Figure 3.37: NOT Gate IC 7408

INPUT	OUTPUT
A	$\overline{A}$
0	1
1	0

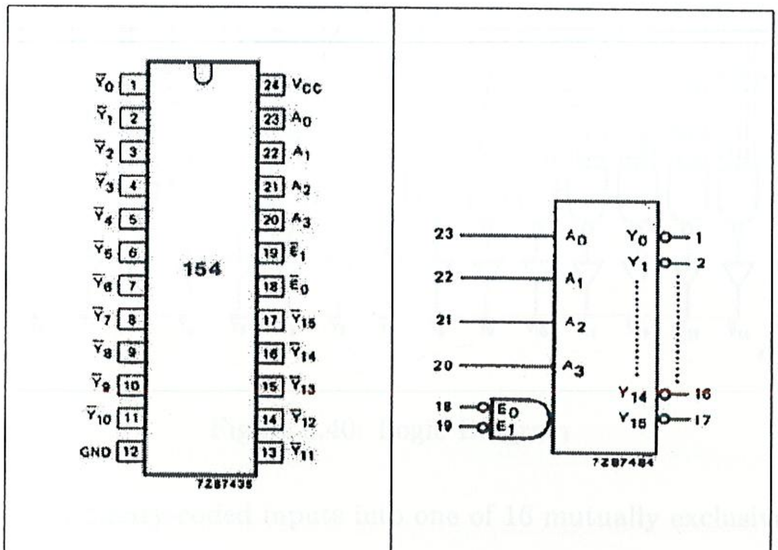
Table 3.3: Truth Table:NOT Gate

3.5 74HC/HCT154 4-to-16 line decoder/demultiplexer

3.5.1 General Description

The 74HC/HCT154 are high-speed Si-gate CMOS devices and are pin compatible with low power Schottky TTL (LSTTL). They are specified in compliance with JEDEC standard no. 7A.The 74HC/HCT154 decoders accept four active HIGH binary address inputs and provide 16 mutually exclusive active LOW outputs.

The 2-input enable gate can be used to strobe the decoder to eliminate the



(a)Pin Out (b)Logic Symbol

Figure 3.38: IC 74154

normal decoding "glitches" on the outputs, or it can be used for the expansion of the decoder. The enable gate has two AND'ed inputs which must be LOW to enable the outputs. The "154" can be used as a 1-to-16 demultiplexer by using one of the enable inputs as the multiplexed data input. When the other enable is LOW, the addressed output will follow the state of the applied data.

3.5.2 Features

- 16-line demultiplexing capability

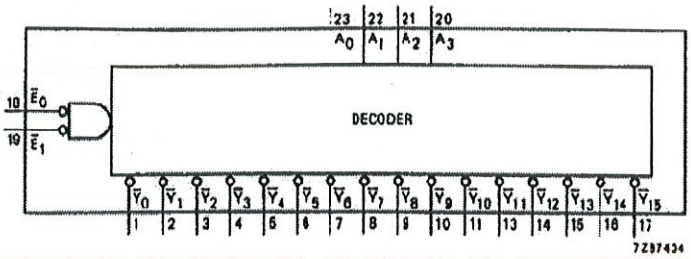


Figure 3.39: Functional Diagram

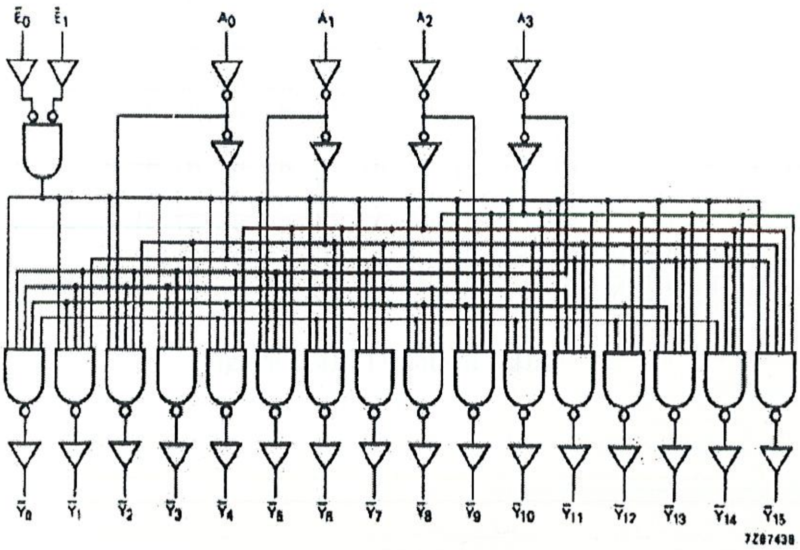


Figure 3.40: Logic Diagram

- Decodes 4 binary-coded inputs into one of 16 mutually exclusive outputs
- 2-input enable gate for strobing or expansion
- Output capability: standard
- I_{CC} category: MSI

		INPUTS				OUTPUTS															
$\overline{E}_0$	$\overline{E}_1$	A_0	A_1	A_2	A_3	$\overline{Y}_0$	$\overline{Y}_1$	$\overline{Y}_2$	$\overline{Y}_3$	$\overline{Y}_4$	$\overline{Y}_5$	$\overline{Y}_6$	$\overline{Y}_7$	$\overline{Y}_8$	$\overline{Y}_9$	$\overline{Y}_{10}$	$\overline{Y}_{11}$	$\overline{Y}_{12}$	$\overline{Y}_{13}$	$\overline{Y}_{14}$	$\overline{Y}_{15}$
H	H	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
H	L	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	H	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	L	L	L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	H	L	L	L	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	H	L	L	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	H	H	L	L	H	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	L	H	L	H	H	H	H	L	H	H	H	H	H	H	H	H	H	H	H
L	L	H	L	H	L	H	H	H	H	H	L	H	H	H	H	H	H	H	H	H	H
L	L	L	H	H	L	H	H	H	H	H	H	L	H	H	H	H	H	H	H	H	H
L	L	H	H	H	L	H	H	H	H	H	H	H	L	H	H	H	H	H	H	H	H
L	L	L	L	L	H	H	H	H	H	H	H	H	H	L	H	H	H	H	H	H	H
L	L	H	L	L	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H	H	H
L	L	L	H	L	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H	H
L	L	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H
L	L	L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H
L	L	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H
L	L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H
L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L

Figure 3.41: Function Table

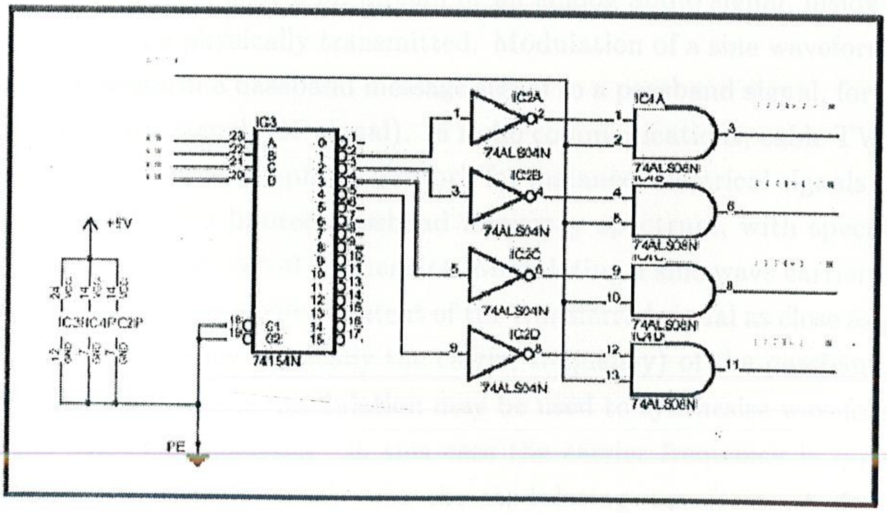


Figure 3.42: Logic Formation

Chapter 4

MODULATION

4.1 Introduction

In electronics, modulation is the process of varying one or more properties of high frequency periodic waveform, called the carrier signal, with respect to a modulating signal. This is done in a similar fashion as a musician may modulate a tone (a periodic waveform) from a musical instrument by varying its volume, timing and pitch. The three key parameters of a periodic waveform are its amplitude ("volume"), its phase ("timing") and its frequency ("pitch"), all of which can be modified in accordance with a low frequency signal to obtain the modulated signal. Typically a high-frequency sinusoid waveform is used as carrier signal, but a square wave pulse train may also occur.

In telecommunications, modulation is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform is used in view to transform a baseband message signal to a passband signal, for example a radio-frequency signal (RF signal). In radio communications, cable TV systems or the public switched telephone network for instance, electrical signals can only be transferred over a limited passband frequency spectrum, with specific (non-zero) lower and upper cutoff frequencies. Modulating a sine wave carrier makes it possible to keep the frequency content of the transferred signal as close as possible to the centre frequency (typically the carrier frequency) of the passband.

In music synthesizers, modulation may be used to synthesise waveforms with a desired overtone spectrum. In this case the carrier frequency is typically in the same order or much lower than the modulating waveform. A device that performs modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator (sometimes detector or demod). A device that can do both operations is a modem (short for

"Modulator-Demodulator").

4.2 Aim

- The aim of digital modulation is to transfer a digital bit stream over an analog passband channel, for example over the public switched telephone network (where a bandpass filter limits the frequency range to between 300 and 3400 Hz), or over a limited radio frequency band.
- The aim of analog modulation is to transfer an analog baseband (or low-pass) signal, for example an audio signal or TV signal, over an analog passband channel, for example a limited radio frequency band or a cable TV network channel.
- Analog and digital modulation facilitate frequency division multiplexing (FDM), where several low pass information signals are transferred simultaneously over the same shared physical medium, using separate passband channels.
- The aim of digital baseband modulation methods, also known as line coding, is to transfer a digital bit stream over a baseband channel, typically a non-filtered copper wire such as a serial bus or a wired local area network.
- The aim of pulse modulation methods is to transfer a narrowband analog signal, for example a phone call over a wideband baseband channel or, in some of the schemes, as a bit stream over another digital transmission system.

4.3 Modulation Types

There are two types of modulation:

- Anlog Modulation
- Digital Modulation

4.3.1 Analog Modulation

In analog modulation, the modulation is applied continuously in response to the analog information signal. Common analog modulation methods are:

1. **Amplitude modulation (AM)**(here the amplitude of the carrier signal is varied in accordance to the instantaneous amplitude of the modulating signal)
    - Double-sideband modulation (DSB)
    - Double-sideband modulation with unsuppressed carrier (DSB-WC) (used on the AM radio broadcasting band)
    - Double-sideband suppressed-carrier transmission (DSB-SC)
    - Double-sideband reduced carrier transmission (DSB-RC)
    - Single-sideband modulation (SSB, or SSB-AM)
    - SSB with carrier (SSB-WC)
    - SSB suppressed carrier modulation (SSB-SC)
    - Vestigial sideband modulation (VSB, or VSB-AM)
    - Quadrature amplitude modulation (QAM)
2. **Angle Modulation**
    - Frequency modulation (FM) (here the frequency of the carrier signal is varied in accordance to the instantaneous frequency of the modulating signal)
    - Phase modulation (PM) (here the phase shift of the carrier signal is varied in accordance to the instantaneous phase shift of the modulating signal)

4.3.2 Digital Modulation

In digital modulation, an analog carrier signal is modulated by a digital bit stream. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of M alternative symbols. According to one definition of digital signal, the modulated signal is a digital signal, and according to another definition, the modulation is a form of digital-to-analog conversion. Most textbooks would consider digital modulation schemes as a form of digital transmission, synonymous to data transmission; very few would consider it as analog transmission. These are the most fundamental digital modulation techniques:

1. In the case of **PSK**, a finite number of phases are used.
2. In the case of **FSK**, a finite number of frequencies are used.

3. In the case of **ASK**, a finite number of amplitudes are used.

4. In the case of **QAM**, a finite number of at least two phases, and at least two amplitudes are used.

In QAM, an inphase signal (the I signal, for example a cosine waveform) and a quadrature phase signal (the Q signal, for example a sine wave) are amplitude modulated with a finite number of amplitudes, and summed. It can be seen as a two-channel system, each channel using ASK. The resulting signal is equivalent to a combination of PSK and ASK.

In all of the above methods, each of these phases, frequencies or amplitudes are assigned a unique pattern of binary bits. Usually, each phase, frequency or amplitude encodes an equal number of bits. This number of bits comprises the symbol that is represented by the particular phase. f the alphabet consists of M $= 2^N$ alternative symbols, each symbol represents a message consisting of N bits. If the symbol rate (also known as the baud rate) is f_S symbols/second (or baud), the data rate is Nf_S bit/second. For example, with an alphabet consisting of 16 alternative symbols, each symbol represents 4 bits. Thus, the data rate is four times the baud rate.

4.4 Amplitude Shift Keying

Amplitude-shift keying (ASK) is a form of modulation that represents digital data as variations in the amplitude of a carrier wave.
The amplitude of an analog carrier signal varies in accordance with the bit stream (modulating signal), keeping frequency and phase constant. The level of amplitude can be used to represent binary logic 0s and 1s. We can think of a carrier signal as an ON or OFF switch. In the modulated signal, logic 0 is represented by the absence of a carrier, thus giving OFF/ON keying operation and hence the name given.
Like AM, ASK is also linear and sensitive to atmospheric noise, distortions, propagation conditions on different routes in PSTN, etc. Both ASK modulation and demodulation processes are relatively inexpensive. The ASK technique is also commonly used to transmit digital data over optical fiber. For LED transmitters, binary 1 is represented by a short pulse of light and binary 0 by the absence of light. Laser transmitters normally have a fixed "bias" current that causes the device to emit a low light level. This low level represents binary 0, while a higher-amplitude lightwave represents binary 1.

4.4.1 Encoding

The simplest and most common form of ASK operates as a switch, using the presence of a carrier wave to indicate a binary one and its absence to indicate a binary zero. This type of modulation is called on-off keying, and is used at radio frequencies to transmit Morse code (referred to as continuous wave operation). More sophisticated encoding schemes have been developed which represent data in groups using additional amplitude levels. For instance, a four-level encoding scheme can represent two bits with each shift in amplitude; an eight-level scheme can represent three bits; and so on. These forms of amplitude-shift keying require a high signal-to-noise ratio for their recovery, as by their nature much of the signal is transmitted at reduced power.

Here is a diagram showing the ideal model for a transmission system using an ASK modulation:

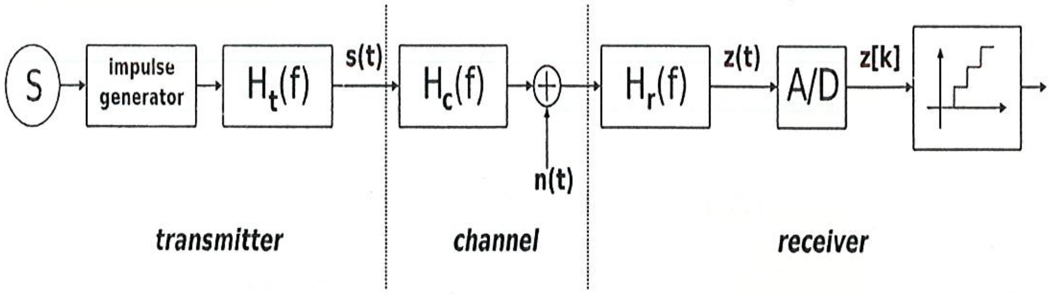


Figure 4.1: ASK Transmission System

It can be divided into three blocks. The first one represents the transmitter, the second one is a linear model of the effects of the channel, the third one shows the structure of the receiver. The following notation is used:

- $h_t(t)$ is the carrier signal for the transmission
- $h_c(t)$ is the impulse response of the channel
- $n(t)$ is the noise introduced by the channel
- $h_r(t)$ is the filter at the receiver
- L is the number of levels that are used for transmission
- T_s is the time between the generation of two symbols

Different symbols are represented with different voltages. If the maximum allowed value for the voltage is A, then all the possible values are in the range

[-A,A] and they are given by:

$$v_i = \frac{2A}{L-1}i - A; \quad i = 0, 1, \ldots, L-1$$

the difference between one voltage and the other is:

$$\Delta = \frac{2A}{L-1}$$

Considering the picture, the symbols v[n] are generated randomly by the source S, then the impulse generator creates impulses with an area of v[n]. These impulses are sent to the filter ht to be sent through the channel. In other words, for each symbol a different carrier wave is sent with the relative amplitude. Out of the transmitter, the signal s(t) can be expressed in the form:

$$s(t) = \sum_{n=-\infty}^{\infty} v[n] \cdot h_t(t - nT_s)$$

In the receiver, after the filtering through hr (t) the signal is:

$$z(t) = n_r(t) + \sum_{n=-\infty}^{\infty} v[n] \cdot g(t - nT_s)$$

where we use the notation:

$$nr(t) = n(t) * hr(f)$$

$$g(t) = ht(t) * hc(f) * hr(t)$$

where * indicates the convolution between two signals. After the A/D conversion the signal z[k] can be expressed in the form:

$$z[k] = n_r[k] + v[k]g[0] + \sum_{n \neq k} v[n]g[k-n]$$

In this relationship, the second term represents the symbol to be extracted. The others are unwanted: the first one is the effect of noise, the second one is due to the intersymbol interference.

If the filters are chosen so that g(t) will satisfy the Nyquist ISI criterion, then there will be no intersymbol interference and the value of the sum will be zero, so:

$$z[k] = nr[k] + v[k]g[0]$$

the transmission will be affected only by noise.

4.4.2 Probability of Error

The probability density function to make an error after a certain symbol has been sent can be modelled by a Gaussian function; the mean value will be the relative sent value, and its variance will be given by:

$$\sigma_N = \int_{-\infty}^{+\infty} \Phi_N(f) \cdot |H_r(f)|^2 df$$

where ΦN(f) is the spectral density of the noise within the band and $H_r(f)$ is the continuous Fourier transform of the impulse response of the filter hr (f).

The possibility to make an error is given by:

$$P_e = P_{e/H_0} \cdot P_{H_0} + P_{e/H_1} \cdot P_{H_1} + \cdots + P_{e/H_{L-1}} \cdot P_{H_{L-1}}$$

where P_{e/H_0} is the conditional probability of making an error after a symbol vi has been sent and P_{H_0} is the probability of sending a symbol v0.

If the probability of sending any symbol is the same, then:

$$P_{H_i} = \frac{1}{L}$$

If we represent all the probability density functions on the same plot against the possible value of the voltage to be transmitted, we get a picture like this (the particular case of L=4 is shown): The possibility of making an error after

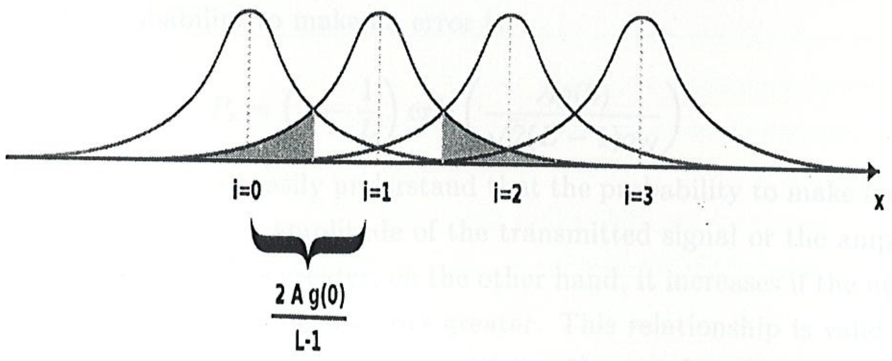


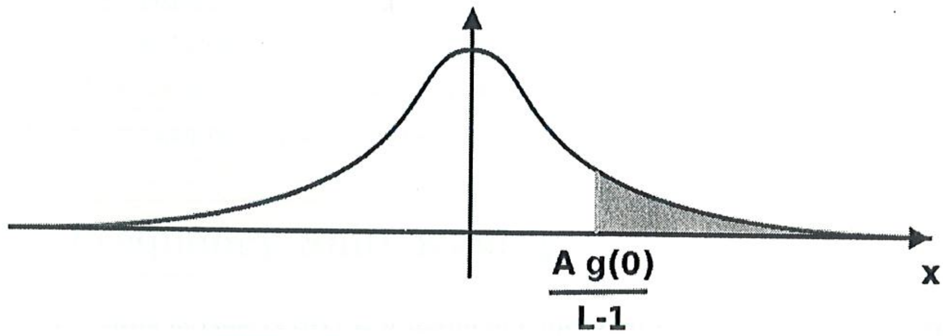
Figure 4.2: Probability Density Functions

a single symbol has been sent is the area of the Gaussian function falling under the other ones. It is shown in cyan just for one of them. If we call P+ the area under one side of the Gaussian, the sum of all the areas will be: $2LP^+ - 2P^+$.

The total probability of making an error can be expressed in the form:

$$P_e = 2\left(1 - \frac{1}{L}\right) P^+$$

We have now to calculate the value of P^+. In order to do that, we can move the origin of the reference wherever we want: the area below the function will not change. We are in a situation like the one shown in the following picture: it



does not matter which Gaussian function we are considering, the area we want to calculate will be the same. The value we are looking for will be given by the following integral:

$$P^+ = \int_{\frac{Ag(0)}{L-1}}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_N} e^{-\frac{x^2}{2\sigma_N^2}} dx = \frac{1}{2}\,\mathrm{erfc}\left(\frac{Ag(0)}{\sqrt{2}(L-1)\sigma_N}\right)$$

where erfc() is the complementary error function. Putting all these results together, the probability to make an error is:

$$P_e = \left(1 - \frac{1}{L}\right) \mathrm{erfc}\left(\frac{Ag(0)}{\sqrt{2}(L-1)\sigma_N}\right)$$

from this formula we can easily understand that the probability to make an error decreases if the maximum amplitude of the transmitted signal or the amplification of the system becomes greater; on the other hand, it increases if the number of levels or the power of noise becomes greater. This relationship is valid when there is no intersymbol interference, i.e. g(t) is a Nyquist function.

4.5 On-Off Keying

On-off keying (OOK) the simplest form of amplitude-shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave. In its simplest form, the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero.

Some more sophisticated schemes vary these durations to convey additional information. It is analogous to unipolar encoding line code.
On-off keying is most commonly used to transmit Morse code over radio frequencies (referred to as CW (continuous wave) operation), although in principle any digital encoding scheme may be used. OOK has been used in the ISM bands to transfer data between computers, for example. OOK is more spectrally efficient than FSK, but more sensitive to noise. In addition to RF carrier waves, OOK is also used in optical communication systems (e.g. IrDA). In aviation, some possibly unmanned airports have equipment that let pilots key their VHF radio a number of times in order to request an Automatic Terminal Information Service broadcast, or turn on runway lights.

4.6 Frequency Shift Keying

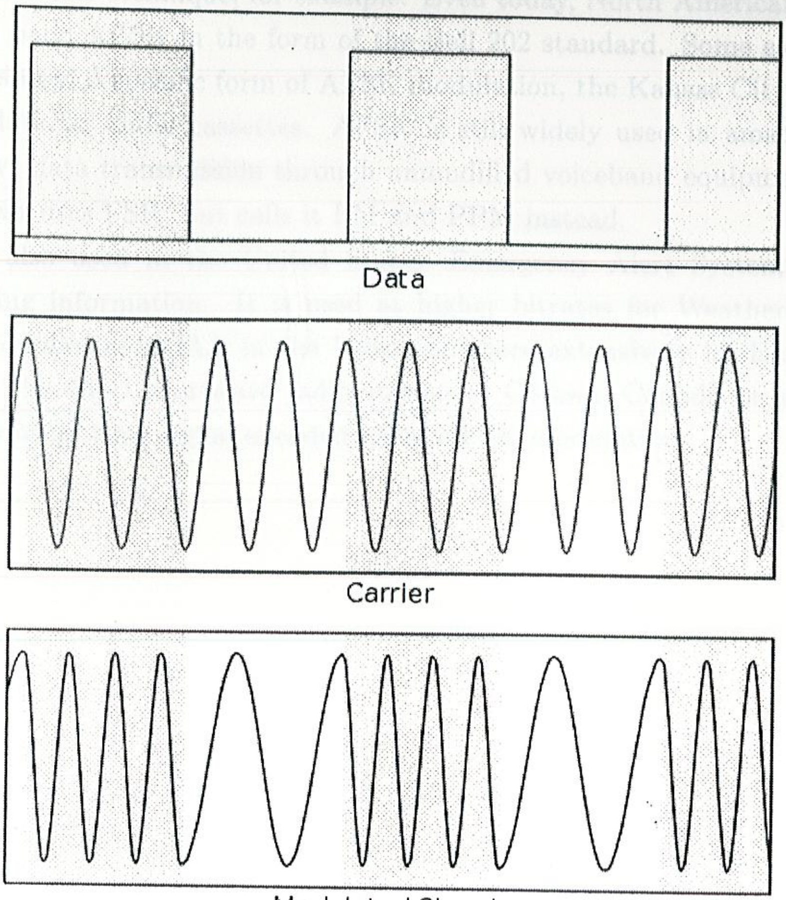
Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes of a carrier wave. The simplest FSK is binary FSK (BFSK). BFSK literally implies using a pair of discrete frequencies to transmit binary (0s and 1s) information. With this scheme, the "1" is called the mark frequency and the "0" is called the space frequency. The time domain of an FSK modulated carrier is illustrated in the figures to the right.

4.6.1 Minimum Shift Keying

Minimum frequency-shift keying or minimum-shift keying (MSK) is a particular spectrally efficient form of coherent FSK. In MSK the difference between the higher and lower frequency is identical to half the bit rate. Consequently, the waveforms used to represent a 0 and a 1 bit differ by exactly half a carrier period. This is the smallest FSK modulation index that can be chosen such that the waveforms for 0 and 1 are orthogonal. A variant of MSK called GMSK is used in the GSM mobile phone standard. FSK is commonly used in Caller ID and remote metering applications: see FSK standards for use in Caller ID and remote metering for more details.

4.6.2 Audio FSK

Audio frequency-shift keying (AFSK) is a modulation technique by which digital data is represented by changes in the frequency (pitch) of an audio tone, yielding an encoded signal suitable for transmission via radio or telephone. Normally, the



transmitted audio alternates between two tones: one, the "mark", represents a binary one; the other, the "space", represents a binary zero.

AFSK differs from regular frequency-shift keying in performing the modulation at baseband frequencies. In radio applications, the AFSK-modulated signal normally is being used to modulate an RF carrier (using a conventional technique, such as AM or FM) for transmission.

AFSK is not always used for high-speed data communications, since it is far less efficient in both power and bandwidth than most other modulation modes. In addition to its simplicity, however, AFSK has the advantage that encoded signals will pass through AC-coupled links, including most equipment originally designed to carry music or speech.

Applications

Most early telephone-line modems used audio frequency-shift keying to send and receive data, up to rates of about 300 bits per second. The common Bell 103 modem used this technique, for example. Even today, North American caller ID uses 1200 baud AFSK in the form of the Bell 202 standard. Some early microcomputers used a specific form of AFSK modulation, the Kansas City standard, to store data on audio cassettes. AFSK is still widely used in amateur radio, as it allows data transmission through unmodified voiceband equipment. Radio control gear uses FSK, but calls it FM and PPM instead.

AFSK is also used in the United States' Emergency Alert System to transmit warning information. It is used at higher bitrates for Weathercopy used on Weatheradio by NOAA in the U.S., and more extensively by Environment Canada. The CHU shortwave radio station in Ottawa, Canada broadcasts an exclusive digital time signal encoded using AFSK modulation.

Chapter 5

CONCLUSION AND FUTURE SCOPE

Our project is finally implemented on the PCB board with the help of our project guide and is in working condition.
It can be used in following fields:-

- **Used in industries for controlling machinery.**
  This project is very useful in industries for controlling the machinery required in industries. It can control the 4-10 machines in a same time.

- **Can be used in homes for controlling home appliances.**
  At home it can control all the appliances like fan, iron, T.V, tube lights, bulb, fridge, cooler, etc.

Future Scope

- Password protection can be added.
- Range of operation can be increased.
- We can implement it using computer and control our appliances via internet.
- This technology is already being used by various mobile phone companies where the mobile phone acts as a universal remote for controlling elctrical appliances.

Every day technological advancements are being made in this field, and this technology promises to be a part of various research projects in the future. Technology never stops developing and there is always a scope for future expansion.

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