MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Design and Analysis of Therapeutic Ultrasound Systems to Develop a Diathermy Device

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DECLARATION OF CANDIDATE

It is here by declared that this thesis or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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DEDICATION

This thesis is dedicated to my beloved parents and all my well wishers helping me to accomplish this work.

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LIST OF SYMBOLS AND ABBREVIATIONS

US	Ultrasound
Hz, MHz, GHz	Hertz, Mega Hertz, Giga Hertz
cps	Cycle per second
PZT	Piezoelectric Transducer
RF	Radio Frequency
BW	Bandwidth
ROM	Range of Motion
TTL	Transistor-Transistor-Logic
HIFU	High Intensity Focused Ultrasound
↑	Increase of
↓	Decrease of
PDI	Phase-Detector Input
PDO	Phase-Detector Output
PA	Power Amplifier
IF	Intermediate Frequency
RF	Radio Frequency
VHF	Very High Frequency
FET	Field Effect Transistor
dB	Decibel
AM	Amplitude Modulation
Θ	Conduction Angle
CMOS	Complementary Metal–Oxide–Semiconductor
μ, p	10^{-6} (Micro), 10^{-12} (Pico)
Ω	Ohm
RCA	Radio Corporation of America

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Design and Analysis of Therapeutic Ultrasound Systems to Develop a Diathermy Device

Abstract

Ultrasound continues to be one of the major tissue heating modalities used for the diathermy treatment of a number of medical conditions. Therefore there is innovation that is continually increasing the quality of the ultrasound diathermy systems currently available. However focus is just beginning to shift into the field of low-cost systems to facilitate the mass population. In this work a high power ultrasound system is developed that can deliver therapeutic acoustical energy waves to the ultrasound transducer probe at user defined frequency of 1MHz and 3MHz. Different output power and customized RCA connector facilitate the use of multi-applicator or probe. Output parameter of tone-burst mode is introduced along with continuous and pulsed mode. BJT is used for switching instead of FET, which has added some extra consumption of power but has greatly reduced the price. Still the low cost system is slightly held back with the high cost burden of piezoelectric probe, but enhanced with the new parameter of tone-burst mode. Experimental results are compared with simulation and practical tests with existing products. The total system is implemented using local hardware resources and hence the system is cost effective and beneficial for the third world countries.

CHAPTER 1

INTRODUCTION

1.1 Prologue to Ultrasound Diathermy

Ultrasound is acoustic energy consisting of inaudible high frequency vibrations that may produce thermal and non-thermal effects upon the tissue. This biological effect is used as a common modality of diathermy which referred as heating tissue electromagnetically or ultrasonically for therapeutic purposes in medicine. Ultrasound causes molecular collision in a medium, which allows the transmission by propagation of the wave through vibration of molecules and a progressive loss of the intensity of the energy occurs with passage through the tissue (attenuation), due to absorption and dispersion.

Ultrasound waves are created when a generator passes electrical energy through a piezoelectric crystal located within the transducer causing mechanical deformation in the crystal. The transducer is held over the area of the body that is being targeted for Ultrasound diathermy therapy. Devices are introduced at the market for years in this purpose of physical medicine. Parametric evaluation and analysis of these systems can enhance the usability and availability of the Ultrasound Diathermy.

1.2 Ultrasound

Ultrasound (US) is a form of mechanical energy. Sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing and of a level sufficiently strong to be heard, or the sensation stimulated in organs of hearing by such vibrations. The normal human sound range is from 16Hz to something approaching 15Hz - 20,000Hz (in children and young adults). Beyond this upper limit, the mechanical vibration is known as Ultrasound. The frequencies used in therapy are typically between 1.0MHz and 3.0MHz.

Ultrasound can also be defined as the cyclic sound pressure wave with a frequency greater than the upper limit of human hearing. Ultrasound is thus not separated from "normal" (audible) sound based on differences in physical properties, only the fact that humans cannot hear it. Although this limit varies from person to person, it is approximately 20 KHz in healthy, young adults. The ultrasound is used in many different fields, typically to penetrate a medium and measure the reflection signature or supply focused energy. The reflection signature can reveal details about the inner structure of the medium, a property also used by animals such as bats for hunting. The most well known application of ultrasound is its use in sonography to produce pictures of fetuses in the human womb and the use in diathermy as heating modality. There are a vast number of other applications as well [1].

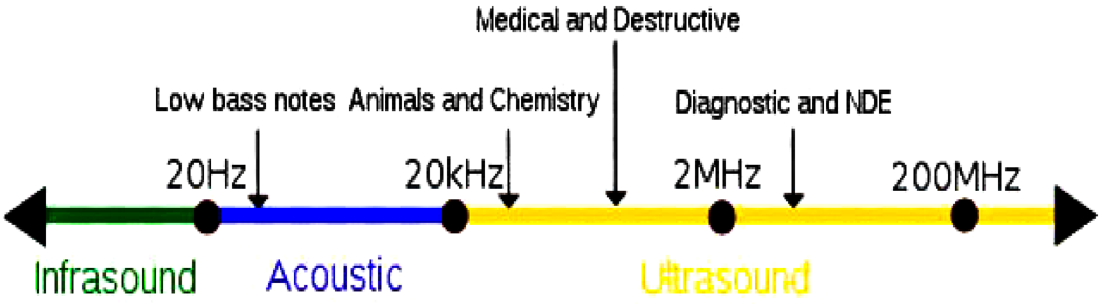


Fig. 1.1: Approximate frequency ranges corresponding to ultrasound

Ultrasonic signals (or even sonic ones - ones we can hear) are generated by a device called a transducer. The transducer has a crystal driver that converts electrical energy into mechanical energy (and sound is mechanical energy) and vice versa because of piezoelectric effect. A crystal can be made to change shape (get a tiny bit longer or shorter) by electrical stimulation. And changing the shape of a crystal, squeezing it a bit, can cause it to generate an electrical signal. That's piezoelectric effect. It can be called a bi-directional process. Send an electrical signal to a transducer and it will convert the electrical energy (signal) into mechanical energy (sound). Because the process works in reverse, the transducer is used to send out a signal and then be used to listen the return echo. Medical ultrasonic diagnostic transducers work at well in excess of 1,000,000 cps. Neither any dog nor any bat in the neighborhood can hear that. One of the many ways is piezoelectric generation, a high frequency current is put across a certain type of crystal and it causes the crystal to oscillate [2].

1.3 Diathermy

The term diathermy means "induced heat" and it is a method of heating tissue electromagnetically or ultrasonically for therapeutic purposes in medicine. the use of high-frequency electromagnetic currents as a form of physical therapy and in surgical procedures. The term diathermy is derived from the Greek words ‘dia’ and ‘therma’, and literally means “heating through.” Diathermy is used in physical therapy to deliver moderate heat directly to pathologic lesions in the deeper tissues of the body. Surgically, the extreme heat that can be produced by diathermy may be used to destroy neoplasm, warts, and infected tissues, and to cauterize blood vessels to prevent excessive bleeding. The technique is particularly valuable in neurosurgery and surgery of the eye [3].

The three forms of diathermy employed by physical therapists are short wave, ultrasound, and microwave. Long wave diathermy is seldom used. The application of moderate heat by diathermy increases blood flow and speeds up metabolism and the rate of ion diffusion across cellular membranes. The fibrous tissues in tendons, joint capsules, and scars are more easily stretched when subjected to heat, thus facilitating the relief of stiffness of joints and promoting relaxation of the muscles and decrease of muscle spasms.

Ultrasound diathermy employs high-frequency acoustic vibrations which, when propelled through the tissues, are converted into heat [3]. This type of diathermy is especially useful in the delivery of heat to selected musculatures and structures because there is a difference in the sensitivity of various fibers to the acoustic vibrations; some are more absorptive and some are more reflective. For example, in subcutaneous fat, relatively little energy is converted into heat, but in muscle tissues there is a much higher rate of conversion to heat.

The therapeutic ultrasound apparatus generates a high-frequency alternating current, which is then converted into acoustic vibrations. The apparatus is moved slowly across the surface of the part being treated. Ultrasound is a very effective agent for the application of heat [4]. In general diathermy can be classified as:

- Long wave diathermy
- Short wave diathermy
- Micro wave diathermy
- Ultrasound diathermy

1.3.1 Clinical Effects of Diathermy

Effects on circulation:

- Local Effects:
    - Active arterial hyperemia
    - Increased flow of lymph

- General Effects:
    - Rapid dilatation of peripheral blood vessels
    - Increase in the pulse rate, respiration, perspiration, general body metabolism.

Effects on nervous tissue:

Diathermy exerts a marked sedative effect on the irrigative conditions of sensory nerves (spasms and cramps) makes its use indicated in irritation of sensory and motor nerves [5]. The temperature rise and distribution of heat that are associated with these modalities are superimposed on the physiologic temperature distribution in the tissues prior to diathermy application. Usually, the superficial temperature is low at the skin surface and higher at the core.

The physiologic effects of temperature occur at the site of the application and in distant tissue. The local effects are caused by the elevated temperature response of cellular function by direct and reflex action. Locally, there is a rise in blood flow with associated capillary dilatation and increased capillary permeability. Initial tissue metabolism increases, and there may be changes in the pain threshold. Distant changes from the heated target location include reflex vasodilatation and a reduction in muscle spasm (as a result of skeletal muscle relaxation).

Vigorous heating produces the highest temperature at the site where the therapeutic result is desired [6]. The tissue undergoes a rapid temperature rise, with the temperature coming close to the tolerance level. Vigorous heating is used for chronic conditions that require deep structures, such as large joints, to be heated. When acute inflammatory processes are occurring, deep heating requires extreme care, because it can obscure inflammation.

Local tissue temperature is maintained during mild heating, the primary effect being the production of a higher temperature at a site distant from the heating modality's application. Reflex vasodilatation occurs when the rise in temperature is slow for short periods, such as during a sub-acute process. With the proper application, superficial and deep heating methods can accomplish mild heating [6].

1.3.2 Why Diathermy?

Diathermy offers:

- Relief of pain, muscle spasms and joint contractures
- Healing soft tissue injuries

This makes it the most popular alternative modality to pharmacological approach as because pain alleviating medications have some serious disadvantages. Some of them are:

- Drug dependency
- Side effects
- Drug interaction
- Liver and gastroenterological damage

That is why diathermy, the Physical Medicine comes [7].

1.4 Review of Relevant Literatures

In the last two decades, researchers and clinicians have shown that therapeutic ultrasound can be an effective tool in diathermy, relieving arthritis, improving rehabilitation and enhancing wound healing [8-11]. Ultrasound at higher energy has proven useful in surgical applications such as prostate therapy and brain tumor and cardiac tissue ablation [11-14]. Ultrasound may also be useful in improving a variety of drug delivery platforms, including large-molecule transdermal delivery, targeted chemotherapy for brain cancer, and cellular gene transfer [15-18]. In addition, the combination of ultrasound-based imaging with ultrasound-based therapy has potential for important military and medical applications [19-21].

Despite the widespread use of ultrasound, the basic idea in producing ultrasound power has not changed significantly in the past 50 years [13,20,22]. Established methods for ultrasound driving systems, such as high voltage switching and RF amplifiers, often require bulky and expensive equipment. Thus, the development of a cost-effective, portable system for delivering ultrasound could greatly enhance the use of ultrasound across a broad range of medical therapies.

In the late 1920's initial studies of the biological effects of ultrasound were performed by Wood and Loomis [23]. Since then, researchers have proposed systems to produce high power ultrasound. The use of ultrasonics in physical therapy dates back to the 1940s. The destructive ability of high intensity ultrasound had been recognised from the time of Paul Langevin when he noted destruction of school of fishes in the sea and pain induced in the hand when placed in a water tank insonated with high intensity ultrasound. In 1938, Raimar Pohlman demonstrated the 'therapeutic" effects of ultrasonic waves in human tissues. He introduced ultrasonic physiotherapy as a medical practice at the Charite in Berlin. He suggested that the power of the transducer should be limited to 5 W/cm^2, the transducer must be kept in motion, and insonifying the bone must be avoided.

In 1942 Lynn et al. introduced an effective 836 kHz high voltage (3000−6000 V) low current (900 mAmp) ultrasound driver for biological research, which was based on vacuum tube technology and radio transmitter design [24]. Since in-house power and very high voltages were used in this design, precautions were taken to avoid electrical shock and RF interference. Lynn's system and power outputs were measured crudely by measuring the rise of a conical oil cone from the radiation force exerted by the focused ultrasound energy.

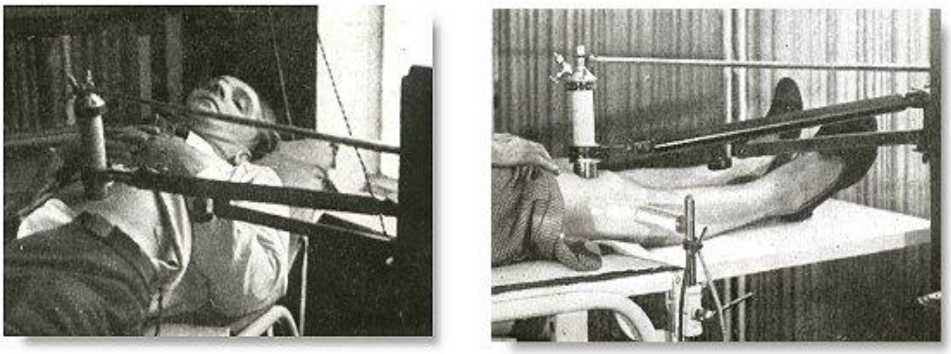


Fig. 1.2: Uses of ultrasonic energy in the 1940s.
Left: in gastric ulcers, Right: in arthritis [24]

Fry et al. in 1986 presented a focused ultrasound system for tissue volume ablation of brain tumors [25]. The phase controls to produce local hyperthermia in vitro and in vivo [26]. The amplifier stage of the system used Transistor-Transistor-Logic (TTL) timing with an unspecified in-house built circuit to amplify the drive signal. The 8.0 MHz array Lee et al. developed produced acoustic powers from 0−1 W. Owen et al. in 2003 developed a 12-lb plug-in class D switch-mode amplifier to drive single element high intensity focused ultrasound (HIFU) transducers [22]. The system provided 140 W of acoustic energy from a 70% efficient PZT (transducer) with 33mm diameter and 55mm radius of curvature. Owen et al. compared the device to products on the market at the time and found their device favorable because of its light weight and ability to cause hemostasis and tissue necrosis.

Jerome Gersten reported in 1953 the use of ultrasound in the treatment of patients with rheumatic arthritis. Several groups such as the Peter Wells group in Bristol, England, the Mischele Arslan group in Padua, Italy and the Douglas Gordon group in London used ultrasonic energy in the treatment. Ultrasound energy is absorbed and transformed into heat energy as it propagates through tissue. The therapeutic dose is computed by the power output (total W) and the size of the ultrasound PZT head. The usual initial dose is 1 W/cm^2 and is adjusted to patient tolerance, as well as to the treatment goals. The practitioner must select the wave form (continuous or pulsed), intensity, and duration. The patient should experience a comfortable heating or no sensation at all. The treatment time is 5-10 minutes, taking into account the patient's tolerance and comfort. After the skin is cleansed, a coupling agent, such as an ultrasound gel, is required to provide effective conduction between the ultras ultrasound head/transducer and the skin surface [22]. To avoid hot spots, the ultrasound head must be continuously moved over the treatment site.

Fig. 1.3: Ultrasonic therapy generator, the "Medi-Sonar" in the 1950s.

Therapeutic ultrasound produces the following biologic effects:

- Temporary analgesia
- Increased peripheral blood flow
- Increased vascularity with associated hyperemia/inflammatory response
- Increased cell membrane permeability
- Peripheral nerve conduction changes (reversible conduction block with high-intensity ultrasound exposure)
- Relief of muscle spasms

The following factors influence the propagation of ultrasound in biologic tissue [17,18]:

- Transmission
- Absorption
- Refraction
- Reflection

Therapeutic ultrasound is ideal for providing deep heat to large joints. For example, it is effective in treating the shoulder or hip, because a standing wave is produced as a result of the curved reflection of the glenoid or the acetabulum; this effect concentrates heat energy at the articular surfaces of the joint.

In combination with a physical therapy program utilizing range of motion (ROM) and stretching activities, the localized, intra-articular heating produced by ultrasound greatly facilitates the mobilization of joint adhesions or capsular restrictions caused by tightness or scarring.

A number of ultrasound diathermy devices have been introduced to the market in the recent years. Most of the devices used are of output frequency with 1MHz and 3 MHz.

Commercially available ultrasound drivers and RF amplifiers are generally built with 50 Ω output impedance that has high voltage amplification and switching of the applied AC signal. To date, many of the developed ultrasound drivers have been impedance matched to enhance power transfer as stated in the maximum power-transfer theorem: to obtain maximum external power from a source with a finite internal impedance, the impedance of the load must be made the same as that of the source. The 50 Ω output impedance is matched to the transducer using special impedance-matching circuitry to maximize power transfer and minimize reflections from the ultrasound transducer [13,20,22]. From voltage division, the voltage across the transducer is inversely related to the impedance of the source. Therefore, if the source has a 50 Ω output impedance and the transducer has a 10 Ω purely resistive impedance, only 17% of the energy from the source will be supplied to the transducer. The rest will be reflected or lost as heat.

When impedance-matching circuitry is used, half of the power from the source is transferred, and the driver becomes more efficient. In matching the characteristic impedance of the driver to the ultrasound probe, which generally has complex impedance, automatic tuning devices are used that add to the cost and bulk of the system [22]. Now a days one of the very commonly used US diathermy device is Intelect® Legend Ultrasound features with dual frequency ultrasound (1 and 3.3 MHz) having 5 cm2 sound head, which offers 20% pulsed and Continuous Duty Cycle selections and head warming.

Fig. 1.4: US Diathermy Device, the "Intelect® Legend Ultrasound ".

During the recent years numbers of ultrasound devices are tested and sold in the market. Many of the products vary in their features of frequency and applicators. Most of the commercial US diathermy devices available in the market use the frequency of 1MHz or 3 MHz. Output wave shapes are continuous and pulsed mode of 10%, 20% and 50% duty cycle. Expensive ones are supported with multi-applicator mode.

1.5 Problem identification and Statement of the problem

Literature reviews and historical background suggests that the US Diathermy devices have effective applications in pain alleviation. It is scientifically proven that the side effect of this therapy is minimum (tends to none) except for some special cases. But this radical device is yet to be widely used in third world countries as well as Bangladesh. The commonly identified problem in respect to our country is:

- Unavailability in Local Market
- High Price
- Scarcity of Technical Support
- Limitations of Spare Parts and Repairing Service

Again the need of different products in different purpose lessens the wide spread use. Table 1.1 of the following page gives the idea of different mode used in US diathermy device and their indications and contraindications [27-29]. At first analyze of the existing products along with different parameters is done. Problem identification gets resolved within the revise. Suitable parameter is selected to be implemented into the proposed design of a Ultrasound Diathermy Device.

While designing the product, main priority is assigned to the successful implementation of the desired parameter to the new device. The use of the different components of the total circuitry is chosen or made limited to the ones available in the local market to facilitate availability of the local service and technical support. Cost effectiveness is also an associated priority while building the product in hardware.

Table 1.1: Physical effects of different mode of US therapy

Mode of therapeutic Ultrasound	**Effect**	**Indications**	**Contraindications**
Pulsed Mode	Non-Thermal	↑Circulation and joint mobility ↑Muscle re-education and strength ↑Wound and fracture healing ↑Nonunion fracture healing ↓Muscle spasm/spasticity ↓Pain and edema	Patients with pacemakers, Pregnancy (abdominal and/or pelvic area), Pain of unknown origin
Continuous Mode	Thermal	↑Circulation and wound healing ↓Pain, acute and chronic ↓Reduction of muscle spasm/guarding ↓Posttraumatic and chronic edema	Same as Pulsed Mode
Tone-Burst Mode	Both Thermal and Non-Thermal	↑Nonunion wound healing ↑Fracture healing *Additional: All advantages of Pulsed and Continuous Mode.	Same as Pulsed Mode

Here, the important parameter for work can be selected as Tone-Burst mode. A device with tone-burst mode is still rare in the market and tested seldom commercially. So, a novel design with this parameter can be introduced as a new product, which will come up with the following advantages:

- Locally developed product
- Available technical support and Service
- Multi-frequency (1-3 MHz) Application
- Multi-applicator support (1cm^2, 2cm^2, 5cm^2)
- Continuous and Pulsed Mode
- Tone Burst Mode (New parameter selected)

1.6 Motivations

The main motivation of doing this work is to facilitate the large number of general people suffering from pains of arthritis and such and in need of rehabilitation with a portable and cost effective ultrasound diathermy device. While pain alleviating medications may provide relief for certain pain disorders their use is often associated with serious disadvantages including drug dependency, side effects. In addition, according to a recent review, analgesics are useful when there is a specific nociceptive component, but are often of limited usefulness in non-specific or chronic widespread pain [26,27]. Alternatively, Ultrasound (US) comes as a non-pharmacological pain treatment modality.

Working with the parameter of Tone-burst mode can minimize the use of different devices in different proposes and unify into one product of all possible treatment modalities in the US Diathermy.

Having so many advantages over pain alleviating pills, the ultrasound diathermy device is still a hard-to-get equipment in our country as well as the third world countries because of its high price, unavailability and scarcity of servicing. Locally developed equipment with all the technical support and integrated with multimode user oriented features should subside the existing predicament along with an introduction of immense future improvement and optimization.

1.7 Organization of the Thesis

The dissertation is mainly divided into five chapters. Introduction to Ultrasound Diathermy and main objectives of the thesis have already been expressed in Chapter 1.

Chapter 2 provides the overview of the proposed design of the Ultrasound Diathermy device based on the literature review and parameter selected. Description of the different parts of the design is given separately in details. The hardware implementation of the proposed design is discussed in Chapter 3.

The output results of the hardware, simulation results and comparison are shown and discussed in Chapter 4. Also the practical test on subject is also discussed in the chapter. A comparison with existing products along with the cost is briefly discussed in this chapter.

Finally conclusive discussion and scope for future works are described in the fifth chapter.

CHAPTER 2

PROPOSED DESIGN OF ULTRASOUND DIATHERMY DEVICE

2.1 Design Overview

A simple ultrasound diathermy device should consist of four main building parts. Firstly the oscillator will generate the high frequency signal which will be amplified and automated before sending to the ultrasound probe which is actually a PZT (Transducer). So the main fractions of the design:

- Oscillator design
- Amplifier design
- Automation circuit
- Transducer (Probe)

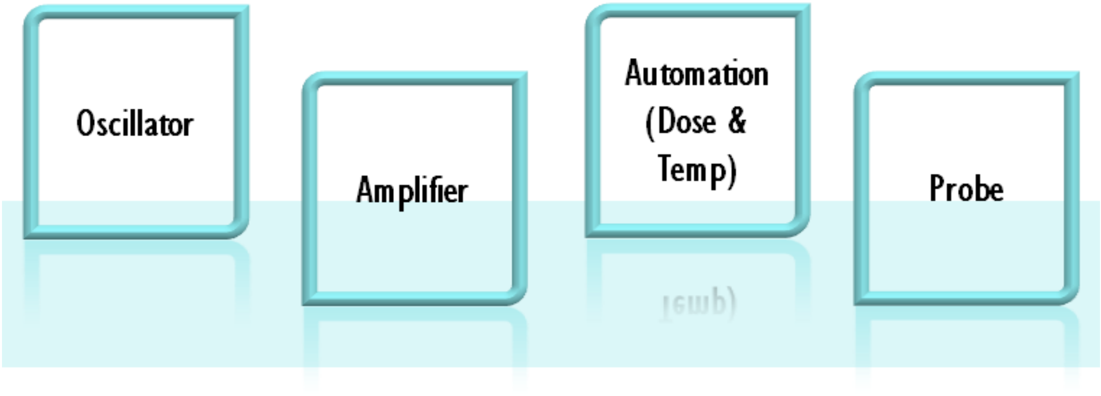


Fig. 2.1: Different parts of the Ultrasound Diathermy Device

After designing the different blocks of the whole device, they should be tested individually for proper working. If the individual block works accordingly to the desired output, they are being connected with each other. Microprocessor can be introduced for user friendly control along with automation. User accessible control panel will be used for the dose control. A display panel will facilitate the user with the control and use of the diathermy device. The block diagram of a complete finalized device for commercialization will look like Figure 2.2 of the following page. Our initial experimental design, which we will propose as the design of the Ultrasound Diathermy Device is given in the figure 2.3.

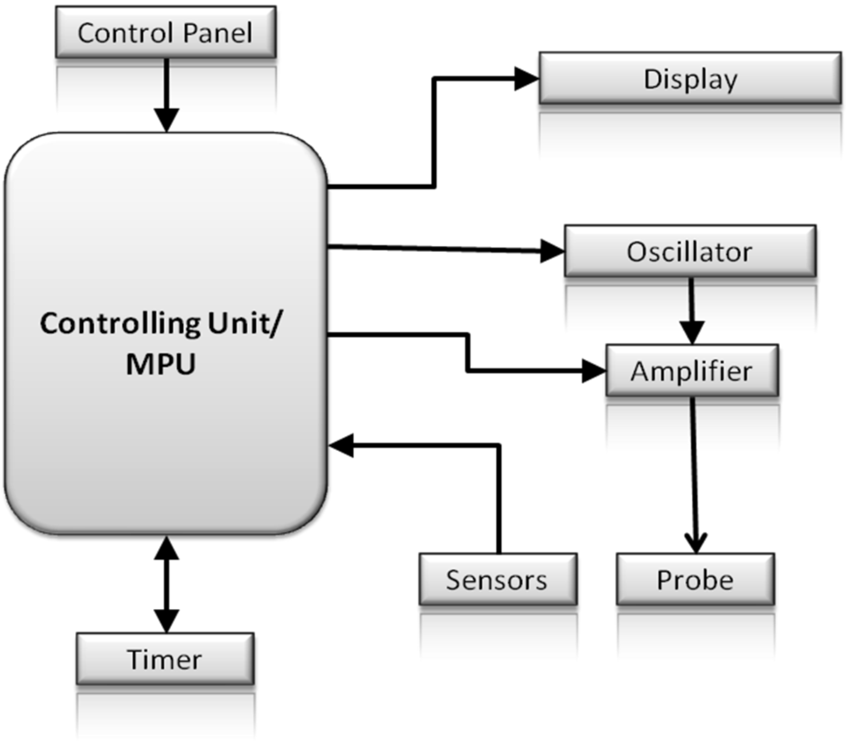


Fig. 2.2: Block Diagram of finalized US diathermy device for commercialization

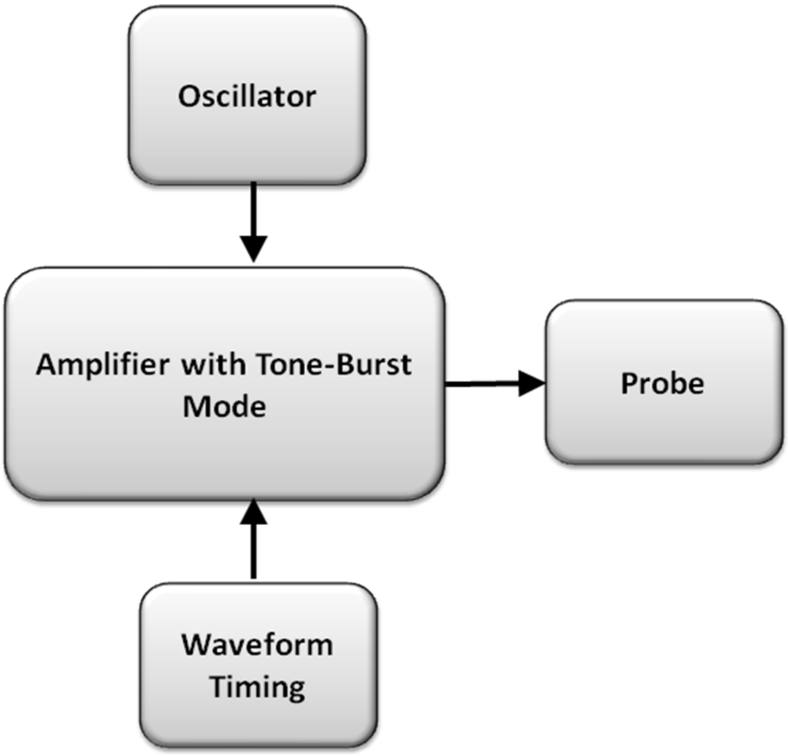


Fig. 2.3: Block Diagram of our proposed experimental US diathermy device

2.2 Oscillator Design

An electronic oscillator is an electronic circuit that produces a repetitive electronic signal, often a sine wave or a square wave. To produce the ultrasound energy output at the head of Transducer, we must have a high frequency signal generated beforehand. Our selected parameter for the generated signal is 1MHz and 3MHz [38,39]. Usual high frequency signal generator circuits have complicated design along with distortion. The frequency of 1MHz with minimum distortion is needed. To fulfill our requirement we need a robust precision high-frequency signal generator chip. In the proposed design of Ultrasound Diathermy Device we use MAX 038 signal generator.

2.2.1 MAX O38 Overview

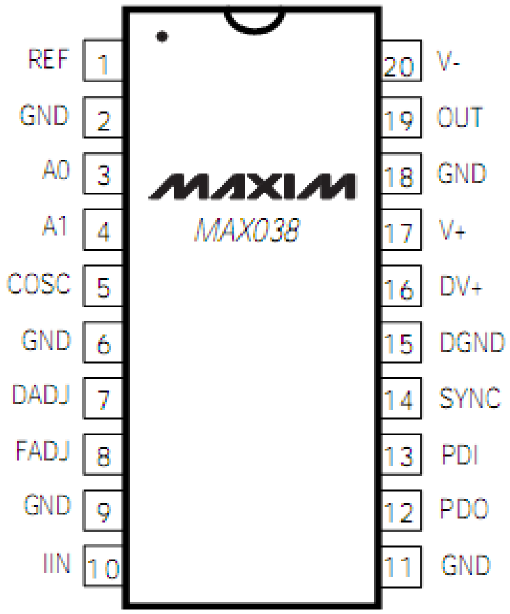


Fig. 2.4: Top view of MAX 038

The MAX 038 is a high-frequency, precision function generator producing accurate, and high-frequency triangle, and saw tooth, sine, square, and pulse waveforms with a minimum of external components. The output frequency can be controlled over a frequency range of 0.1Hz to 20 MHz by an internal 2.5 V band gap voltage reference and an external resistor and capacitor. The duty cycle can be varied over a wide range by applying a ±2.3V control signal, facilitating pulse-width modulation and the generation of saw tooth waveforms. Frequency modulation and frequency sweeping are achieved in the same way. The duty cycle and frequency controls are independent. Sine, square, or triangle waveforms can be selected at the output by setting the appropriate code at two TTL-compatible select pins. The output signal for all waveforms is a $2V_{P-P}$ signal that is symmetrical around ground. The low -impedance output can drive up to ±20mA.The TTL-compatible SYNC output from the internal oscillator maintains a 50% duty cycle—regardless of the duty cycle of the other waveforms—to synchronize other devices in the system. The internal oscillator can be synchronized to an external TTL clock connected to PDI.

Table 2.1: MAX 038 PIN description

PIN	**NAME**	**FUNCTION**
1	REF	2.50V band-gap voltage reference output
2,6,9, 11, 18	GND	Ground
3	A0	Waveform selection input; TTL/CMOS compatible
4	A1	Waveform selection input; TTL/CMOS compatible
5	COSC	External capacitor connection
7	DADJ	Duty-cycle adjust input
8	FADJ	Frequency adjust input
10	IIN	Current input for frequency control
12	PDO	Phase detector output. Connect to GND if phase detector is not used.
13	PDI	Phase detector reference clock input. Connect to GND if phase detector is not used.
14	SYNC	TTL/CMOS-compatible output, referenced between DGND and DV+.
15	DGND	Digital ground
16	DV+	Digital +5V supply input. Can be left open if SYNC is not
17	V+	+5V supply input
19	OUT	Sine, square, or triangle output
20	V-	-5V supply input

2.2.2 Working Principle of MAX 038

The MAX038 is a high-frequency function generator that produces low-distortion sine, triangle, saw tooth, or square (pulse) waveforms at frequencies from less than 1Hz to 20MHz or more, using a minimum of external components. Frequency and duty cycle can be independently controlled by programming the current, voltage, or resistance. The desired output waveform is selected under logic control by setting the appropriate code at the A0 and A1 inputs. A SYNC output and phase detector is included to simplify designs requiring tracking to an external signal source. The MAX038 operates with ±5V ±5% power supplies. The basic oscillator is a relaxation type that operates by alternately charging and discharging a capacitor, C_F, with constant currents, simultaneously producing a triangle wave and a square wave (Figure 1). The charging and discharging currents are controlled by the current flowing into IIN, and are modulated by the voltages applied to FADJ and DADJ. The current into IIN can be varied from 2µA to 750µA, producing more than two decades of frequency for any value of C_F. Applying ±2.4V to FADJ changes the nominal frequency (with VFADJ = 0V) by ±70%; this procedure can be used for fine control. Duty cycle (the percentage of time that the output waveform is positive) can be controlled from 10% to 90% by applying ±2.3V to DADJ. This voltage changes the C_F charging and discharging current ratio while maintaining nearly constant frequency. A stable 2.5V reference voltage, REF, allows simple determination of IIN, FADJ, or DADJ with fixed resistors, and permits adjustable operation when potentiometers are connected from each of these inputs to REF.

FADJ and/or DADJ can be grounded, producing the nominal frequency with a 50% duty cycle. The output frequency is inversely proportional to capacitor C_F. C_F values can be selected to produce frequencies above 20MHz.A sine-shaping circuit converts the oscillator triangle wave into a low-distortion sine wave with constant amplitude. The triangle, square, and sine waves are input to a multiplexer. Two address lines, A0 and A1, control which of the three waveforms is selected. The output amplifier produces constant $2V_{P\text{-}P}$ amplitude (±1V), regardless of wave shape or frequency. The triangle wave is also sent to a comparator that produces a high-speed square-wave SYNC waveform that can be used to synchronize other oscillators. The SYNC circuit has separate power-supply leads and can be disabled. Two other phase-quadrature square waves are generated in the basic oscillator and sent to one side of an “exclusive-OR” phase detector. The other side of the phase-detector input (PDI) can be connected to an external oscillator. The phase-detector output (PDO) is a current source that can be connected directly to FADJ to synchronize the MAX038 with the external oscillator.

2.2.3 Oscillator circuit for sine-wave output

MAX 038 can be used to generate high frequency sine, square and triangular wave. For our proposed design, we will use sine wave as our output of the signal generator. The circuit design is shown in figure 2.5. The details of the waveform selection, programming FADJ, calculations of waveform timing and duty cycle is given in chapter 4 of hardware implementation.

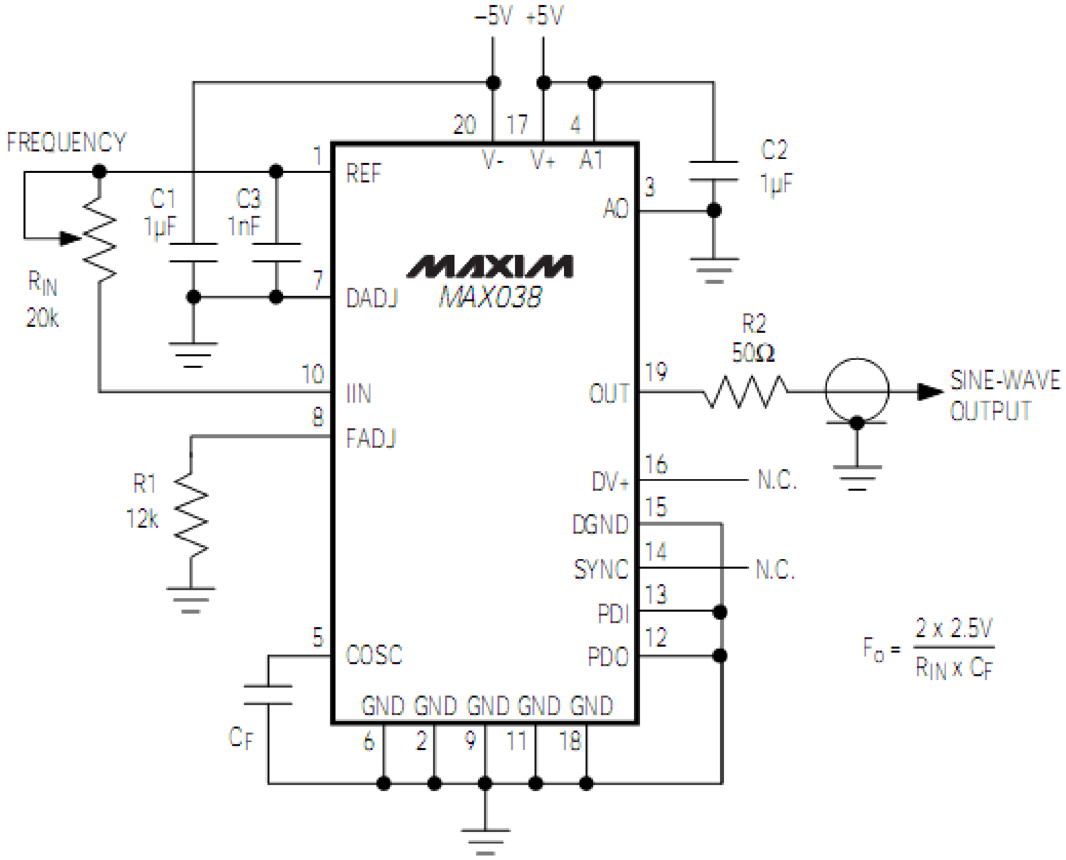


Fig. 2.5: MAX 038 operating circuit with sine-wave output

2.3 Amplifier Design

Generally an amplifier or simply amp is any device that changes, usually increases, the amplitude of a signal. The relationship of the input to the output of an amplifier—usually expressed as a function of the input frequency—is called the transfer function of the amplifier, and the magnitude of the transfer function is termed the gain [31].

In popular use, the term usually describes an electronic amplifier, in which the input "signal" is usually a voltage or a current. In audio applications, amplifiers drive the loudspeakers used in PA systems to make the human voice louder or play recorded music. Amplifiers may be classified according to the input (source) they are designed to amplify (such as a guitar amplifier, to perform with an electric guitar), the device they are intended to drive (such as a headphone amplifier), the frequency range of the signals (Audio, IF, RF, and VHF amplifiers, for example), whether they invert the signal (inverting amplifiers and non-inverting amplifiers), or the type of device used in the amplification (valve or tube amplifiers, FET amplifiers, etc.). A related device that emphasizes conversion of signals of one type to another (for example, a light signal in photons to a DC signal in amperes) is a transducer, a transformer, or a sensor. However, none of these amplify power [34].

2.3.1 Gain

The gain of an amplifier is the ratio of output to input power or amplitude, and is usually measured in decibels. (When measured in decibels it is logarithmically related to the power ratio: G (dB) =10 log (Pout / (Pin)). RF amplifiers are often specified in terms of the maximum power gain obtainable, while the voltage gain of audio amplifiers and instrumentation amplifiers will be more often specified (since the amplifier's input impedance will often be much higher than the source impedance, and the load impedance higher than the amplifier's output impedance). Example: an audio amplifier with a gain given as 20 dB will have a voltage gain of ten (but a power gain of 100 would only occur in the unlikely event the input and output impedances were identical).

2.3.2 Bandwidth

The bandwidth of an amplifier is the range of frequencies for which the amplifier gives "satisfactory performance". The definition of "satisfactory performance" may be different for different applications. However, a common and well-accepted metric is the half power points on the output vs. frequency curve. Therefore bandwidth can be defined as the difference between the lower and upper half power points. This is therefore also known as the −3 dB bandwidth. Bandwidths for other response tolerances are sometimes quoted −1 dB, −6 dB etc. or "plus or minus 1dB" [34].

2.3.3 Linearity

An ideal amplifier would be a totally linear device, but real amplifiers are only linear within limits. When the signal drive to the amplifier is increased, the output also increases until a point is reached where some part of the amplifier becomes saturated and cannot produce any more output; this is called clipping, and results in distortion.

In most amplifiers a reduction in gain takes place before hard clipping occurs; the result is a compression effect, which (if the amplifier is an audio amplifier) sounds much less unpleasant to the ear. For these amplifiers, the 1 dB compression point is defined as the input power (or output power) where the gain is 1 dB less than the small signal gain. Sometimes this nonlinearity is deliberately designed in to reduce the audible unpleasantness of hard clipping under overload [31].

2.3.4 Noise

This is a measure of how much noise is introduced in the amplification process. Noise is an undesirable but inevitable product of the electronic devices and components, also much noise results from intentional economies of manufacture and design time. The metric for noise performance of a circuit is noise figure or noise factor. Noise figure is a comparison between the output signal to noise ratio and the thermal noise of the input signal.

2.3.5 Types of amplifier

Amplifiers can be specified according to their input and output properties. They have some kind of gain, or multiplication factor relating the magnitude of the output signal to the input signal. The gain may be specified as the ratio of output voltage to input voltage (voltage gain), output power to input power (power gain), or some combination of current, voltage and power. In many cases, with input and output in the same units, gain will be unit less (although often expressed in decibels); for others this is not necessarily so. The power gain of an amplifier depends on the source and load impedances used as well as its voltage gain; while an RF amplifier may have its impedances optimized for power transfer, audio and instrumentation amplifiers are normally employed with amplifier input and output impedances optimized for least loading and highest quality. So an amplifier that is said to have a gain of 20 dB might have a voltage gain of ten times and an available power gain of much more than 20 dB (100 times power ratio), yet be delivering a much lower power gain if, for example, the input is a 600 ohm microphone and the output is a 47 kilo-ohms power amplifier's input socket [34].

In most cases an amplifier should be linear; that is, the gain should be constant for any combination of input and output signal. If the gain is not constant, e.g., by clipping the output signal at the limits of its capabilities, the output signal will be distorted. There are however cases where variable gain is useful.

2.3.6 Power amplifier classes

Power amplifier circuits (output stages) are classified as A, B, AB and C for analog designs, and class D and E for switching designs based upon the conduction angle or angle of flow, Θ, of the input signal through the (or each) output amplifying device, that is, the portion of the input signal cycle during which the amplifying device conducts. The image of the conduction angle is derived from amplifying a sinusoidal signal. (If the device is always on, $\Theta = 360°$.) The angle of flow is closely related to the amplifier power efficiency. The various classes are introduced below, followed by more detailed discussion under individual headings later on.

Class A: 100% of the input signal is used (conduction angle Θ = 360° or 2π); i.e., the active element remains conducting (works in its "linear" range) all of the time. Where efficiency is not a consideration, most small signal linear amplifiers are designed as Class A. Class A amplifiers are typically more linear and less complex than other types, but are very inefficient. This type of amplifier is most commonly used in small-signal stages or for low-power applications (such as driving headphones). Subclass A2 is sometimes used to refer to vacuum tube Class A stages where the grid is allowed to be driven slightly positive on signal peaks, resulting in slightly more power than normal Class A (A1; where the grid is always negative), but incurring more distortion.

Class B: 50% of the input signal is used (Θ = 180° or π; i.e., the active element works in its linear range half of the time and is more or less turned off for the other half). In most Class B, there are two output devices (or sets of output devices), each of which conducts alternately (push–pull) for exactly 180° (or half cycle) of the input signal; selective RF amplifiers can also be implemented using a single active element.

These amplifiers are subject to crossover distortion if the transition from one active element to the other is not perfect, as when two complementary transistors (i.e., one PNP, one NPN) are connected as two emitter followers with their base and emitter terminals in common, requiring the base voltage to slew across the region where both devices are turned off.

Class AB: Here the two active elements conduct more than half of the time as a means to reduce the cross-over distortions of Class B amplifiers. In the example of the complementary emitter followers a bias network allows for more or less quiescent current thus providing an operating point somewhere between Class A and Class B. Sometimes a figure is added (e.g., AB1 or AB2) for vacuum tube stages where the grid voltage is always negative with respect to the cathode (Class AB1) or may be slightly positive (hence drawing grid current, adding more distortion, but giving slightly higher output power) on signal peaks (Class AB2); another interpretation being higher figures implying a higher quiescent current and therefore more of the properties of Class A.

Class C: Less than 50% of the input signal is used (conduction angle Θ < 180°). The advantage is potentially high efficiency, but a disadvantage is high distortion.

Class D: These use switching to achieve very high power efficiency (more than 90% in modern designs). By allowing each output device to be either fully on or off, losses are minimized. The analog output is created by pulse-width modulation; i.e., the active element is switched on for shorter or longer intervals instead of modifying its resistance. There are more complicated switching schemes like sigma-delta modulation, to improve some performance aspects like lower distortions or better efficiency.

Class B and AB: Class B amplifiers only amplify half of the input wave cycle, thus creating a large amount of distortion, but their efficiency is greatly improved and is much better than Class A. Class B has a maximum theoretical efficiency of 78.5% (i.e., π/4). This is because the amplifying element is switched off altogether half of the time, and so cannot dissipate power. A single Class B element is rarely found in practice, though it has been used for driving the loudspeaker in the early IBM Personal Computers with beeps, and it can be used in RF power amplifier where the distortion levels are less important. However Class C is more commonly used for this.

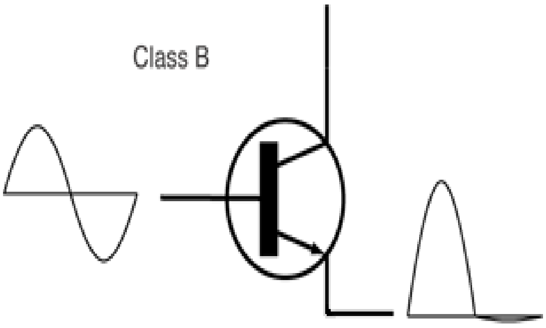


Fig. 2.6: Class B Amplifier

A practical circuit using Class B elements is the push-pull stage, such as the very simplified complementary pair arrangement shown in figure 2.7. Here, complementary or quasi-complementary devices are each used for amplifying the opposite halves of the input signal, which is then recombined at the output. This arrangement gives excellent efficiency, but can suffer from the drawback that there is a small mismatch in the cross-over region - at the "joins" between the two halves of the signal, as one output device has to take over supplying power exactly as the other finishes. This is called crossover distortion. An improvement is to bias the devices so they are not completely off when they're not in use. This approach is called Class AB operation.

In Class AB operation, each device operates the same way as in Class B over half the waveform, but also conducts a small amount on the other half. As a result, the region where both devices simultaneously are nearly off (the "dead zone") is reduced. The result is that when the waveforms from the two devices are combined, the crossover is greatly minimized or eliminated altogether. The exact choice of quiescent current, the standing current through both devices when there is no signal, makes a large difference to the level of distortion (and to the risk of thermal runaway, that may damage the devices); often the bias voltage applied to set this quiescent current has to be adjusted with the temperature of the output transistors (for example in the circuit at the beginning of the article the diodes would be mounted physically close to the output transistors, and chosen to have a matched temperature coefficient). Another approach (often used as well as thermally-tracking bias voltages) is to include small value resistors in series with the emitters.

Class AB sacrifices some efficiency over class B in favor of linearity, thus is less efficient (below 78.5% for full-amplitude sine waves in transistor amplifiers, typically; much less is common in Class AB vacuum tube amplifiers). It is typically much more efficient than class A.

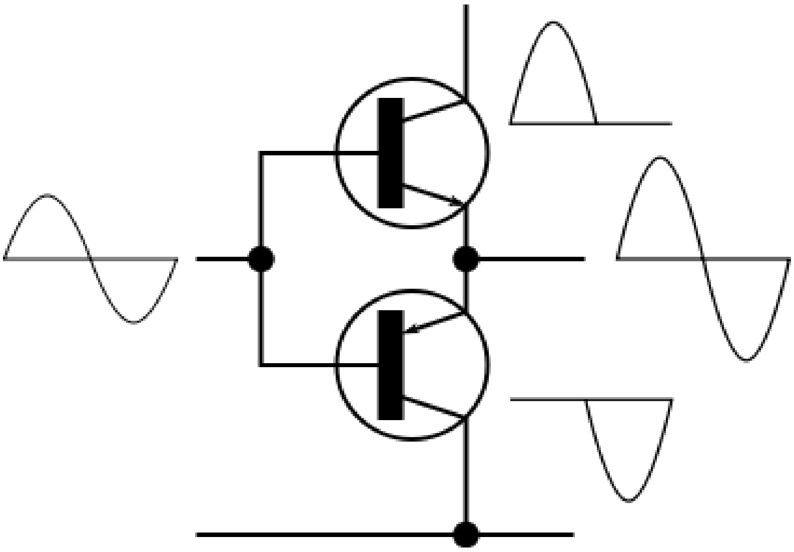


Fig. 2.7: Class B push–pull amplifier

Class B or AB push–pull circuits are the most common design type found in audio power amplifiers. Class AB is widely considered a good compromise for audio amplifiers, since much of the time the music is quiet enough that the signal stays in the "class A" region, where it is amplified with good fidelity, and by definition if passing out of this region, is large enough that the distortion products typical of class B are relatively small. The crossover distortion can be reduced further by using negative feedback. Class B and AB amplifiers are sometimes used for RF linear amplifiers as well. Class B amplifiers are also favored in battery-operated devices, such as transistor radios.

A push–pull output is a type of electronic circuit that can drive either a positive or a negative current into a load. Push–pull outputs are present in TTL and CMOS digital logic circuits and in some types of amplifiers, and are usually realized as a complementary pair of transistors, one dissipating or sinking current from the load to ground or a negative power supply, and the other supplying or sourcing current to the load from a positive power supply.

A special configuration of push-pull, though in fact an exception, is the outputs of TTL and related families. The upper transistor is functioning as an active pull-up, in linear mode, while the lower transistor works digitally. For this reason they aren't capable of supplying as much current as they can sink (typically 20 times less). Because of the way these circuits are drawn schematically, with two transistors stacked vertically, normally with a protection diode in between, they are called "totem pole" outputs. Vacuum tubes (valves) are not available in complementary types (as are pnp/npn transistors) so that the tube push-pull amplifier has a pair of identical output tubes or groups of tubes with the control grids driven in antiphase; these tubes drive current through the two halves of the primary winding of a center-tapped output transformer in such a way that the signal currents add, while the distortion signals due to the non-linear characteristic curves of the tubes subtract. These amplifiers were first designed long before the development of solid-state electronic devices; they are still in use by both audiophiles and musicians who consider them to sound better.

2.3.7 Amplifier used in the Design

Depending on the various features, we use Class B push-pull one. In our amplifier circuit two transistors are used, one as a source of current and one as a sink, to amplify a signal. One device “pushes’’ current out into the load, while the other “pulls” current from it when necessary.

An npn transistor can source (push) current from a positive power supply into the load, or a pnp transistor can sink (pull) it into the negative power supply. The circuit functions as an amplifier in that the current levels at the output are larger than those at the input.

- Because of load line & Q point
- Common Collector i.e. Emitter follower
- Better frequency response than CE & CB
- Gain=1

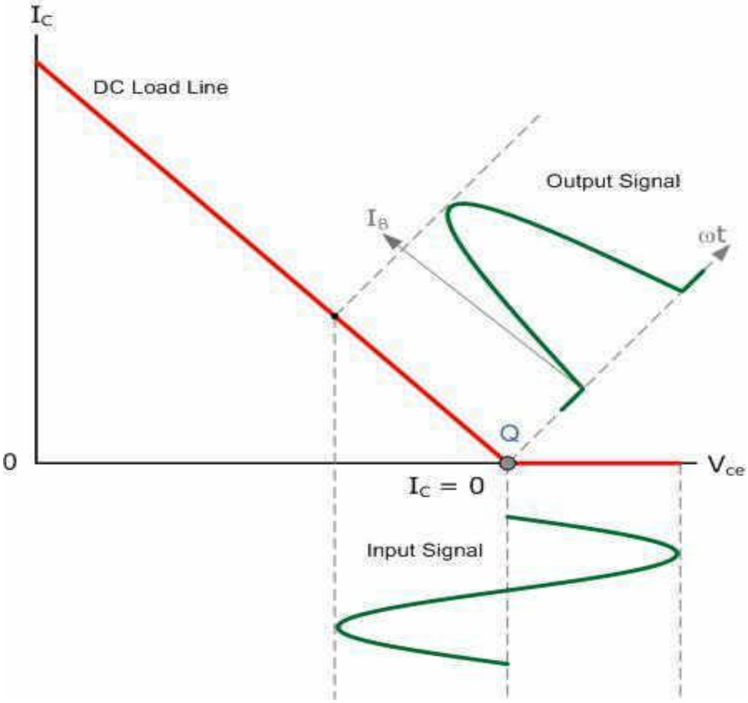


Fig. 2.8: Amplifier’s I vs V curve

2.4 Tone Burst Mode and Control Circuit

To implement the tone-burst mode, it is needed to make the output of the amplifier modified in such a way that the output will be there for a fixed period of cycle and suppressed for the other time.

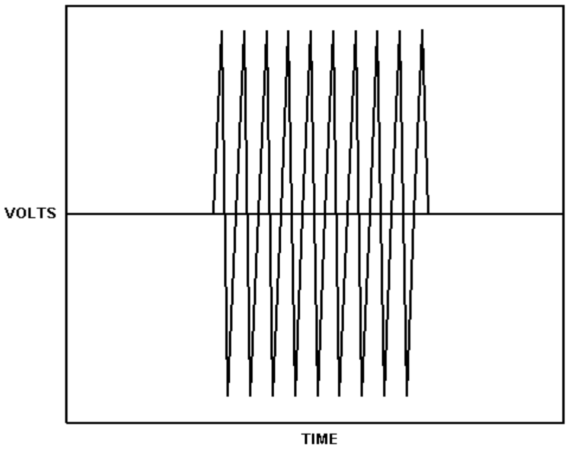


Fig. 2.9: Typical Tone-Burst Signal

The new parameter ‘Tone-burst mode’ of the proposed Ultrasound Diathermy device can be achieved by modifying our amplifier portion as shown in figure 2.10. This is our proposed design for tone burst output.

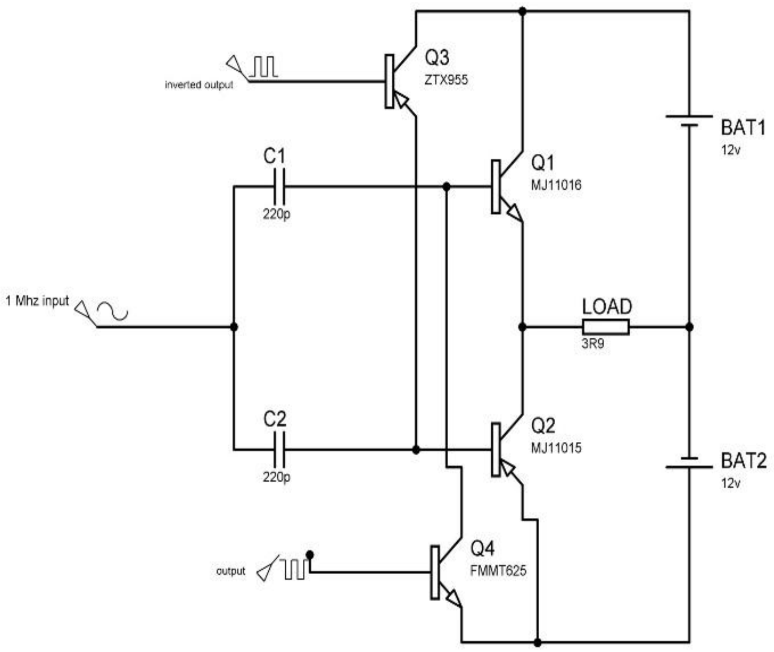


Fig. 2.10: Circuit Diagram for Tone-burst mode

The circuit for Tone-burst mode needs a control circuit of waveform timing allowing inverted and non-inverted output. This circuit will facilitate the continuous and pulsed mode by the choice of suitable waveform. For the timer circuit we have used 555 timer chip.

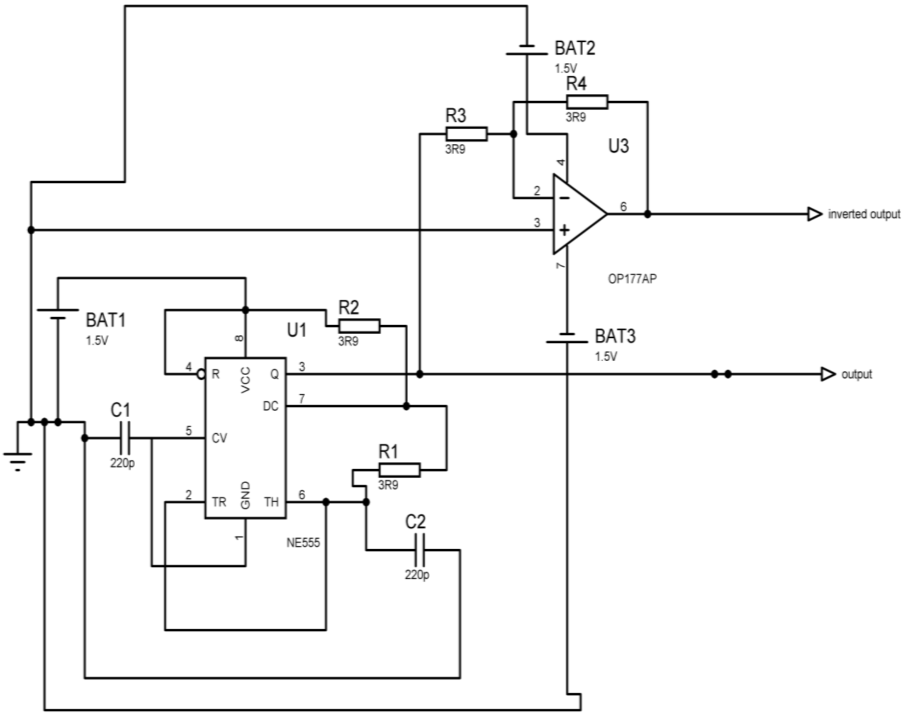


Fig. 2.11: Circuit Diagram for Wave-form timing

2.5 Ultrasound Transducer or Probe

An ultrasound transducer is a device that converts energy into ultrasound, or sound waves above the normal range of human hearing. While technically a dog whistle is an ultrasonic transducer that converts mechanical energy in the form of air pressure into ultrasonic sound waves, the term is more apt to be used to refer to piezoelectric transducers that convert electrical energy into sound. Piezoelectric crystals have the property of changing size when a voltage is applied, thus applying an alternating current (AC) across them causes them to oscillate at very high frequencies, thus producing very high frequency sound waves. The location at which a transducer focuses the sound can be determined by the active transducer area and shape, the ultrasound frequency, and the sound velocity of the propagation medium [32].

Ultrasound Transducers or Probes make contact with the skin with the use of a special conducting gel that makes a continuous connection with the skin surface. A similar ultrasound probe delivers higher levels of US when this is used in physical therapy. US heats the tissue through the vibrations these high speed sound waves produce [33]. Care must be taken to avoid overheating an area by always keeping the transducer in motion and limiting treatment duration.

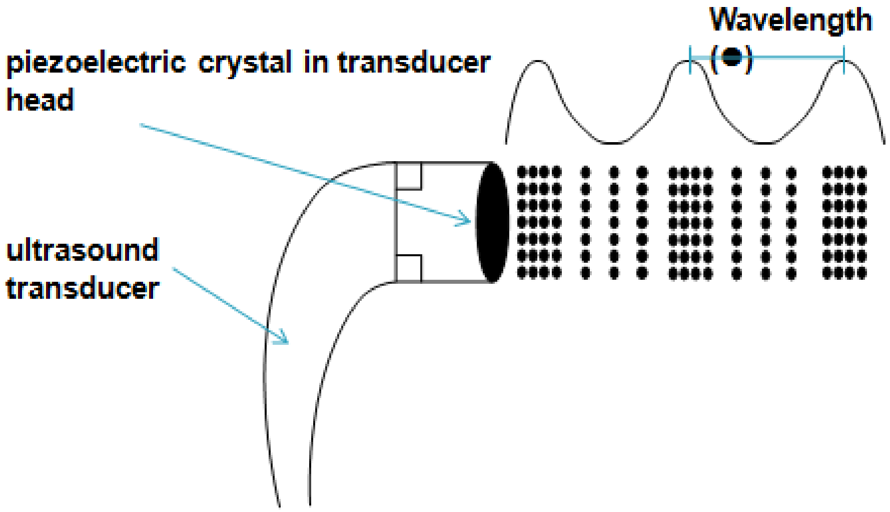


Fig. 2.12: Ultrasound Transducer Probe

The transducer probe generates and receives sound waves using a principle called the piezoelectric **(**pressure electricity**)** effect, which was discovered by Pierre and Jacques Curie in 1880. In the probe, there is one or more quartz crystals called piezoelectric crystals. When an electric current is applied to these crystals, they change shape rapidly. The rapid shape changes, or vibrations, of the crystals produce sound waves that travel outward. Conversely, when sound or pressure waves hit the crystals, they emit electrical currents. Therefore, the same crystals can be used to send and receive sound waves [36]. The probe also has a sound absorbing substance to eliminate back reflections from the probe itself, and an acoustic lens to help focus the emitted sound waves [37].

In the design of the proposed Ultrasound Diathermy Device, a Ultrasound Transducer probe is needed which will match the output of the total circuitry. It can be concluded as:

- Probe is the Ultrasound transducer
- It’s a Piezoelectric device
- It acts as a load to the main circuitry
- Probe specification must match output of the design Circuitry.

2.6 Total Circuitry

The total circuitry of our proposed design of Ultrasound Diathermy Device will be the addition of the parts of Oscillator, Amplifier, Tone-burst and waveform timing circuit. The final circuit diagram is visualized in figure 2.13.

The Ultrasound transducer or the probe will be attached as the load to circuit as shown in the figure 2.13.

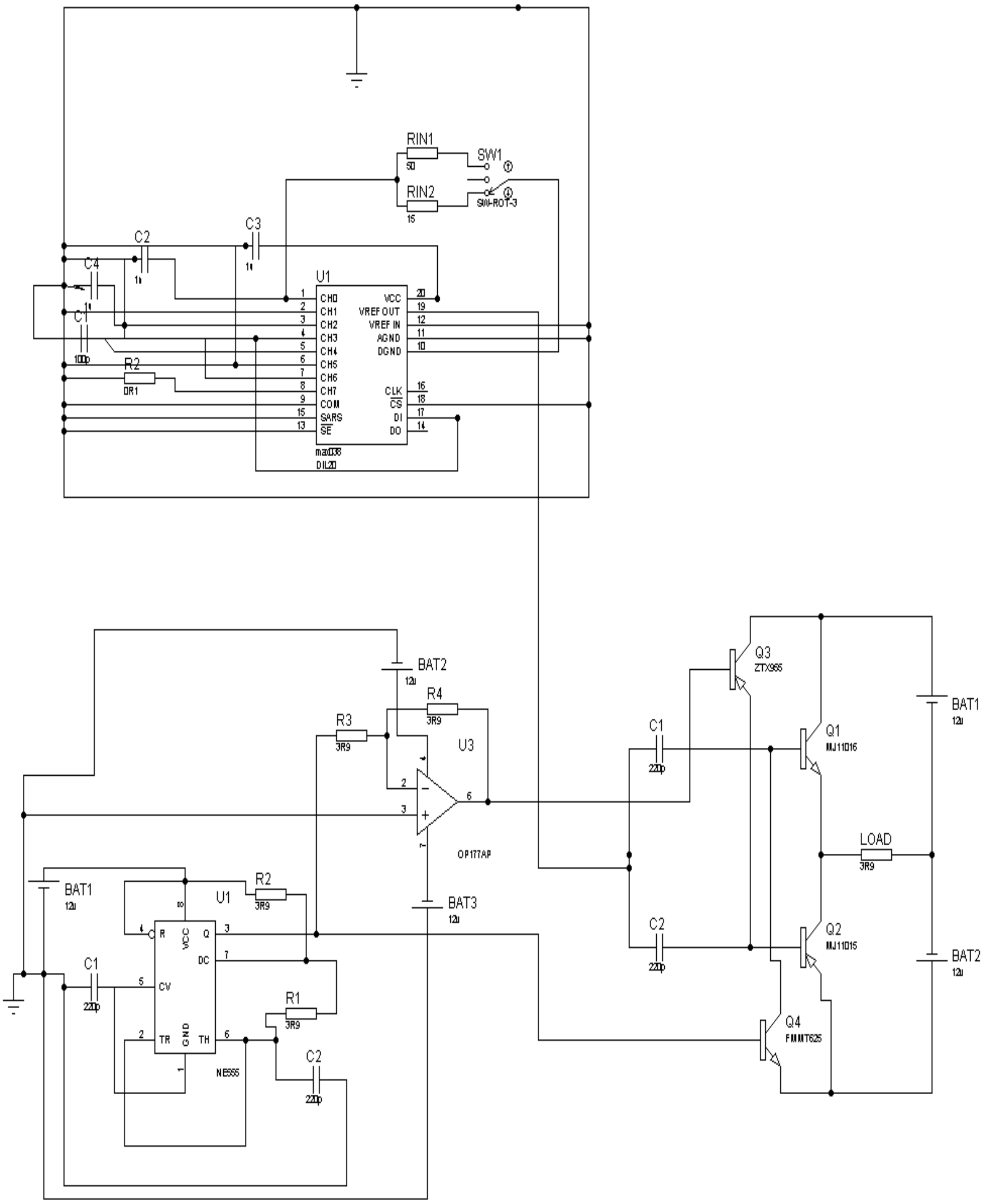


Fig. 2.13: Final Circuit Diagram for Proposed US Diathermy device

CHAPTER 3

HARDWARE IMPLEMENTATION

3.1 Main Body of the Device

Implementing the hardware of the proposed ultrasound diathermy device starts with the construction of the oscillator circuit. MAX 038 high frequency signal generator is used for generating 1MHz sinusoidal signal. The programming of the pins and necessary calculations are done accordingly.

3.1.1 Waveform Selection

The MAX038 can produce sine, square, or triangle waveforms. The TTL/CMOS-logic address pins (A0 and A1) set the waveform, as shown below:

Table 3.1: MAX 038 Waveform selection

A0	**A1**	**WAVEFORM**
X	1	Sine wave
0	0	Square wave
1	0	Triangle wave
		X = don’t care

Waveform switching can be done at any time, without regard to the phase of the output. Switching occurs within 0.3µs, but there may be a small transient in the output waveform that lasts 0.5µs.

3.1.2 Waveform Timing

The waveform timing of the MAX 038 has several control phenomenons. They are discussed accordingly.

3.1.2.1 Output Frequency

The output frequency is determined by the current injected into the I_{IN} pin, the COSC capacitance (to ground), and the voltage on the FADJ pin.

When V_{FADJ}= 0V, the fundamental output frequency (F_o) is given by the formula:

F_o (MHz) = I_{IN} (µA) ÷ C_F (pF)

The period (t_o) is:

t_o (µs) = C_F (pF) ÷ I_{IN} (µA)

Where:

I_{IN} = current injected into IIN (between 2µA and 750µA)

C_F = capacitance connected to COSC and GND (20pF to >100µF).

For example:

0.5MHz = 100µA ÷ 200pF

And

2µs = 200pF ÷ 100µA

Optimum performance is achieved with I_{IN} between 10µA and 400µA, although linearity is good with I_{IN} between 2µA and 750µA. Current levels outside of this range are not recommended. For fixed-frequency operation, set I_{IN} to approximately 100µA and select a suitable capacitor value. This current produces the lowest temperature coefficient, and produces the lowest frequency shift when varying the duty cycle.

The capacitance can range from 20pF to more than 100µF, but stray circuit capacitance must be minimized by using short traces. Surround the COSC pin and the trace leading to it with a ground plane to minimize coupling of extraneous signals to this node. Oscillation above 20MHz is possible, but waveform distortion increases under these conditions. The low frequency limit is set by the leakage of the COSC capacitor and by the required accuracy of the output frequency. Lowest frequency operation with good accuracy is usually achieved with 1 0 µF or greater non -polarized capacitors. An internal closed-loop amplifier forces I_{IN} to virtual ground, with an input offset voltage less than ±2mV. I_{IN} may be driven with either a current source (I_{IN}), or a voltage (V_{IN}) in series with a resistor (R_{IN}). (A resistor between REF and I_{IN} provides a convenient method of generating I_{IN}: I_{IN} = V_{REF}/R_{IN}.) When using a voltage in series with a resistor, the formula for the oscillator frequency is:

F_o (MHz) = $V_{IN} \div [R_{IN} \times C_F$ (pF)]

And:

t_o (µs) = C_F (pF) x $R_{IN} \div V_{IN}$

When the MAX038's frequency is controlled by a volt-age source (V_{IN}) in series with a fixed resistor (R_{IN}), the output frequency is a direct function of V_{IN} as shown in the above equations. Varying V_{IN} modulates the oscillator frequency. For example, using a 10kΩ resistor for R_{IN} and sweeping V_{IN} from 20mV to 7.5V produces large frequency deviations (up to 375:1). Select R_{IN} so that I_{IN} stays within the 2µA to 750µA range. The band-width of the I_{IN} control amplifier, which limits the modulating signal's highest frequency, is typically 2MHz. I_{IN} can be used as a summing point to add or subtract currents from several sources. This allows the output frequency to be a function of the sum of several variables. As V_{IN} approaches 0V, the I_{IN} error increases due to the offset voltage of I_{IN}. Output frequency will be offset 1% from its final value for 10 seconds after power-up.

3.1.2.2 FADJ Input

The output frequency can be modulated by FADJ, which is intended principally for fine frequency control, usually inside phase-locked loops. Once the fundamental, or center frequency (F_o) is set by I_{IN}, it may be changed further by setting FADJ to a voltage other than 0V. This voltage can vary from -2.4V to +2.4V, causing the output frequency to vary from 1.7 to 0.30 times the value when FADJ is 0V (F_o ±70%). Voltages beyond ±2.4V can cause instability or cause the frequency change to reverse slope.

The voltage on FADJ required causing the output to deviate from Fo by Dx (expressed in %) is given by the formula:

$V_{FADJ} = -0.0343 \times D_x$

Where V_{FADJ}, the voltage on FADJ, is between -2.4V and +2.4V.

The voltage on FADJ for any frequency is given by the formula:

$V_{FADJ} = (F_o - F_x) \div (0.2915 \times F_o)$

Where:

F_x = output frequency

F_o = frequency when $V_{FADJ} = 0V$.

Likewise, for period calculations:

$V_{FADJ} = 3.43 \times (tx - to) \div tx$

Where:

t_x = output period

t_o = period when $V_{FADJ} = 0V$.

Conversely, if V_{FADJ} is known, the frequency is given by:

$F_x = F_o \times (1 - [0.2915 \times V_{FADJ}])$

And the period (t_x) is:

$t_x = t_o \div (1 - [0.2915 \times V_{FADJ}])$

3.1.2.3 Programming FADJ

FADJ has a 250µA constant current sink to V- that must be furnished by the voltage source. The source is usually an op-amp output, and the temperature coefficient of the current sink becomes unimportant. For manual adjustment of the deviation, a variable resistor can be used to set V_{FADJ}, but then the 250µA current sink's temperature coefficient becomes significant. Since external resistors cannot match the internal temperature coefficient curve, using external resistors to program VFADJ is intended only for manual operation, when the operator can correct for any errors. This restriction does not apply when VFADJ is a true voltage source.

A variable resistor, RF, connected between REF (+2.5V) and FADJ provides a convenient means of manually setting the frequency deviation. The resistance value (R_F) is:

$R_F = (V_{REF} - V_{FADJ}) \div 250\mu A$

V_{REF} and V_{FADJ} are signed numbers, so use correct algebraic convention. For example, if V_{FADJ} is -2.0V (+58.3% deviation), the formula becomes:

$$\begin{aligned} RF &= (+2.5V - (-2.0V)) \div 250\mu A \\ &= (4.5V) \div 250\mu A \\ &= 18k\Omega \end{aligned}$$

3.1.2.4 Duty Cycle

The voltage on DADJ controls the waveform duty cycle (defined as the percentage of time that the output waveform is positive). Normally, V_{DADJ} = 0V, and the duty cycle is 50%. Varying this voltage from +2.3V to -2.3V causes the output duty cycle to vary from 15% to 85%, about -15% per volt. Voltages beyond ±2.3V can shift the output frequency and/or cause instability. DADJ can be used to reduce the sine-wave distortion. The unadjusted duty cycle (V_{DADJ} = 0V) is 50% ±2%; any deviation from exactly 50% causes even order harmonics to be generated. By applying a small adjustable voltage (typically less than ±100mV) to VDADJ, exact symmetry can be attained and the distortion can be minimized. The voltage on DADJ needed to produce a specific duty cycle is given by the formula:

$V_{DADJ} = (50\% - dc) \times 0.0575$

Or:

$V_{DADJ} = (0.5 - [t_{on} \div t_o]) \times 5.75$

Where:

V_{DADJ} = DADJ voltage

dc = duty cycle (in %)

t_{ON} = ON (positive) time

t_o = waveform period.

Conversely, if V_{DADJ} is known, the duty cycle and ON time are given by:

$dc = 50\% - (V_{DADJ} \times 17.4)$

$t_{on} = to \times (0.5 - [V_{DADJ} \times 0.174])$

3.1.2.5 Programming DADJ

DADJ is similar to FADJ; it has a 250µA constant current sink to V- that must be furnished by the voltage source. The source is usually an op-amp output, and the temperature coefficient of the current sink becomes unimportant. For manual adjustment of the duty cycle, a variable resistor can be used to set V_{DADJ}, but then the 250µA current sink's temperature coefficient becomes significant. Since external resistors cannot match the internal temperature-coefficient curve, using external resistors to program V_{DADJ} is intended only for manual operation, when the operator can correct for any errors. This restriction does not apply when V_{DADJ} is a true voltage source .A variable resistor, R_D, connected between REF (+2.5V) and DADJ provides a convenient means of manually setting the duty cycle. The resistance value (R_D) is:

$$R_D = (V_{REF} - V_{DADJ}) \div 250\mu A$$

Both V_{REF} and V_{DADJ} are signed values, so observe correct algebraic convention. For example, if VDADJ is -1.5V (23% duty cycle), the formula becomes:

$$R_D = (+2.5V - (-1.5V)) \div 250\mu A$$
$$= (4.0V) \div 250\mu A = 16k\Omega$$

Varying the duty cycle in the range 15% to 85% has minimal effect on the output frequency—typically less than 2% when $25\mu A < I_{IN} < 250\mu A$. The DADJ circuit is wideband, and can be modulated at up to 2MHz.

3.1.3 Output

The output amplitude is fixed at $2V_{P-P}$, symmetrical around ground, for all output waveforms. OUT has an output resistance of under 0.1Ω, and can drive ±20mA with up to a 50pF load. Isolate higher output capacitance from OUT with a resistor (typically 50Ω) or buffer amplifier.

3.1.4 Reference Voltage

REF is a stable 2.50V band gap voltage reference capable of sourcing 4mA or sinking 100µA. It is principally used to furnish a stable current to IIN or to bias DADJ and FADJ. It can also be used for other applications external to the MAX038. Bypass REF with 100nF to minimize noise.

3.1.5 Selecting Resistors and Capacitors

The MAX038 produces a stable output frequency over time and temperature, but the capacitor and resistors that determine frequency can degrade performance if they are not carefully chosen. Resistors should be metal film, 1% or better. Capacitors should be chosen for low temperature coefficient over the whole temperature range. NPO ceramics is usually satisfactory. The voltage on COSC is a triangle wave that varies between 0V and -1V. Polarized capacitors are generally not recommended(because of their outrageous temperature dependence and leakage currents), but if they are used, the negative terminal should be connected to COSC and the positive terminal to GND. Large-value capacitors, necessary for very low frequencies, should be chosen with care, since potentially large leakage currents and high dielectric absorption can interfere with the orderly charge and discharge of C_F. If possible, for a given frequency, use lower I_{IN} currents to reduce the size of the capacitor.

3.1.6 Layout Considerations

Realizing the full performance of the MAX038 requires careful attention to power-supply bypassing and board layout. Use a low-impedance ground plane, and connect all five GND pins directly to it. Bypass V+ and V-directly to the ground plane with 1μF ceramic capacitors or 1μF tantalum capacitors in parallel with 1nF ceramics. Keep capacitor leads short (especially with the 1nF ceramics) to minimize series inductance. If SYNC is used, DV+ must be connected to V+, DGND must be connected to the ground plane, and a second 1nF ceramic should be connected as close as possible between DV+ and DGND (pins 16 and 15). It is not necessary to use a separate supply or run separate traces to DV+. If SYNC is disabled, leave DV+ open. Do not open DGND .Minimize the trace area around COSC (and the ground plane area under COSC) to reduce parasitic capacitance, and surround this trace with ground to prevent coupling with other signals. Take similar precautions with DADJ, FADJ, and IIN. Place C_F so its connection to the ground plane is close to pin 6 (GND).

3.1.7 Transistor

Our Class B push pull amplifier design need high power high frequency transistor. Depending on the availability, in our design we have used:

1. MJ 11015 (pnp)
2. MJ 11016 (npn)

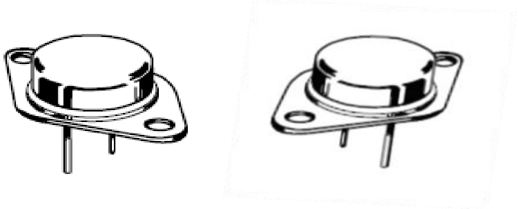


Fig. 3.1: Picture of transistors

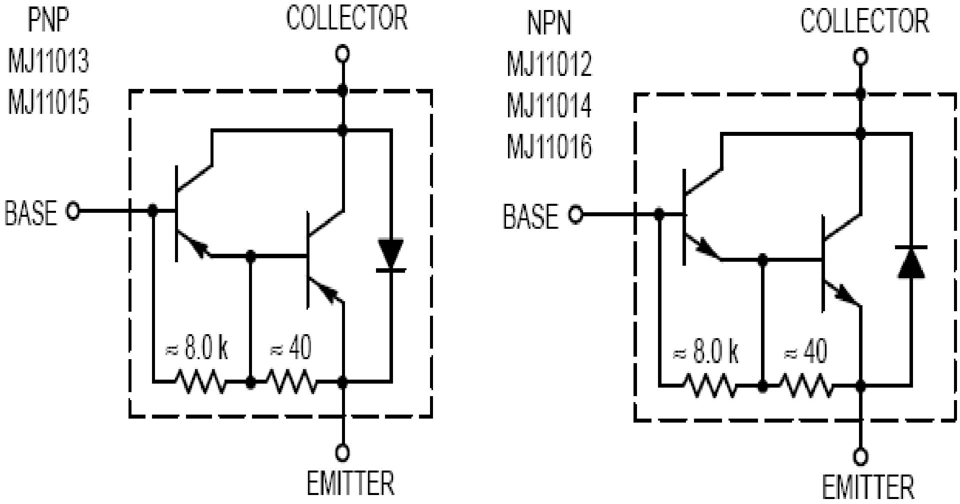


Fig. 3.2: Internal Diagram of the Transistors we used

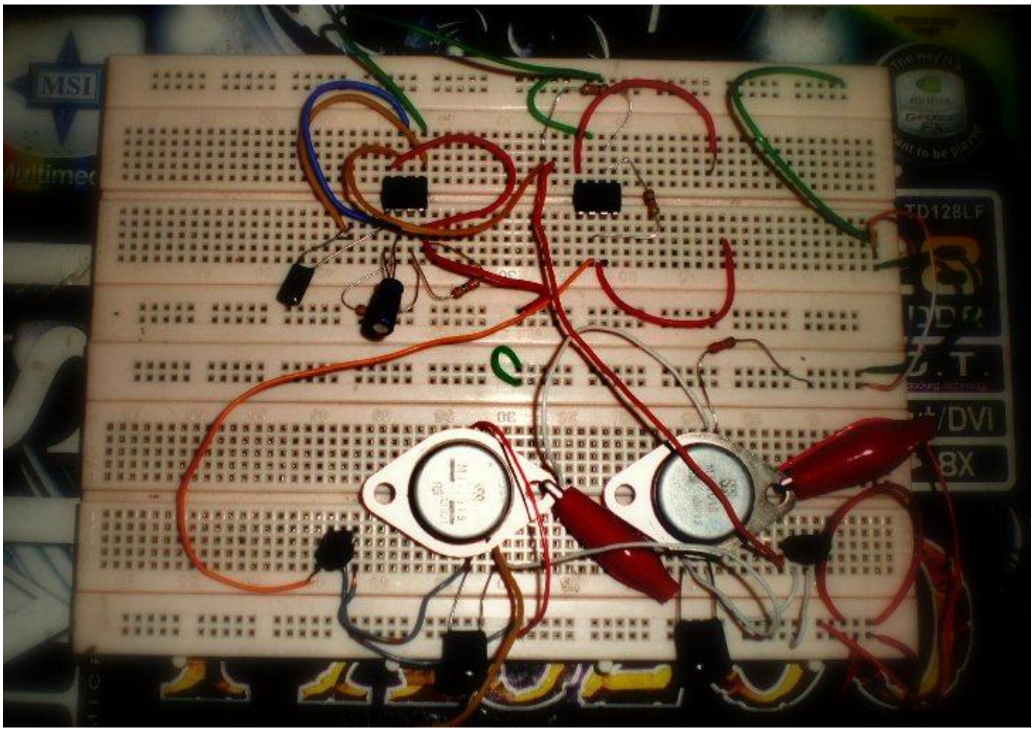


Fig. 3.3: Hardware Circuit of Amplifier and waveform timing

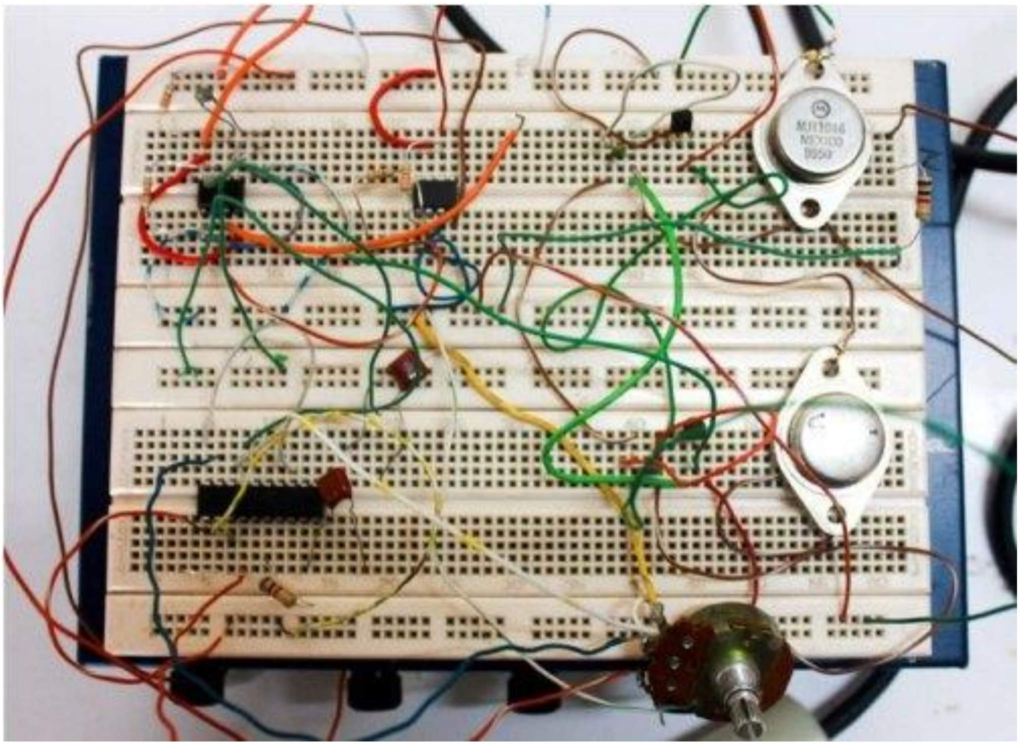


Fig. 3.4: Hardware Circuit of the main body of the total design

3.2 Probe

Ultrasound transducer probe is needed which makes contact with the skin with the use of a special conducting gel that makes a continuous connection with the skin surface to give the therapy by converting the output signal of our designed circuit into US form. The probe also needs to be specified with our circuit output. The description of the probe is as follows:

- Manufacturer: Mettler® Electronics
- Brand Name: Sonicator® 7331A
- Size: 1 sq-cm
- Operating Frequency: 1MHz – 3.3MHz
- Output Power: up to 5 W/cm^2

This specific probe is very well adjusted to our proposed and developed design of the US diathermy device. The picture of the probe is visualized in the figure

Fig. 3.5: Ultrasound Transducer Probe Mettler® Sonicator® 7331A

3.2.1 *Connector of the Probe*

To connect the US transducer probe with the main circuitry, RCA connector is used. It is an electro-mechanical device for joining electrical circuits as an interface using a mechanical assembly

The male RCA plug consists of a central pin measuring approximately two millimeters (mm) in diameter, and an outer shell whose inside diameter is approximately six mm. The plug shell is slotted rather than threaded, to facilitate quick insertion to, and removal from, the female jack or receptacle. Contact is maintained by physical pressure between the slotted shell of the plug and the smooth cylindrical barrel of the jack. The plug shell is connected to the outer conductor, or shield, of the coaxial cable, normally at electrical ground. The center pin of the plug is connected to the cable center conductor, which carries the signal. In the jack, the barrel is grounded and the center hole is plated inside to conduct the signal. For our easy purpose of use, we have modified the design of our RCA connector to facilitate different kind of probes.

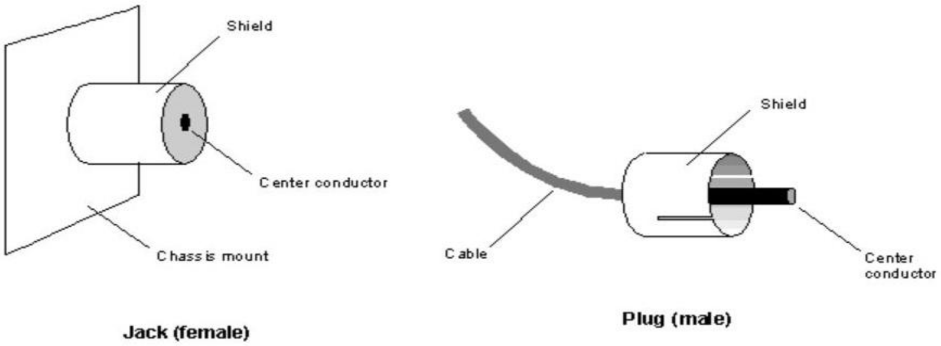


Fig. 3.6: Basic RCA connectors; Jack and Plug

Fig. 3.7: Customized RCA connector we used to connect the probe with the device

3.3 Power Supply

To facilitate the different level of DC voltage among the parts of the total circuit of the US diathermy device, we have constructed a regulated power supply device having output DC voltage levels of +5V, 0 to +15V, 0 to -15V. The details on the power supply circuit are given on Appendix A.

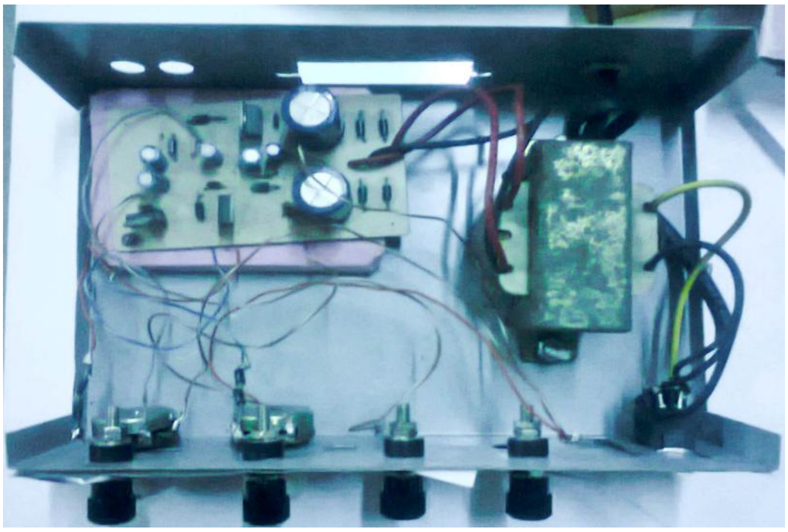


Fig. 3.8: Circuit for the power supply device

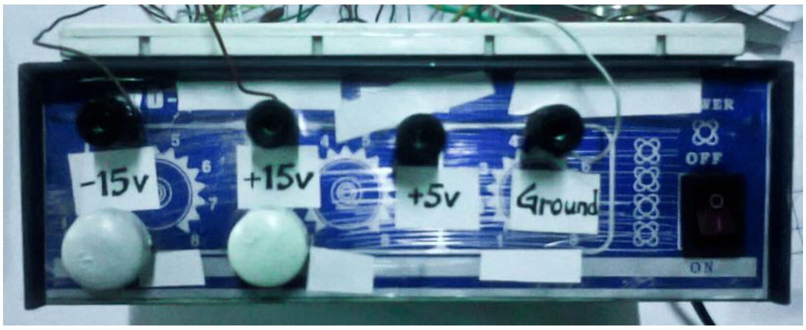


Fig. 3.9: Front view of the power supply device

3.4 The Ultrasound Diathermy Device

Construction of the proposed ultrasound diathermy device is just the adjoining of the above discussed parts of hardware. As this is an experimental setup and a proposed prototype, the circuit of the device is kept open for testing and modifications. The final device will have compact packaging with sophisticated and user friendly control.

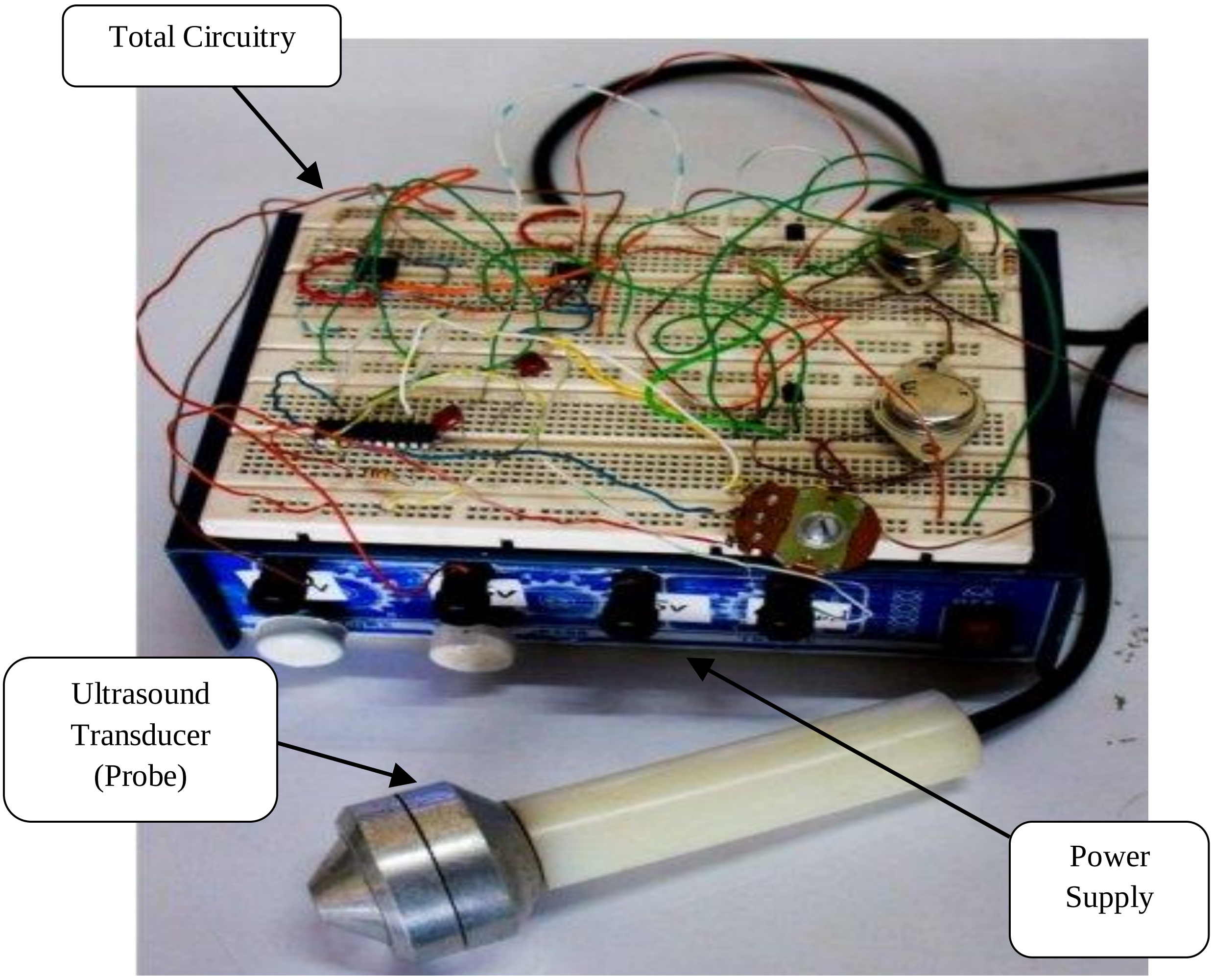


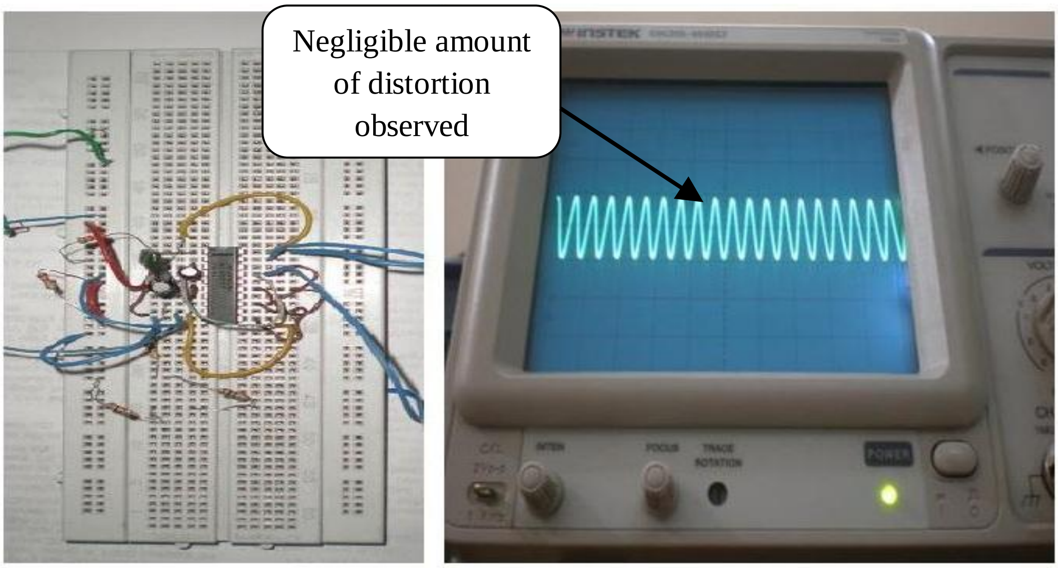
Fig. 3.10: The Ultrasound Diathermy Device constructed based on the proposed design

CHAPTER 4

EVALUATION OF OUTPUT

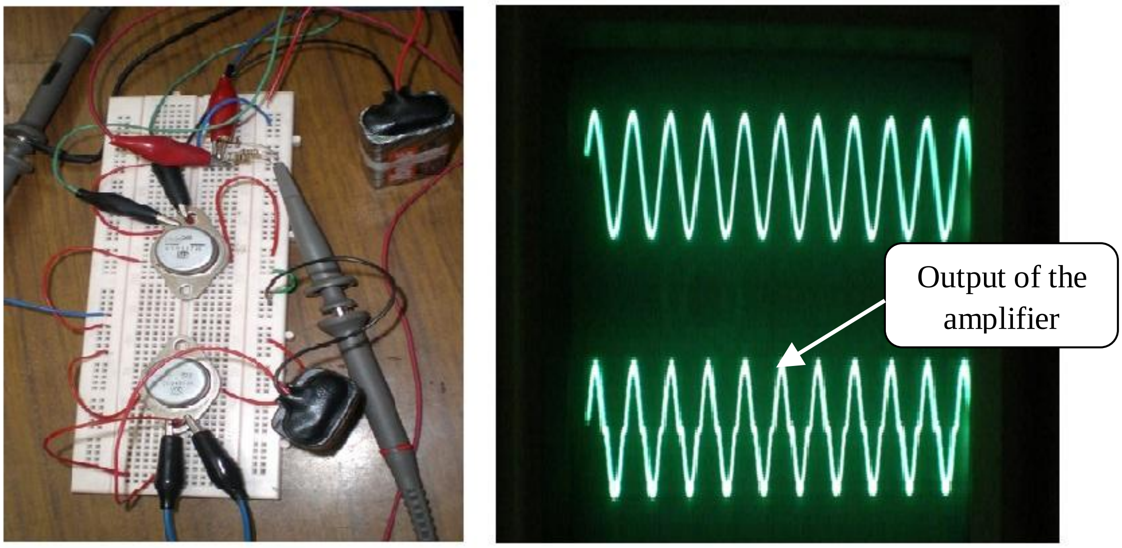
4.1 Hardware output results

To interpret the output result of the designed ultrasound diathermy device, first the viausalized the different real-time output of the different portion of the circuit individualy from figure 4.1 to figure 4.3.



Negligible amount of distortion observed

Fig. 4.1: The 1Mhz MAX 038 oscillator circuit and the output



Output of the amplifier

Fig. 4.2: The Push-Pull Amplifier circuit and the output in response to 1MHz signal

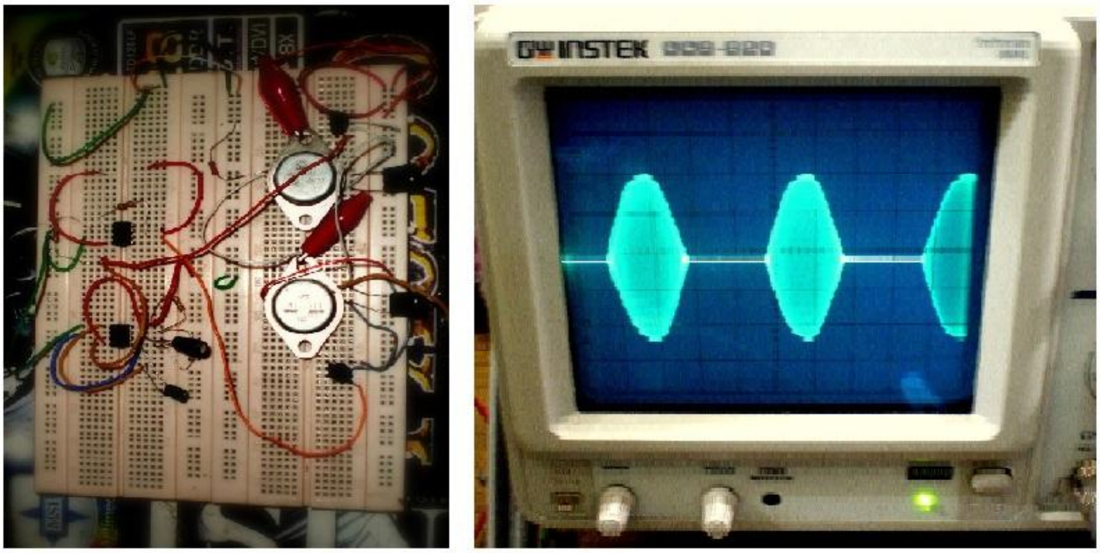


Fig. 4.3: The circuit for Tone-Burst mode and the output in response to 1MHz signal

In the prepared device Tone-burst mode is used as the input of the Probe at initial stage for all the calculations and interpretations. The continuous and pulse mode are rather easy and covered with in the tone-burst mode.

Theoritically there would be no visible effect of the probe under the 1MHz operating condition on the water. To visualize that, some water is put on the transducer head to see the effect. Practically their were some slightly visible vibration in the water found (Figure 4.4).

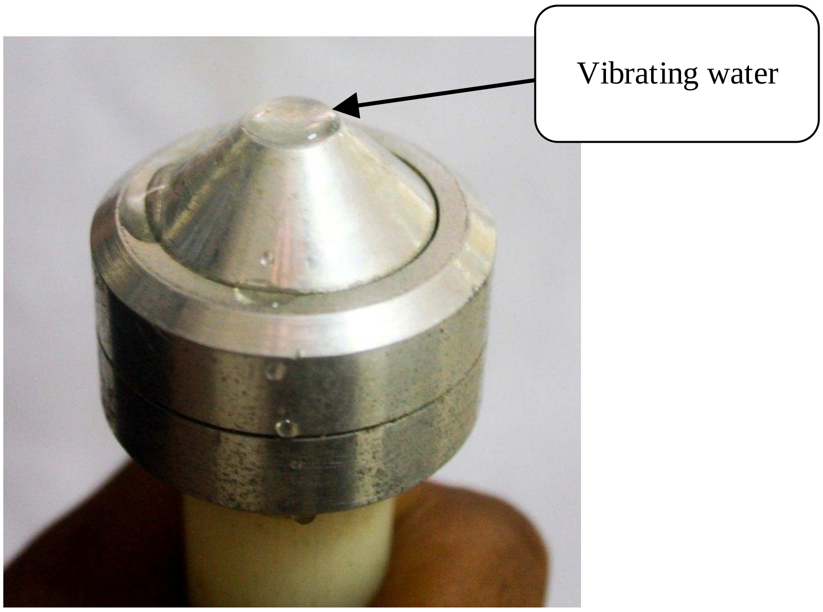


Fig. 4.4: The vibrating water on the transducer head under operating condition

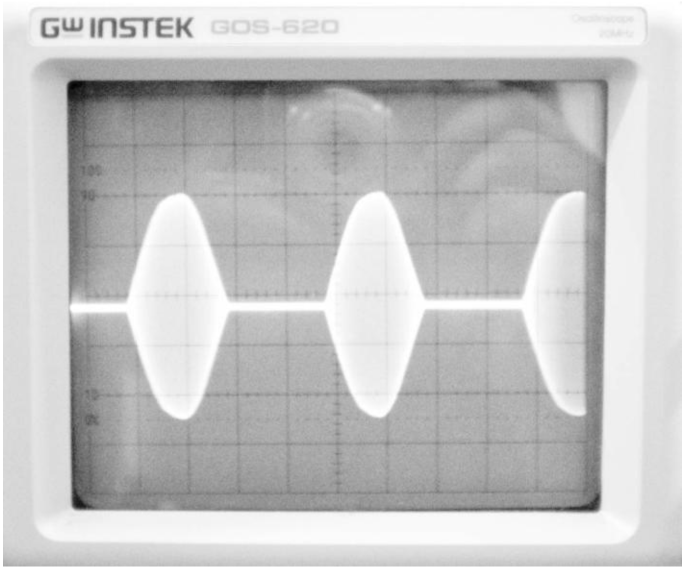


Fig. 4.5: The Tone-Burst output of the circuit fed to as the input of the Probe

The visible vibrating water can be described as the effect of the tone-burst mode of the device. There are also the quick rise of temperature in the water is found. The rise of the temperature is very much obvious because of the US propagation through the water.

4.2 Simulations

Several simulation tests is done of the proposed design using simulation software (details in Appendix B). The results are given as follows.

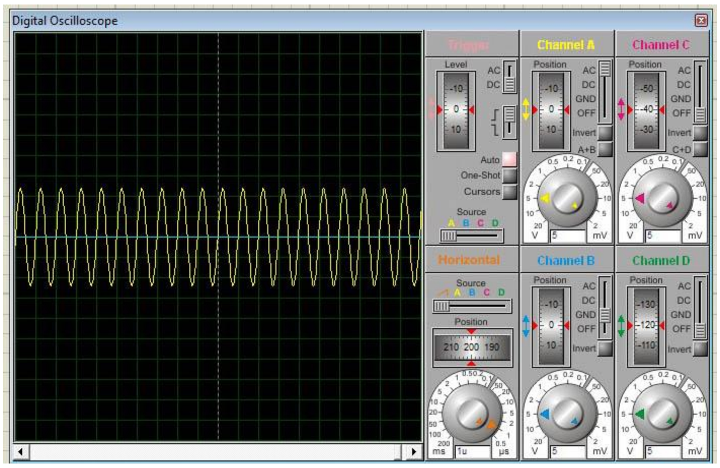


Fig. 4.6: Simulation Result of the Oscillator Output

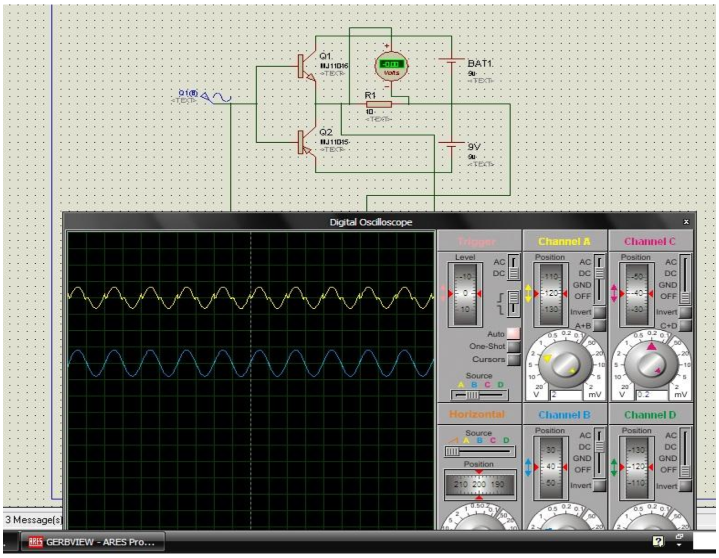


Fig. 4.7: Simulation Result of the Amplifier Circuit

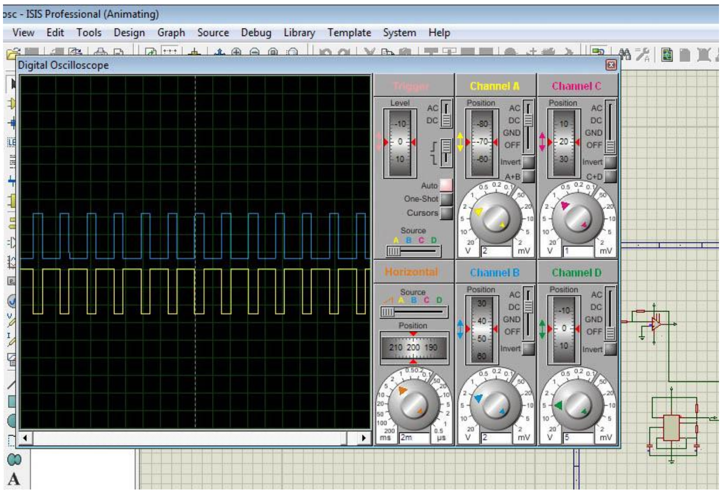


Fig. 4.8: Simulation Result of the Timer circuit

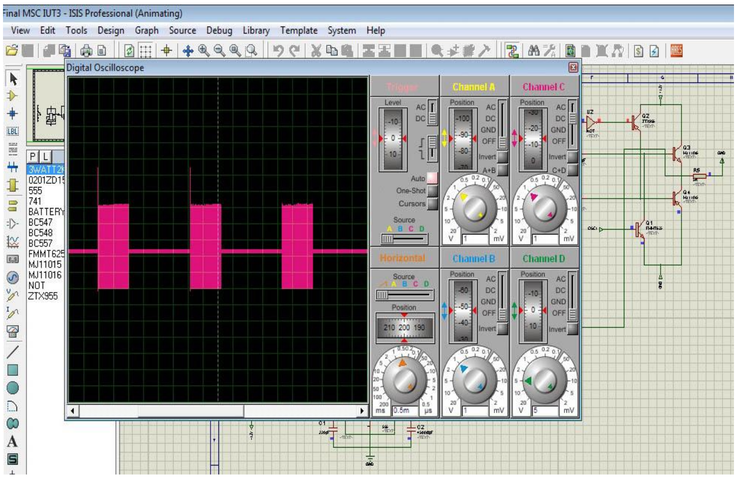


Fig. 4.9: Simulation Result of the output of total circuit

4.3 Comparison

First the comparison between the hardware circuit and the simulation is done. The discussion is given in parts.

4.3.1 Oscillator Circuit

Figure 4.1 and figure 4.6 are the output of the oscillator circuit from the real setup and the simulation respectively. They both are almost same, only a slight distortion is visualized. The effect of this distortion in minimum and can be ignored in this case because the amplitude level of the voltage is same, only slight anomaly on the continuous sine wave is observed. The reason for this distortion can be identified as the heating of the resistances due to high frequency drive as well as the resistances among connection between the elements.

4.3.2 Amplifier Circuit

Figure 4.2 and figure 4.7 are the output of the Amplifier circuit from the real setup and the simulation respectively, in response to a 1MHz sine wave signal. In the Amplifier case, the initial result exactly matches with the simulation result. Using the voltage regulated power supply sustains this output, but using battery makes some deviation with the simulation result.

Initial test was done using $2V_{p-p}$. The results are as follows.

Table 4.1: Comparison of voltages for amplifier circuit

Mode of setup	Using Regulated voltage from Power supply			Using Lithium-Ion Rechargeable battery		
Time duration	After 5 Minutes	After 15 Minutes	After 25 Minutes	After 5 Minutes	After 15 Minutes	After 25 Minutes
Simulation Circuit	$2V_{p-p}$	$2V_{p-p}$	$2V_{p-p}$	$2V_{p-p}$	$2V_{p-p}$	$2V_{p-p}$
Actual Circuit	$1.95V_{p-p}$	$1.95V_{p-p}$	$1.90V_{p-p}$	$1.95V_{p-p}$	$1.88V_{p-p}$	$1.75V_{p-p}$

The output of the amplifier circuit is very much working with a continuous regulated supply. With a rechargeable battery, the output is satisfactory with some lessening in the voltage level. Theoretically it should be same until the battery exhaust, but along with to the decrement of the battery power level its regulation also gets slightly distorted.

Battery will be used for a portable device. Our initial design uses the regulated power supply, so the battery problem subsides. Yet, the portable version will sustain up to 20-25 minutes with minimal lessening of voltage, which should be fare enough for light use of the version. More improvement can be done while designing a portable one.

4.3.3 Tone-Burst Output

Figure 4.5 and figure 4.9 are the output of the total circuit from the real setup and the simulation respectively, in response to a 1MHz sine wave signal which is the input to load (Probe). There are some visual deformations of the actual signal from the simulated result. The rectangular form of the burst portion of the simulation output is narrowed down to the upper and lower end of the actual output. This condition has occurred due to the high power dissipation, noise and temperature sensitivity of the power BJTs we have used here. But the change is not significant here as the desired Tone-burst mode is already achieved. The voltage level has not shown any significant change.

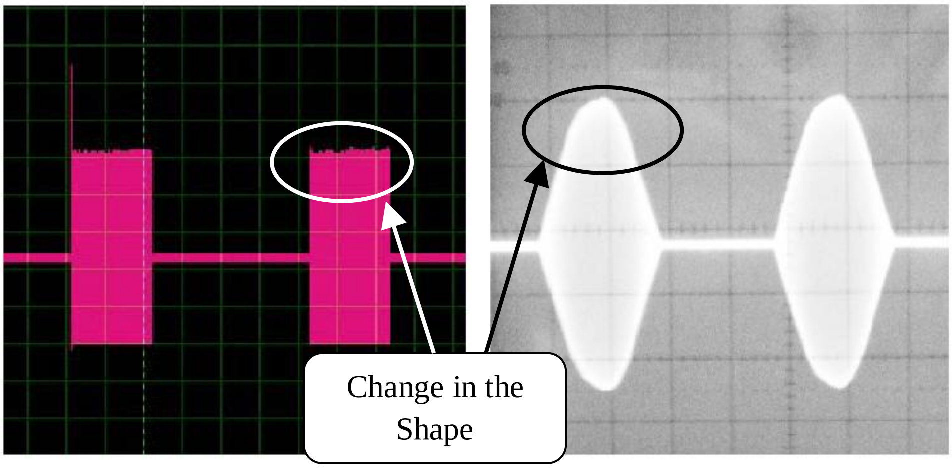


Fig. 4.10: Final Output comparison between Simulation Result and Actual Result

4.3.4 Comparison with latest similar works

One portable ultrasound diathermy device was developed by two researchers from Cornell University in recent times [30]. They measured output waveform and power spectrum of the device were collected using a Tektronics model TDS2002B oscilloscope with the ultrasound probe attached and placed in an acoustically insulated water bath. The ultrasonic power output was determined with a force balance technique in which they measured the force that the ultrasound exerted on an acoustic absorbing object.

The measurement of the acoustic energy cannot be done accurately due to some constrains. But the electrical outputs such as the output impedance, resistance, and reactance of the device were measured by attaching a 20 Ω power resistor across the output of the device and measuring the phase and voltage changes across the component.

Using Voltage setting of $19.2V_{p\text{-}p}$ they measured electrical power output of 5.25W [30]. Our design shows the output of 2.5W for a voltage setting of $12V_{p\text{-}p}$. The result is relatively lower but in the working range and satisfactory. The reason is we have used BJTs for switching where as they have used MOSFETs. Cost effectiveness is our advantage here. Again they have only used continuous and pulsed mode of output, not the Tone-burst mode.

4.4 Practical Tests

The newly designed ultrasound diathermy device is tested (under proper supervision) to 5 test subject along with one of the existing product (Intelect® Legend Ultrasound) with similar specification. The tests were done in the facility of the Department of Biomedical Physics and Engineering of Dhaka University. The area of the body selected was from wrist to elbow to avoid any kind of injury due to malfunctioning.

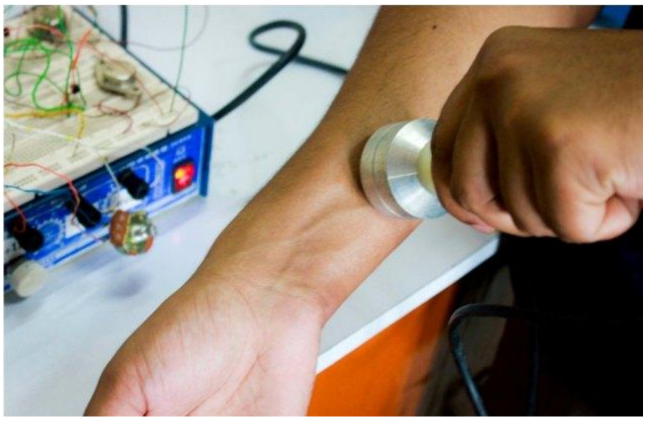


Fig. 4.11: Application of Ultrasound Diathermy to test subject

Primary results found are satisfactory on the basis of the response of the test subject. These results are not certified by any registered doctor, but only the direct replies from the subjects. All the test subjects were within the range of 22-28 years.

Table 4.2: Response of Test Subjects up on practical Diathermy
(n/c = no change)

	Response of the Test Subject (Time in minutes after continuous application of US)					
	Existing US Diathermy Device			Our proposed Device		
	2 Mins	4 Mins	7 Mins	2 Mins	4 Mins	7 Mins
Subject A	warm	Warm	hot	n/c	warm	warm
Subject B	warm	Warm	hot	warm	warm	hot
Subject C	warm	Warm	hot	n/c	warm	warm
Subject D	warm	Warm	hot	warm	warm	hot
Subject E	warm	Warm	hot	n/c	warm	hot

These results show the effectiveness of our designed US diathermy device. The required time is slightly higher to heat the subject area, which indicates a lesser amount (approximately 15-20%) of efficiency of our device.

4.5 Cost and Commercial Viability

Table 4.3: Cost calculation of the Device components

Name of the components	App. Price in local market, in BDT (As on January 2012, updated on July 2012)
Signal Generator (MAX 038)	1,500.00
High Power Transistors (MJ11015, MJ11016)	2,000.00
Ultrasound Transducer Probe (Mettler® Sonicator® 7331A)	9,000.00
Additional Ics (NE555, 7805, LM317, LM337 etc)	1,000.00
Circuit components (Capacitors, resistors, wires etc)	5,00.00
Power supply casing	5,00.00
Making PCB (Projected)	5,00.00
Case for whole device (Projected)	2,000.00
LCD display	500.00
Miscellaneous	500.00
Total Price:	18,000.00

This price is only for making this single prototype of the designed Ultrasound Diathermy Device. The commercialization of the product will add some more amounts to the proposition of marketing, distribution and other additional matters. Again the gross production will add up some cost effectiveness.

4.6 Evaluation of output and Insight of study

All the output results show satisfactory outcomes of the proposed design of Ultrasound Diathermy Device. The loss is slightly higher making the efficiency of the device 10-20% lesser than the existing ones. This situation can easily be overcome by the use of MOSFET instead of BJT. As because the FET has high input impedance, low noise, better temp stability compared to BJT. But the BJT has better driving capability and high speed switching compared to FET. The most important factor is the cost effectiveness of the BJT over FET. For the portable version, there has battery power limitation where FET can be used overlooking its high cost. But for the proposed design, BJT can well serve all the purposes.

By going through the insight of the parametric study, it can be conclude on fulfilling our objectives of designing this particular US Diathermy device. It is found working Tone-burst mode with reasonable output power. The key note is that the product price has decreased in notable amount. The market price of Intelect® Legend Ultrasound Diathermy Device is USD 1800 (as on July 2012) and with commercialization price, the product should not reach the limit of USD 600. Which is definitely an advantage compensating the power losses. Again the locally developed product will get all the technical supports and services. At last, the introduction of Tone-Burst mode will capitalize and thus subsides the use of multiple devices.

CHAPTER 5
CONCLUSION

5.1 Summary

This work is another addition to the increasing application of the physical medicine and prevention methods instead of pain alleviating pills in the research field of biomedical engineering for people. The proposed design of US diathermy device can be used as a therapeutic modality for heating tissue to get relief of pain, muscle spasms and joint contractures. It is featured with all the facilities of the existing products along with the newly introduced parameter of tone-burst mode in a cost effective package. In conclusion, low-cost portable ultrasound diathermy system has the capability to be developed, but until a suitable replacement to piezoelectric crystals has been developed low-cost portable ultrasound system will be held back slightly by the high cost burden associated with the cost of probe.

The main motivational drive to go for this project was to make the US diathermy equipment obtainable to the local community of Bangladesh as there is a scarcity of availability in the affordable price and technical support. It was tried to improve these limitations and make its cost lesser and handy as well. Another drive was to introduce the new parameter of Tone-burst mode into the existing devices. During the project a few problems were faced like finding high frequency compatible ICs, transistor with high power & frequency withstand capability in the local market, still the total hardware are implemented using locally available resources. Now the device is forwarded to have sufficient support from relevant manufacturers and industries to manufacture this product commercially.

Contribution done by this work can be finalized as follows:

- Locally developed fully functioning device
- Available technical support and service
- Provision of changing the operating frequency
- Customized connector is facilitates multi-probe
- New parameter of tone-burst mode is implemented

5.2 Future scope of work

Additional works can be done with the proposed design of the ultrasound diathermy device. Use of automation through micro-controller can be introduced depending on the user requirements along with LCD panel. Complete and compact packaging with suitable casing is required for mass and viable production. More prototypes should be introduced to test in field and get the permission to use as commercial medical equipment from the concerned authority. At last, more modeling and finalization can be done to minimize the losses and finalize a feasible localized Ultrasound Diathermy Device.

APPENDIX A

DESIGN OF THE POWER SUPPLY AND PROBE

A.1 Total Circuit Diagram of the power supply design

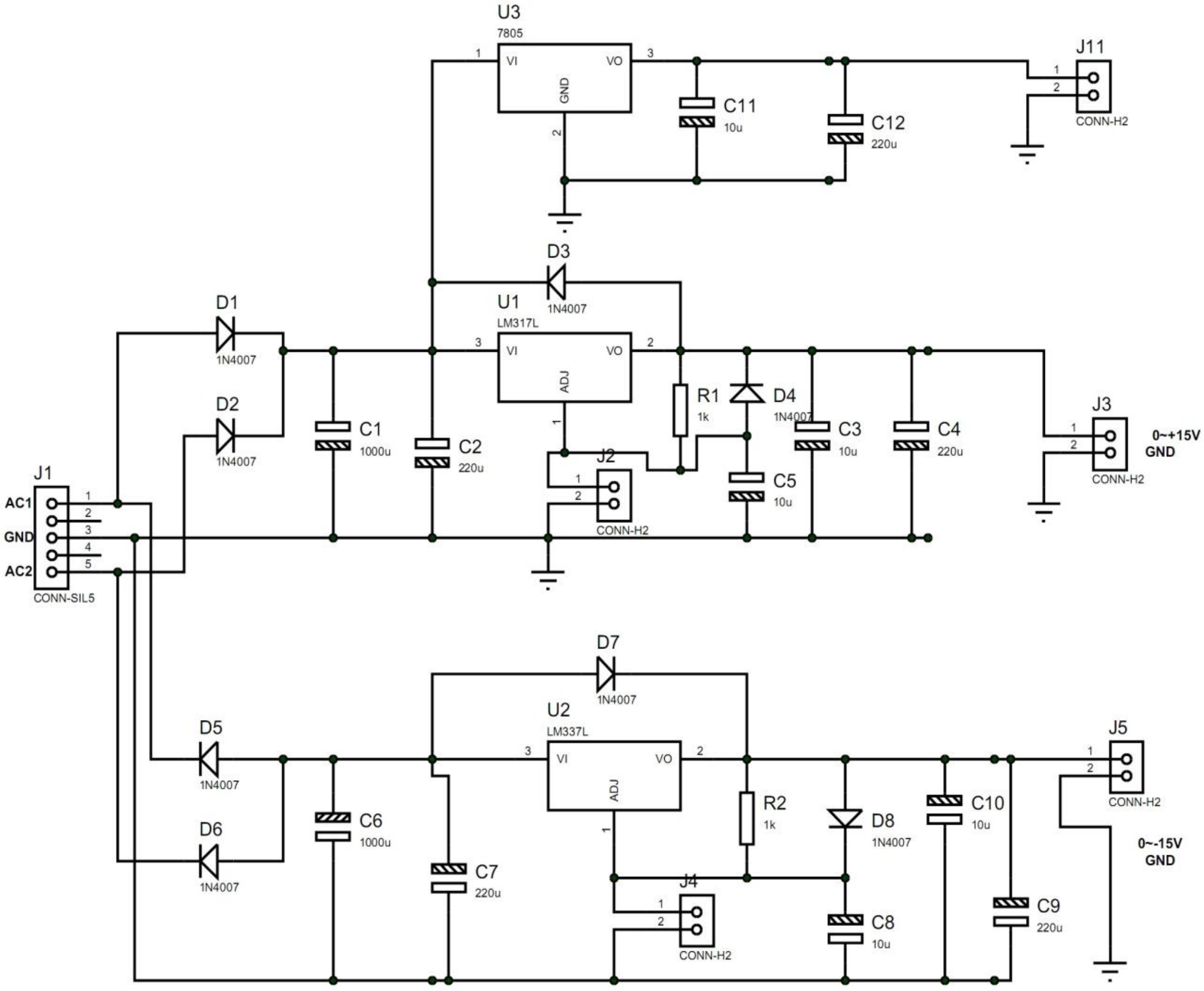


Fig. A.1: Circuit Diagram of the power supply design

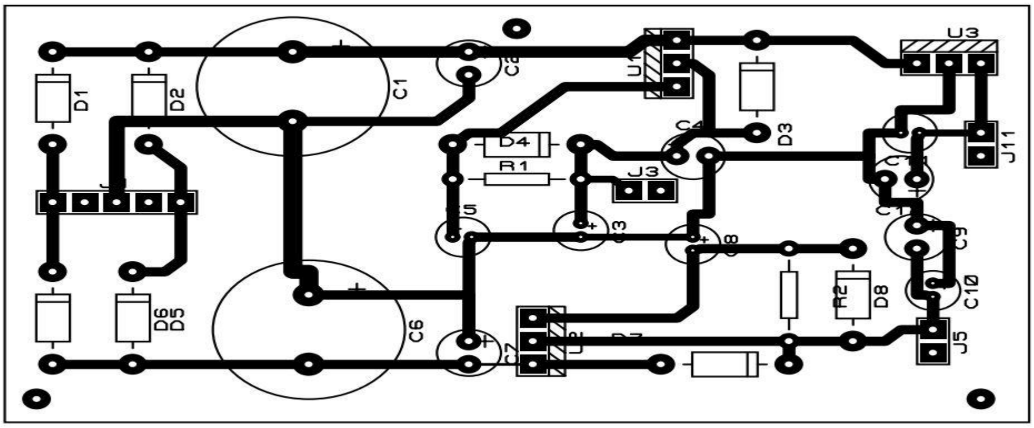


Fig. A.2: PCB design of the power supply

A.2 Ultrasound Probe

The transducer probe is an important part of the ultrasound machine. The transducer probe makes the sound waves and receives the echoes. It is, so to speak, the mouth and ears of the ultrasound machine. The transducer probe generates and receives sound waves using a principle called the piezoelectric (pressure electricity) effect, which was discovered by Pierre and Jacques Curie in 1880. In the probe, there are one or more quartz crystals called piezoelectric crystals. When an electric current is applied to these crystals, they change shape rapidly. The rapid shape changes, or vibrations, of the crystals produce sound waves that travel outward. Conversely, when sound or pressure waves hit the crystals, they emit electrical currents. Therefore, the same crystals can be used to send and receive sound waves. The probe also has a sound absorbing substance to eliminate back reflections from the probe itself, and an acoustic lens to help focus the emitted sound waves.

A.2.1 Mechanism

The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The latter may either be induced for ions on crystal lattice sites with asymmetric charge surroundings (as in $BaTiO_3$ and PZTs) or may directly be carried by molecular groups (as in cane sugar). The dipole density or polarization (dimensionality [Cm/m^3]) may easily be calculated for crystals by summing up the dipole moments per volume of the crystallographic unit cell. As every dipole is a vector, the dipole density P is also a vector or a directed quantity. Dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned using the process of *poling* (not the same as magnetic poling), a process by which a strong electric field is applied across the material, usually at elevated temperatures. Not all piezoelectric materials can be poled.

Of decisive importance for the piezoelectric effect is the change of polarization P when applying a mechanical stress. This might either be caused by a re-configuration of the dipole-inducing surrounding or by re-orientation of molecular dipole moments under the influence of the external stress. Piezoelectricity may then manifest in a variation of the polarization strength, its direction or both, with the details depending on 1. the orientation of *P* within the crystal, 2. Crystal symmetry and 3. The applied mechanical stress. The change in *P* appears as a variation of surface charge density upon the crystal faces, i.e. as a variation of the electrical field extending between the faces, since the units of surface charge density and polarization are the same, [C/m^2] = [Cm/m^3]. However, piezoelectricity is not caused by a change in charge density on the surface, but by dipole density in the bulk. For example, a 1 cm^3 cube of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12500 V.

Piezoelectric materials also show the opposite effect, called converse piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal.

A.2.2 Mathematical description

Piezoelectricity is the combined effect of the electrical behavior of the material:

$$D = \varepsilon E$$

Where *D* is the electric charge density displacement (electric displacement), ε is permittivity and *E* is electric field strength, and

Hooke's Law:

$$S = sT$$

Where *S* is strain, *s* is compliance and *T* is stress.

These may be combined into so-called *coupled equations*, of which the strain-charge form is:

$$\{S\} = \left[s^E\right]\{T\} + [d^t]\{E\}$$

$$\{D\} = [d]\{T\} + \left[\varepsilon^T\right]\{E\},$$

Where $[d]$ the matrix for the direct is piezoelectric effect and $[d^t]$ is the matrix for the converse piezoelectric effect. The superscript *E* indicates a zero, or constant, electric field; the superscript *T* indicates a zero, or constant, stress field; and the superscript *t* stands for transposition of a matrix.

The strain-charge for a material of the 4mm (C_{4v}) crystal class (such as a poled piezoelectric ceramic such as tetragonal PZT or $BaTiO_3$) as well as the 6mm crystal class may also be written as (ANSI IEEE 176):

$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} = \begin{bmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 \\ s_{21}^E & s_{22}^E & s_{23}^E & 0 & 0 & 0 \\ s_{31}^E & s_{32}^E & s_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{44}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{66}^E = 2\left(s_{11}^E - s_{12}^E\right) \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} + \begin{bmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{32} \\ 0 & 0 & d_{33} \\ 0 & d_{24} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

$$\begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{24} & 0 & 0 \\ d_{31} & d_{32} & d_{33} & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} + \begin{bmatrix} \varepsilon_{11} & 0 & 0 \\ 0 & \varepsilon_{22} & 0 \\ 0 & 0 & \varepsilon_{33} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

Where the first equation represents the relationship for the converse piezoelectric effect and the latter for the direct piezoelectric effect.

Although the above equations are the most used form in literature, some comments about the notation are necessary. Generally *D* and *E* are vectors, that is, Cartesian tensor of rank-1; and permittivity ε is Cartesian tensor of rank 2. Strain and stress are, in principle, also rank-2 tensors. But conventionally, because strain and stress are all symmetric tensors, the subscript of strain and stress can be re-labeled in the following fashion: 11 → 1; 22 → 2; 33 → 3; 23 → 4; 13 → 5; 12 → 6. (Different convention may be used by different authors in literature. Say, some use 12 → 4; 23 → 5; 31 → 6 instead.) That is why *S* and *T* appear to have the "vector form" of 6 components. Consequently, *s* appears to be a 6 by 6 matrix instead of rank-4 tensor. Such a re-labeled notation is often called Voigt notation.

In total, there are 4 piezoelectric coefficients, d_{ij}, e_{ij}, g_{ij}, and h_{ij}defined as follows:

$$d_{ij} = \left(\frac{\partial D_i}{\partial T_j}\right)^E = \left(\frac{\partial S_j}{\partial E_i}\right)^T$$

$$e_{ij} = \left(\frac{\partial D_i}{\partial S_j}\right)^E = -\left(\frac{\partial T_j}{\partial E_i}\right)^S$$

$$g_{ij} = -\left(\frac{\partial E_i}{\partial T_j}\right)^D = \left(\frac{\partial S_j}{\partial D_i}\right)^T$$

$$h_{ij} = -\left(\frac{\partial E_i}{\partial S_j}\right)^D = -\left(\frac{\partial T_j}{\partial D_i}\right)^S$$

Where the first set of 4 terms correspond to the direct piezoelectric effect and the second set of 4 terms correspond to the converse piezoelectric effect. A formalism has been worked out for those piezoelectric crystals, for which the polarization is of the crystal-field induced type, that allows for the calculation of piezoelectrical coefficients $d_{ij}$from electrostatic lattice constants or higher-order Madelung constants.

APPENDIX B

SOFTWARE AND SIMULATIONS

For all our necessary circuit simulation purposes we have used the ISIS Proteus 6 software. Here is some important discussion regarding the software.

B.1 ABOUT ISIS

ISIS has evolved over twelve years' research and development and has been proven by thousands of users worldwide. The strength of its architecture has allowed us to integrate first conventional graph based simulation and now – with PROTEUS VSM – interactive circuit simulation into the design environment. For the first time ever it is possible to draw a complete circuit for a micro-controller based system and then test it interactively, all from within the same piece of software. Meanwhile, ISIS retains a host of features aimed at the PCB designer, so that the same design can be exported for production with ARES or other PCB layout software.

For the educational user and engineering author, ISIS also excels at producing attractive schematics like you see in the magazines. It provides total control of drawing appearance in turns of line widths, fill styles, colors and fonts. In addition, a system of templates allows you to define a 'house style' and to copy the appearance of one drawing to another.

Other general features include:

- Runs on Windows 98/Me/2k/XP and later.
- Automatic wire routing and dot placement/removal.
- Powerful tools for selecting objects and assigning their properties.
- Full support for buses including component pins, inter-sheet terminals, module ports and wires.
- Bill of Materials and Electrical Rules Check reports.
- Netlist outputs to suit all popular PCB layout tools.

B.2 Icon Reference Chart

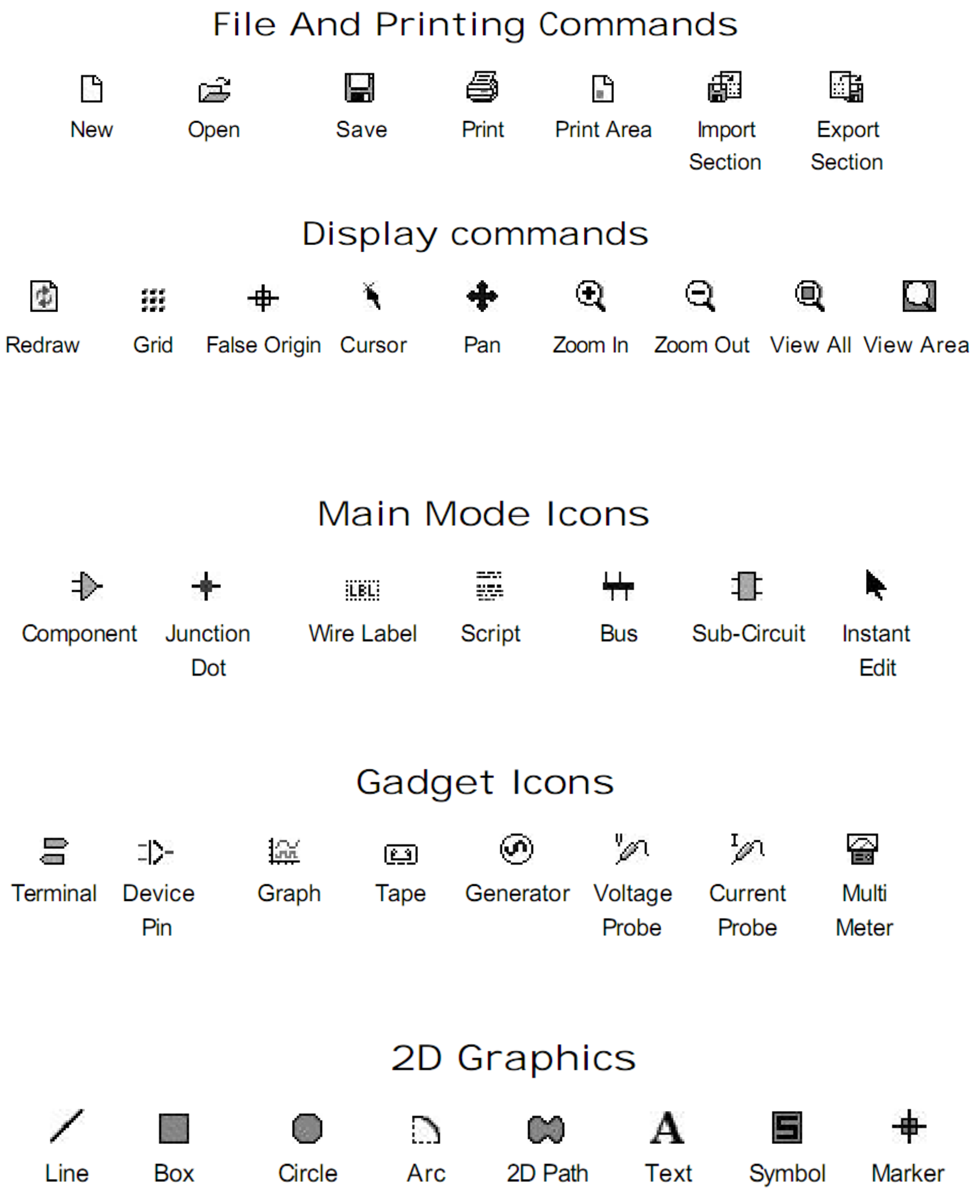


Fig. B.1: Icon Reference Chart

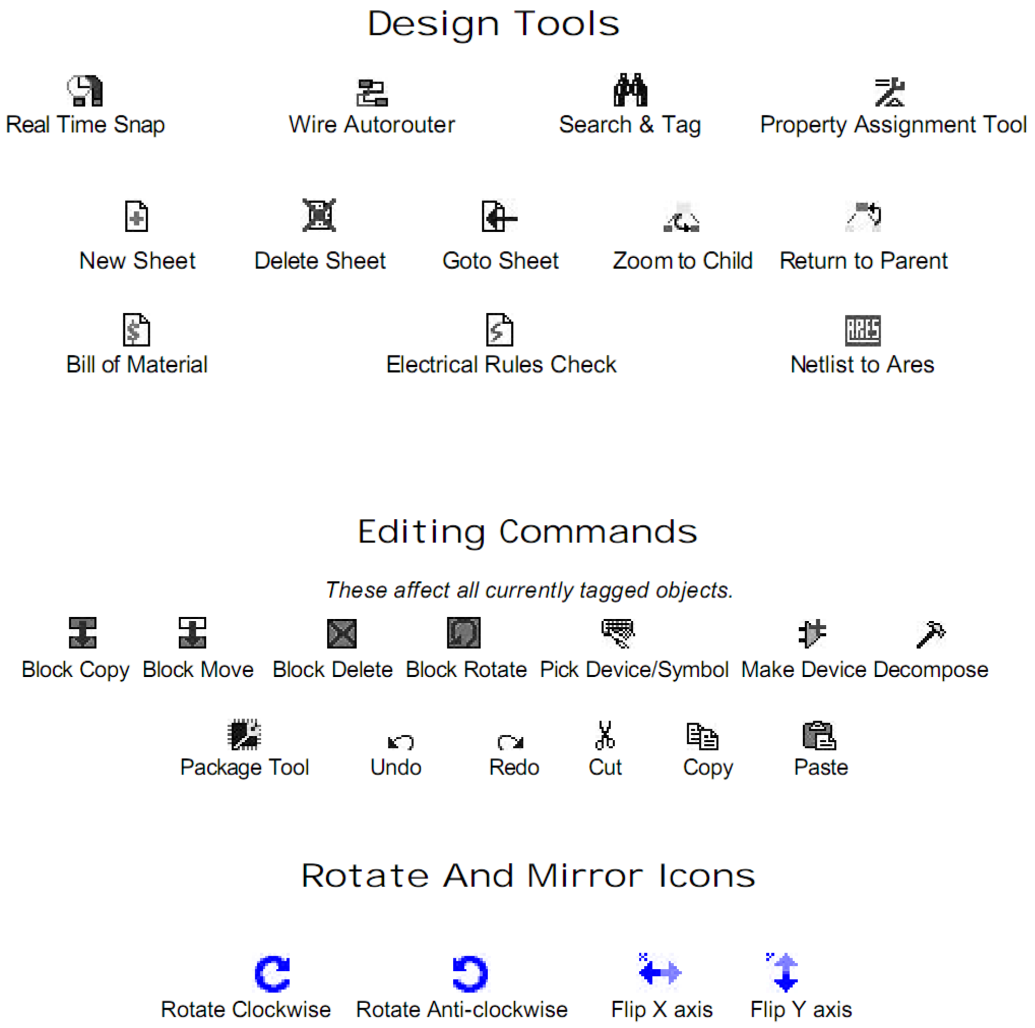


Fig. B.2: Icon Reference Chart

To start the ISIS program, click on the *Start* button and select *Programs*, *Proteus 6 Professional*, and then the *ISIS 6 Professional* option. The ISIS schematic editor will then load and run. Along the top of the screen is the Menu Bar.

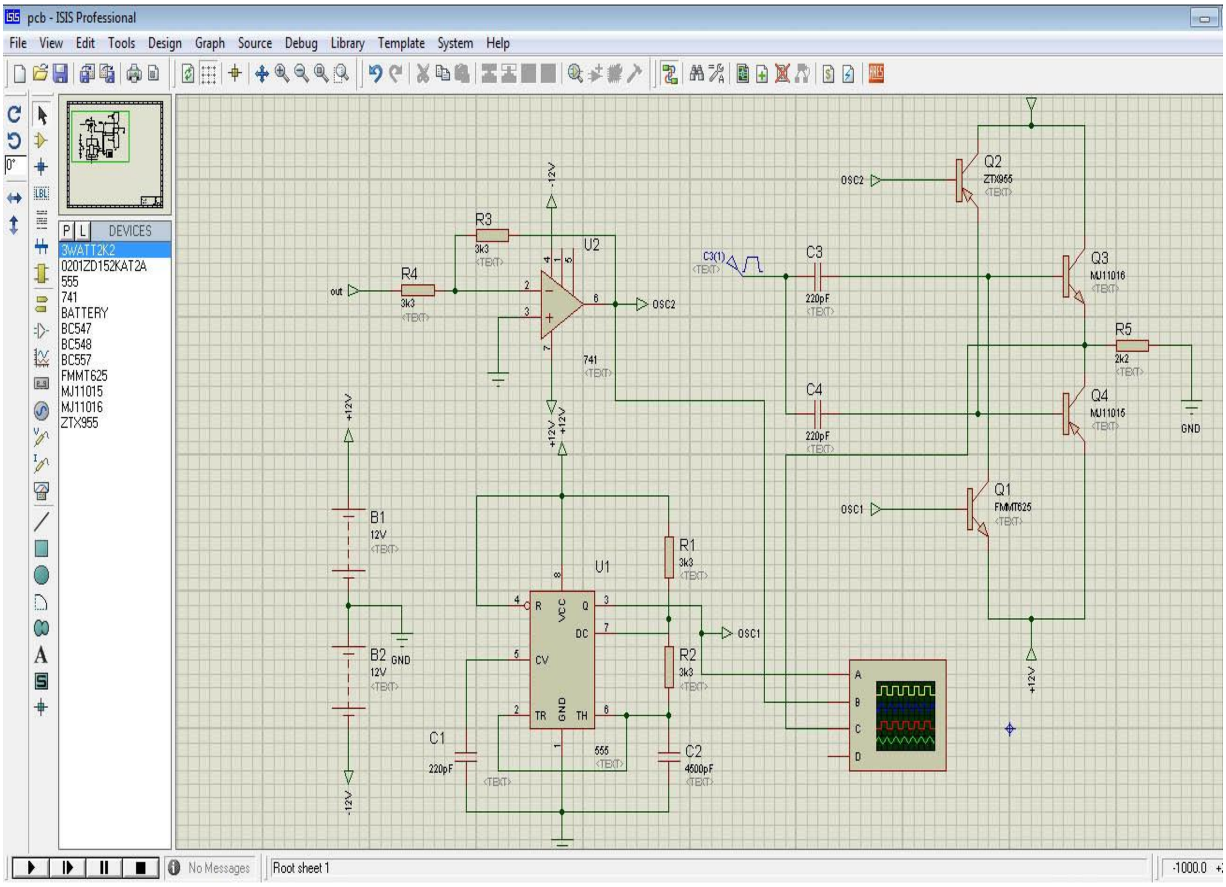
The largest area of the screen is called the *Editing Window*, and it acts as a window on the drawing. The smaller area at the top right of the screen is called the *Overview Window*. In normal use the *Overview Window* displays, as its name suggests, an overview of the entire drawing - the blue box shows the edge of the current sheet and the green box the area of the sheet currently displayed in the *Editing Window*. However, when a new object is selected from the *Object Selector* the *Overview Window* is used to preview the selected object - this is discussed later.

We can adjust the area of the drawing displayed in the *Editing Window* in a number of ways: To simply 'pan' the *Editing Window* up, down, left or right, position the mouse pointer over the desired part of the *Editing Window* and press the F5 key. Hold the SHIFT key down and bump the mouse against the edges of the Editing Window to pan up, down, left or right. We call this *Shift Pan***.**

ISIS has a very powerful feature called *Real Time Annotation* which can be found on the *Tools Menu* and is enabled by default. Full information can be found on page 12 but basically, when enabled, this feature annotates components as you place them on the schematic. If you zoom in on any resistor you have placed you will see that ISIS has labeled it with both the default value (RES) and a unique reference. To edit/input part references and values click left on the *Instant Edit* icon and then click left on the object you wish to edit. Do the resistors first, entering R1, 1k and R2, 1k as appropriate. Now do the op-amp and the two terminals. To move the 'U1' and the '741' labels to correspond with the diagram, press F2 to reduce the snapping grid to 50th (it starts off at 100th) and then tag the op-amp. Now point at the label

Begin by drawing the device body of the new device. Select the *Box* icon. We will see that the *Object Selector* on the right displays a list of *Graphics Styles*. A graphics style determines how the graphic we are about to draw will appear in terms of line colour, line thickness, fill style, fill colour, etc. Each style listed is a different set of such attributes and define the way different parts of the schematic appear.

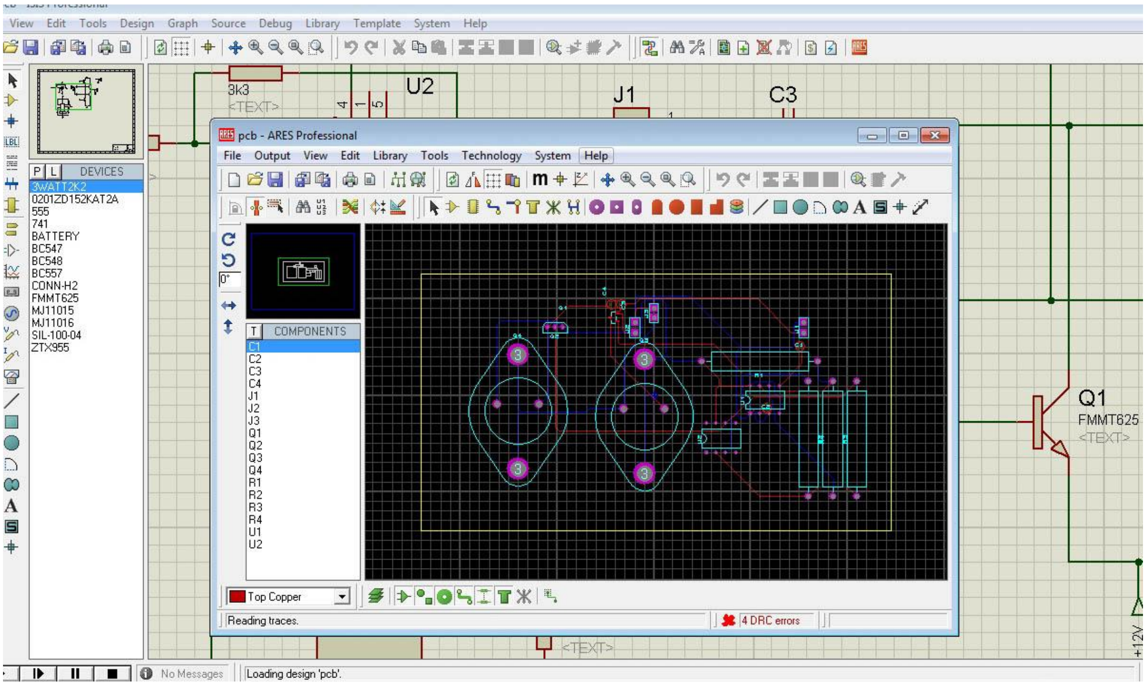
ISIS supports a powerful graphics style system of local and global styles and the ability of local styles to ‘follow’ or ‘track’ global styles that allows you to easily and flexibly customize the appearance of your schematic. See the section *Graphics And Text Styles* on page 49 for a complete explanation of how styles work and how they are used.



No Messages

Root sheet 1

Fig. B.3: Total Experimental Setup for simulation



Reading traces.

4 DRC errors

No Messages

Loading design 'pcb'.

Fig. B.4: Creating PCB for the citcuit

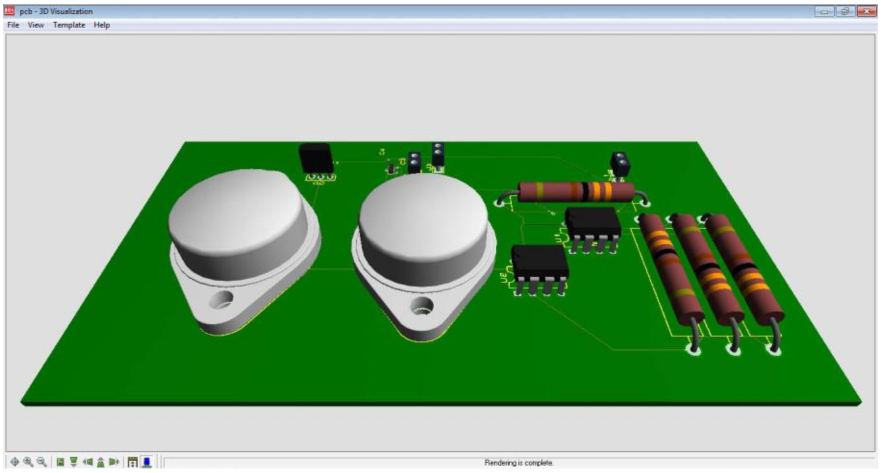


Fig. B.5: 3D visualization of PCB 1

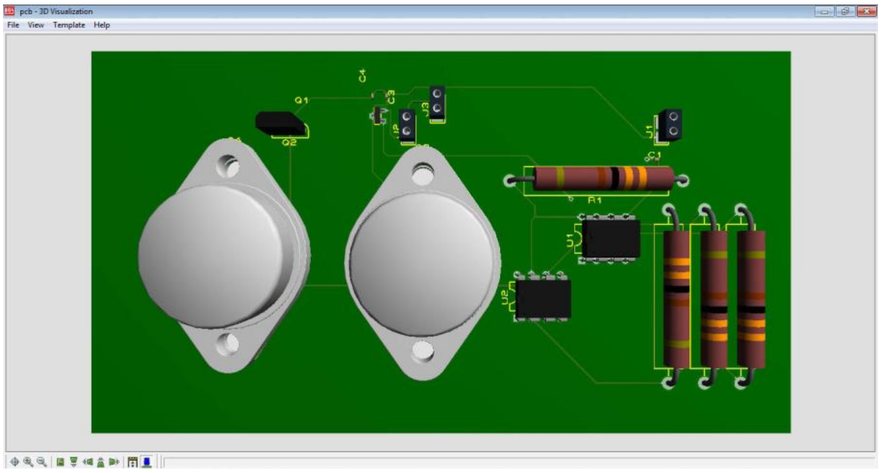


Fig. B.6: 3D visualization of PCB 2

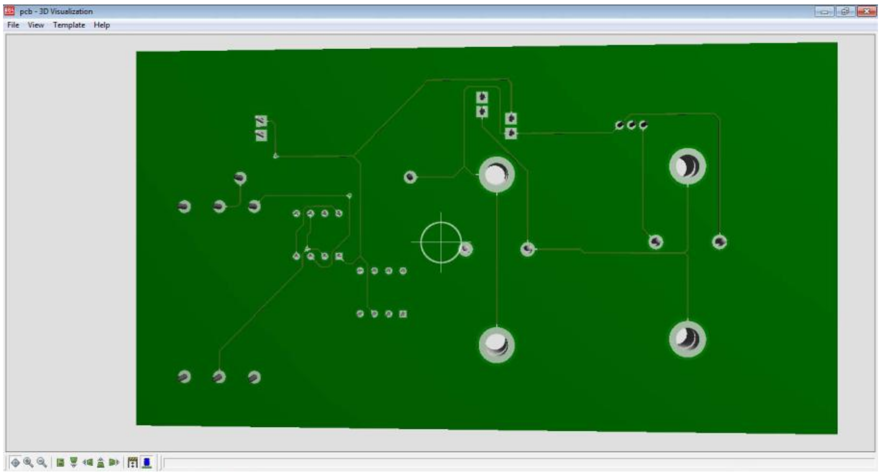


Fig. B.7: 3D visualization of PCB 3

APPENDIX C

SPECIFICATIONS AND DATA SHEETS

TECHNICAL DATA OF MAX 038, HIGH-FREQUENCY WAVEFORM GEN.; TOTAL PAGE-4

NAME OF MANUFACTURER: MAXIM

General Description

The MAX038 is a high-frequency, precision function generator producing accurate, high-frequency triangle, sawtooth, sine, square, and pulse waveforms with a minimum of external components. The output frequency can be controlled over a frequency range of 0.1Hz to 20MHz by an internal 2.5V bandgap voltage reference and an external resistor and capacitor. The duty cycle can be varied over a wide range by applying a ±2.3V control signal, facilitating pulse-width modulation and the generation of sawtooth waveforms. Frequency modulation and frequency sweeping are achieved in the same way. The duty cycle and frequency controls are independent.

Sine, square, or triangle waveforms can be selected at the output by setting the appropriate code at two TTL-compatible select pins. The output signal for all waveforms is a $2V_{P\text{-}P}$ signal that is symmetrical around ground. The low-impedance output can drive up to ±20mA.

The TTL-compatible SYNC output from the internal oscillator maintains a 50% duty cycle—regardless of the duty cycle of the other waveforms—to synchronize other devices in the system. The internal oscillator can be synchronized to an external TTL clock connected to PDI.

Features

- **0.1Hz to 20MHz Operating Frequency Range**
- **Triangle, Sawtooth, Sine, Square, and Pulse Waveforms**
- **Independent Frequency and Duty-Cycle Adjustments**
- **350 to 1 Frequency Sweep Range**
- **15% to 85% Variable Duty Cycle**
- **Low-Impedance Output Buffer: 0.1Ω**
- **Low-Distortion Sine Wave: 0.75%**
- **Low 200ppm/°C Temperature Drift**

Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX038CPP	0°C to +70°C	20 Plastic DIP
MAX038CWP	0°C to +70°C	20 SO
MAX038C/D*	0°C to +70°C	Dice*
MAX038EPP*	-40°C to +85°C	20 Plastic DIP
MAX038EWP*	-40°C to +85°C	20 SO

**Contact factory.*

Applications

Precision Function Generators

Voltage-Controlled Oscillators

Frequency Modulators

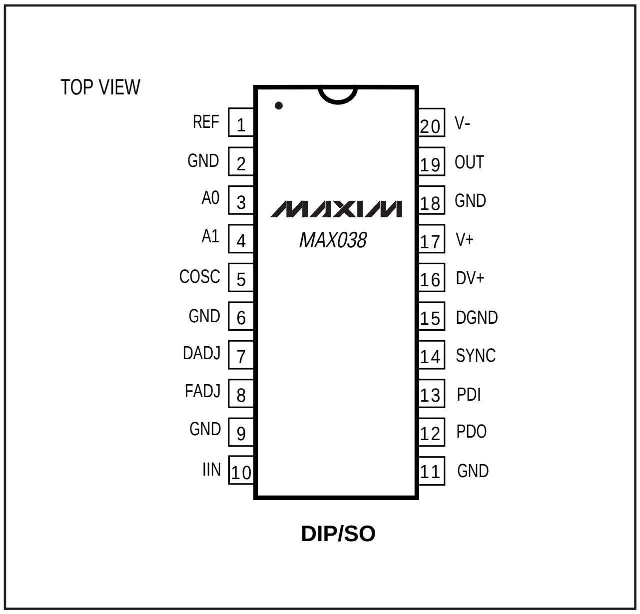
Pulse-Width Modulators

Phase-Locked Loops

Frequency Synthesizer

FSK Generator—Sine and Square Waves

Pin Configuration



ABSOLUTE MAXIMUM RATINGS

V+ to GND ....-0.3V to +6V
DV+ to DGND ....-0.3V to +6V
V- to GND ....+0.3V to -6V
Pin Voltages
  IIN, FADJ, DADJ, PDO ....(V- - 0.3V) to (V+ + 0.3V)
  COSC ....+0.3V to V-
  A0, A1, PDI, SYNC, REF...................................-0.3V to V+
  GND to DGND ....±0.3V
Maximum Current into Any Pin ....±50mA
OUT, REF Short-Circuit Duration to GND, V+, V- 30sec

Continuous Power Dissipation (T_A = +70°C)
  Plastic DIP (derate 11.11mW/°C above +70°C) 889mW
  SO (derate 10.00mW/°C above +70°C).......................800mW
  CERDIP (derate 11.11mW/°C above +70°C)...............889mW
Operating Temperature Ranges
  MAX038C_ _ ....0°C to +70°C
  MAX038E_ _ ....-40°C to +85°C
Maximum Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +150°C
Lead Temperature (soldering, 10s) ....+300°C

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

ELECTRICAL CHARACTERISTICS

(Circuit of Figure 1, GND = DGND = 0V, V+ = DV+ = 5V, V- = -5V, V_{DADJ} = V_{FADJ} = V_{PDI} = V_{PDO} = 0V, C_F = 100pF, R_{IN} = 25kΩ, R_L = 1kΩ, C_L = 20pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
FREQUENCY CHARACTERISTICS						
Maximum Operating Frequency	F_O	15pCF ≤ 15pF, I_{IN} = 500µA	20.0	40.0		MHz
Frequency Programming Current	I_{IN}	V_{FADJ} = 0V	2.50		750	µA
		V_{FADJ} = -3V	1.25		375	
IIN Offset Voltage	V_{IN}			±1.0	±2.0	mV
Frequency Temperature Coefficient	ΔF_O/°C	V_{FADJ} = 0V		600		ppm/°C
	F_O/°C	V_{FADJ} = -3V		200		
Frequency Power-Supply Rejection	$\frac{(\Delta F_O/F_O)}{\Delta V+}$	V- = -5V, V+ = 4.75V to 5.25V		±0.4	±2.00	%/V
	$\frac{(\Delta F_O/F_O)}{\Delta V-}$	V+ = 5V, V- = -4.75V to -5.25V		±0.2	±1.00	
OUTPUT AMPLIFIER (applies to all waveforms)						
Output Peak-to-Peak Symmetry	V_{OUT}			±4		mV
Output Resistance	R_{OUT}			0.1	0.2	Ω
Output Short-Circuit Current	I_{OUT}	Short circuit to GND		40		mA
SQUARE-WAVE OUTPUT (R_L = 100Ω)						
Amplitude	V_{OUT}		1.9	2.0	2.1	V_{P-P}
Rise Time	t_R	10% to 90%		12		ns
Fall Time	t_F	90% to 10%		12		ns
Duty Cycle	dc	V_{DADJ} = 0V, dc = t_{ON}/t x 100%	47	50	53	%
TRIANGLE-WAVE OUTPUT (R_L = 100Ω)						
Amplitude	V_{OUT}		1.9	2.0	2.1	V_{P-P}
Nonlinearity		F_O = 100kHz, 5% to 95%		0.5		%
Duty Cycle	dc	V_{DADJ} = 0V (Note 1)	47	50	53	%
SINE-WAVE OUTPUT (R_L = 100Ω)						
Amplitude	V_{OUT}		1.9	2.0	2.1	V_{P-P}
Total Harmonic Distortion	THD	Duty cycle adjusted to 50%		0.75		%
		Duty cycle unadjusted		1.50		

ELECTRICAL CHARACTERISTICS (continued)

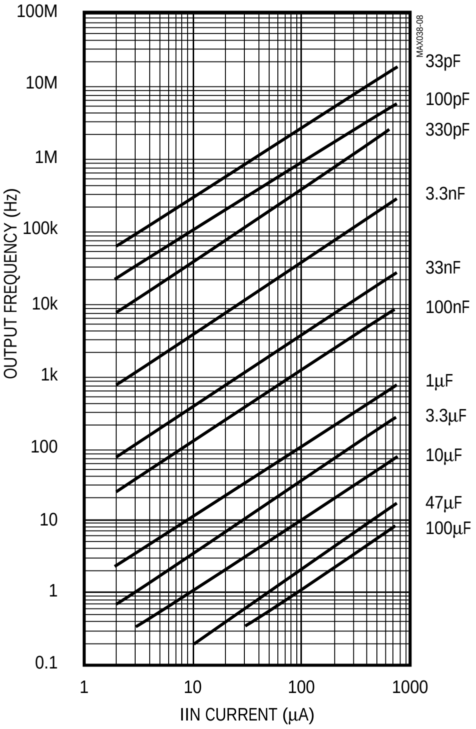
(Circuit of Figure 1, GND = DGND = 0V, V+ = DV+ = 5V, V- = -5V, V_{DADJ} = V_{FADJ} = V_{PDI} = V_{PDO} = 0V, C_F = 100pF, R_{IN} = 25kΩ, R_L = 1kΩ, C_L = 20pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SYNC OUTPUT						
Output Low Voltage	V_{OL}	I_{SINK} = 3.2mA		0.3	0.4	V
Output High Voltage	V_{OH}	I_{SOURCE} = 400µA	2.8	3.5		V
Rise Time	t_R	10% to 90%, R_L = 3kΩ, C_L = 15pF		10		ns
Fall Time	t_F	90% to 10%, R_L = 3kΩ, C_L = 15pF		10		ns
Duty Cycle	dc_{SYNC}			50		%
DUTY-CYCLE ADJUSTMENT (DADJ)						
DADJ Input Current	I_{DADJ}		190	250	320	µA
DADJ Voltage Range	V_{DADJ}			±2.3		V
Duty-Cycle Adjustment Range	dc	-2.3V ≤ V_{DADJ} ≤ 2.3V	15		85	%
DADJ Nonlinearity	dc/V_{FADJ}	-2V ≤ V_{DADJ} ≤ 2V		2	4	%
Change in Output Frequency with DADJ	F_o/V_{DADJ}	-2V ≤ V_{DADJ} ≤ 2V		±2.5	±8	%
Maximum DADJ Modulating Frequency	F_{DC}			2		MHz
FREQUENCY ADJUSTMENT (FADJ)						
FADJ Input Current	I_{FADJ}		190	250	320	µA
FADJ Voltage Range	V_{FADJ}			±2.4		V
Frequency Sweep Range	F_o	-2.4V ≤ V_{FADJ} ≤ 2.4V		±70		%
FM Nonlinearity with FADJ	F_o/V_{FADJ}	-2V ≤ V_{FADJ} ≤ 2V		±0.2		%
Change in Duty Cycle with FADJ	dc/V_{FADJ}	-2V ≤ V_{FADJ} ≤ 2V		±2		%
Maximum FADJ Modulating Frequency	F_F			2		MHz
VOLTAGE REFERENCE						
Output Voltage	V_{REF}	I_{REF} = 0	2.48	2.50	2.52	V
Temperature Coefficient	V_{REF}/°C			20		ppm/°C
Load Regulation	V_{REF}/I_{REF}	0mA ≤ I_{REF} ≤ 4mA (source)		1	2	mV/mA
		-100µA ≤ I_{REF} ≤ 0µA (sink)		1	4	
Line Regulation	V_{REF}/V+	4.75V ≤ V+ ≤ 5.25V (Note 2)		1	2	mV/V
LOGIC INPUTS (A0, A1, PDI)						
Input Low Voltage	V_{IL}				0.8	V
Input High Voltage	V_{IH}		2.4			V
Input Current (A0, A1)	I_{IL}, I_{IH}	V_{A0}, V_{A1} = V_{IL}, V_{IH}			±5	µA
Input Current (PDI)	I_{IL}, I_{IH}	V_{PDI} = V_{IL}, V_{IH}			±25	µA
POWER SUPPLY						
Positive Supply Voltage	V+		4.75		5.25	V
SYNC Supply Voltage	DV+		4.75		5.25	V
Negative Supply Voltage	V-		-4.75		-5.25	V
Positive Supply Current	I+			35	45	mA
SYNC Supply Current	I_{DV+}			1	2	mA
Negative Supply Current	I-			45	55	mA

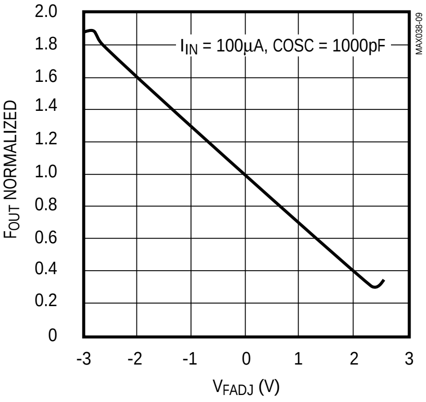
Note 1: Guaranteed by duty-cycle test on square wave.
Note 2: V_{REF} is independent of V-.

Typical Operating Characteristics

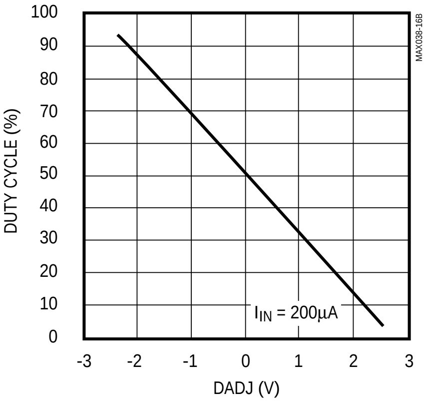
(Circuit of Figure 1, V+ = DV+ = 5V, V- = -5V, $V_{DADJ} = V_{FADJ} = V_{PDI} = V_{PDO}$ = 0V, R_L = 1kΩ, C_L = 20pF, T_A = +25°C, unless otherwise noted.)



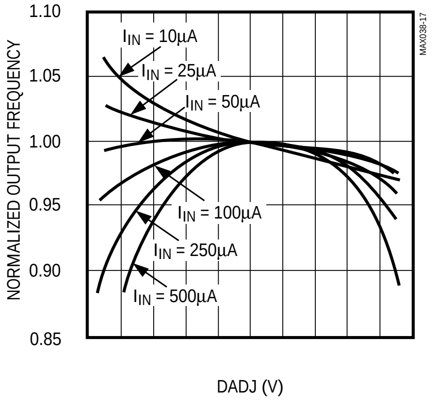
OUTPUT FREQUENCY vs. IIN CURRENT



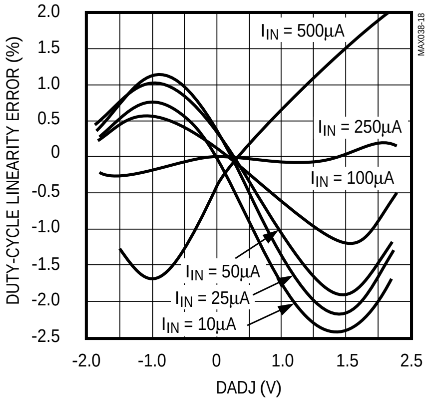
NORMALIZED OUTPUT FREQUENCY vs. FADJ VOLTAGE



DUTY CYCLE vs. DADJ VOLTAGE



NORMALIZED OUTPUT FREQUENCY vs. DADJ VOLTAGE



DUTY-CYCLE LINEARITY vs. DADJ VOLTAGE

Maxim cannot assume responsibility for use of any circuitry other than circuitry entirely embodied in a Maxim product. No circuit patent licenses are implied. Maxim reserves the right to change the circuitry and specifications without notice at any time.

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SEMICONDUCTOR TECHNICAL DATA OF MJ11015 & MJ11016; TOTAL PAGE-4

NAME OF MANUFACTURER: MOTOROLA

PNP
MJ11015
NPN
MJ11016

High-Current Complementary Silicon Transistors

. . . for use as output devices in complementary general purpose amp tions.

- High DC Current Gain — h_{FE} = 1000 (Min) @ I_C – 20 Adc
- Monolithic Construction with Built–in Base Emitter Shunt Resistor
- Junction Temperature to +200°C

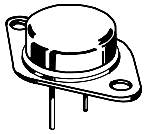
30 AMPERE
DARLINGTON
POWER TRANSISTORS
COMPLEMENTARY
SILICON
60–120 VOLTS
200 WATTS

MAXIMUM RATINGS

Rating	Symbol	MJ11012	MJ11013 MJ11014	MJ11015 MJ11016	Unit
Collector–Emitter Voltage	V_{CEO}	60	90	120	Vdc
Collector–Base Voltage	V_{CB}	60	90	120	Vdc
Emitter–Base Voltage	V_{EB}	5			Vdc
Collector Current	I_C	30			Adc
Base Current	I_B	1			Adc
Total Device Dissipation @T_C = 25°C Derate above 25°C @ T_C = 100°C	P_D	200 1.15			Watts W/°C
Operating Storage Junction Temperature Range	T_J, T_{stg}	–55 to +200			°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.87	°C/W
Maximum Lead Temperature for Soldering Purposes for ≤ 10 Seconds.	T_L	275	°C



CASE 1–07
TO–204AA
(TO–3)

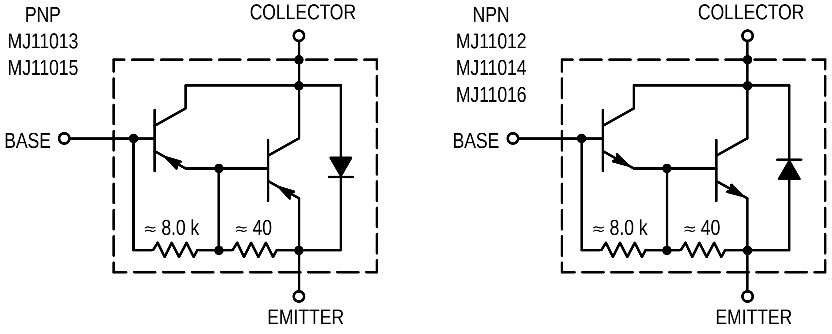


Figure 1. Darlington Circuit Schematic

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted.)

Characteristics		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector–Emitter Breakdown Voltage(1)		$V_{(BR)CEO}$			Vdc
(I_C = 100 mAdc, I_B = 0)	MJ11012		60	—	
	MJ11013, MJ11014		90	—	
	MJ11015, MJ11016		120	—	
Collector–Emitter Leakage Current		I_{CER}			mAdc
(V_{CE} = 60 Vdc, R_{BE} = 1k ohm)	MJ11012		—	1	
(V_{CE} = 90 Vdc, R_{BE} = 1k ohm)	MJ11013, MJ11014		—	1	
(V_{CE} = 120 Vdc, R_{BE} = 1k ohm)	MJ11015, MJ11016		—	1	
(V_{CE} = 60 Vdc, R_{BE} = 1k ohm, T_C = 150°C)	MJ11012		—	5	
(V_{CE} = 90 Vdc, R_{BE} = 1k ohm, T_C = 150°C)	MJ11013, MJ11014		—	5	
(V_{CE} = 120 Vdc, R_{BE} = 1k ohm, T_C = 150°C)	MJ11015, MJ11016		—	5	
Emitter Cutoff Current (V_{BE} = 5 Vdc, I_C = 0)		I_{EBO}	—	5	mAdc
Collector–Emitter Leakage Current (V_{CE} = 50 Vdc, I_B = 0)		I_{CEO}	—	1	mAdc
ON CHARACTERISTICS(1)					
DC Current Gain		h_{FE}			—
(I_C = 20 Adc,V_{CE} = 5 Vdc)			1000	—	
(I_C = 30 Adc, V_{CE} = 5 Vdc)			200	—	
Collector–Emitter Saturation Voltage		$V_{CE(sat)}$			Vdc
(I_C = 20 Adc, I_B = 200 mAdc)			—	3	
(I_C = 30 Adc, I_B = 300 mAdc)			—	4	
Base–Emitter Saturation Voltage		$V_{BE(sat)}$			Vdc
(I_C = 20 A, I_B = 200 mAdc)			—	3.5	
(I_C = 30 A, I_B = 300 mAdc)			—	5	
DYNAMIC CHARACTERISTICS					
Current–Gain Bandwidth Product (I_C = 10 A, V_{CE} = 3 Vdc, f = 1 MHz)		h_{fe}	4	—	MHz

(1) Pulse Test: Pulse Width = 300 µs, Duty Cycle ≤ 2.0%.

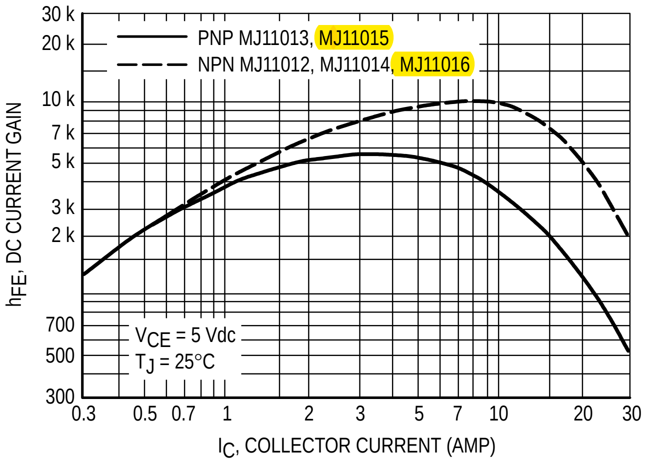


Figure 2. DC Current Gain (1)

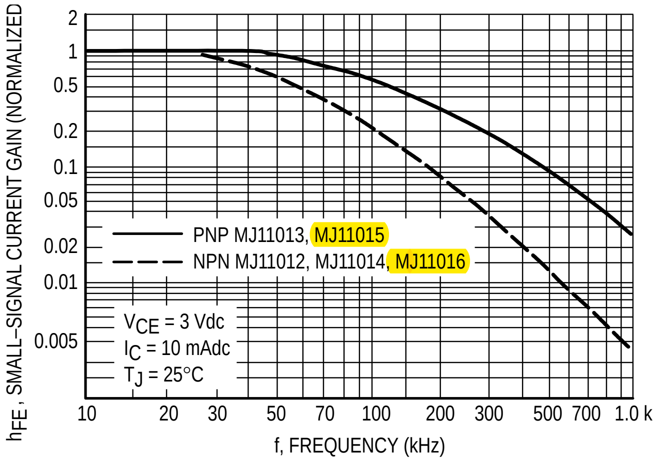


Figure 3. Small–Signal Current Gain

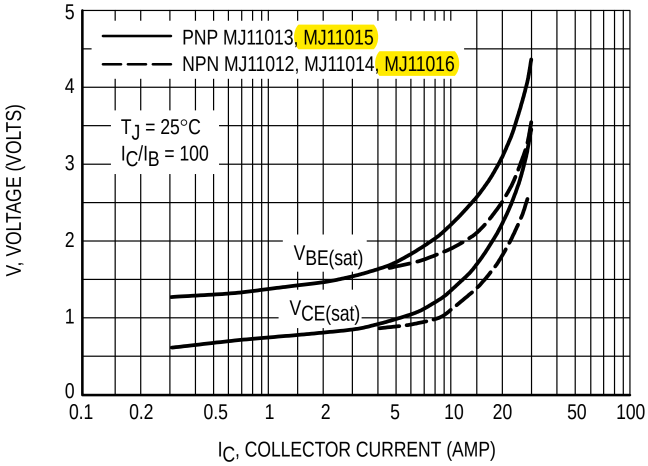


Figure 4. “On” Voltages (1)

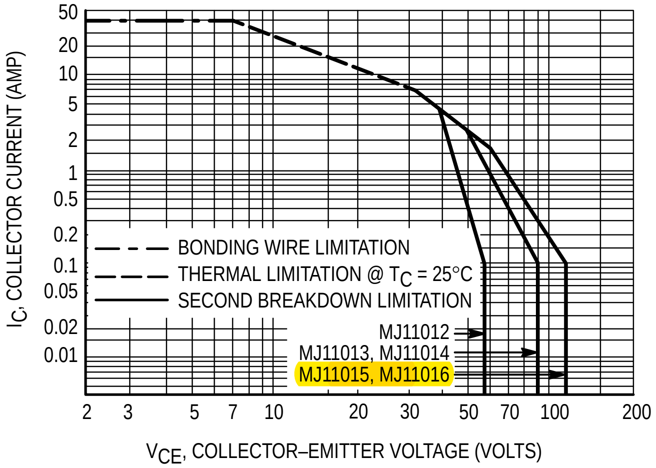
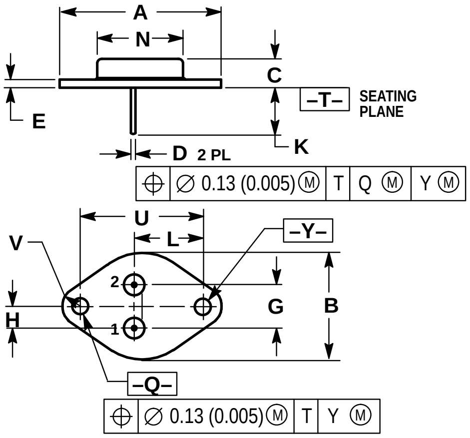


Figure 5. Active Region DC Safe Operating Area

There are two limitations on the power handling ability of a transistor average junction temperature and secondary breakdown. Safe operating area curves indicate $I_C - V_{CE}$ limits of the transistor that must be observed for reliable operations e.g., the transistor must not be subjected to greater dissipation than the curves indicate.

At high case temperatures, thermal limitations will reduce the power that can be handled to values less than the limitations imposed by secondary breakdown.

PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. ALL RULES AND NOTES ASSOCIATED WITH REFERENCED TO–204AA OUTLINE SHALL APPLY.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.550 REF		39.37 REF	
B	—	1.050	—	26.67
C	0.250	0.335	6.35	8.51
D	0.038	0.043	0.97	1.09
E	0.055	0.070	1.40	1.77
G	0.430 BSC		10.92 BSC	
H	0.215 BSC		5.46 BSC	
K	0.440	0.480	11.18	12.19
L	0.665 BSC		16.89 BSC	
N	—	0.830	—	21.08
Q	0.151	0.165	3.84	4.19
U	1.187 BSC		30.15 BSC	
V	0.131	0.188	3.33	4.77

STYLE 1:
PIN 1. BASE
2. EMITTER
CASE: COLLECTOR

CASE 1–07
TO–204AA (TO–3)
ISSUE Z

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TECHNICAL DATA OF LM317L; TOTAL PAGE-5

NAME OF MANUFACTURER: NATIONAL SEMICONDUCTOR

LM317L
3-Terminal Adjustable Regulator

General Description

The LM317L is an adjustable 3-terminal positive voltage regulator capable of supplying 100mA over a 1.2V to 37V output range. It is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM317L is available packaged in a standard TO-92 transistor package which is easy to use.

In addition to higher performance than fixed regulators, the LM317L offers full overload protection. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM317L is useful in a wide variety of other applications. Since the regulator is “floating” and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input-to-output differential is not exceeded.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM317L can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

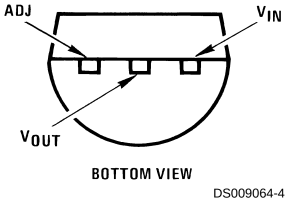
The LM317L is available in a standard TO-92 transistor package, the SO-8 package, and 6-Bump micro SMD package. The LM317L is rated for operation over a −25°C to 125°C range.

Features

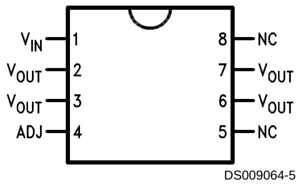
- Adjustable output down to 1.2V
- Guaranteed 100 mA output current
- Line regulation typically 0.01%V
- Load regulation typically 0.1%
- Current limit constant with temperature
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Available in TO-92, SO-8, or 6-Bump micro SMD package
- Output is short circuit protected
- See AN-1112 for micro SMD considerations

Connection Diagrams

TO-92 Plastic package



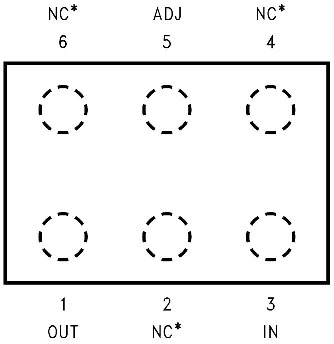
8-Pin SOIC



Top View

Connection Diagrams (Continued)

6-Bump micro SMD

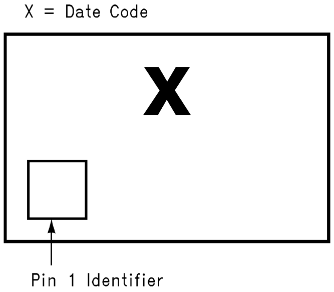


DS009064-49

*NC = Not Internally connected.

Top View
(Bump Side Down)

micro SMD Laser Mark



DS009064-50

Package	Part Number	Package Marking	Media Transport	NSC Drawing
TO-92	LM317LZ	LM317LZ	1.8k Units per Box	Z03A
8-Pin SOIC	LM317LM	LM317LM	Rails	M08A
6-Bump micro SMD	* LM317LIBP	–	250 Units Tape and Reel	BPA06HPA
	* LM317LIBPX	–	3k Units Tape and Reel	

Note: The micro SMD package marking is a single digit manufacturing Date Code only.

Absolute Maximum Ratings (Note 1)

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

Power Dissipation	Internally Limited
Input-Output Voltage Differential	40V
Operating Junction Temperature Range	−40˚C to +125˚C
Storage Temperature	−55˚C to +150˚C
Lead Temperature (Soldering, 4 seconds)	260˚C

Output is Short Circuit Protected

ESD rating to be determined.

Electrical Characteristics (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
Line Regulation	T_J = 25˚C, 3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, I_L ≤ 20mA (Note 3)		0.01	0.04	%/V
Load Regulation	T_J = 25˚C, 5mA ≤ I_{OUT} ≤ I_{MAX}, (Note 3)		0.1	0.5	%
Thermal Regulation	T_J = 25˚C, 10ms Pulse		0.04	0.2	%/W
Adjustment Pin Current			50	100	µA
Adjustment Pin Current Change	5mA ≤ I_L ≤ 100mA 3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, P ≤ 625mW		0.2	5	µA
Reference Voltage	3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, (Note 4) 5mA ≤ I_{OUT} ≤ 100mA, P ≤ 625mW	1.20	1.25	1.30	V
Line Regulation	3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, I_L ≤ 20mA (Note 3)		0.02	0.07	%/V
Load Regulation	5mA ≤ I_{OUT} ≤ 100mA, (Note 3)		0.3	1.5	%
Temperature Stability	T_{MIN} ≤ T_J ≤ T_{Max}		0.65		%
Minimum Load Current	(V_{IN} − V_{OUT}) ≤ 40V		3.5	5	mA
	3V ≤ (V_{IN} − V_{OUT}) ≤ 15V		1.5	2.5	
Current Limit	3V ≤ (V_{IN} − V_{OUT}) ≤ 13V	100	200	300	mA
	(V_{IN} − V_{OUT}) = 40V	25	50	150	mA
Rms Output Noise, % of V_{OUT}	T_J = 25˚C, 10Hz ≤ f ≤ 10kHz		0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120Hz, C_{ADJ} = 0		65		dB
	C_{ADJ} = 10µF	66	80		dB
Long-Term Stability	T_J = 125˚C, 1000 Hours		0.3	1	%
Thermal Resistance Junction to Ambient	Z Package 0.4" Leads		180		˚C/W
	Z Package 0.125 Leads		160		˚C/W
	SO-8 Package		165		˚C/W
	6-Bump micro SMD		290		˚C/W
Thermal Rating of SO Package			165		˚C/W

Note 1: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

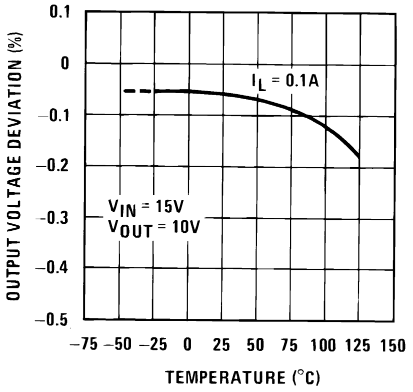
Note 2: Unless otherwise noted, these specifications apply: −25˚C ≤ T_j ≤ 125˚C for the LM317L; V_{IN} − V_{OUT} = 5V and I_{OUT} = 40 mA. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 625 mW. I_{MAX} is 100 mA.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

Note 4: Thermal resistance of the TO-92 package is 180˚C/W junction to ambient with 0.4" leads from a PC board and 160˚C/W junction to ambient with 0.125" lead length to PC board.

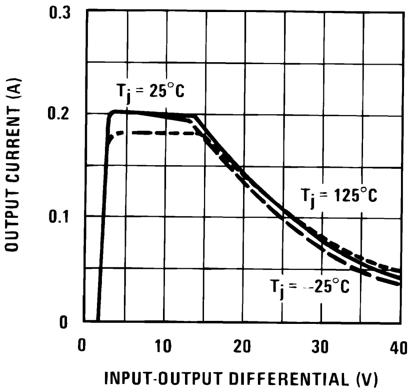
Typical Performance Characteristics (Output capacitor = 0µF unless otherwise noted.)

Load Regulation



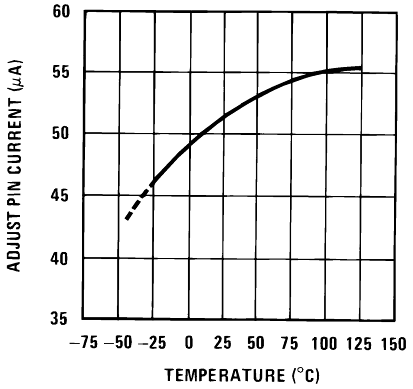
DS009064-34

Current Limit



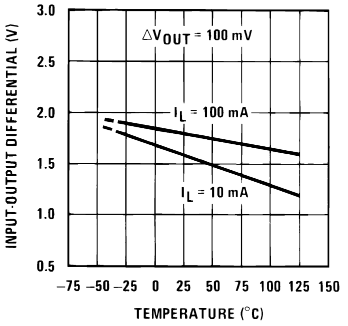
DS009064-35

Adjustment Current



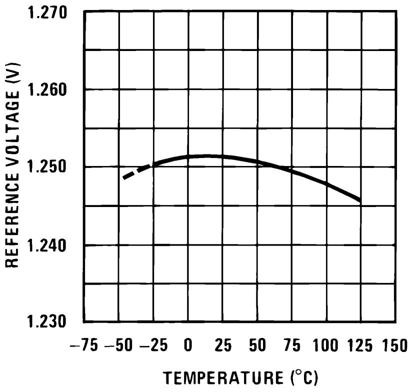
DS009064-36

Dropout Voltage



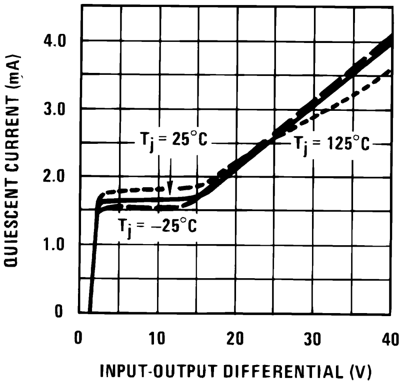
DS009064-37

Reference Voltage Temperature Stability



DS009064-38

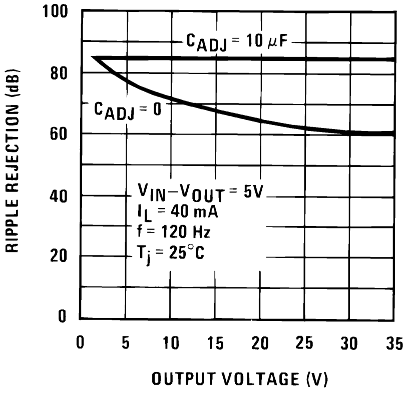
Minimum Operating Current



DS009064-39

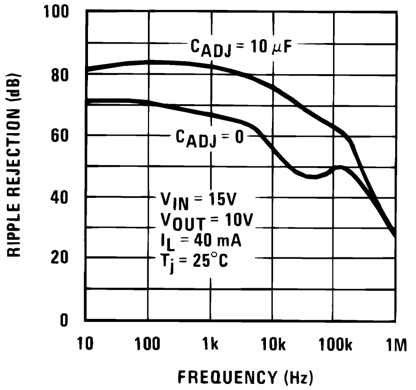
Typical Performance Characteristics (Output capacitor = 0µF unless otherwise noted.) (Continued)

Ripple Rejection



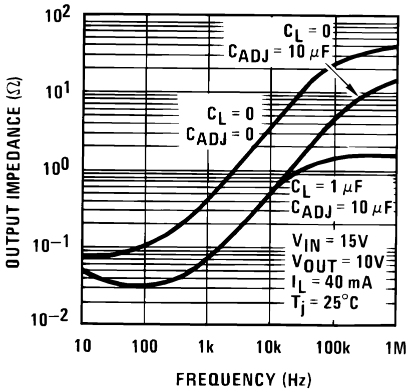
DS009064-40

Ripple Rejection



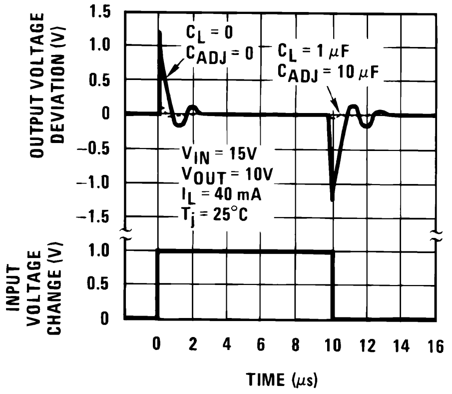
DS009064-41

Output Impedance



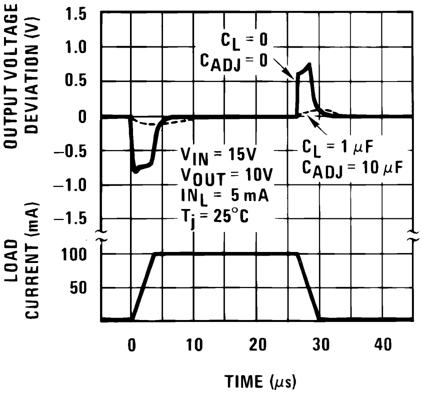
DS009064-42

Line Transient Response



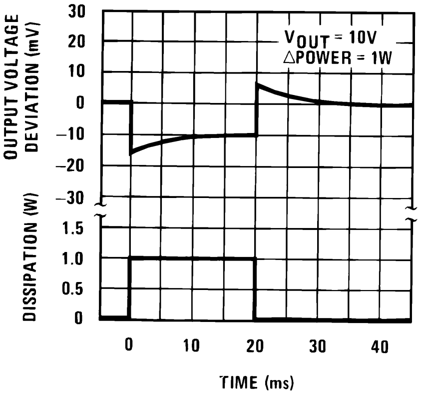
DS009064-43

Load Transient Response



DS009064-44

Thermal Regulation



DS009064-45

TECHNICAL DATA OF LM337L; TOTAL PAGE-3

NAME OF MANUFACTURER: NATIONAL SEMICONDUCTOR

LM337L

3-Terminal Adjustable Regulator

General Description

The LM337L is an adjustable 3-terminal negative voltage regulator capable of supplying 100mA over a 1.2V to 37V output range. It is exceptionally easy to use and requires only two external resistors to set the output voltage. Furthermore, both line and load regulation are better than standard fixed regulators. Also, the LM337L is packaged in a standard TO-92 transistor package which is easy to use.

In addition to higher performance than fixed regulators, the LM337L offers full overload protection. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, only a single 1µF solid tantalum output capacitor is needed unless the device is situated more than 6 inches from the input filter capacitors, in which case an input bypass is needed. A larger output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM337L is useful in a wide variety of other applications. Since the regulator is “floating” and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input-to-output differential is not exceeded.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM337L can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

The LM337L is available in a standard TO-92 transistor package, SO-8 surface mount package, and in our new 12 mil diameter bump micro SMD package. The LM337L is rated for operation over a −25˚C to +125˚C range.

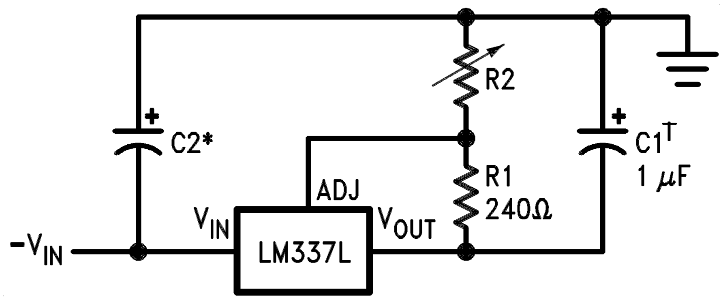
For applications requiring greater output current in excess of 0.5A and 1.5A, see LM137 series data sheets. For the positive complement, see series LM117 and LM317L data sheets.

Features

- Adjustable output down to 1.2V
- Guaranteed 100mA output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short circuit protected
- Available in the 6-Bump micro SMD package
- See AN-1112 for micro SMD considerations

Typical Application

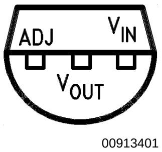
1.2V-25V Adjustable Regulator



00913403

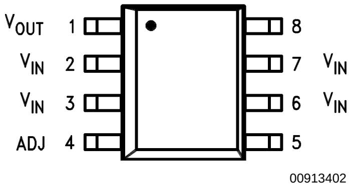
Connection Diagrams

3-Pin TO92



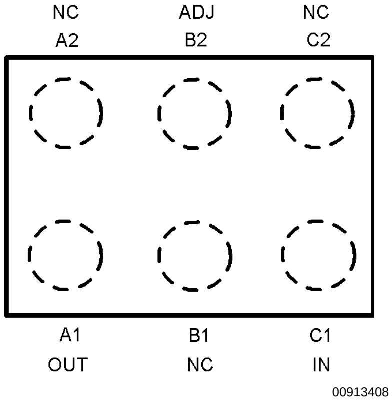
Bottom View

8-Pin SOIC

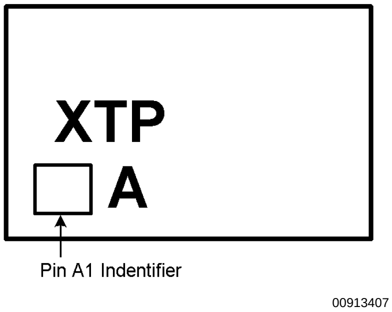


Top View

6-Bump micro SMD



micro SMD Laser mark



Ordering Information

Package	Part Number	Package Marking	Transport Media	NSC Drawing
3-Pin TO92	LM337LZ	LM337LZ	1800 per Bag	Z03A
8-Pin SOIC	LM337LM	LM337LM	Rails	M08A
	LM337LMX		2.5k Units Tape and Reel	
6-Bump micro SMD	LM337LBL	PA	250 Units Tape and Reel	BLA06FNB
	LM337LBLX		3k Units Tape and Reel	

Absolute Maximum Ratings (Note 1)

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

Power Dissipation	Internally Limited
Input–Output Voltage Differential	40V
Operating Junction Temperature Range	−25˚C to +125˚C
Storage Temperature	−55˚C to +150˚C
Lead Temperature (Soldering, 10 sec.)	300˚C
Plastic Package (Soldering 4 sec.)	260˚C
ESD Rating	1.5kV (Note 5)

Electrical Characteristics (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
Line Regulation	T_A = 25˚C, 3V ≤ $\lvert V_{IN} - V_{OUT}\rvert$ ≤ 40V, (Note 3)		0.01	0.04	%/V
Load Regulation	T_A = 25˚C, 5mA ≤ I_{OUT} ≤ I_{MAX}, (Note 3)		0.1	0.5	%
Thermal Regulation	T_A = 25˚C, 10ms Pulse		0.04	0.2	%/W
Adjustment Pin Current			50	100	µA
Adjustment Pin Current Change	5mA ≤ I_L ≤ 100mA 3V ≤ $\lvert V_{IN} - V_{OUT}\rvert$ ≤ 40V		0.2	5	µA
Reference Voltage	3V ≤ $\lvert V_{IN} - V_{OUT}\rvert$ ≤ 40V, (Note 4) 10mA ≤ I_{OUT} ≤ 100mA, P ≤ 625mW	1.20	1.25	1.30	V
Line Regulation	3V ≤ $\lvert V_{IN} - V_{OUT}\rvert$ ≤ 40V, (Note 3)		0.02	0.07	%/V
Load Regulation	5mA ≤ I_{OUT} ≤ 100mA, (Note 3)		0.3	1.5	%
Temperature Stability	$T_{MIN} \le T_j \le T_{MAX}$		0.65		%
Minimum Load Current	$\lvert V_{IN} - V_{OUT}\rvert$ ≤ 40V		3.5	5	mA
	3V ≤ $\lvert V_{IN} - V_{OUT}\rvert$ ≤ 15V		2.2	3.5	mA
Current Limit	3V ≤ $\lvert V_{IN} - V_{OUT}\rvert$ ≤ 13V	100	200	320	mA
	$\lvert V_{IN} - V_{OUT}\rvert$ = 40V	25	50	120	mA
Rms Output Noise, % of V_{OUT}	T_A = 25˚C, 10Hz ≤ f ≤ 10kHz		0.003		%
Ripple Rejection Ratio	V_{OUT} = −10V, F = 120 Hz, C_{ADJ} = 0		65		dB
	C_{ADJ} = 10µF	66	80		dB
Long-Term Stability	T_A = 125˚C		0.3	1	%

Note 1: “Absolute Maximum Ratings” indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Note 2: Unless otherwise specified, these specifications apply −25˚C ≤ T_J ≤ + 125˚C for the LM337L; $\lvert V_{IN} - V_{OUT}\rvert$ = 5V and I_{OUT} = 40mA. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 625 mW. I_{MAX} is 100mA.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

Note 4: Thermal resistance of the TO-92 package is 180˚C/W junction to ambient with 0.4" leads from a PC board and 160˚C/W junction to ambient with 0.125" lead length to PC board. The M package θ_{JA} is 180˚C/W in still air. The 6-Bump micro SMD package θ_{JA} is 290˚C/W in still air.

Note 5: Human body model, 1.5kΩ in series with 100pF.

SEMICONDUCTOR TECHNICAL DATA OF KA7805; TOTAL PAGE-3

NAME OF MANUFACTURER: FAIRCHILD SEMICONDUCTOR CORP.

KA78**05**

3-Terminal 1A Positive Voltage Regulator

Features

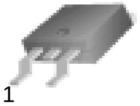
- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The KA7805 series of three-terminal positive regulator are available in the TO-220/D-PAK 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.

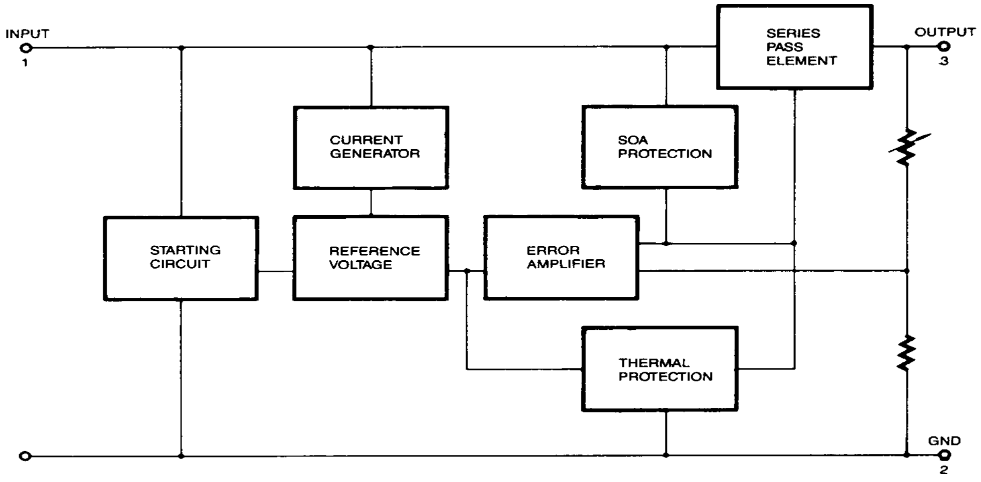
TO-220

D-PAK



1. Input 2. GND 3. Output

Internal Block Digram



Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (KA78XX/A/R)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (KA7805)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =10V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	µV/V_O
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_o due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Typical Perfomance Characteristics

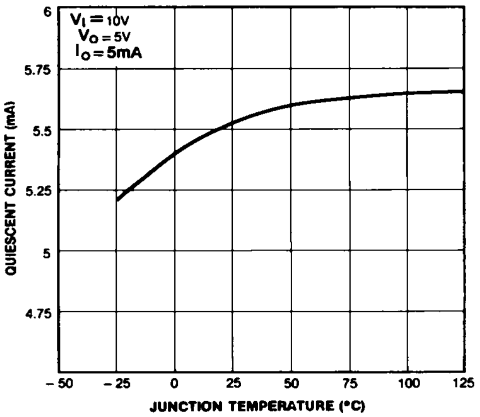


Figure 1. Quiescent Current

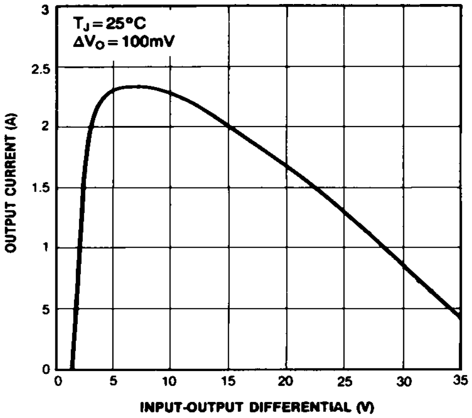


Figure 2. Peak Output Current

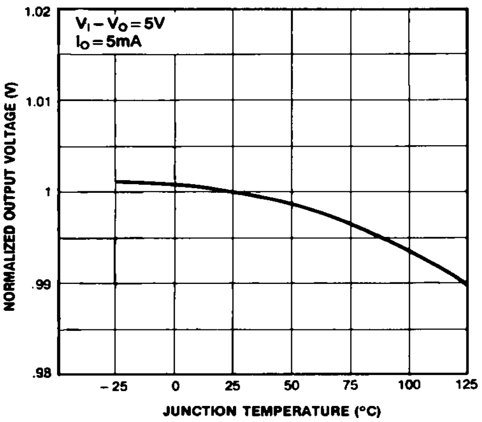


Figure 3. Output Voltage

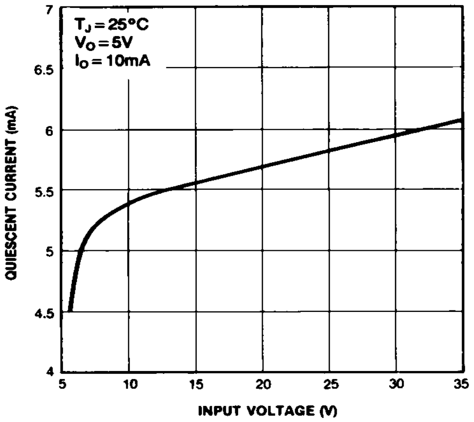


Figure 4. Quiescent Current

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TECHNICAL DATA OF NE555; TOTAL PAGE-3

NAME OF MANUFACTURER: PHILIPS SEMICONDUCTOR

DESCRIPTION

The 555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays, or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200 mA.

FEATURES

- Turn-off time less than 2 µs
- Max. operating frequency greater than 500 kHz
- Timing from microseconds to hours
- Operates in both astable and monostable modes
- High output current
- Adjustable duty cycle
- TTL compatible
- Temperature stability of 0.005% per °C

APPLICATIONS

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation

PIN CONFIGURATION

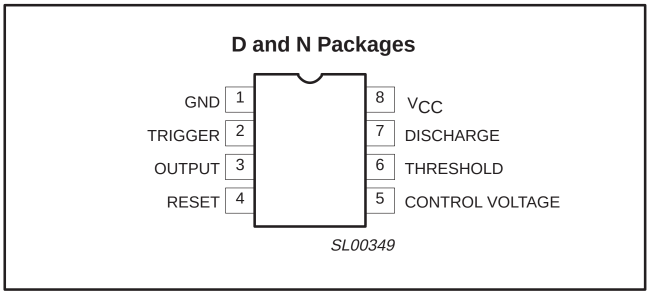


Figure 1. Pin configuration

BLOCK DIAGRAM

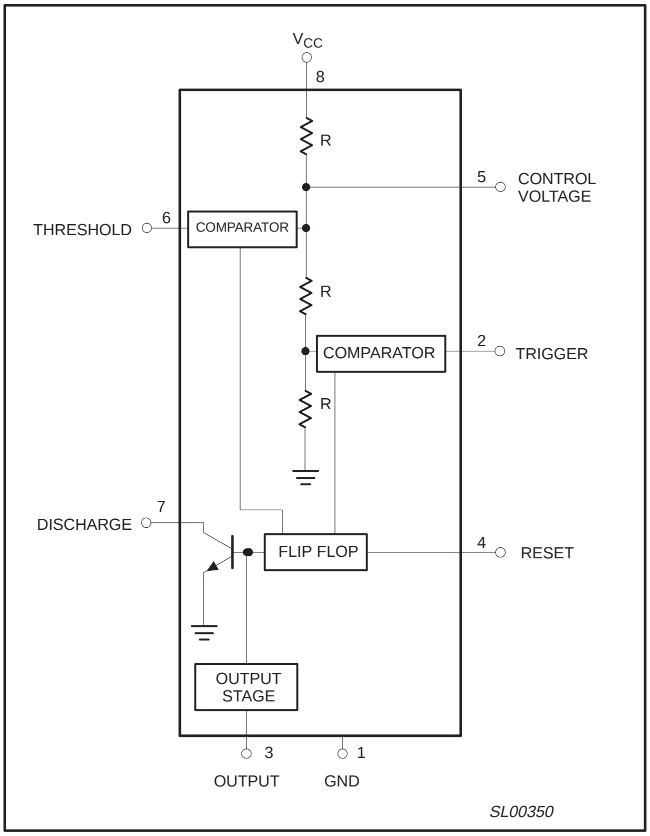
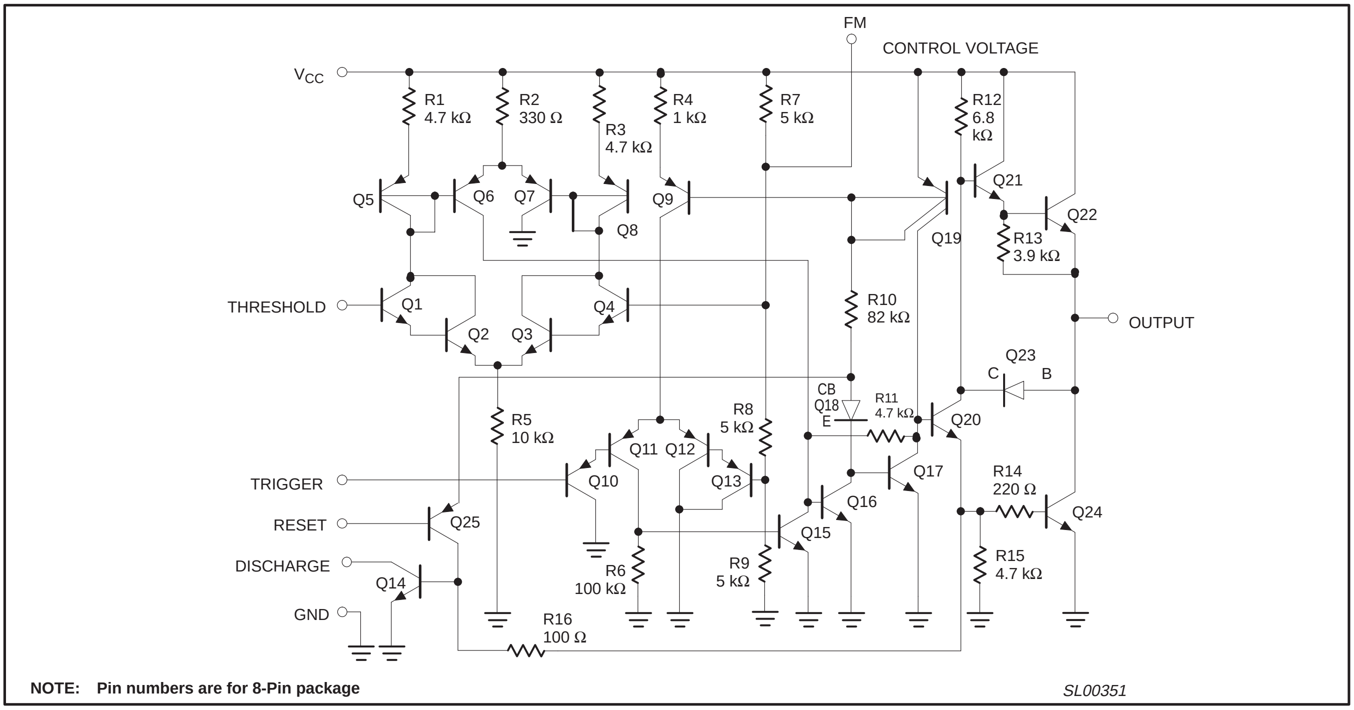


Figure 2. Block Diagram

ORDERING INFORMATION

DESCRIPTION	TEMPERATURE RANGE	ORDER CODE	DWG #
8-Pin Plastic Small Outline (SO) Package	0 to +70 °C	NE555D	SOT96-1
8-Pin Plastic Dual In-Line Package (DIP)	0 to +70 °C	NE555N	SOT97-1
8-Pin Plastic Small Outline (SO) Package	–40 °C to +85 °C	SA555D	SOT96-1
8-Pin Plastic Dual In-Line Package (DIP)	–40 °C to +85 °C	SA555N	SOT97-1
8-Pin Plastic Dual In-Line Package (DIP)	–55 °C to +125 °C	SE555CN	SOT97-1
8-Pin Plastic Dual In-Line Package (DIP)	–55 °C to +125 °C	SE555N	SOT97-1

EQUIVALENT SCHEMATIC



NOTE: Pin numbers are for 8-Pin package

Figure 3. Equivalent schematic

ABSOLUTE MAXIMUM RATINGS

SYMBOL	PARAMETER	RATING	UNIT
V_{CC}	Supply voltage SE555 NE555, SE555C, SA555	 +18 +16	 V V
P_D	Maximum allowable power dissipation[1]	600	mW
T_{amb}	Operating ambient temperature range NE555 SA555 SE555, SE555C	 0 to +70 –40 to +85 –55 to +125	 °C °C °C
T_{stg}	Storage temperature range	–65 to +150	°C
T_{SOLD}	Lead soldering temperature (10 sec max)	+230	°C

NOTE:

1. The junction temperature must be kept below 125 °C for the D package and below 150°C for the N package. At ambient temperatures above 25 °C, where this limit would be derated by the following factors:
   D package 160 °C/W
   N package 100 °C/W

DC AND AC ELECTRICAL CHARACTERISTICS

T_{amb} = 25 °C, V_{CC} = +5 V to +15 V unless otherwise specified.

SYMBOL	PARAMETER	TEST CONDITIONS	SE555			NE555/SA555/SE555C			UNIT
			Min	Typ	Max	Min	Typ	Max	
V_{CC}	Supply voltage		4.5		18	4.5		16	V
I_{CC}	Supply current (low state)[1]	V_{CC} = 5 V, $R_L = \infty$		3	5		3	6	mA
		V_{CC} = 15 V, $R_L = \infty$		10	12		10	15	mA
	Timing error (monostable)	R_A = 2 kΩ to 100 kΩ							
t_M	Initial accuracy[2]	C=0.1 µF		0.5	2.0		1.0	3.0	%
$\Delta t_M/\Delta T$	Drift with temperature			30	100		50	150	ppm/°C
$\Delta t_M/\Delta V_S$	Drift with supply voltage			0.05	0.2		0.1	0.5	%/V
	Timing error (astable)	R_A, R_B = 1 kΩ to 100 kΩ							
t_A	Initial accuracy[2]	C = 0.1 µF		4	6		5	13	%
$\Delta t_A/\Delta T$	Drift with temperature	V_{CC} = 15 V			500			500	ppm/°C
$\Delta t_A/\Delta V_S$	Drift with supply voltage			0.15	0.6		0.3	1	%/V
V_C	Control voltage level	V_{CC} = 15 V	9.6	10.0	10.4	9.0	10.0	11.0	V
		V_{CC} = 5 V	2.9	3.33	3.8	2.6	3.33	4.0	V
V_{TH}	Threshold voltage	V_{CC} = 15 V	9.4	10.0	10.6	8.8	10.0	11.2	V
		V_{CC} = 5 V	2.7	3.33	4.0	2.4	3.33	4.2	V
I_{TH}	Threshold current[3]			0.1	0.25		0.1	0.25	µA
V_{TRIG}	Trigger voltage	V_{CC} = 15 V	4.8	5.0	5.2	4.5	5.0	5.6	V
		V_{CC} = 5 V	1.45	1.67	1.9	1.1	1.67	2.2	V
I_{TRIG}	Trigger current	V_{TRIG} = 0 V		0.5	0.9		0.5	2.0	µA
V_{RESET}	Reset voltage[4]	V_{CC} = 15 V, V_{TH} = 10.5 V	0.3		1.0	0.3		1.0	V
I_{RESET}	Reset current	V_{RESET} = 0.4 V		0.1	0.4		0.1	0.4	mA
	Reset current	V_{RESET} = 0 V		0.4	1.0		0.4	1.5	mA
V_{OL}	LOW-level output voltage	V_{CC} = 15 V							
		I_{SINK} = 10 mA		0.1	0.15		0.1	0.25	V
		I_{SINK} = 50 mA		0.4	0.5		0.4	0.75	V
		I_{SINK} = 100 mA		2.0	2.2		2.0	2.5	V
		I_{SINK} = 200 mA		2.5			2.5		V
		V_{CC} = 5 V							
		I_{SINK} = 8 mA		0.1	0.25		0.3	0.4	V
		I_{SINK} = 5 mA		0.05	0.2		0.25	0.35	V
V_{OH}	HIGH-level output voltage	V_{CC} = 15 V							
		I_{SOURCE} = 200 mA		12.5			12.5		V
		I_{SOURCE} = 100 mA	13.0	13.3		12.75	13.3		V
		V_{CC} = 5 V							
		I_{SOURCE} = 100 mA	3.0	3.3		2.75	3.3		V
t_{OFF}	Turn-off time[5]	$V_{RESET} = V_{CC}$		0.5	2.0		0.5	2.0	µs
t_R	Rise time of output			100	200		100	300	ns
t_F	Fall time of output			100	200		100	300	ns
	Discharge leakage current			20	100		20	100	nA

NOTES:

1. Supply current when output high typically 1 mA less.
2. Tested at V_{CC} = 5 V and V_{CC} = 15 V.
3. This will determine the max value of R_A+R_B, for 15 V operation, the max total R = 10 MΩ, and for 5 V operation, the max. total R = 3.4 MΩ.
4. Specified with trigger input HIGH.
5. Time measured from a positive-going input pulse from 0 to $0.8 \times V_{CC}$ into the threshold to the drop from HIGH to LOW of the output. Trigger is tied to threshold.

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