Designing Force Probe to Monitor and Treat Teeth Grinding

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Abstract :

Due to various and increasing human medical needs and requirements in dental medicine , several techniques and applications have been developed to facilitate Dealing with different oral conditions , situations and abnormalities such as Bruxism.

Bruxism is a health problem which can be presented by grinding or tightly clenching the upper and lower teeth of the jaw. Teeth grinding behavior is affected by the amount of force that can be generated when teeth are contacting with each other.
A force probe or teeth prototype which consists of two force sensors will be used to monitor and detected teeth grinding .The two sensors were embedded inside it above the third molars since they are responsible for producing most of teeth force. It is made from silicon which is biocompatible material, does not have any side effects and it has a little contribution in absorbing some amounts of the applied force .A specific electrical circuits were designed to convert the sensor response to a readable voltage values which are easier to deal with. Voltage signals will be compared to a reference voltage which represents the force amplitude at Bruxism state, the result will control triggering safe electrotherapy treatment to provide relaxation to mastication hyperactive muscles and facial nerves .

Forty five person, from both genders male and female, were selected for this purpose That measure the left and right jaw force, then the results were analyzed by SPSS software . The mean maximum bite force for right jaw was statistically higher for males (59.3989 lb) when compared to right jaw females (44.5778 lb) ($P< 0.05$), and also the mean maximum bite force for left jaw was statistically higher for males (54.2662 lb) when compared to left jaw females (44.2344 lb) ($P< 0.05$). The previous statistical analysis demonstrated that there is no statistically significant difference between the mean right female force value and the mean value of left male force (T-value = -1.906- and P-value = 0.063) .

Also results illustrated that Bruxism peak force was detected and noticed clearly during night, without recognition any difference in force level or range between Bruxist and normal people biting force during midday.

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List of Abbreviation :

TENS : Transcutaneous Electrical Nerve Stimulation .

TMJ : Temporo-Mandibular Joint .

TMD : Temporo-Mandibular Disorders

DC : Direct Current .

SPSS : Statistical Package For Social Sciences .

Chapter One : Introduction

1.1 Project Overview :

The project will support and contribute in developing dentistry field by Implementation of a force probe , which will measure teeth's force that is generated during oral occlusion to control teeth grinding . A suitable and special kind of sensors will be used in order to determine the force which is generated between teeth surfaces during oral occlusion in different mouth's Locations . Moreover ,TENS technique and its principleswill be employed to produce an electrical current from the measured force between teeth to achieve facial muscles relaxation for bruxisers .

1.2 Project Motivation :

1. Bruxism is a Serious health problem with progressive side effects .
2. Disability of diagnosis bruxism during initial stages .
3. Repeated replacement for night guards without efficiency due to high teeth force .
4. Burn out efforts for dental technicians due to repeated replacement for night guards and high cost for the patient .

1.3ProjectObjectives :

1. Design a force probe to monitor teeth grinding .
2. Offering new treatment for bruxism depending on teeth force .
3. Providing a limitation of using night guard and their repeated replacement And as a result reducing costs and wasted efforts .
4. display the numerical value of the teeth force and the curves of both right and left side of teeth .
5. Relaxation of hyperactive muscles and nerves that is surrounding oral cavity .

1.4Literature Review :

Several techniques have been used for the measurement of human biting Forces. The instrumentwhich used for this purpose referred to asa Gnathodynamometer.Several studies review the types of instruments that have Beendeveloped to overcome many of the problems found in earlier gnathodynamometer[1] .

Mouth Guard for Treating Bruxism withElectro Stimulation technique using an electrical stimulus to stop thepatient from bruxing .The components of the device are a transducer to sense thebruxing, circuitry to convert the signal to pulse of specificfrequency and width,electrodes to stimulate the patient, and a mouth guard to contain the entire system[2] .

1.5 Time Plan :

The Table 1.1 shows the activities that done in the project, and the time of each one.

Table 1.1 :Activities Planning .

Weeks / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Obtaining required components																
System Design																
Recording Results																
Results analysis and conclusion																
Documentation																

1.6 : Project Cost :

Table 1.2 : Project cost .

Component	Cost JD
operational amplifiers Resistors , Potentiometers connectors.	15 JD
2-Flexi-force sensor	42 JD
LCD display , Arduino .	66 JD
Outer cover "case"	33 JD
Total	156 JD

Chapter Two : Dental Anatomy

2.1 Introduction :

The teeth provide an efficient system of mastication with incision tearing , and grinding capabilities . The unique composition and structure of teeth allow them to bear the force and wear of mastication . Alteration of the composition or in the structure the oral cavity . It is important to have knowledge of the anatomy and development of your teeth in order to preserve the health of the teeth . By understanding normal teeth development and learning to recognize abnormal conditions , you will be able to spot the early warning signs of problems or disease . Early intervention can make a big difference in correction health issues before they become a major problem . This chapter offers helpful understanding to the anatomy and development of the teeth .

2.2 Dental Anatomy :

Is a field of anatomy related to the study of human tooth structures . The development , appearance , and of teeth fall within its purview . Tooth formation begins before birth , and teeth eventually morphology is dictated during this time . Dental anatomy is also taxonomic science ; it is concerned with the naming of teeth and the structure of which they are made , this information offering practical purpose in dental treatment . [4]

2.3 Basic Terminology :

Before beginning the study of the teeth themselves it is necessary to define some terms that are basic to learning about dental anatomy . [5]

2.3.1 The maxilla and Mandible Bones :

The facial bones making up the oral cavity and its associated structures are of the utmost importance to all dental care professionals .

1. The maxilla :

The maxilla forms the upper jaw by fusing together two irregularly-shaped bones along the palatal fissure. The maxillary bones on each side join in the middle at the intermaxillary suture and help to support the posterior teeth . The maxilla effectively forms the middle - third of the face , and as with various cranial bones , it has several foramina and bony projections that are dentally relevant . See Figure 2.1[6]

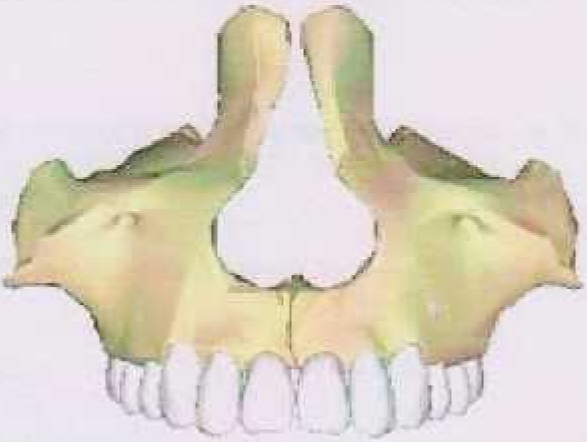


Figure 2.1 : The Maxilla Bones .

2. The mandible :

The mandible is the single, horseshoe-shaped bone that forms the lower jaw and is the only movable bone of the skull Its front horizontal portion extends into the alveolar process which holds the lower teeth , while its two posterior vertical struts allow articulation with the temporal bone at the TMJ and allows the insertion at various points for the muscles of mastication . Looking at the mandible from an right lateral view . See Figure 2.2 [7] , the following anatomical landmarks are visible :

a. Angle of mandible: the corner of bone where the horizontal section turns upwards to form The vertical bony strut of the mandible .

b. Ramus of mandible: the vertical bony strut of the mandible, and the area of insertion of a Muscle of mastication .

c. Head of condyle : the articulation point of the mandible with the temporal bone, at the TMJ , and the point of insertion of some muscles of mastication .

d. Coronoid process : the front bony projection of the ramus , and a point of insertion of a Muscle of mastication .

e. Sigmoid notch: the dipped area between the condyle and the coronoid process , at the top of the ramus .

f. Coronoid notch: the concave anterior surface of the ramus , as it slopes to join the body of the mandible .

g. Alveolar process: the tooth bearing area of the mandible (upper part of the body of the mandible) .

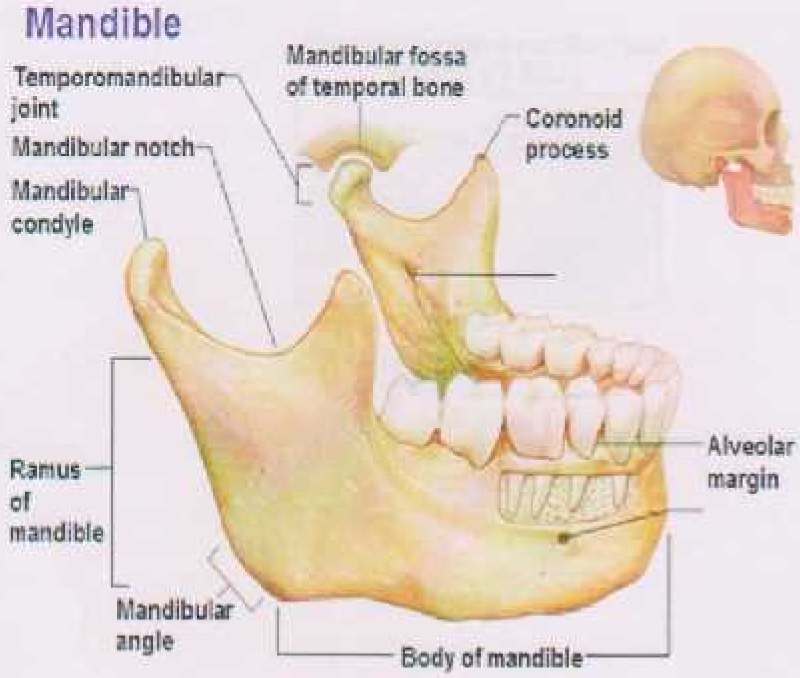


Figure 2.2 : Mandible, Right lateral View.

2.3.2 Temporo - mandibular joint :

TMJ is the movable joint between the mandible (lower jaw bone) and part of the Cranium called the temporal bone. It is a complicated joint and the two hard bones Surfaces are separated by a circular piece of softer cartilage which acts like a cushion. This joint is in constant use during chewing, swallowing, talking, and laughing. Some of these movements involve rotation of the joint and some are sliding Movements. The joint is separated into a superior and an inferior compartment by the Articular disc . The superior compartment is bordered superiorly by the mandibular Fossa of the temporal bone and inferiorly by the articular disc itself. It contains 1.2mL Of synovial fluid and is responsible for the translational movement of the joint. The Inferior compartment has the articular disc as a superior border and the condyle of the Mandible as an inferior border.[8] It is slightly smaller with an average synovial fluid Volume of 0.9mL and allows rotational movements. See Figure 2.3 [9]

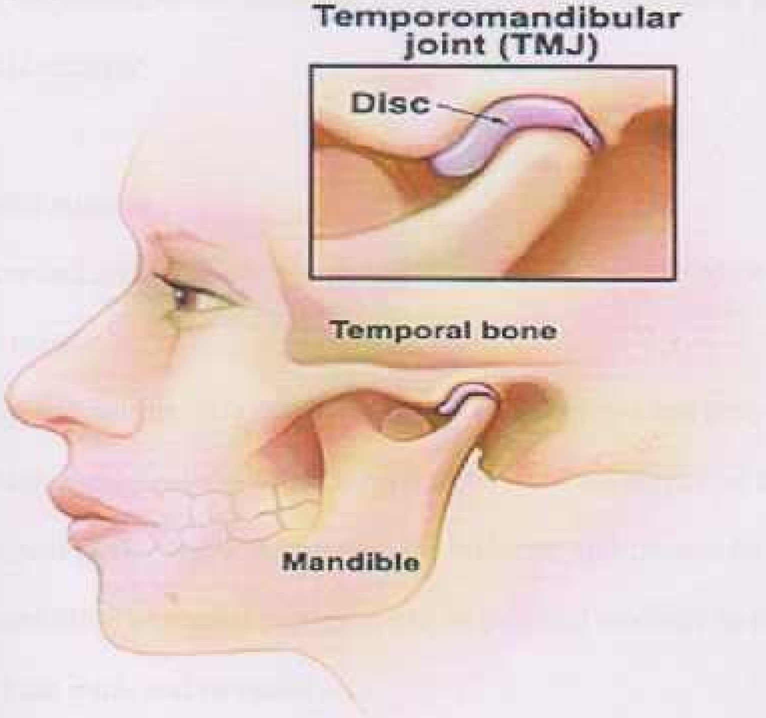


Figure 2.3 : Temporo-Mandibular Joint .

2.3.3 Muscles dental jaw :

1. The masseter muscle :

The masseter is a jaw muscle that gets its name from the Greek work " to chew ". It is the major muscle of mastication (chewing) of the human jaw and serves primarily to elevate the mandible (lower jaw) while the deep tissues help to protrude (protract) it forward. Although we rarely think of it, the mandible is the only bone of the skull that is actually moveable[10] . The upper jaw is fixed . There is a lot of moving for the mandible to do, therefore, and the masseter is the primary worker . Located on each side of the face in the parotid region at the back of the jaw, these muscles are easily visible or palpable when you clench your jaw, as they contract strongly just in front of the lower ears . The action of the muscle during bilateral contraction of the entire muscle is to elevate the mandible, raising the lower jaw. Elevation of the mandible occurs during the closing of the jaws. The masseter parallels the medial pterygoid muscle, but it is stronger .

2. The pterygoid muscles :

The pterygoid muscles (" wing muscles ") are two jaw muscles located on the inner surface of the mandible .

a. Medial pterygoid muscle: originates from the pterygoid fossa and pterygoid process of the sphenoid. Distally it inserts on the pterygoid tuberosity on the inner surface of the mandibular angle. Along with the masseter, this muscle forms a sling around the mandible. The medial pterygoid can be palpated medially to the ramus of the mandible both intra- and extraoral .

b. Lateral pterygoid muscle: has two heads which lie almost horizontally to each other The small superior head runs from the infratemporal crest of the sphenoid to the articular disc of the temporomandibular joint. The much larger inferior head courses from the pterygoid process of sphenoid to the condylar process of mandible. Due to its anatomy, palpation of the lateral pterygoid is quite difficult.

3. The temporal muscle :

The temporal muscle, or temporalis muscle, is one of several chewing muscles that is Necessary for crushing objects between the molars. Due to its location and use, this Muscle may be a primary center for tension headache pain according to neurological Research.The temporal muscle is broad, fan-shaped, and situated along the side of The head, occupying the temporal fossa .

4. The buccinator muscle :

The buccinator muscle is the major facial muscle underlying the cheek. It holds the Cheek to the teeth and prevents sagging. This muscle is involved in a wide variety of Activities from smiling to chewing.The buccinator muscle is served by the cranial Nerve, also known as the facial nerve. See Figure 2.4 [11]

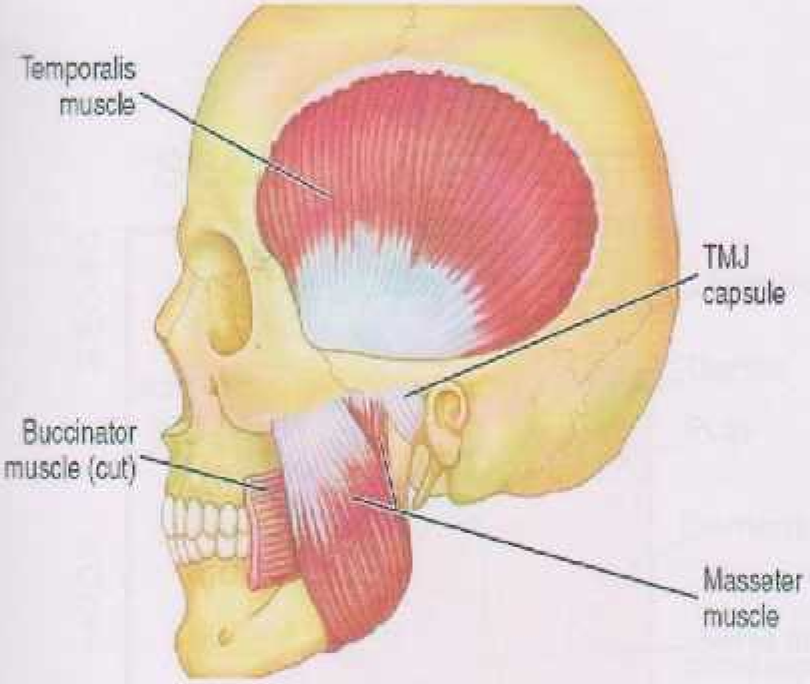


Figure 2.4 : Muscle Dental Jaw.

2.3.4 Dental tissues :

Each tooth in the mouth contains four different tissues that serve different functions the teeth are made up of two major parts: the crown and the root the Crown of the tooth is what is visible in the mouth. The root of the tooth is the Portion which normally not visible in the mouth and is anchored within the bone Within each tooth the four different tissues that are present are the enamel, the dentin And the pulp and the cementum . See Figure 2.5 [12]

1. Enamel : Makes up the protective outer surface of the crown of the tooth .

2. Dentin : Makes up the majority of the inner surface of the tooth . It cannot normally be seen except on x-rays .

3. Pulp : This is the area inside the tooth that holds the nerves and blood vessels of The tooth . It is in the center of the tooth and is in both the crown and the root of Tooth [13] .

4 Cementum : Makes up the outer surface of the root of the tooth. It is much softer Than enamel .

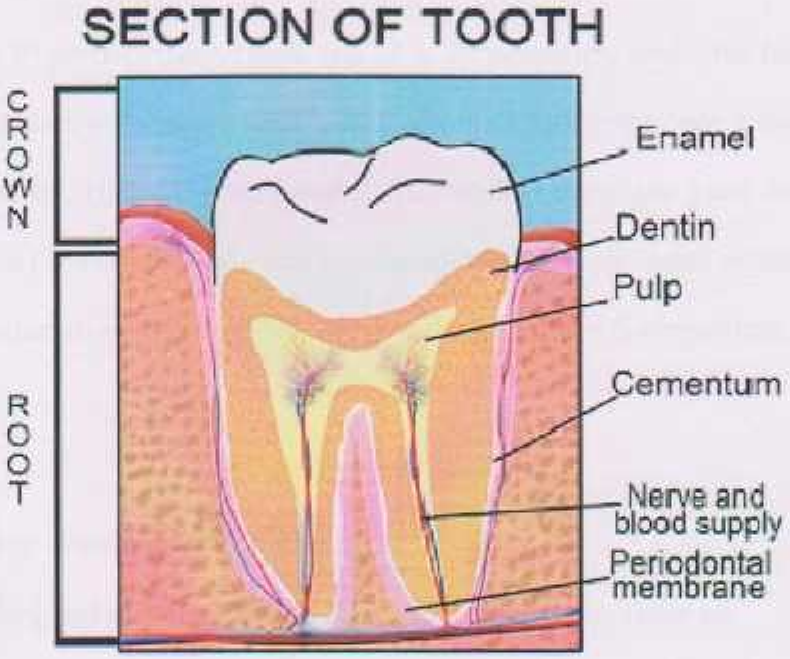


Figure 2.5 : Dental Tissues .

2.3.5 Periodontal anatomy :

Anatomically , the periodontium is the collective term used for those structures That supports the teeth in the jawbone, and traditionally includes the following Tissues :

1. Cementum : hard tissue covering of the root that anchors the periodontal ligament To the tooth .
2. Periodontal ligament – connective tissue attachment between the tooth and the Alveolar bone .
3. Alveolar bone – specialized ridge of bone over each jaw , where the teeth sit in Their sockets.
4. Gingiva – specialised soft tissue covering of the alveolar processes that are also in attachment with the teeth at their necks.

2.4 Classification Teeth:

2.4.1 Teeth during our lifetime :

Usually, there are 20 primary (baby) teeth and 28 to 32 permanent teeth , the last four being third molars or "wisdom teeth", each of which may or may not grow in . Among primary teeth , 10 usually are found in the maxilla (upper jaw) and the other 10 in the mandible (lower jaw) . Among permanent teeth , 16 are found in the maxilla and the other 16 in the mandible. Most of the teeth have distinguishing features .

2.4.2 Teeth during situation and function:

In both the maxillary and mandibular arch there are similar teeth. There are four types of teeth in both arches . These include the incisors, the canines, the Premolars and the molars. Each of these teeth are located in a different area of the Mouth and serve different functions. See Figure 2.6[14]

1. Incisors: The four front teeth in the mouth are known as incisors. They are located in both the maxillary and mandibular arches. The two center teeth are known as Central incisors and the teeth on either side of them are known as lateral incisors. All Of these teeth are responsible for cutting or biting food. They act like scissors.

2. Canines: The teeth located distal to the lateral incisors are known as canines. These teeth form the corners of the mouth. There are two canines in the maxillary Arch and two canines in the mandibular arch . These teeth are responsible for tearing Food particles when chewing .

3. Premolars: The teeth located distal to the canines are known as premolars. There Are four premolars in each arch and two are located behind each canine in the arch These teeth are smaller than the molars and are responsible for crushing food in the Chewing process .

4. Molars: There are normally six molars in each arch ; three on the left and three on The right side They are referred to as first , second and third molars . Some people Never develop third molar sand often these are the molars that are so far back in the Mouth.

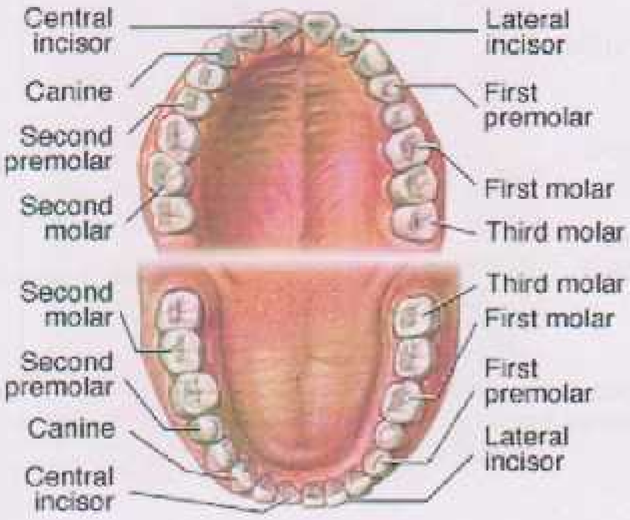


Figure 2.6 : Four Types of Teeth.

2.4.3 The tooth and supporting structures:

1. The anatomic crown: Each tooth is divided into the crown and the root (or roots) The crown is that part of the tooth which is covered by enamel. The term clinical Crown is often used to refer to that part of the tooth which is visible in the mouth.
2. The anatomic root: The root (or roots) is that part of the tooth which is covered by cementum. It is mostly embedded in the bony process of the jaw. The tip (or end) of The root is called the apex.
3. The pulp chamber: houses the dental pulp, an organ of myelinated and unmyelinated nerves , arteries , veins , lymph channels , connective tissue cells , and Various other cells . See Figure 2.7[15].

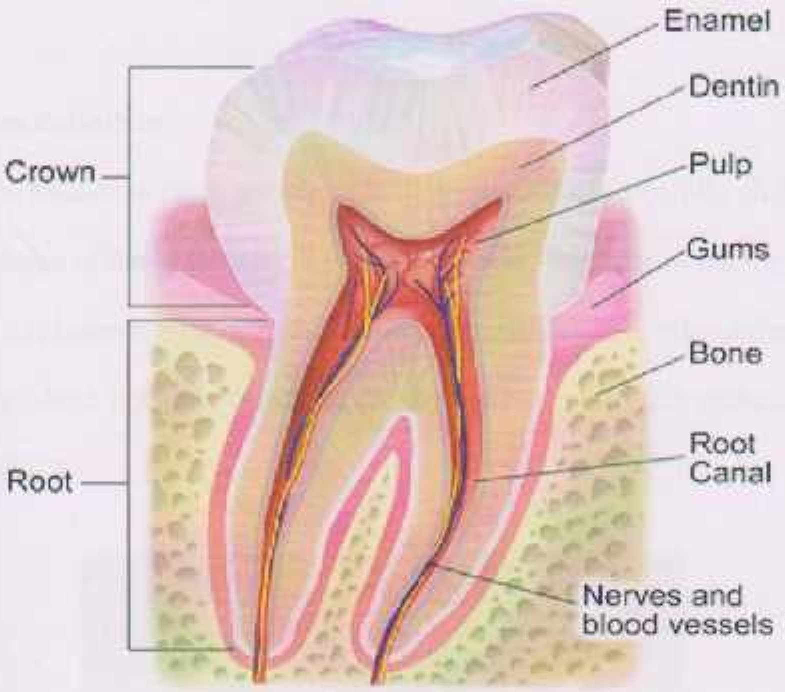


Figure 2.7 : Supporting Structures Of The Tooth .

2.5 Dental Disorder :

Most people probably grind and clench their teeth from time to time. Occasional teeth grinding, medically called bruxism, does not usually cause harm, but When teeth grinding occurs on a regular basis the teeth can be damaged and other Oral health complications can arise.

It is clear the patients with TMD who report high levels of bruxism have more Severe signs and symptoms of TMD and more advanced tooth wear than patients with TMD who report lower levels of bruxism .The cause of bruxism is not completely Agreed upon. Consuming stimulants such as caffeine appears to increase the risk of bruxism however a variety of psychological and physical factors are also thought to Be responsible. In many cases, bruxism has been linked to stress, however bruxism be The body's reaction to poor tooth alignment, an uncommon side effect of some Psychiatric medications, a complication of severe brain injury or a symptom of certain

Rare neuromuscular diseases involving the face. [16]

2.5.1 Bruxism definition :

Bruxism , also known as tooth grinding , is the condition of forcefully sliding the Chewing surfaces of the bottom teeth over the chewing surfaces of the top teeth Generally in a sideways, back-and-forth movement. Bruxism is often accompanied By clenching which is tightly clamping the top and bottom teeth together. See Figure 2.8 [17]

Figure 2.8 : Grinding Teeth .

2.5.2 Causes of Bruxism:

Why bruxism occurs is not always clear? In the dental profession the belief that bruxism and dental occlusion are causally related has been widespread. However There is little evidence to support this belief recent research concluded that neither occlusal interference nor factors related to the oral facial skeleton have a role in the Etiology of bruxism. Recent studies suggest that sleep bruxism is secondary to sleep Related arousals (defined by a rise in autonomic cardiac and respiratory activity that Tends to be repeated 8-14 times per hour of sleep). The rhythmic muscle activity that Occurs in sleep bruxism peaks in the minutes before rapid eye movement sleep. This

Suggests that there is some mechanism related to sleep stage transitions that influence he motor neurons of bruxism [18]

2.5.3 Symptoms :

Clenching the teeth puts pressure on the muscles, tissues, and other structures around Your jaw. The symptoms can cause TMJ problems . Grinding can wear down your teeth. Grinding can be noisy enough at night to bother Sleeping partners .

- **Symptoms include :**

- Anxiety, stress, tension and depression.
- Earache (due in part because the structures of the TMJ are very close to the ear Canal, and because you can feel pain in a different location) than its source this is Called referred pain [19]
- Eating disorders .
- Headache .
- Hot, cold, or sweet sensitivity in the teeth .
- Insomnia .
- Sore or painful jaw .

2.5.4 Complications :

In some cases, chronic teeth grinding can result in a fracturing, loosening, or loss of Teeth. The chronic grinding may wear their teeth down to stumps. When these Events happen, bridges, crowns, root canals, implants, partial dentures, and even Complete dentures may be needed. Not only can severe grinding damage teeth and Result in tooth loss, Tension-type headaches, Facial pain, it can also affect your Jaws, result in hearing loss, cause or worsen TMD . See Figure 2.9[20].

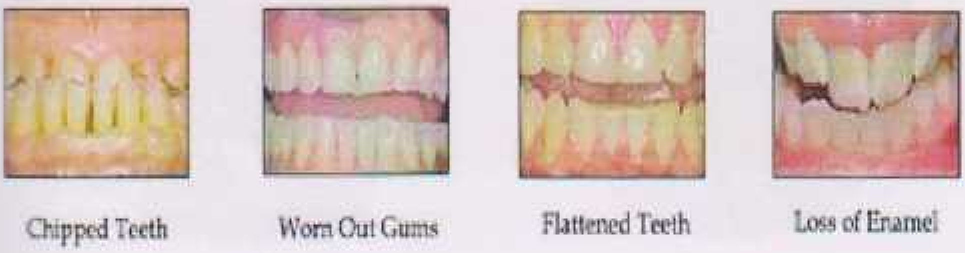


Figure 2.9 : Bruxism Complications .

2.5.5 Temporo-mandibular disorder :

Bruxism is an abnormal clenching or grinding of the teeth, either while awake or During sleep. Bruxism may play a role in TMD although the exact link is unclear. A Number of studies has shown a strong relationship between bruxism and TMD. Manfredini looked at 212 patients with a diagnosis of TMD and found bruxism in 87.5% of patients with myofascial pain with disc displacement and in 68.9% of Patients with myofascial pain without disc displacement. However, show a causal link Between the two. The relationship is complex and it may be that bruxism leads to Symptoms of TMD . See Figure 2.10 [21]

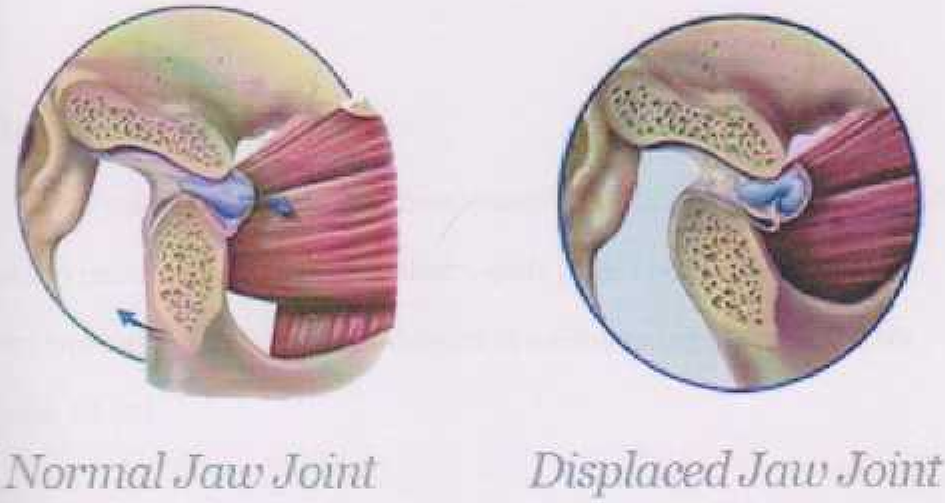


Figure 2.10 : Normal and Displaced Jaw Joint.

2.5.6 Monitoring bruxism :

There are different methods that contribute in reducing the side effects of bruxism Including medical doses and night guards .On the other hand, medical doses cannot Be effective enough with patients who suffer from progressive side effect and severe bruxism . Also , night guard can be destroyed several times due to the huge biting Force which is generated between teeth thus increasing the financial expenses and Cost for the patient which as a result causing feeling of dissatisfaction for both Doctors and dental technicians. So here is our work in this project , to provide a limitation for these insufficient Treatment techniques and replace them with more reliable one such as electrotherapy Principles .

Chapter Three : Basics Of Electrotherapy

3.1 Electrotherapy:

It is a physical therapeutic treatment whereby electrical stimulation is applied to Nerves and muscle-motor fibers via electro-pads placed on the skin. There are Different types of electrotherapeutic devices in rehabilitation including TENS . See Figure 3.1 [22]

Figure 3.1 : Transcutaneous Electrical Nerve Stimulation .

3.1.1 Transcutaneous Electrical Nerve Stimulation:

TENS is a highly effective treatment for pain whereby electrodes are placed on or Near the area of pain and soothing pulses are sent via the electrodes through the Skin and along the nerve fibers. The pulses suppress pain signals to the brain also Encourages the body to produce higher levels of its own natural pain killing Chemicals called Endorphins and Encephalin . Electrotherapeutic programs, utilizing prescribed variations in electrical frequencies And intensities, serve to interrupt , alter or induce specific electrical impulses in Order to affect the perception of pain and facilitate wound healing and muscle Rehabilitation .

How Does Electrotherapy Reduce Pain ?

1. Blocking the information travelling along the nociceptive fibers (those that Produce pain).

2. Stimulating release of natural pain-relieving chemical substances in the Body which the body usually releases when there is injury or stress . The chemical Substances released are known as endorphins and enkephalins .

3.1.2 Stimulation Parameters :

Briefly we will describes the parameters of current, the waveform, frequency pulse Duration and intensity which we have to adjust according to patient comfort and These are followed by a description of the four different modes of TENS that are Basically different combinations of these parameters in order to chose the most Appropriate one for the patient .

- Current: TENS is a pulsed current, i.e. a current in which the unidirectional Or bidirectional flow of current periodically ceases over time .
- Waveform: The waveform of a current simply refers to its shape as seen on a Graph of amplitude versus time. Usually TENS waveforms are described as Asymmetrical biphasic rectangular or symmetrical biphasic rectangular . Figure 2.12 illustrates a typical TENS waveform. A biphasic waveform means that Current flows in both directions, therefore each electrode acts as a cathode (negative) For some part of the waveform . The waveform therefore has two components (or Phases) , a positive and a negative component which represent the change in current Flow .

TENS waveforms usually have a zero net direct current , this means that the Amount of charge under the positive portion of the waveform is equal to the amount Of charge under the negative portion of the waveform . The production of a this Current reduces the likelihood of chemical skin irritation , a direct current can Potentially cause skin irritation due to the buildup of ions of one charge under the Electrodes .

- Frequency : The frequency of a current refers to the number of pulses Delivered per second therefore a frequency of 200Hz means that 200 pulses are Delivered per second .
- Pulse Duration/Width :The unit of pulse duration is usually given in Microseconds (μs) which are units time, hence it is more correct to use the term 'Duration' rather than 'width'. The pulse duration is usually defined as the duration Of only the positive component of the waveform .TENS pulse durations are in the μs Range ($1\mu s = 1 \times 10^{-6}s$) .
- Intensity/Amplitude :Intensity refers to the magnitude of current or voltage Applied by the TENS unit TENS units are typically designed with a constant current Or constant voltage output .

Basically this means that either the voltage or current (respectively) will vary to Maintain a constant current or voltage amplitude (within limits) as the impedance (Resistance) of the electrode-patient system changes. The intensity of a constant Current unit is measured in milliamps and the intensity of a constant voltage unit is Measured in volts .

3.1.3 TENS Modes :

- Conventional TENS :

Conventional or High frequency/Low intensity TENS is the most commonly used Mode of TENS. The stimulation parameters are a low intensity, a high frequency Typically above 100Hz and a short pulse duration (50-80μs) .

- Acupuncture - like TENS :

Acupuncture-like or Low frequency/High intensity TENS parameters include a low Frequency (usually 1- 4Hz), a high intensity (high enough to produce visible muscle Contractions) and a long pulse duration (~200μs).

- Burst Train TENS :

The Burst Train mode of TENS is really a mixture of Conventional and Acupuncture Like TENS, and comprises a baseline low frequency current together with high Frequency trains of pulses. Typically, the frequency of the trains is 1- 4 Hz with the Internal frequency of the trains around 100Hz .

- Brief , Intense TENS :

This mode of TENS uses a high frequency (100-150Hz), long pulse duration (150-250 μs) at the patient's highest tolerable intensity for short periods of time (< 15minutes) .

- Modulated output:

The modulated output means that there is a variation in either pulse duration Frequency or amplitude parameters in a cyclic fashion. Indeed, some units have Modulation of two or all three of these parameters. If the output is set for amplitude Modulation, a cyclic modulation in amplitude is produced which increases from zero To a pre-set level then back to zero again. This choice of modulated output has been Included by manufacturers apparently to overcome accommodation of nerve fibers And to provide more comfort to the patient .

3.1.4 Take Into Consideration :

When using electrotherapy techniques there are several factors that we have to take Into account as illustrated below .

- TENS Pad Placement :

The small electrical signal which is developed by the TENS device is delivered to the Body by specialized pads or electrodes. The two electrodes that attach to the TENS Machine are called the anode and the cathode. The anode is positively charged and The cathode is negatively charged , they are designed to ensure safe and effective Treatment . It is important though to take into consideration the location in which the Electrodes will be placed on to keep the electrodes working properly and optimally. The distance between the electrodes is very essential . If they are too close together The current will "short" and bypass the person, but if they are too far away from each Other stimulation may be lost .

On the other hand it is essential to know that inter-electrode distance will affect both The current density and depth of penetration of the current. Current density decreases With distance from the electrodes due to a high electrical impedance of the deeper Tissues. If the inter electrode distance is decreased, current density in the area Between the electrodes will increase and the depth of penetration decreases. Conversely with a greater inter electrode distance, the current density is less but the Depth of penetration is greater .

- Treatment Periods:

Studies have shown that in most cases at least 20 minutes is needed for a TENS. Treatment to begin to be effective . However, in the case of using low-frequency or " Burst " mode for acupuncture-like effects , 20 minutes would be considered the Maximal treatment time , though it could be repeated later in the day. On the other Hand , for high-frequency or "conventional" TENS . there are no rules governing Total treatment times .

Chapter Four :ForceProbe Prototype &Its Electrical Circuit

4.1 Design Principles :

This project aims to design a complete circuit which can identify the excessive forces which is generated during oral occlusion . Also a treatment for this pathological situation will be provided to reduce its side effects by using electrotherapy principles.

This can be achieved by using specific type of force sensor called "Flexiforce-A201". According to teeth distribution and their surface area ,2sensors were needed for acquiring the force from teeth's surface that are responsible for generating it .

The two sensors will be connected to a suitable conditioning circuit to provide the user a meaningful reading that expresses the amount of the applied force .Each biting force (Right/Left or Average) has an analogousvoltagevalue which will be compared to a Reference voltage which representexcessive teeth force " Bruxism " . If the patient biting voltage is greater than orequal to the reference voltage ,Arduino programming will control producing a stimulating pulses thatwill be applied to the patient by a specifickind of electrodes to achieve muscle-nerverelaxation" mastication muscle and facial nerve " . Also biting forces will be displayed numericallyin Newton which is very essential in dental applications . The block diagram below summarizes work destination .

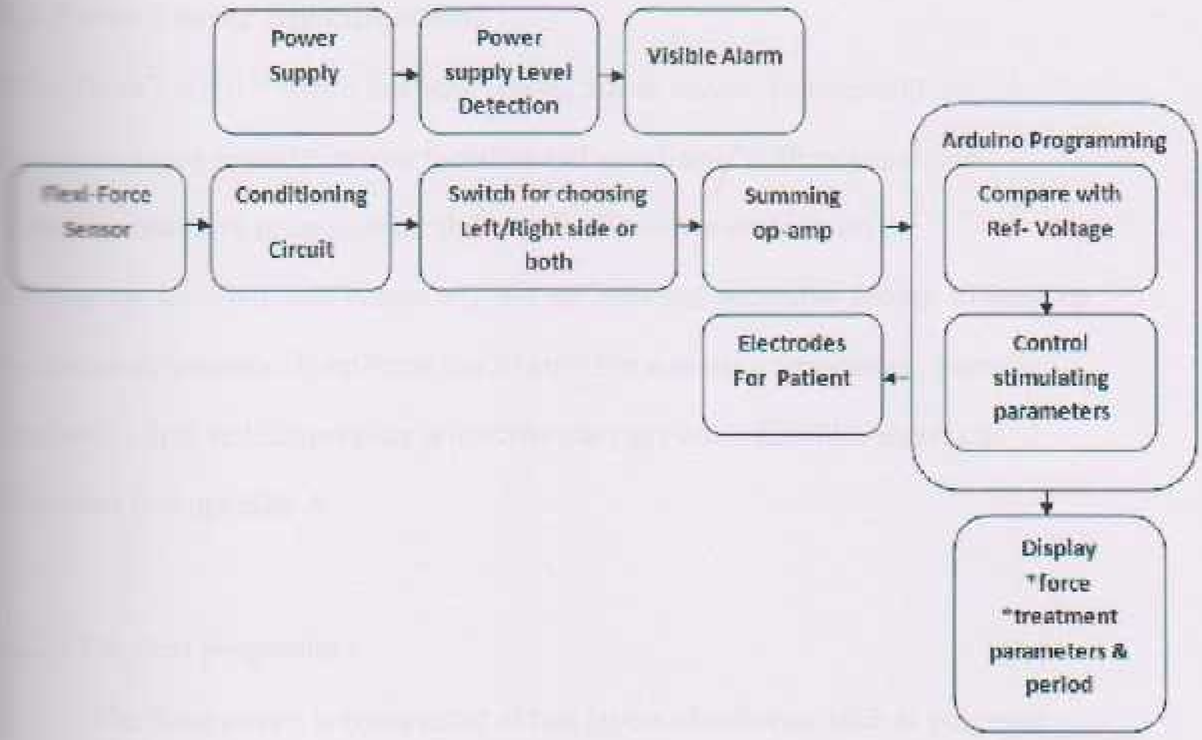


Figure4.1 : General Block Diagram .

To measure the force which is generated between teeth surfaces (vertical forces) , the type of sensor which we should chose , must be thin as much as possible so it can belocated and settle between teeth easily without motion artifacts . Also the surfacearea of the sensor must cover the teeth's surface area to insure detecting the wholegenerated force. Also , according to related study the maximum bite force that canbegeneratedfrombruxist is approximately 500Newton[23],so the sensors must bear this range of force .

4.2 Force Sensor Specifications :

"FlexiForce – A201 " sensor has been chosen due to several features and properties which provide various facilities and simplicity .With its paper thin , flexibility and force measurement ability , the Flexiforce sensors can measure the force between almost any two surfaces and is durable enough to stand up to most environments . FlexiForce has a better force sensing proprieties , linearity hysteresis , drift and temperature sensitivity than any other thin-film sensors as illustrated in **Appendix A** .

4.2.1 Physical properties :

The force sensor is constructed of two layers of substrate such as polyester Filmso it is safe . On each layer a conductive material (silver) is applied , followed by a layer of pressure sensitive area . The active sensing area is defined by the silver circle on top of thepressure sensitive area . Silver extends from the sensing area to the connectors at the other end of the sensor , forming the conductive leads . A 201 are terminated with a male square pins instead of the standard berg connectors . These are much thinner connectors and therefore less intrusive and allows sensors to be incorporated into a circuit . The outer pins of the connector are active and the center pin is inactive . See Figure 4.2[24]

Figure 4.2 : Flexi - Force Sensor .

The new and improved FlexiForce is an ultra-thin sensor with a thickness of 0.203 mm . It is 14 mm wide and 203mmin full length .The active force sensing area is 9.53 mm diameter circle at the end of the force sensor .

4.2.2 Force range :

The sensor has a wide force measurement range 0 – 100lb approximately 440 Newton.This range of measurement is an appropriate one , since the maximum biting force for bruxist can be approximately 500 N .

4.2.3 Conditions could damage the sensor :

the sensor is not waterproof , water-submersion can damage the sensor (as the adhesive holding the top & bottom layers together would likely separate) ,sharp objects, shear forces, creasing the sensor , loads that are around or above 10,000 PSI and temperature above 155°F .[25]

the sensors will be coated with silicon as will be described later . this will insure protecting them from saliva secretion and from sharp edges for the teeth .

4.2.4Comparison with other force sensors :

- FlexiForce sensor-A201 were compared with similar thin force sensorsas FSR 402&[26]FSR 406[27],those in figure 4.3 .

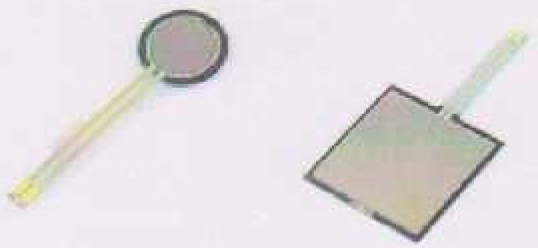


Figure4.3 :Force Sensors .

Flexi- Force –A201 has a suitable shape , small size and a suitable diameter that can cover teeth's surface area without any parts outside the target area .

- Strain gauges and FlexiForce sensors are resistance based technologies available in a variety of shapes and sizes. Flexi- Force sensors provide a flexible, paper-thin solution at only 0.2mm thick and with Larger dynamic resistance range from MΩ to KΩwithless sensitivity to temperature[28] .

4.2.5 Typical performance

The FlexiForce single element force sensor acts as a force sensing resistor in an electrical circuit. When the force sensor is unloaded, its resistance is very high. When a force is applied to the sensor, this resistance decreases. The resistance can be read by connecting a multimeter to the outer two pins, then applying a force to the sensing area .The conductance for this sensor distinguishes that it has a linear relationship with the applied force . See Table 4.1.

Table 4.1 : Force Vs. Conductance Relation

Force (lb)	Conductance (mS)
5 lb	0.001
10 lb	0.002
20 lb	0.004
30 lb	0.0045
40 lb	0.006
50lb	0.008
60 lb	0.009
70 lb	0.0105
80 lb	0.013
90 lb	0.014
100 lb	0.016
110 lb	0.017

Note : Force "lb" = 4.448 N .

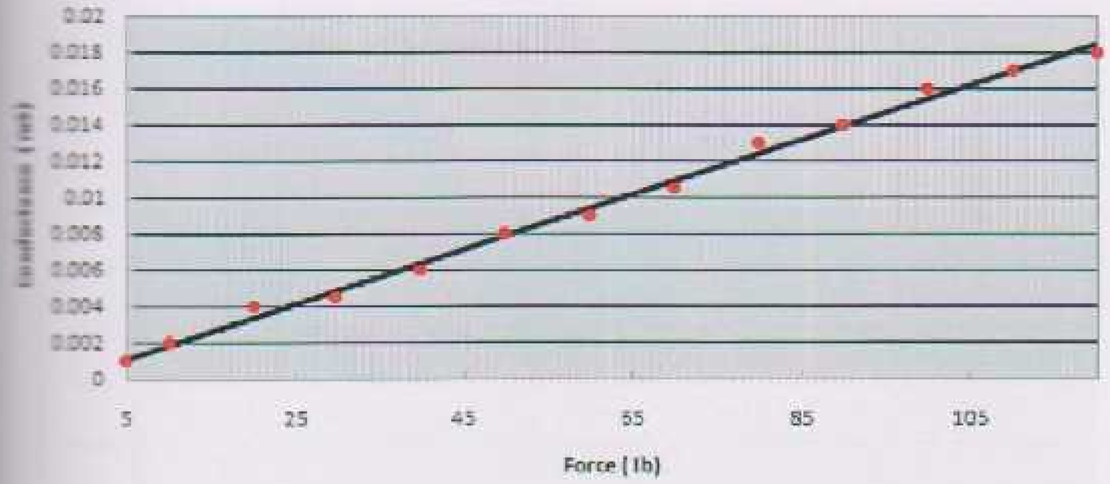


Figure 4.4 : Conductance-Force Relation[29]

According to table 4.1 above , we can calculate the value of resistance by this relation conductance = $(\frac{1}{R})$. See Table 4.2

Table 4.2 : Force - Resistance Relation .

Force (lb)	Resistance (Ω)
5 lb	1 M
10 lb	500 k
20 lb	250 k
30 lb	222k
40 lb	166k
50lb	125k
60 lb	111k
70 lb	95.24k
80 lb	76k
90 lb	71.43k
100 lb	62.5k
110 lb	58.82k
120 lb	55.56k

Note : Force "lb" = 4.448 N .

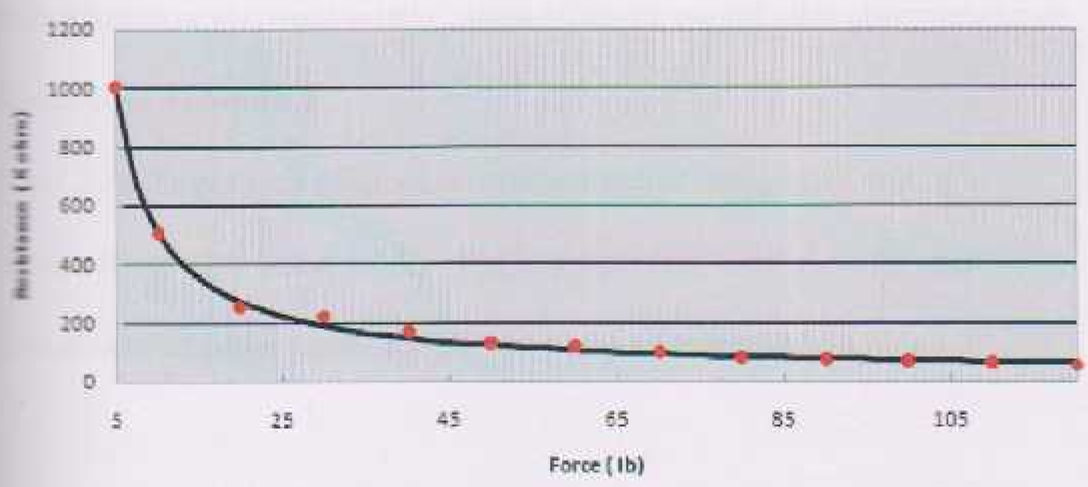


Figure 4.5: Resistance-Force Relation .[29]

4.2.6 Flexi -Force - electrical circuit :

According to the performance of The sensor and since it is a variable resistance that changes its value according to the input force , If the variable resistance is connected with a supply voltage , the voltage Between the resistance's terminals will vary according to changes in the resistance Value itself due to the applied force .

An operation amplifier Was chosen toamplify the output voltage from the sensor .the maximum and suitable output voltage from the sensor will be calibrated at5-DC voltage Since it is a valid voltage input to Arduino environment .

Since the output voltage is DC , a positive single supply op-amp is an appropriate choice . Also this will eliminate the necessity to connect a negative supply voltage (-Vcc) and as a result reducing hardware components & cost .

LM324Npositive single supply op-amp was chosen since it has a wide input voltage range3 - 32 V and a several acceptable features as power supply rejection ratio,common mode rejection ratio , input offset current and other characteristics as illustrated in **Appendix B** .

Since FlexiForce circuit designed at maximum output voltage of 5 volt , it is suitable to use a DC power supply equal or greater than 7 volt avoid op-amps saturation 9volt power supply was preferred as it commercially available .

Three LM324N op-amp were used , two for representing the voltage related to right and left side of Jaw , the third to the obtain the average for both sides . See figure 4.6

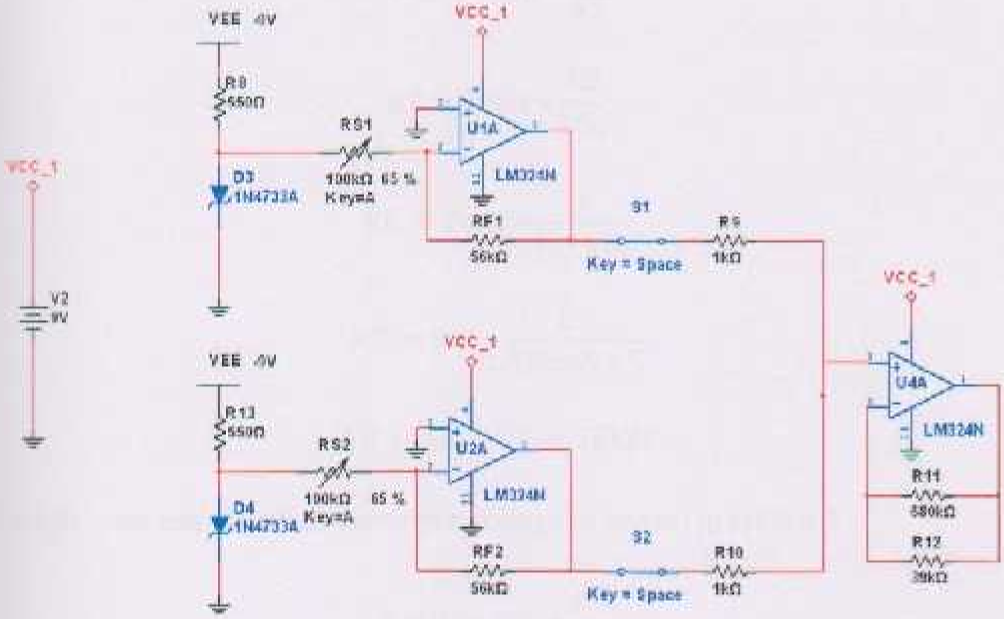


Figure 4.6: Flexi -Force-Electrical Circuit .

According to Appendix CThe recommended input voltage for the sensor is -5 volt .To avoid changes in it , a -9 volt DCpower supply was connected tozener regulator diode 1N4733A .see **Appendix C** .

LM324N was connected as inverting op-amp since it produces more linear output voltage than non-inverting op-amp[30]. To obtain 5 volt as maximum output voltage , feedback resistance should be adjusted as

To calibrate 5 output voltage at maximum load " 120 lb" with an input of 5 volt, the conductance of the sensor will be 0.018 mS as illustrated in table 4.1 as a result feedback resistance should be adjusted as below.

$$Vout = Vin * \frac{RF}{RS}$$

$$RF = Vout * \frac{RS}{Vin}$$

$$RF = Vout * \frac{1}{C * Vin}$$

$$RF = 5 * \frac{1}{0.018mS * 5}$$

$$RF = 55.5\ k\Omega \approx 56K\Omega$$

As a result , we can calculate the output voltage as shown in table 4.3 .

$$Vout = Vin * \frac{RF}{RS}$$

Where Vin = -5 volt , RF =56KΩ , and Rs as shown in table 4.2.

Table 4.3 : Force - Output Voltage Relation .

Force (lb)	Vout(v)
5 lb	0.28
10 lb	0.56
20 lb	1.12
30 lb	1.26
40 lb	1.686
50lb	2.24
60 lb	2.52
70 lb	2.94
80 lb	3.684
90 lb	3.92
100 lb	4.48
110 lb	4.76
120 lb	5.04

Note : Force "lb" = 4.448 N .

After getting the voltage signal of right, left side or the average of them , the signalwill inter Ardino environment and be compared with a reference voltage which represent Bruxism force . if the input voltage is greater or equal to reference voltage , a programmable code will trigger stimulating pulses for electrotherapy treatment .see **Appendix D .**

the maximum output voltage that can be obtained from Arduino is 5 volt . But according to electrotherapy principles the advised stimulating amplitude or intensity is 9 volt so pulsed signal should be amplified .

4.3 Amplification Voltage Circuit :

As the main power supply voltage and the recommended stimulating intensity is 9volt , a rail to rail op-amp should be used . AD822N op-amp was used since it is rail to rail with a wide range of single supply voltage with several acceptable specifications as power supply rejection ratio , common mode rejection ratio , input offset current and other characteristics as illustrated in Appendix E .

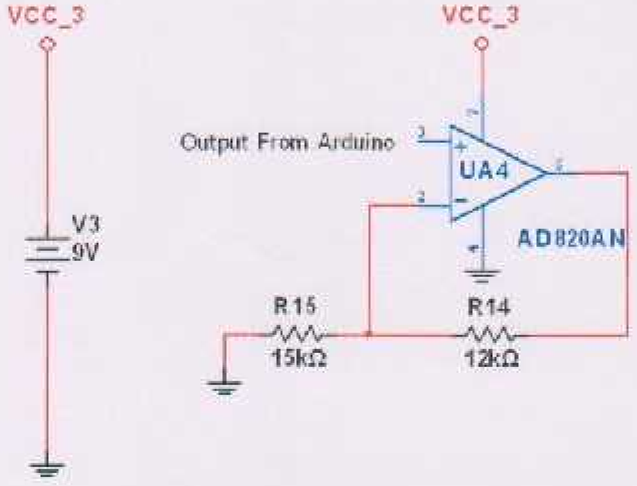


Figure 4.7: Amplification Voltage Circuit .

For Vout =9volt , with Vin =5volt from Arduino :

$$G = \frac{Vout}{Vin}$$

$$G = \frac{9}{5}$$

$$G = 1.8 .$$

$$vout = \left(1 + \frac{Rf14}{R15}\right) \times Vin$$

$$\text{Let } R = 15k\Omega$$

$$Rf3 = 12k\Omega$$

4.4 Power Supply Level Detection Circuit :

- Magnitude of supply voltage have to be checked to insure providing op-amps with the required input voltage (Vcc =9 volt) . see figure 4.8. this circuit was designed to provide a visible alarm when supply voltage "9V" decreases for less than 5 volt .

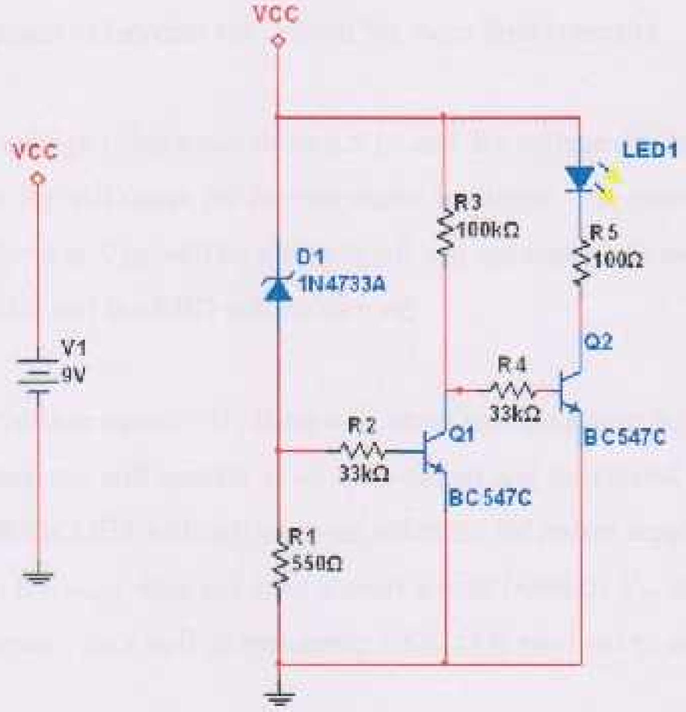


Figure 4.8 : Power Supply Level Detection Circuit of 9 Volt .

- According to **Appendix C** , for zener diode to drive it with the suitable current , Rz = 500Ω .

- According to **Appendix F**, for both transistors BC547C the minimum and maximum base current are 125μA & 909 μA respectively . So bias resistor can be determined within the range as illustrated below .

$R_{min} = \frac{Vmax - Vdiode}{Imax} = \frac{9-0.7}{909\mu A} = 9.1$ KΩ .

$R_{max} = \frac{Vmax - Vdiode}{Imin} = \frac{5-0.7}{125\mu A} = 34.4$ KΩ .

We choose R_{bias} to be 33 KΩ .

- for the Yellow LED , the required current for it is 20mA and forward voltage is 1.83V . It is required to make the LED turn on when the power supply voltage drop less than 5 volt , as a result LED resistance equal :

$R_{led} = \frac{5.1-1.83}{20} = 163.5\ \Omega$.

100 Ω was chosen to increase the current for more light intensity .

- when supply voltage is between 9v and 5.1v and by voltage divider , the voltage across Rz will cause the first transistor to switch . At saturation region $I_C = I_E = 0$ & V_{CE} will be a very small and not enough to switch on the second transistor and the LED will be turn off .

- when supply voltage equals 5V , there will be no voltage across Rz terminals so the first transistor will operate as an open circuit and the second one will be switched on & the LED will turn on as an indicator for power supply dropping . In this case , if $R_{100k\Omega}$ does not exist a short circuit between V_{cc} and the ground will occur . So a pull up resistance 100K Ω is required to avoid that .

- FlexiForce supply voltage have to be checked to insure delivering it -5 volt by negative supply voltage -9 volt. see figure 4.9.

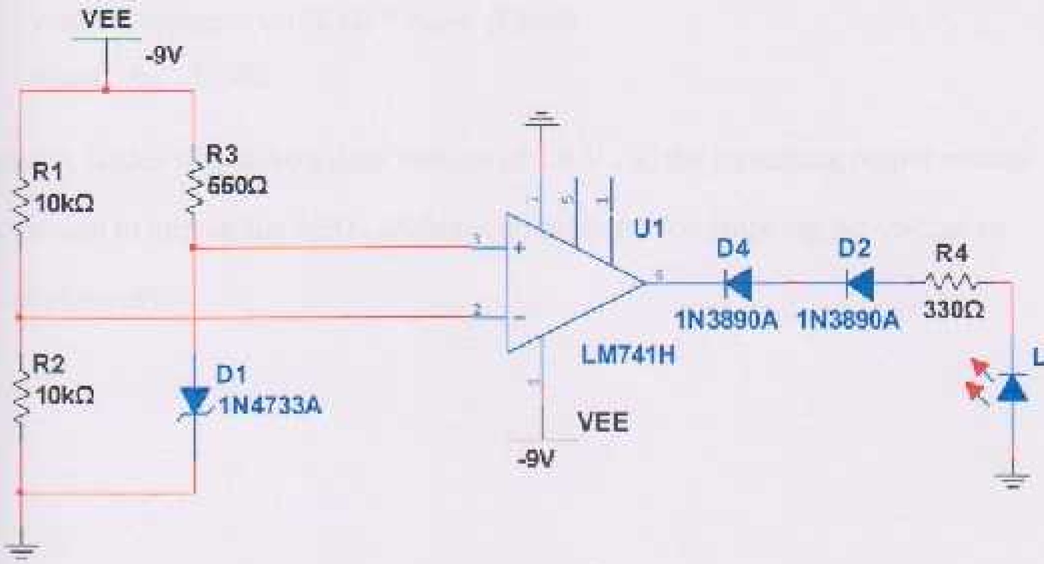


Figure 4.9 :Power Supply Level Detection Circuit of - 9 Volt .

For zener diode 1N4733A voltage regulator -5 volt . in order to operate onreversebiasregion it should be supplied with greater than -5 volt . LM741 comparator was used to control LED lighting to express power supply level according to comparator principle of operation , output of comparator depend on the difference of the two inputs "inverting and non inverting" .

- When power supply value is greater than -5 volt , suppose -9 volt . the comparator inverting input will equal - 4.5 volt and non inverting input by voltage divider equals -5 volt . so the difference between the two inputs is negative ,so the output will be (-vsat) and LED light is activated ,

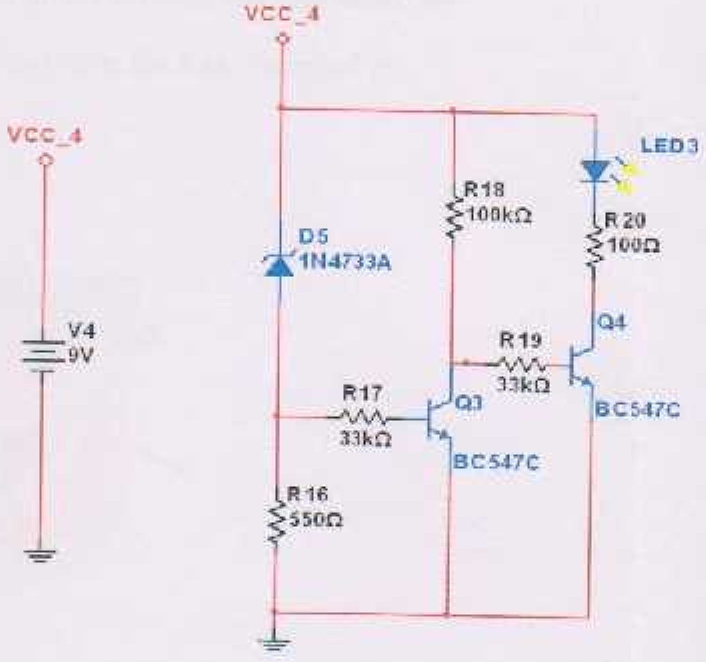
vout = (-vzener – v 10KΩ) * A_{ol} = -7volt
where A_{ol} = 20000.

- When power supply value is less than or equal -5 volt , suppose -5 volt .the comparator inverting input will equal -2.5 volt and non inverting input by voltage divider equals -4.4 volt .

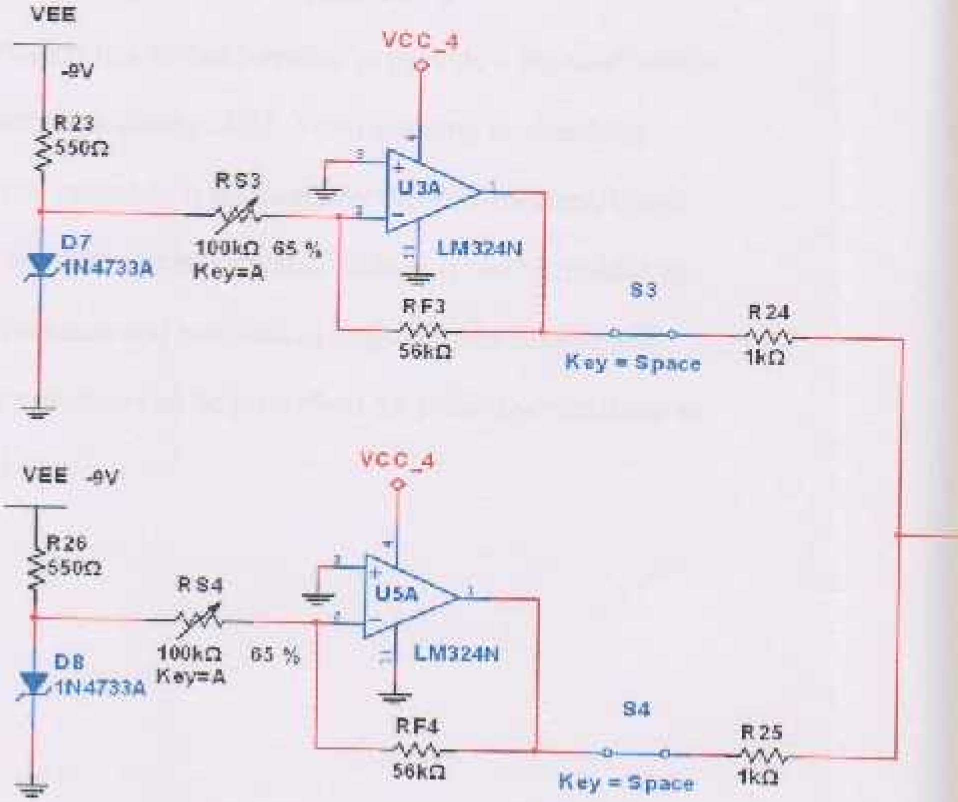
  $vout = (-vzener - v\ 10K\Omega) * A_{ol} = -3.8volt$

  where $A_{cl} = 20000$.

But silicon diodes will make a drop voltage of 1.4 V , so the remaining output voltage is not enough to turn on the LED , so this is an indicator for dropping the voltage of the power supply .

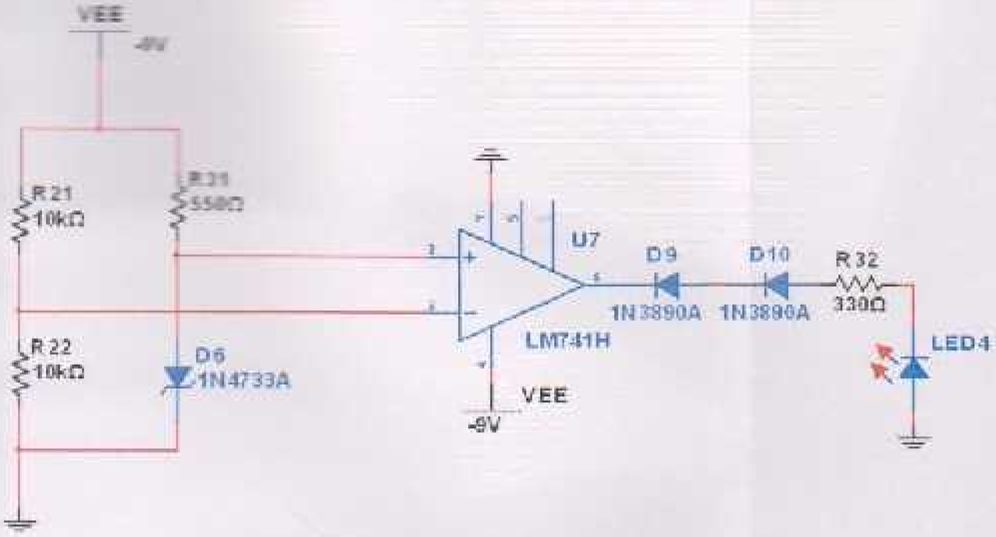


Circuit #1 : Simple Low - Battery Level Circuit of 9 volt .

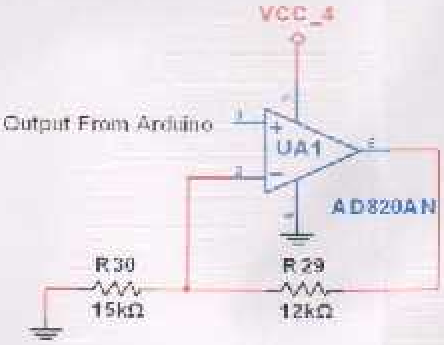


Ciruit #3 : Flexi Force Sensor Conditining Circuit (Average Output) .

Figure 4.10 :Schen



Circuit #2: Simple Low - Battery Level Circuit of -9 volt .



Circuit #4 : Voltage Amplification (Therapy).

).

chematic Diagram

4.5 Oral Design :

The force sensors will be located within Night guard molding and distributed on teethsurfaces that are responsible for generating biting force as illustrated in Figure 4.11.

Figure 4.11: Teeth Generating Force .

- **Night Guard (Manufacturing and biocompatibility)**

Dental mouth guard for bruxism is a device intended to provide a physical barrier between the upper and the lower teeth during night .Teeth grinding or clenching . Night guard is made from silicon material . It is inherently flexible, resilient, tough, and show excellent resistance toenvironmental stress cracking . it can be molded to many different sizes , shapes thickness and hardness to make it more durable and comfortable for the patient .The product can be prescribed for either the maxillary or mandibular arch . See Figure 4.12.

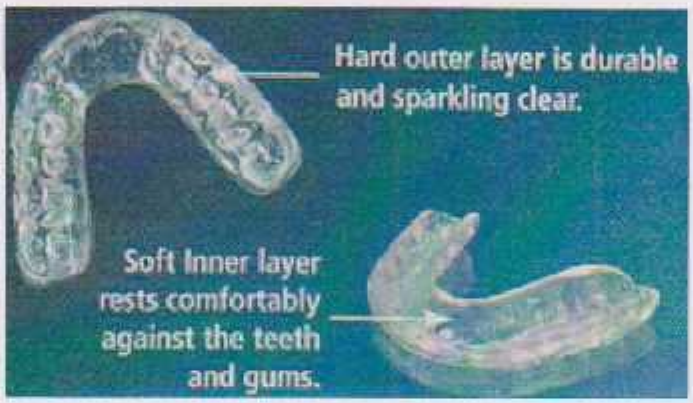


Figure 4.12 : NightGuard's HardnessLevels .

This material is stable and does not have any chemical reaction with bio fluids such as saliva .Safety, genotoxity, irritation, toxity ,and cytotoxicity have been performed on this product to demonstrate not causing any unacceptable side effects .Force sensors werefixedinside a similar design to night guard geometry . theshapewill take the samepatient's oral cavity structure to guarantee avoiding movements artifacts that can cause discomfort for the patient and to reduce losses in the generated force between teeth .see figure4.13& figure 4.14

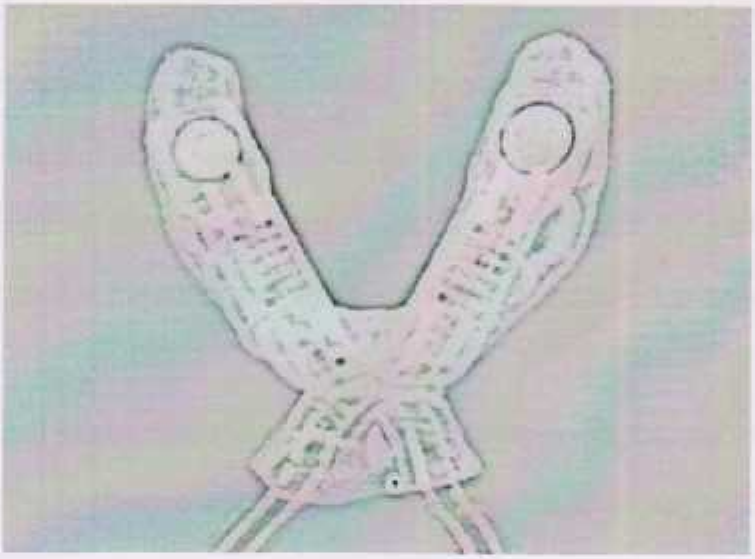


Figure4.13 : Bruxism Detection Prototype During Night .

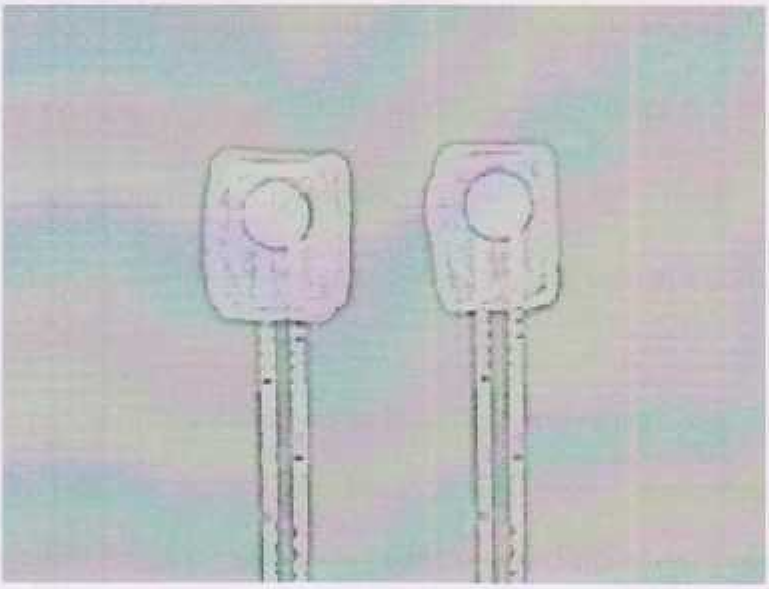


Figure4.14 : Bruxism Detection Prototype During Midday .

4.6 Electrotherapy Treatment :

4.6.1 Electrotherapymodes :

Electrotherapy treatment will be used in order to reduce the side effects of bruxismBy muscle relaxation mechanism . As the most common used stimulating signal is a square pulsed one , timer 555 can be used to generate this type of signal , But there was an obvious difficulty in adjusting the characteristics of these signals such as frequency and pulse width since they are varying quickly with respect to time .Arduino programming is used to stimulate treatment signal by depending on theprevious electrical circuits .the output voltage from summation amplifier will control triggering the pulsed signal from Arduino by specific programming code .

The pulsed signal parameters will satisfy electrotherapy principles and modes . Frequency , pulse width and amplitude will be controlled according to TENS 3000 Device .[31]

there are several modes that this device can provide , the most common used are :

- Normal mode :the frequency and pulse width remain constant during treatment period . A frequency of 90Hz and a pulse width of 0.15 ms will be chosen according to physiotherapist .
- Modulation mode : frequency and pulse width will vary in a periodic form [31].

Electrotherapy period differs from patient to another according to the pathological level that the she/he suffer from . In most cases , electrotherapy treatmentcanapplied for 15 minutes up to 30 minutes and signal can be translated through electrodes .

4.6.2Electrodes :

stimulating current will be sent by two pairs of electrodes which have to be located in check muscles at both sides of the mouth .In general we have two kind of electrodes , unipolar and bipolar . bipolar recordings measure the bioelectric potential difference between adjacent pairs of electrodeswhereas unipolar electrodes measure thebioelectric potential difference between each electrode and a common indifferent reference .

One significant advantage of unipolar is that the potential difference is recorded irrespective of the orientation of the advancing wave front . bipolar recording contrast are directionally sensitive , such that the voltage gradient detected is dependent on the orientation of the wave front relative to the electrode pair . bipolar electro gram offers noise reduction advantages (when noise occur simultaneously in a bipolar electrode pair , they cancel each other) .

In our project we will use unipolar Ag/AgClelectrode . The silver/silver-chloride electrode is by far the most common type of electrode used in research and industry due to its simple construction. It has a low impedance so it will not affect the potential of the original signal .The reference electrode must have a high exchange current density, must be reversible and non-polarizeable. These properties will allow exchange of charge between the electrode-electrolyte interface due to electrochemical reactions and other environmental factors without significantly changing the electrode potential .

In order to guarantee minimizing noise signal , through our work we have to take into consideration electrode area and the placement site.[32]

Chapter 5 : Software Design

Programming process for the project was build through the use of Arduino software to control the treatment modes and time in order to be applied later to the patient to achieve facial muscle relaxation for the bruxist . The result of the hardware design and the parameters of treatment are displayed at a 16x4 liquid crystal display, which supports the project requirements .

5.1 Liquid Crystal Display

LCD (Liquid Crystal Display) screen is an electronic display module and have a wide range of applications. 16x4 LCD display is very basic module and is very commonly used in various devices and circuits . [33]

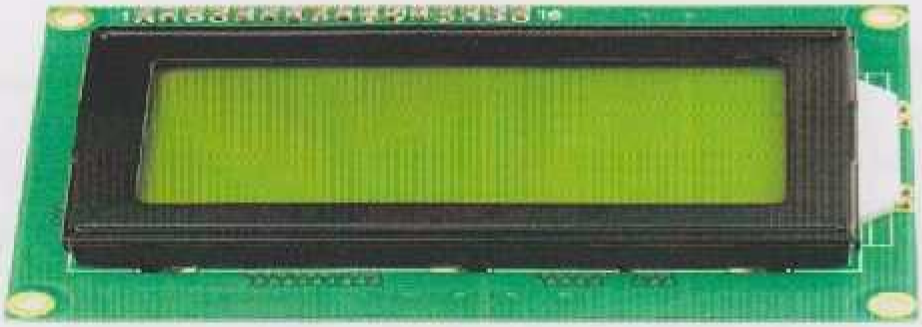


Figure 5.1: 16x4 LCD display .

Dimensions :

- Width : 3.45 inches or 87mm .
- Height : 2.35 inches or 60mm .
- Display : view size 62mm x 26mm

Table 5.1 : LCD Pins Configuration .

Pin Number	Symbol	Level	Description
1	VSS	0V	Ground
2	VDD	5V	Supply Voltage for logic
3	VO	(Variable)	Operating voltage for LCD
4	RS	H/L	H: DATA, L: Instruction code
5	R/W	H/L	H: Read ,L: Write
6	E	H,H->L	Chip enable signal
7	DB0	H/L	Data bus line
8	DB1	H/L	Data bus line
9	DB2	H/L	Data bus line
10	DB3	H/L	Data bus line
11	DB4	H/L	Data bus line
12	DB5	H/L	Data bus line
13	DB6	H/L	Data bus line
14	DB7	H/L	Data bus line
15	A	5V	LED +
16	K	0V	LED-

5.2 Arduino Mega - 2650 :

Arduino is an open-source physical computing platform based on a simple I/O board and a development environment that implements Processing language . The open-source Arduino environment makes it easy to write code and upload it to the I/O board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java , C, and other open source software .

The Arduino Mega is a microcontroller board based on the ATmega2650. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started . It can operate on (7-12) voltage supply ,with a 16Mhz Clock Speed . [34]

Figure 5.2 : Arduino Mega 2650 .

The main parts :

1-The ATmega processor : Main IC " ATmega2650 .

2-Power (USB / Barrel Jack) :Every Arduino board needs a way to be connected to a power . source. The Arduino Mega can be powered from a USB cable coming from your computer or wall power supply that is terminated in a barrel jack.

3-Pins (5V, 3.3V, GND, Analog, Digital, PWM, AREF) : The Arduino has several different kinds of pins .

- **GND** : There are several GND pins on the Arduino, any of which can be used to ground

the circuit .

- **5V & 3.3V**: Most of the simple components used with the Arduino run happily off of 5 or 3.3 volts .

- **Analog** : The area of pins (A0 through A15) are" Analog In" pins . These pins can read the signal from an analog sensor and convert it into a digital value that we can read .
- **Digital**: 54 digital pins (0 through 53) . These pins can be used for both digital input and digital output .
- **PWM**: These pins act as normal digital pins, but can also be used for something called Pulse - Width Modulation (PWM)
- **AREF**: Stands for Analog Reference. It is sometimes used to set an external reference voltage (between 0 and 5 Volts) as the upper limit for the analog input pins.

Reset Button : Pushing it will temporarily connect the reset pin to ground and restart any code that is loaded on the Arduino .

Voltage Regulator: It controls the amount of voltage that is let into the Arduino board .

TX RX LEDs : TX is short for transmit, RX is short for receive. These LEDs will give us visual indications whenever the Arduino is receiving or transmitting data .

Power LED Indicator .

Flow Chart

This diagrammatic representation is helpful for programming the Arduino Mega 2650 First of all , initialize the values of sensors by declare each of them by a variable . According to serial software code and switches selection we will get right , left or average voltage value which related to force on these sides. If the voltage value is greater than the reference voltage value , this means that the patient is in Bruxism state ,then a suitable treatment mode and time will be selected to achieve facial muscle Relaxation .

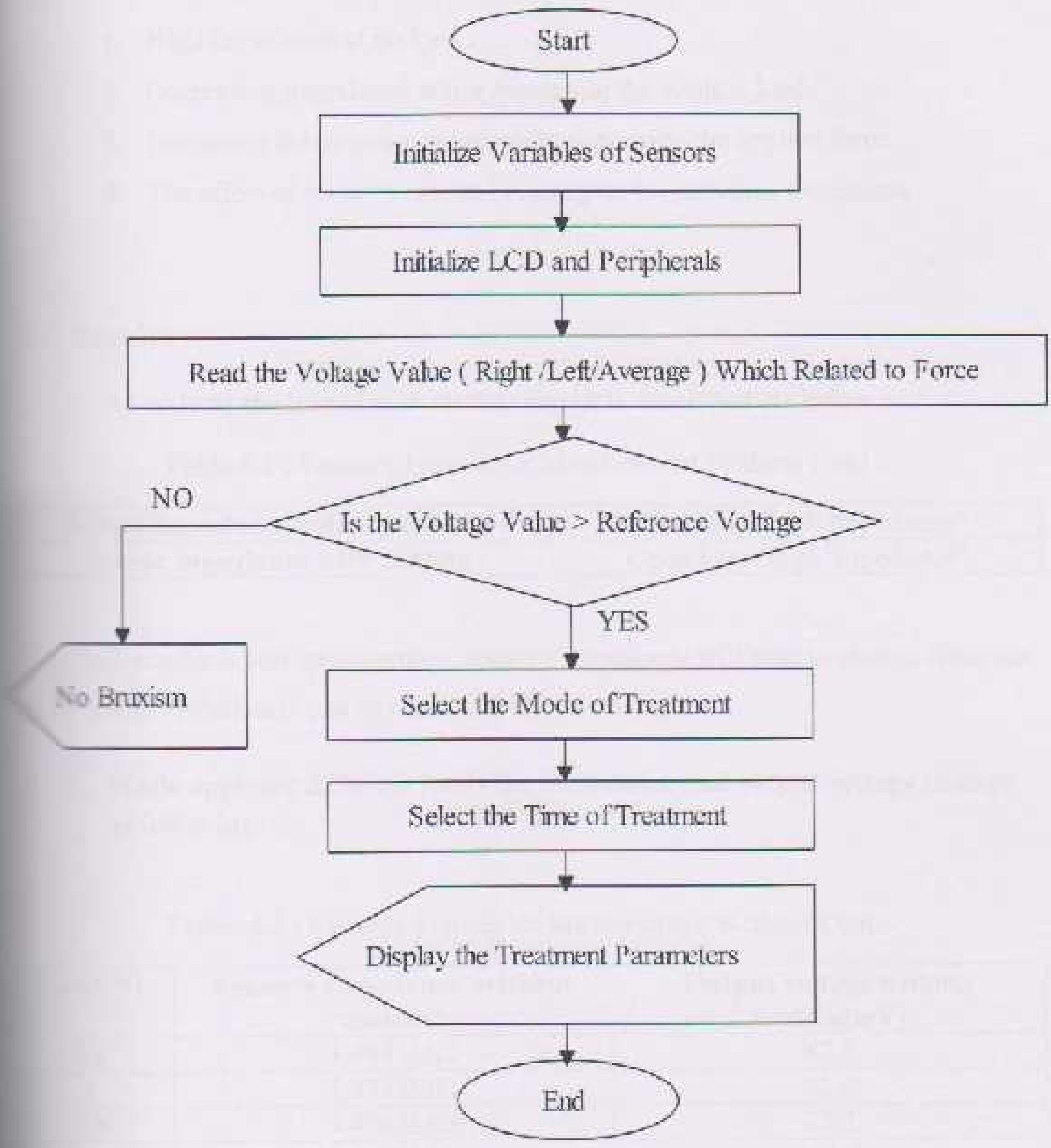


Figure 5.3 : Flow Chart .

Chapter Six : Results & Analysis

6.1Testing Flexi - Force Sensor 's specifications :

To achieve the best results or measurements from flexi force sensor , several parameters have to be tested :

1. High impedance at no load .
2. Decreasing impedance while increasing the applied load .
3. Increasing the output voltage while increasing the applied force .
4. The effect of sensor's external coating on the previous conditions .

6.2 Results :

1. **At no load the impedance measurement is described as below :**

Table 6.1 : Sensor's Impedance Measurement Without Load .

Sensor impedance without coating	Open loop "high impedance"
Sensor impedance with coating	Open loop "high impedance"

This will emphasis that with coating , sensor's impedance will start to change from the same initial impedance , as any sensor without coating .

2. **While applying different loads the impedance and output voltage change as following :**

Table 6.2 : Sensor's Impedance Measurement Without Coat .

Load(N)	Sensor's Impedance without coating*	Output voltage without coating(mV)
0.5	1.4887MΩ	87.6
1	1.4775MΩ	92.4
1.5	1.4663MΩ	97.2
2	1.4551MΩ	101.9
2.5	1.4438MΩ	106.7
3	1.4325MΩ	111.5

The results shows that the impedance decreases when increasing the applied load . Also , It is obvious that the sensor has a linear relationship between the applied force and the output voltage .

6.2.1Take into consideration :

It is important to determine the effect of coating material on the loses of the Real amount of force that is applied . Stiffness of this material has a major role in determining the amount of force that was neglected ." Young Modulus " or " Modulus of Elasticity " describes the relative stiffness or rigidity of a material , which is measured by the slope of the elastic legion of stress-strain .

Because the elastic modulus represents the ratio of the elastic stress to the elastic ,modulus . Modulus of elasticity is given in units of force per unit area, typically giganewtons per square meter (GN/m^2) , or gigapascals (GPa) .

Modulus of elasticity " E "can be expressed as :

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta l/l} = N/m^2 \text{ , where :}$$

σ : The stress .

ε : The strain .

F : The applied force or load .

A : The cross sectional area of the material under stress .

Δl : The increase in length .

l : The original length .

The most and common appropriate material to use in dental applications is silicon It has a young modulus of 0.0003GPa . In order to determine the real applied force with respect to the equation above , cross sectional area of the material and change in length must be taken into consideration .

The original length for silicon cover equals 4mm . Change in length is very small equals approximately 0.5 mm . so the real amount of force can be calculated as the following procedure :

Strain " σ " = $\frac{\Delta l}{l} = \frac{0.5mm}{4mm} = 0.125$

E for Silicon material is of 0.0003GPa or 0.0003×10^9 N/m^2 .

The cross sectional area of the material under stress with a diameter of 9.53 mm :

Sensing area "A" = πr^2

$= \pi \times (9.53 \times 10^{-3})^2 = 2.8 \times 10^{-4}\ m^2$.

So the amount of the applied force :

$$F = E \times \sigma \times A$$

$$= 0.0003 \times 10^9\ N/m^2 \times 0.125 \times 2.8 \times 10^{-4}\ m^2$$

$$= 10.5\ N \text{ or } \approx 2.4\ lb$$

This amount of force must be added to the original amount that was represented by voltage values .

$$\text{Total amount of force} = F_{original} + F_{coating}$$

$$\mathbf{F} = (23.50 \times Vout - 1.903) \times 4.448\ N + 10.5\ N$$

6.3 Normal Biting Force :

Table 6.3 : Voltage & Force Values Analogous To Normal Biting Force .

Right side force (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient Comment
2.52	57.33	59.73	1.96	44.2	46.6	**Female**	**Right** side is more used in normal life
2.35	53.3	55.7	2.18	49.3	51.7	**Female**	**Right** side is more used in normal life
[illegible]	41.3	43.7	2.12	47.9	50.3	**Female**	**Right** side is more used in normal life
2.36	65.3	67.7	2.57	58.5	60.9	**Female**	**Right** side is more used in normal life
1.9	42.7	45.1	2.46	55.9	58.3	**Male**	**Left** side is more used in normal life
2.79	63.7	66.1	2.72	62.03	64.43	**Male**	Right **side is more used in normal life**
2.18	49.3	51.7	2.04	46.04	48.44	**Male**	Right **side is more used in normal life.**

In order to diagnosis bruxism , biting force should be measured for normal people and for bruxist . Table 6.3 shows the output voltage for both sides of mouth with their corresponding force values for both genders .

The relation between voltages and their corresponding force values for both side of mouth was drawn using " On Line Curve Fitting" [35]. Represented in graph 6.1 & 6.2

- **For Right Side :**

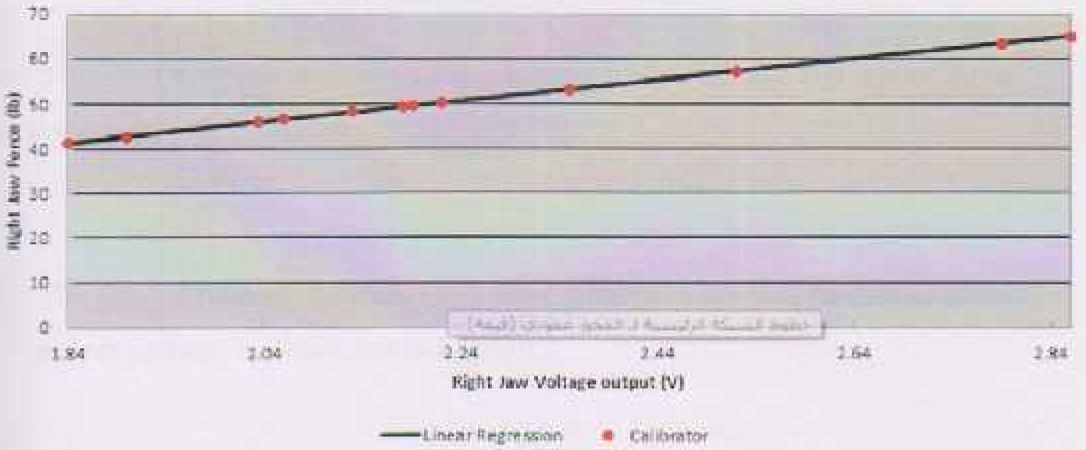


Figure 6.1: Right Side Of Jaw Force (lb) With Output Voltage (V) .

The following equation describe the relationship between the force (Y) in lb unit with the output voltage (X) from Flexiforce Sensor circuit for right side .

$$Y(lb)= 23.53318* X- 1.976947 .$$

- **For the Left Side :**

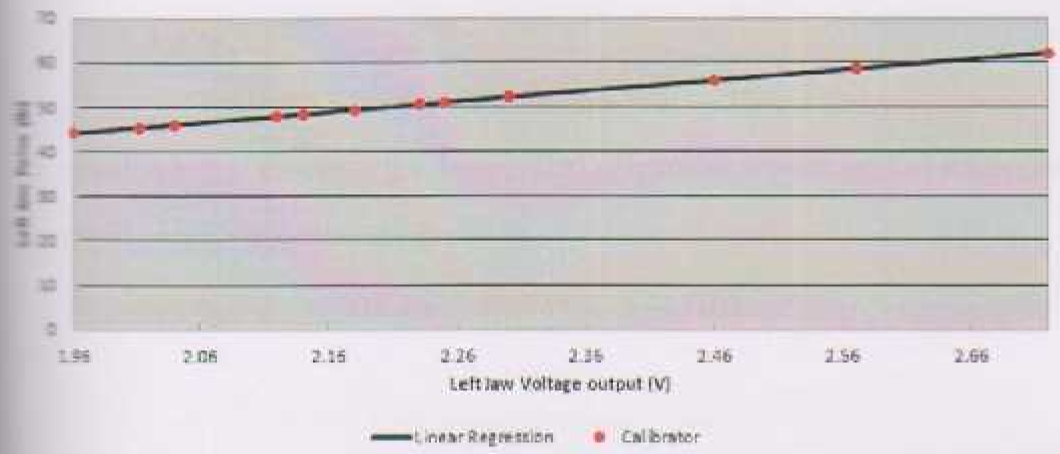


Figure 6.2 : Left Side Of Jaw Focce (lb) With Output Voltage (V) .

The following equation describe the relationship between the force (Y) in lb unit with the output voltage (X) from Flexiforce Sensor circuit for left side .

$$Y(lb)= 23.50273* X- 1.90308$$

It is obvious that the most common used side has a higher voltage and higher force which is the right side .

- The general relation between force from different loads and flexiforce circuit output voltage is illustrated in figure 6.3.

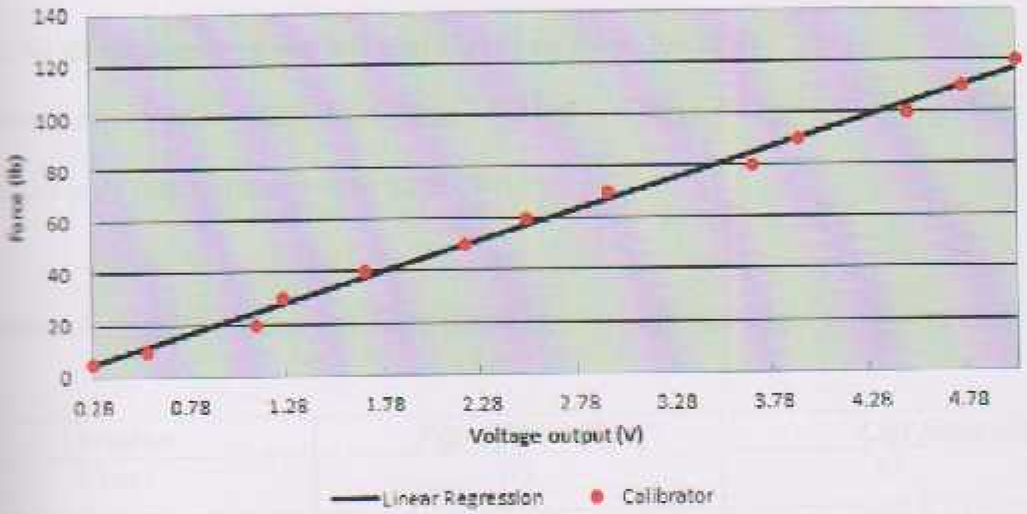


Figure 6.3 : Output With Voltage With Different Loads .

The equation below describes the linear relation between several applied loads and the output voltage from flexiforce circuit .

$$Y(lb)= 23.52178* X- 1.948102 .$$

6.4 Statistical Analysis :

Statistical analysis was performed using SPSS 16.0 software packages . Comparison of means between the simulated results and the actual results was made using paired sample T-test. The t-test tells us if the variation between the means of two groups of "results is " significant . Readings were taken for measurement teeth force of a Group (45 male and 45 female) of young people and their age from 19 to 23 years . Also reading were taken for 13 bruxsers patient and their reference value for teeth force is about 500N . See **Appendix G**

6.5 Results of Statistical Analysis :

6.5.1 The difference between left and right jaw force for male

The first comparison between the right and the left jaw force for male, by using some statistical tests that summarized in table (6.4) .

Table 6.4: Statistical Analysis Tests Between The Left And Right Jaw Force For Male

Variables	*Right force (lb)*	*Left force (lb)*
Count	45	45
Mean value	59.3989 (M_1)	54.2662 (M_2)
Standard Deviation	22.21907 (SD_1)	24.83102 (SD_2)
Std. Error Mean	3.31222	3.70159
Paired Samples Confidence –Limits of Difference Section		
Pair Variables	**Right force – Left force**	
Mean difference	5.13267	
Standard Deviation of difference	19.79490	
Paired Sample , Tow –Samples T-Test (H_0:M_1=M_2 versus H_1:M_1<M_2)		
Variance Assumption	Equal	Unequal
DF	44	44
T-value	1.739	1.739

P-Value of T-test	0.089	0.089
Accept H1 at 5.0% Significant?	NO	NO
Paired Sample Correlations		
Correlation Coefficieat (R)	0.651	
Squared Correlation Coefficient (R^2)	0.4238	
Prob-level (P-Value)	0.000	

The mean value of the right force and left force was 59.3989 ± 3.31222 and 54.2662 ± 3.70159, respectively. The previous statistical analysis demonstrated that there is no statistically significant difference between the mean right force value and the value of mean left force (T-value = 1.739 and P-value = 0.089) . There was significant correlation between right force and left force (R= 0.651, R2= 0.4238 and P = 0.000) .

6.5.2 The difference between left and right jaw force for female :

The second comparison between the right and the left jaw force for female , by using some statistical tests that summarized in Table (6.5) .

Table 6.5 : Statistical Analysis Tests Between The Left And Right Jaw Force For Female

Variables	*Right force (lb)*	*Left force (lb)*
Count	45	45
Mean value	44.5778 (M_1)	44.2344 (M_2)
Standard Deviation	21.47491 (SD_1)	20.41545 (SD_2)
Std. Error Mean	3.20129	3.04336
Paired Samples Confidence –Limits of Difference Section		
Pair Variables	**Right force – Left force**	
Mean difference	0.34333	
Standard Deviation of	21.70741	

difference		
Paired Sample , Tow –Samples T-Test (H_0:M_1=M_2 versus H_1:M_1<M_2)		
Variance Assumption	Equal	Unequal
DF	44	44
T-value	0.106	0.106
P-Value of T-test	0.915	0.915
Accept H1 at 5.0% Significant?	NO	NO
Paired Sample Correlations		
Correlation Coefficient (R)	0.464	
Squared Correlation Coefficient (R^2)	0.2153	
Prob-level (P-Value)	0.001	

The mean value of the right force and left force was 44.5778 ± 3.20129 and 44.2344 ± 3.04336, respectively. The previous statistical analysis demonstrated that there is no statistically significant difference between the mean right force value and the mean value of left force (T-value = 0.106 and P-value = 0.915). There was significant correlation between right force and left force for female (R= 0.464, R2= 0.2153 and P = 0.001) . According to the previous analysis we find maximum bite force is higher in males than females. The greater muscular potential of the males may be attributed to the anatomic differences .The masseter muscles of males have type 2 fibers with larger diameter and greater sectional area than those of the females .The authors have suggested that hormonal differences in males and females might contribute to the composition of the muscle fibers In addition, the correlation of maximum bite force and gender is not evident up to age 18. It is apparent that maximum bite force increases throughout growth and development without gender specificity. During the post-pubertal period, maximum bite force increases at a greater rate in males than in females and thus becomes gender-related[36]

6.5.3 The difference between left force of male and left force for female :

The third comparison between the left force of male and left force for female , by using some statistical tests that summarized in Table (6.6) .

Table 6.6 : Statistical Analysis Tests Between Left Force Of Male And Left Force For Female .

Variables	*Left male force (lb)*	*Left female force (lb)*
Count	45	45
Mean value	54.2662 (M_1)	44.2344 (M_2)
Standard Deviation	24.83102 (SD_1)	20.41545 (SD_2)
Std. Error Mean	3.70159	3.04336
Paired Samples Confidence –Limits of Difference Section		
Pair Variables	*Left male force - Left female force*	
Mean difference	1.00318E1	
Standard Deviation of difference	28.02997	
Paired Sample , Tow –Samples T-Test (H_0:M_1=M_2 versus H_1:M_1<M_2)		
Variance Assumption	Equal	Unequal
DF	44	44
T-value	2.401	2.401
P-Value of T-test	0.021	0.021
Accept H1 at 5.0% Significant?	YES	YES
Paired Sample Correlations		
Correlation Coefficient (R)	0.244	
Squared Correlation Coefficient (R^2)	0.05954	
Prob-level (P-Value)	0.106	

The mean value of the left male force and left female force was 54.2662 + 3.70159 and 44.2344 ± 3.04336, respectively. The previous statistical analysis demonstrated that there is statistically significant difference between the mean left male force value and the mean value of left female force (T-value = 2.401 and P-value = 0.021). There was no significant correlation between left male force and left force (R= 0.244, R2= 0.05954 and P = 0.106) .

6.5.4 The difference between right force of male and right force for female

The fourth comparison between the right force of male and right force for female , by using some statistical tests that summarized in Table (6.7)

Table 6.7 : Statistical Analysis Tests Between Right Force Of Male And Right Force For Female

Variables	*Right male force (lb)*	*Right female force (lb)*
Count	45	45
Mean value	59.3989 (M_1)	44.5778 (M_2)
Standard Deviation	22.21907 (SD_1)	21.47491 (SD_2)
Std. Error Mean	3.31222	3.20129
Paired Samples Confidence –Limits of Difference Section		
Pair Variables	*Right male force – Right female force*	
Mean difference	1.48211E1	
Standard Deviation of difference	30.54159	
Paired Sample , Tow –Samples T-Test (H_0:M_1=M_2 versus H_1:M_1<M_2)		
Variance Assumption	Equal	Unequal
DF	44	44
T-value	3.255	3.255
P-value of T-test	0.002	0.002
Accept H1 at 5.0% Significant?		
Paired Sample Correlations		
Correlation Coefficient (R)	0.023	
Squared Correlation Coefficient (R^2)	0.000529	

Sig-level (P-Value)	0.880

The mean value of the right male force and right female force was 59.3989 ± 3.31222 and 44.5778 ± 3.20129, respectively. The previous statistical analysis demonstrated that there is statistically significant difference between the mean right male force value and the mean value of right female force (T-value = 3.255 and P-value = 0.002). There was no significant correlation between right male force and right female force (R= 0.023, R2= 0.000529 and P = 0.880) .

6.5.5 The difference between right force of female and left force for male :

The fifth comparison between the right force of male and right force for female , by using some statistical tests that summarized in table (6.8) .

Table 6.8 : Statistical analysis tests between right force of Female and Left force for male .

Variables	*Right female force (lb)*	*left male force (lb)*
Count	45	45
Mean value	44.5778 (M_1)	54.2662 (M_2)
Standard Deviation	21.47491 (SD_1)	24.83102 (SD_2)
Std. Error Mean	3.20129	3.70159
Paired Samples Confidence –Limits of Difference Section		
Pair Variables	*Right female force (lb)- left male force (lb)*	
Mean difference	-9.68844E0	
Standard Deviation of difference	34.09315	
Paired Sample , Tow –Samples T-Test (H_0:M_1=M_2 versus H_1:M_1<M_2)		
Variance Assumption	Equal	Unequal
DF	44	44
T-value	-1.906-	-1.906-
P-Value of T-test	0.063	0.063

Accept H1 at 5.0% Significant?	NO	NO
Paired Sample Correlations		
Correlation Coefficient (R)	-0.079-	
Squared Correlation Coefficient (R^2)	0.006241	
Prob-level (P-Value)	0.605	

The mean value of the right female force and left male force was 44.5778 ± 3.20129 and 54.2662 ± 3.70159, respectively. The previous statistical analysis demonstrated that there is no statistically significant difference between the mean right female force value and the mean value of left male force (T-value = -1.906- and P-value = 0.063). There was no significant correlation between right female force and left male force (R= -0.079-, R2= 0.006241 and P = 0.605) .

6.5.6 The difference between right force of male and left force for female :

The sixth comparison between the right force of male and left force for female , by using some statistical tests that summarized in table (6.9) .

Table 6.9 : Statistical analysis tests between right force of male and Left force for Female .

Variables	*Right male force (lb)*	*left female force (lb)*
Count	45	45
Mean value	59.3989 (M_1)	44.2344 (M_2)
Standard Deviation	22.21907 (SD_1)	20.41545 (SD_2)
Std. Error Mean	3.31222	3.04336
Paired Samples Confidence –Limits of Difference Section		
Pair Variables	*Right male force (lb)- left female force (lb)*	
Mean difference	1.51644E1	
Standard Deviation of difference	28.43509	
Paired Sample , Tow –Samples T-Test (H_0:M_1=M_2 versus H_1:M_1<M_2)		

Variance Assumption	Equal	Unequal
DF	44	44
T-value	3.577	3.577
P-Value of T-test	0.001	0.001
Accept H1 at 5.0% Significant?	YES	YES
Paired Sample Correlations		
Correlation Coefficient (R)	0.462	
Squared Correlation Coefficient (R^2)	0.213444	
Prob-level (P-Value)	0.112	

The mean value of the right male force and left female force was 59.3989 ± 3.31222 and 44.2344 ± 3.04336, respectively. The previous statistical analysis demonstrated that there is statistically significant difference between the mean right male force value and the mean value of left female force (T-value = 3.577 and P-value = 0.001) There was no significant correlation between right male force and left female force (R= 0.462, R2= 0.213444 and P = 0.112) .

6.6 Teeth Grinding Questionnaire

According to our visit to 30 Dentist , we make questionnaires and after well analysisto them we get the following results :

- When asking about the percentage of bruxers who visit the doctor monthly the doctors have varying answers . the percentage of bruxsers per month varying from 1% to 40% and reached up to 50% of the patients . But most doctors illustrated that 5 % per month visited then as shown in grey in figure 6.4 .

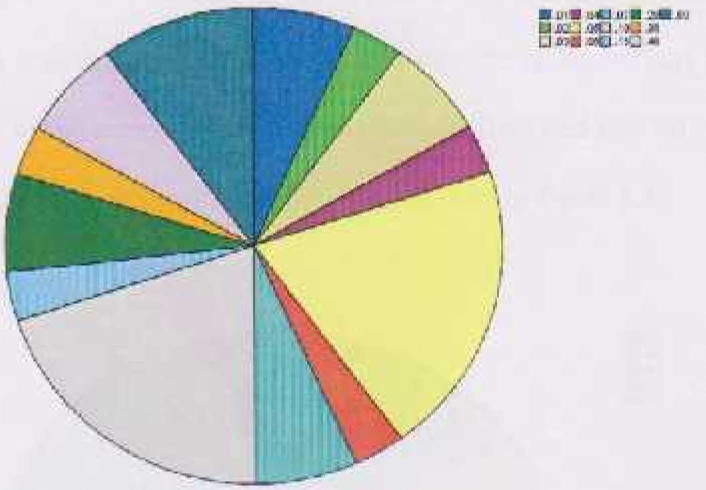


Figure 6.4 : Percentage of Bruxsers Visit the Doctor Monthly.

- When asking about who suffers from bruxism more than other according to the gender , the majority of doctors answers that female suffer from bruxism more than male as shown in figure 6.5.

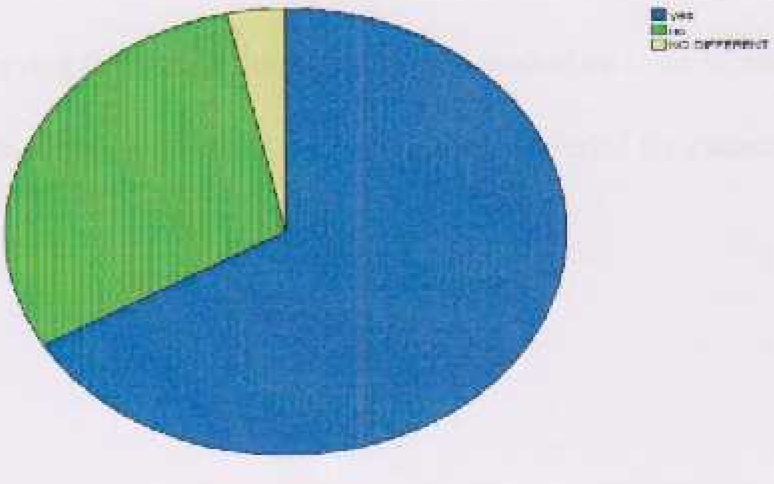


Figure 6. 5 : Female Suffer from Bruxism More than Male .

- When asking about the percentage of bruxsers who have noticeable improvement in their situation using medical drugs, the ratios varying between 20% up to 99% of the bruxisers . But most doctors illustrated that 80 % of patients get better using drugs . as shown in light blue in figure 6.6 .

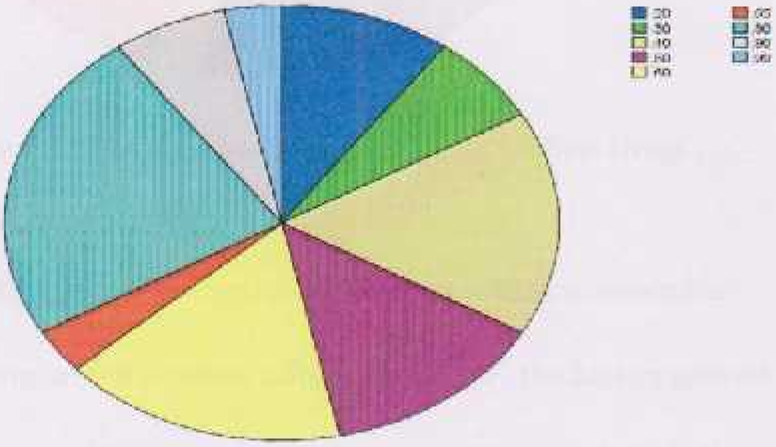


Figure 6.6 : Percentage of Bruxsers Who Have Noticeable Improvement in their Situation Using Medical Drugs .

- When asking about the period of treatment using medical drugs , the doctors answers varying from one to several weeks and reached up to six months . But most doctors illustrated that one month is a good period for treatment as shown in purple in figure 6.7 .

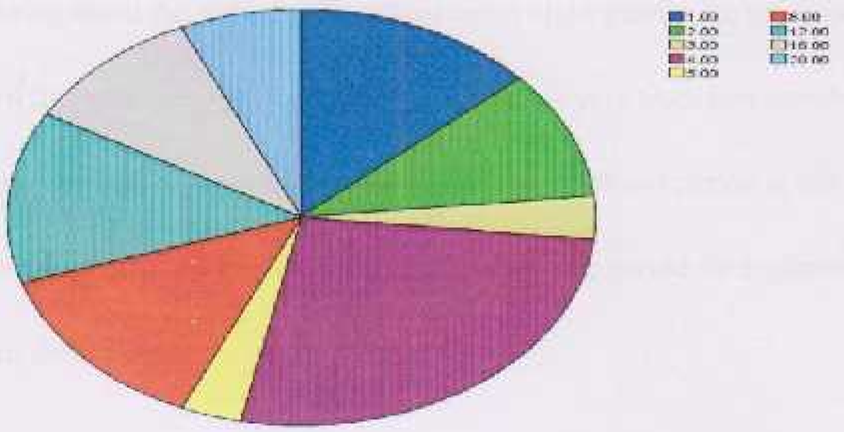


Figure 6.7 : The Period of Treatment Using Medical Drugs .

- When asking about the percentage of bruxsers who have noticeable improvement in their situation using night guards , the doctors answers varying between 1% up to 100% of bruxsers . But most doctors illustrated that 90 % of patients get better using night guard as shown in orange in figure 6.8 .

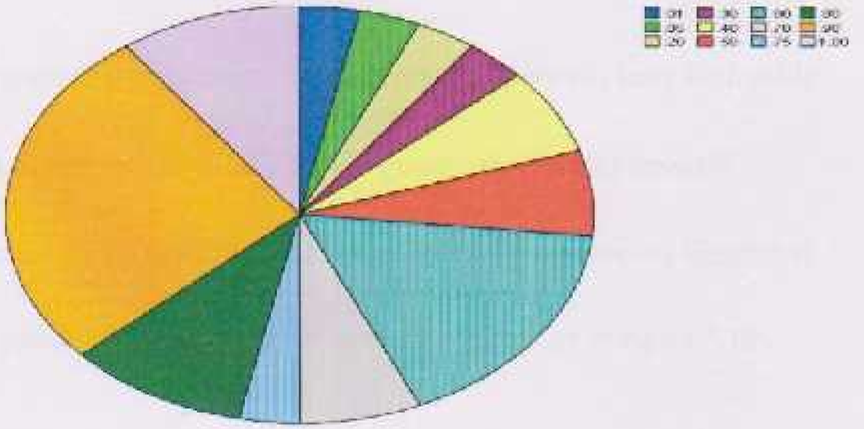


Figure 6.8 : Percentage of Bruxsers Who Have Noticeable Improvement in their Situation Using Night Guards .

- When asking about the period of treatment using night guard , we get a results as shown in figure 6.9. And the treatment period varying from two months up to one year and other doctors answers that the treatment period is life time But most doctors illustrated that one year is a suitable period for treatment as shown in dark green .

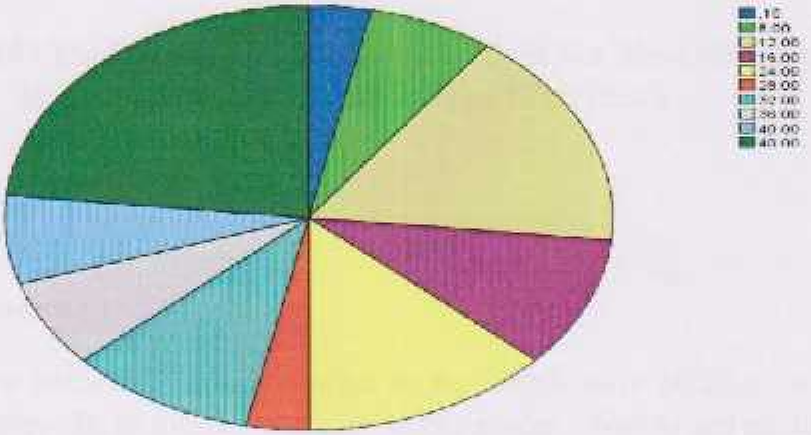


Figure 6.9 : The Period of Treatment Using Night Guard .

- When asking about the percentage of bruxesers who does not have noticeable improvement in their situation using night guard , the doctors answers varying between 1% up to 80% of the bruxsers . But most doctors illustrated that 20 % of patients did not get better as shown in orange in figure 6.10 .

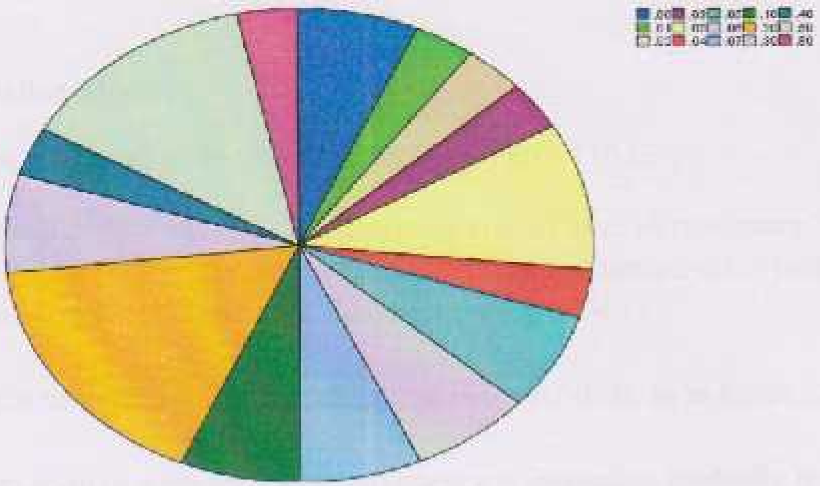


Figure 6.10 : The Percentage of Bruxsers Who Does Not Have Noticeable Improvement in their Situation Using Night Guard .

6.7 TENS Modes :

Through arduino software , signals similar to the TENS were obtained to achieve facial muscle relaxation in two modes , normal and modulation .

Normal Mode :

- In the normal mode , the stimulation signal is continuously within fixed frequency reaches to 90 Hz as in Figure.6.11.

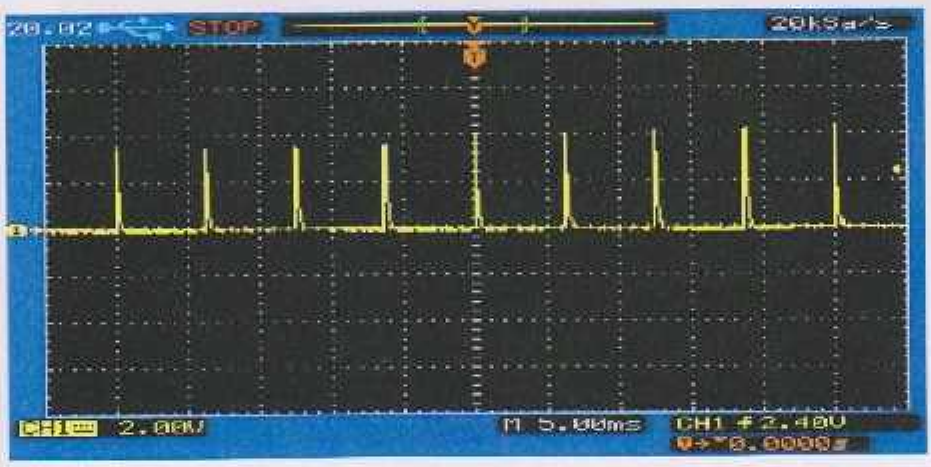


Figure 6.11 : TENS Normal Mode .

Modulation Mode :

There is varying in frequency in the range (60 – 150 Hz) .

- In the first four minutes , the frequency started from its maximum value 150 Hz then it decreases gradually from maximum value to the minimum value 60 Hz as in figure 6.12 & Figure 6.13 .
- in the fifth second , the frequency stabilizes at 60 Hz as in figure 6.14.
- from sixth to ninth second the frequency is increasing gradually from minimum value 60 Hz to maximum value 150 Hz as in figure 6.15& figure 6.16 .
- in the tenth second , the frequency stabilizes at maximum value 150 Hz as in figure 6.17.
- after the tenth second the signal will be repeated at the same procedure as in figure 6.18.

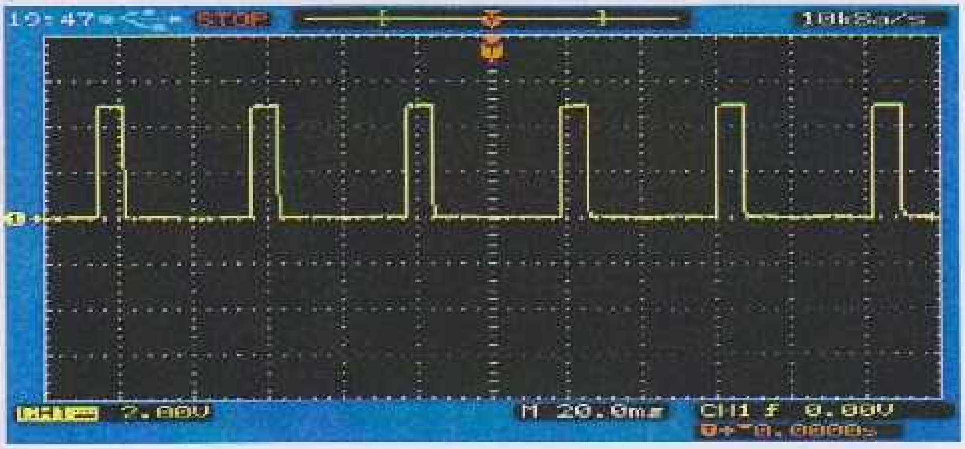


Figure 6.12 : TENS Modulation Mode

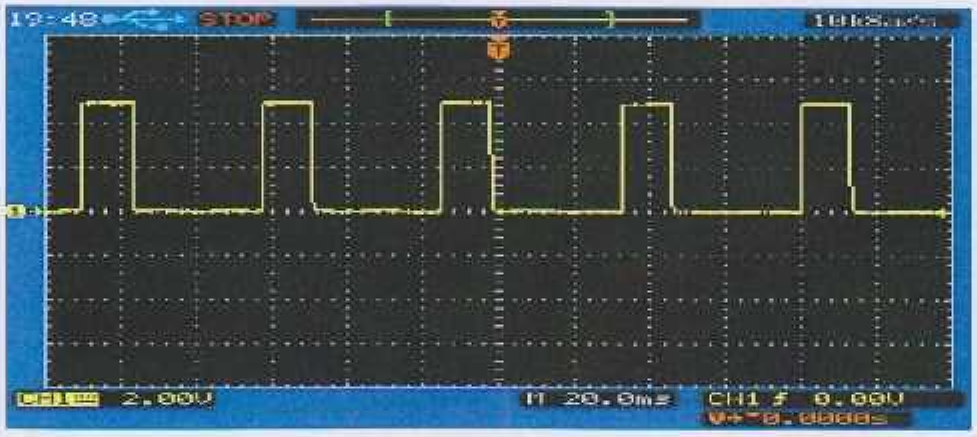


Figure 6.13 : TENS Modulation Mode .

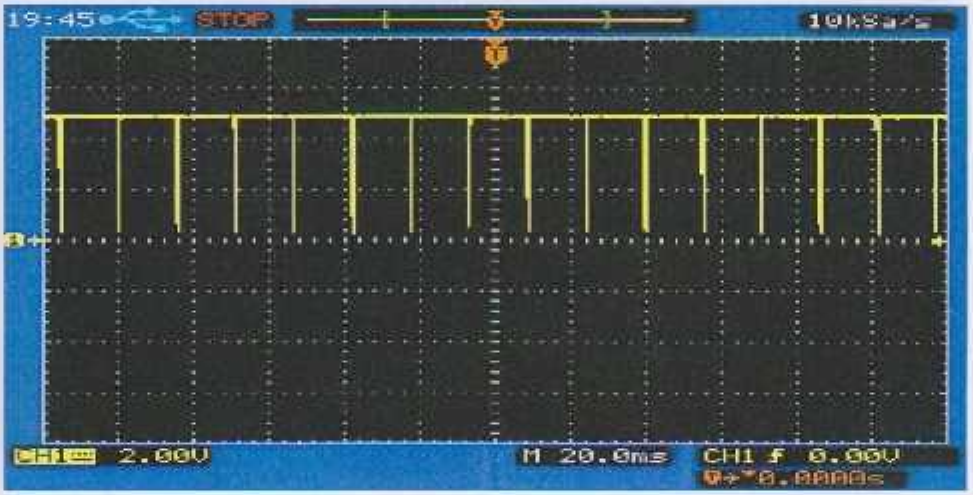


Figure. 6.14 : TENS Modulation Mode

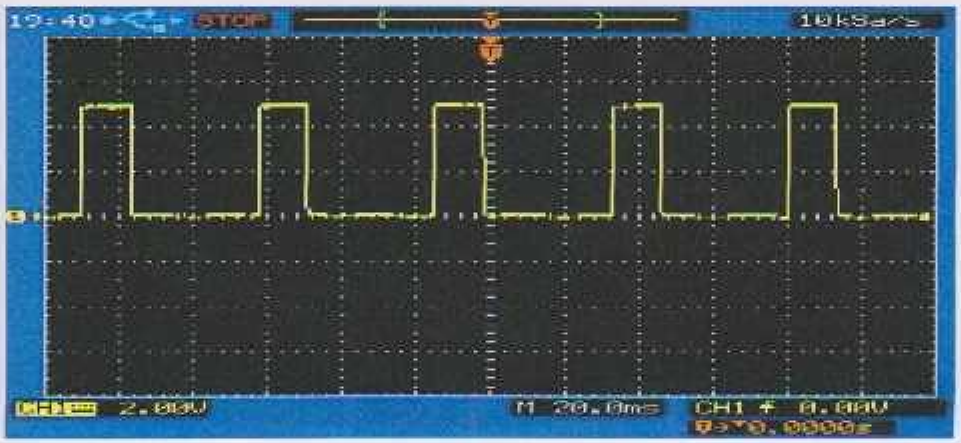


Figure 6.15 : TENS Modulation Mode

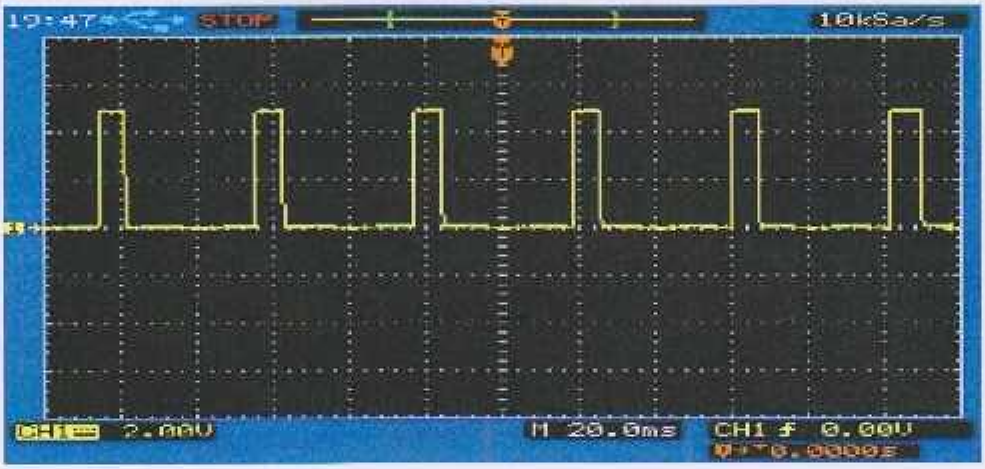


Figure 6.16 : TENS Modulation Mode .

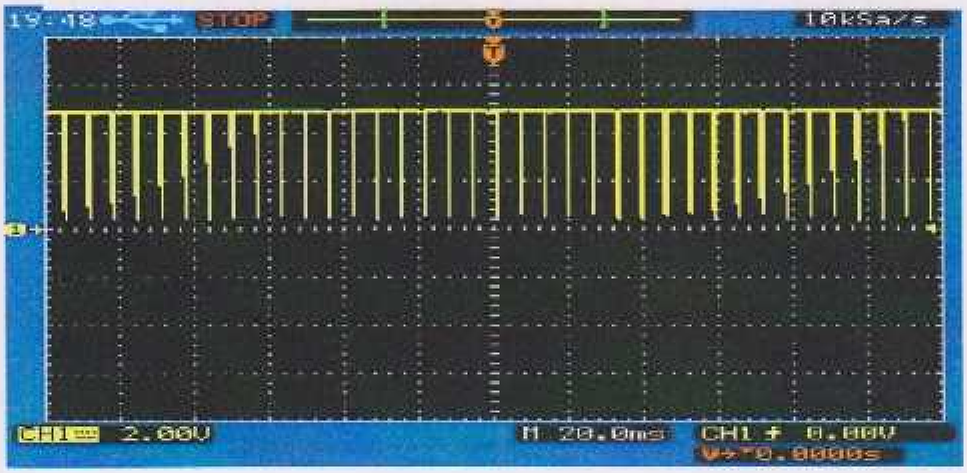


Figure 6.17 : TENS Modulation Mode

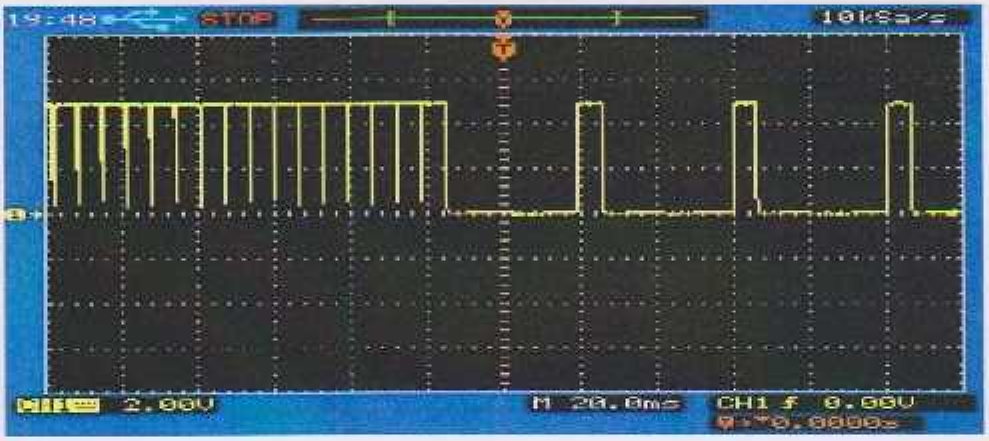


Figure 6.18 : TENS Modulation Mode .

6.8 Acquiring Stimulating Signal :

The output from Arduino has a magnitude of 5 volt , the signals for two modes were amplified as described in previous chapter . The amplified signals illustrated in figures below .

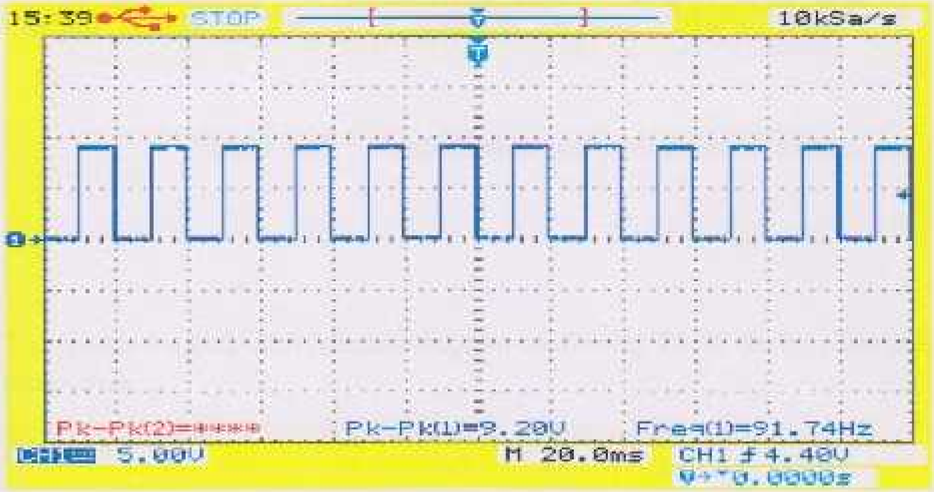


Figure 6.19 : Amplified Signal , Normal Mode .

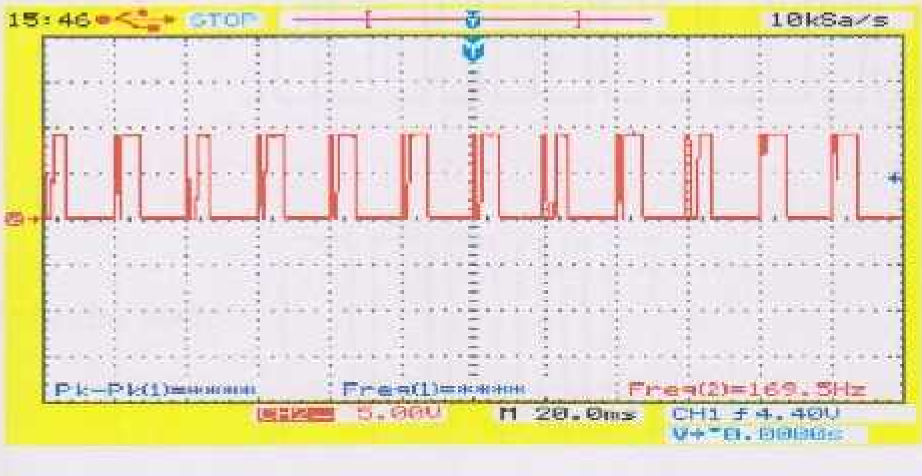


Figure 6.20 : . Amplified Signal , Modulation Mode .

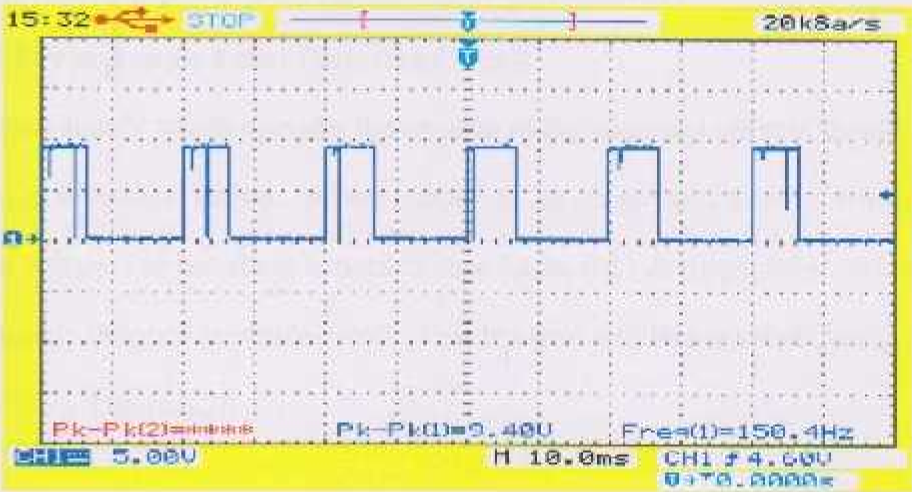


Figure 6.21 : Amplified Signal , Modulation Mode .

- The obtained signal from Arduino program confirming TENS device principle and parameters .

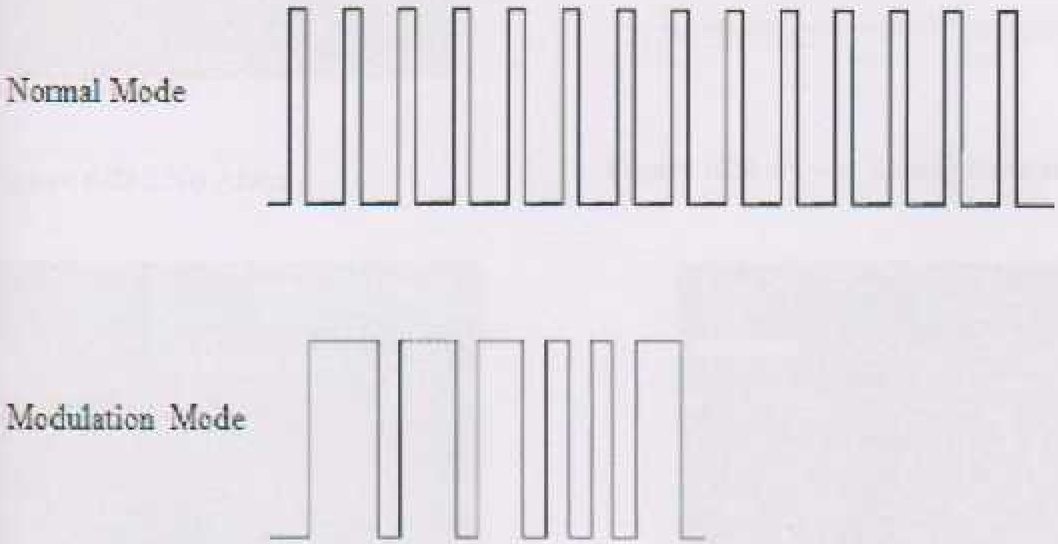


Figure 6.22 : TENS Device Stimulating Signal [37] .

6.9 Power Supply Level Detection Circuit Results

6.9.1 +9 Power Supply Level Detection Circuit

Power supply which operates the op-amp of the electrical circuits should be detected as illustrated before . power supply at the range from 9v – 5 v will give the required voltage . so no alarm is needed . see figure 6.23 & figure 6.24 . When power supply dropped less than 5 volt , visible alarm will be activated . see figure 6.25 & Figure 6.26 .

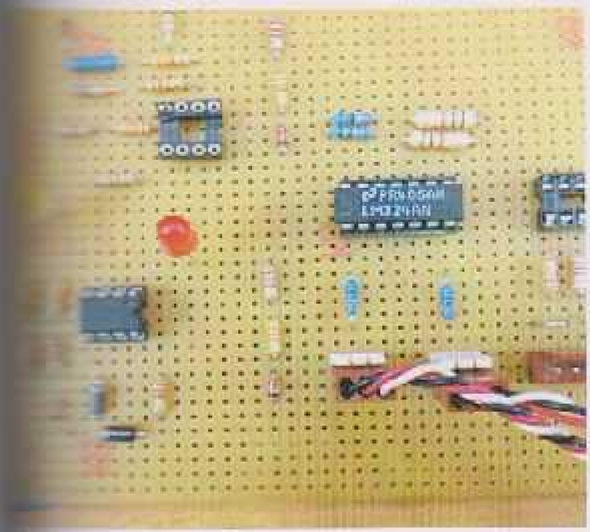


Figure 6.23 : No Alarm .

Figure 6.24 : Power Supply Greater Than 5V.

Figure 6.25 : Activated Alarm.

Figure 6.26 :.Power Supply Less Than 5V.

6.9.2 -9 Power Supply Level Detection Circuit :

Power supply which operates the force sensors of the electrical circuits should be detecteas illustrated before . A Red LED will be turn on while power supply is at the range from -9v to -5v . see figure 6.27 & figure 6.28 . When power supply dropped less than -5 volt .The LED will turn off as an indicator for a power supply which should be replaced see figure 6.29 & Figure 6.30.

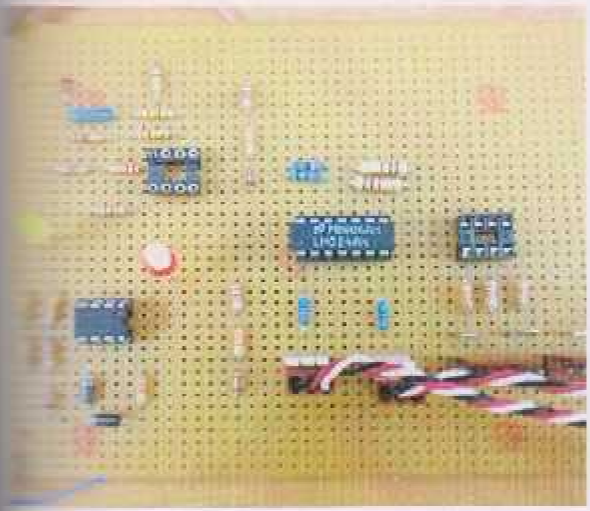


Figure 6.27 : LED Is Turn On .

Figure 6.28: Power Supply Greater Than -5V.

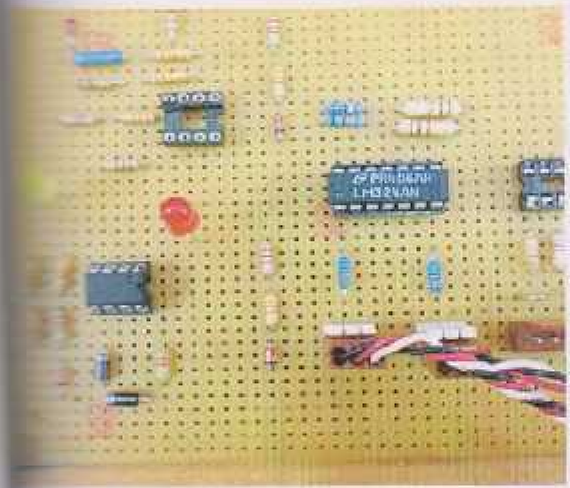


Figure 6.29 : LED Is Turn Off .

Figure 6.30 :Power Supply Less Than -5V.

Chapter Seven : Future Work & Recommendations

- Biting force was measured depending on third molars which are responsible for generating the main force . More accuracy can be achieved if force will measured on other regions to minimize neglected forces .
- TENS device has several modes , two of them Normal & modulation modes were used . other modes could be attached so the device and can treat other discords related to muscles and nerves .
- Electromyograph (EMG) recording could enhance analysis of muscle's activity during bruxism at night to observe relaxation and improvement in muscles state .
- The system can be developed by a computerized system to record and save biting values with respect to time . this will facilitate analyzing data with greater accuracy .
- According to biting force , a study about the ability to find a relation between biting force and the thickness of night guard will be a brilliant solution for doctors since some of them suffer from a difficulty in determining the suitable thickness for the patient .
- additional electrical circuits can be included to increase the safety level of this device . as those which can open the system when there is an unexpected leakage from electrical components .
- to connect the system with phone by using special application with real time monitoring and data acquisition software to allow patients to self diagnosis and monitoring

conditions at home .

- using rechargeable battery can increase the possibility of using the device for a longer period of time without battery repeated replacement .

- connect the system with a keypad , in order to facilitate dealing with it .

7.1 Challenges :

- Choose an appropriate material with U-shaped design and suitable size for patient 's teeth structure . biocompatible which does not have any side effects for the patient . Also to be suitable to cover the sensor without affecting its normal response .

- To determine the reference value for each patient that will trigger electrotherapy treatment .

- To provide the maximum level of safety as much as possible when applying electrotherapy treatment by restricting with its principles .

- To persuade consumers with a new , unique method for diagnosis and treatment of bruxism with less cost and without night guard repeated replacement .

APPENDIX A

Datasheet For Flexi - Force Sensor .

FlexiForce®

A201 Standard Force & Load Sensors

Actual size of sensor

Sensing area

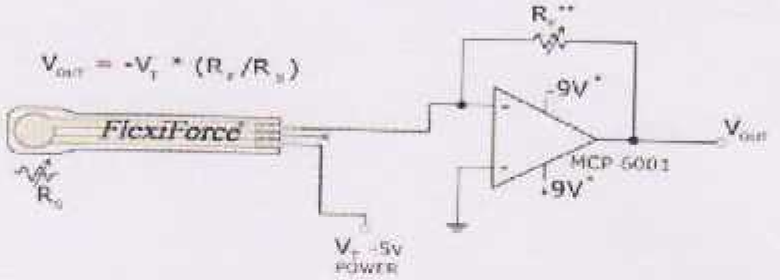
...Properties

0.008" (0.208 mm)
7.75" (197 mm),
optional trimmed lengths: 6" (152 mm), 4" (102 mm), or 2" (51mm)
0.55" (14 mm)
0.375" diameter (9.53 mm)
3-pin Male Square Pin (center pin is inactive)
Polyester (ex: Mylar)

...Ranges (as tested with circuit shown below)

...re forces above 100 lb ... apply a lower drive ... the resistance of the ... (1kΩ min.)

Recommended Circuit



- * Supply Voltages should be constant
- ** Reference Resistance R_F is 1kΩ to 100kΩ
- Sensor Resistance R_S at no load is >5MΩ
- Max recommended current is 2.5mA

...Performance

	Evaluation Conditions
±3%	Line drawn from 0 to 50% load
±2.5% of full scale	Conditioned sensor, 80% of full force applied
< 4.5 % of full scale	Conditioned sensor, 80% of full force applied
< 5% per logarithmic time scale	Constant load of 25 lb (111 N)
< 5 µsec	Impact load, output recorded on oscilloscope *Time required for the sensor to respond to an input force*
15°F - 140°F (-9°C - 60°C)*	
±0.2%/°F (0.36%/°C)	

*For loads less than 10 lbs. the operating temperature can be increased to 165°F (74°C)

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APPENDIX B

Datasheet For LM 324N Operational Amplifier .

LM324, LM324A, LM224, LM2902, LM2902V, NCV2902

Single Supply Quad Operational Amplifiers

The LM324 series are low–cost, quad operational amplifiers with true differential inputs. They have several distinct advantages over standard operational amplifier types in single supply applications. The quad amplifier can operate at supply voltages as low as 3.0 V or as high as 32 V with quiescent currents about one–fifth of those associated with the MC1741 (on a per amplifier basis). The common mode input range includes the negative supply, thereby eliminating the necessity for external biasing components in many applications. The output voltage range also includes the negative power supply voltage.

Features

- Short Circuited Protected Outputs
- True Differential Input Stage
- Single Supply Operation: 3.0 V to 32 V
- Low Input Bias Currents: 100 nA Maximum (LM324A)
- Four Amplifiers Per Package
- Internally Compensated
- Common Mode Range Extends to Negative Supply
- Industry Standard Pinouts
- ESD Clamps on the Inputs Increase Ruggedness without Affecting Device Operation
- NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC–Q100 Qualified and PPAP Capable
- These Devices are Pb–Free, Halogen Free/BFR Free and are RoHS Compliant

ON Semiconductor®

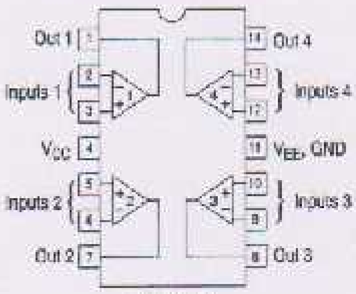
http://onsemi.com

PDIP–14
N SUFFIX
CASE 646

SOIC–14
D SUFFIX
CASE 751A

TSSOP–14
DTB SUFFIX
CASE 948G

PIN CONNECTIONS



(Top View)

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 10 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 11 of this data sheet.

MAXIMUM RATINGS (T_A = +25°C, unless otherwise noted.)

Rating		Symbol	Value	Unit
Power Supply Voltages				Vdc
Single Supply		V_{CC}	32	
Split Supplies		V_{CC}, V_{EE}	±16	
Input Differential Voltage Range (Note 1)		V_{IDR}	±32	Vdc
Input Common Mode Voltage Range (Note 2)		V_{ICR}	−0.3 to 32	Vdc
Output Short Circuit Duration		t_{SC}	Continuous	
Junction Temperature		T_J	150	°C
Thermal Resistance, Junction−to−Air (Note 3)	Case 646	$R_{\theta JA}$	118	°C/W
	Case 751A		156	
	Case 948G		190	
Storage Temperature Range		T_{stg}	−65 to +150	°C
ESD Protection at any Pin		V_{esd}		V
Human Body Model			2000	
Machine Model			200	
Operating Ambient Temperature Range		T_A		°C
	LM224		−25 to +85	
	LM324, 324A		0 to +70	
	LM2902		−40 to +105	
	LM2902V, NCV2902 (Note 4)		−40 to +125	

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

1. Split Power Supplies.
2. For supply voltages less than 32 V, the absolute maximum input voltage is equal to the supply voltage.
3. All $R_{\theta JA}$ measurements made on evaluation board with 1 oz. copper traces of minimum pad size. All device outputs were active.
4. *NCV2902 is qualified for automotive use.*

[illegible]ECTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, V_{EE} = GND, T_A = 25°C, unless otherwise noted.)

Characteristics	Symbol	LM224			LM324A			LM324			LM2902			LM2902V/NCV2902			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
[illegible] Offset Voltage [illegible] = 5.0 V to 30 V [illegible] = 0 V to [illegible] −1.7 V, [illegible] = 1.4 V, R_S = 0 Ω [illegible] [illegible] T_{high} (Note 5) [illegible] T_{low} (Note 5)	V_{IO}	– – –	2.0 – –	5.0 7.0 7.0	– – –	2.0 – –	3.0 5.0 5.0	– – –	2.0 – –	7.0 9.0 9.0	– – –	2.0 – –	7.0 10 10	– – –	2.0 – –	7.0 13 10	mV
[illegible] Temperature [illegible] of Input [illegible] Voltage [illegible] T_{high} to T_{low} [illegible] 5 and 7)	$\Delta V_{IO}/\Delta T$	–	7.0	–	–	7.0	30	–	7.0	–	–	7.0	–	–	7.0	–	µV/°C
[illegible] Offset Current [illegible] T_{high} to T_{low} [illegible]	I_{IO}	– –	3.0 –	30 100	– –	5.0 –	30 75	– –	5.0 –	50 150	– –	5.0 –	50 200	– –	5.0 –	50 200	nA
[illegible] Temperature [illegible] of Input [illegible] Current [illegible] T_{high} to T_{low} [illegible] 5 and 7)	$\Delta I_{IO}/\Delta T$	–	10	–	–	10	300	–	10	–	–	10	–	–	10	–	pA/°C
[illegible] Current [illegible] T_{high} to T_{low} [illegible]	I_{IB}	– –	−90 –	−150 −300	– –	−45 –	−100 −200	– –	−90 –	−250 −500	– –	−90 –	−250 −500	– –	−90 –	−250 −500	nA
[illegible] Common Mode [illegible] Range [illegible] [illegible] 30 V [illegible] [illegible] T_{high} to T_{low} [illegible]	V_{ICR}	0 0	– –	28.3 28	0 0	– –	28.3 28	0 0	– –	28.3 28	0 0	– –	28.3 28	0 0	– –	28.3 28	V
[illegible] Input [illegible] Range	V_{IDR}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	–	–	V_{CC}	V
[illegible] Signal Open [illegible] Voltage Gain [illegible] kΩ [illegible] 15 V [illegible] V_O Swing [illegible] T_{high} to T_{low} [illegible]	A_{VOL}	50 25	100 –	– –	25 15	100 –	– –	25 15	100 –	– –	25 15	100 –	– –	25 15	100 –	– –	V/mV
[illegible] Separation [illegible] f ≤ 20 kHz, [illegible] Referenced	CS	–	−120	–	–	−120	–	–	−120	–	–	−120	–	–	−120	–	dB
[illegible] Mode [illegible], [illegible] kΩ	CMR	70	85	–	65	70	–	65	70	–	50	70	–	50	70	–	dB
[illegible] Supply [illegible]	PSR	65	100	–	65	100	–	65	100	–	50	100	–	50	100	–	dB

[illegible]: T_{low} = −25°C, T_{high} = +85°C
[illegible]/LM324A: T_{low} = 0°C, T_{high} = +70°C
[illegible]: T_{low} = −40°C, T_{high} = +105°C
[illegible]V & NCV2902: T_{low} = −40°C, T_{high} = +125°C
[illegible]2902 is *qualified for automotive use.*
[illegible] common mode voltage or either input signal voltage should not be allowed to go negative by more than 0.3 V. The upper end of [illegible] common mode voltage range is V_{CC} −1.7 V, but either or both inputs can go to +32 V without damage, independent of the magnitude [illegible]
[illegible] by design.

[illegible]CTRICAL CHARACTERISTICS (V_{CC} = 5.0 V, V_{EE} = GND, T_A = 25°C, unless otherwise noted.)

Characteristics	Symbol	LM224			LM324A			LM324			LM2902			LM2902V/NCV2902			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
[illegible] Voltage – [illegible] Limit	V_{OH}																V
[illegible] = 5.0 V, R_L = [illegible], T_A = 25°C		3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	3.3	3.5	–	
[illegible] = 30 V, [illegible] = 2.0 kΩ, [illegible] = T_{high} to T_{low} [illegible]		26	–	–	26	–	–	26	–	–	26	–	–	26	–	–	
[illegible] = 30 V, [illegible] = 10 kΩ, [illegible] = T_{high} to T_{low} [illegible]		27	28	–	27	28	–	27	28	–	27	28	–	27	28	–	
[illegible] Voltage – [illegible] Limit, [illegible] = 5.0 V, [illegible] = 10 kΩ, [illegible] T_{high} to T_{low} [illegible]	V_{OL}	–	5.0	20	–	5.0	20	–	5.0	20	–	5.0	100	–	5.0	100	mV
[illegible] Source Current ([illegible] = +1.0 V, [illegible] = 15 V)	I_{O+}																mA
[illegible] 25°C		20	40	–	20	40	–	20	40	–	20	40	–	20	40	–	
[illegible] T_{high} to T_{low} [illegible]		10	20	–	10	20	–	10	20	–	10	20	–	10	20	–	
[illegible] Sink Current ([illegible] = −1.0 V, [illegible] = 15 V) [illegible] 25°C	I_{O-}	10	20	–	10	20	–	10	20	–	10	20	–	10	20	–	mA
[illegible] T_{high} to T_{low} [illegible]		5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	5.0	8.0	–	
([illegible] = −1.0 V, [illegible] = 200 mV, [illegible] 25°C)		12	50	–	12	50	–	12	50	–	–	–	–	–	–	–	μA
[illegible] Short Circuit [illegible] Ground [illegible]	I_{SC}	–	40	60	–	40	60	–	40	60	–	40	60	–	40	60	mA
[illegible] Supply Current ([illegible] T_{high} to T_{low}) [illegible]	I_{CC}																mA
[illegible] = 30 V, [illegible], R_L = ∞		–	–	3.0	–	1.4	3.0	–	–	3.0	–	–	3.0	–	–	3.0	
[illegible] = 5.0 V, [illegible], R_L = ∞		–	–	1.2	–	0.7	1.2	–	–	1.2	–	–	1.2	–	–	1.2	

[illegible]: T_{low} = −25°C, T_{high} = +85°C
[illegible]/LM324A: T_{low} = 0°C, T_{high} = +70°C
[illegible]: T_{low} = −40°C, T_{high} = +105°C
[illegible]V & NCV2902: T_{low} = −40°C, T_{high} = +125°C
[illegible] is qualified for automotive use.
[illegible] common mode voltage or either input signal voltage should not be allowed to go negative by more than 0.3 V. The upper end of [illegible] mode voltage range is V_{CC} −1.7 V, but either or both inputs can go to +32 V without damage, independent of the magnitude [illegible]

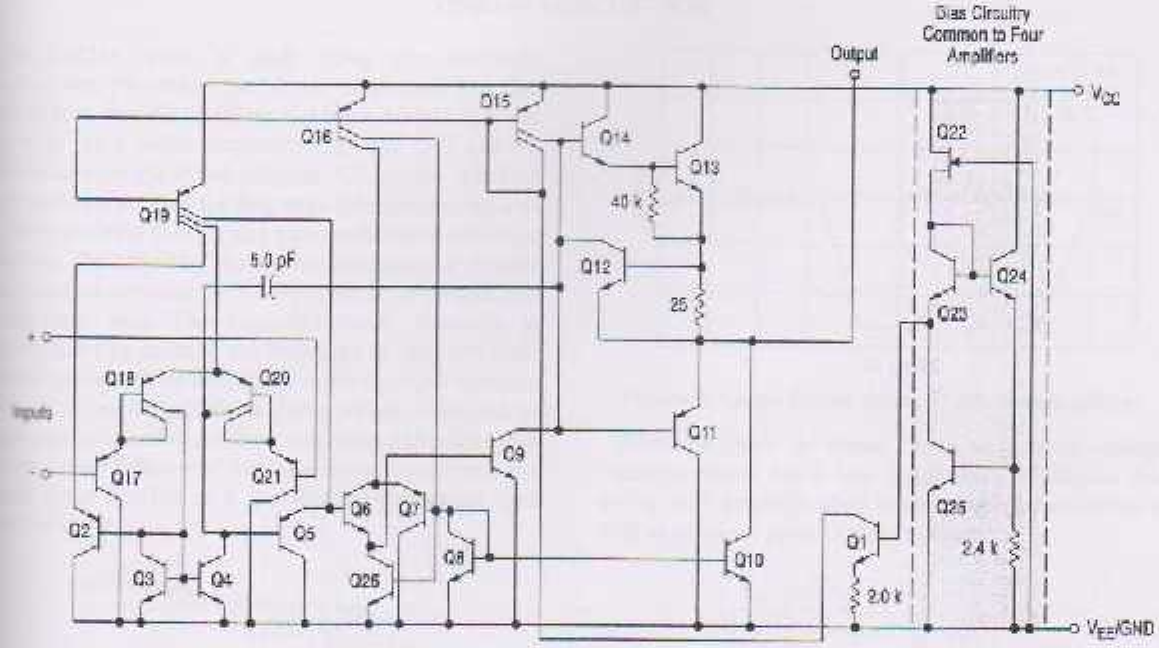


Figure 1. Representative Circuit Diagram
(One-Fourth of Circuit Shown)

CIRCUIT DESCRIPTION

The LM324 series is made using four internally compensated, two–stage operational amplifiers. The first stage of each consists of differential input devices Q20 and Q18 with input buffer transistors Q21 and Q17 and the differential to single ended converter Q3 and Q4. The first stage performs not only the first stage gain function but also performs the level shifting and transconductance reduction functions. By reducing the transconductance, a smaller compensation capacitor (only 5.0 pF) can be employed, thus saving chip area. The transconductance reduction is accomplished by splitting the collectors of Q20 and Q18. Another feature of this input stage is that the input common mode range can include the negative supply or ground, in single supply operation, without saturating either the input devices or the differential to single–ended converter. The second stage consists of a standard current source load amplifier stage.

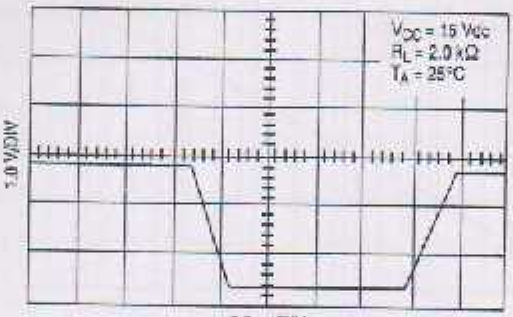


Figure 2. Large Signal Voltage Follower Response

Each amplifier is biased from an internal–voltage regulator which has a low temperature coefficient thus giving each amplifier good temperature characteristics as well as excellent power supply rejection.

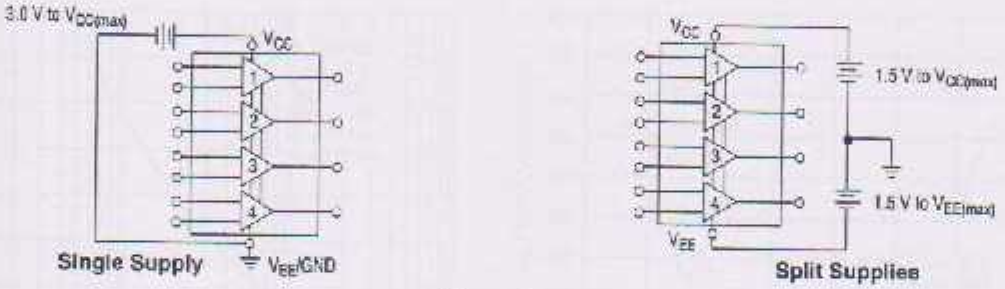


Figure 3.

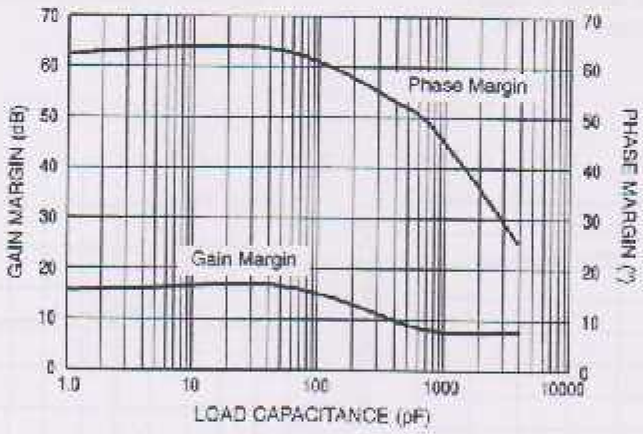


Figure 4. Gain and Phase Margin

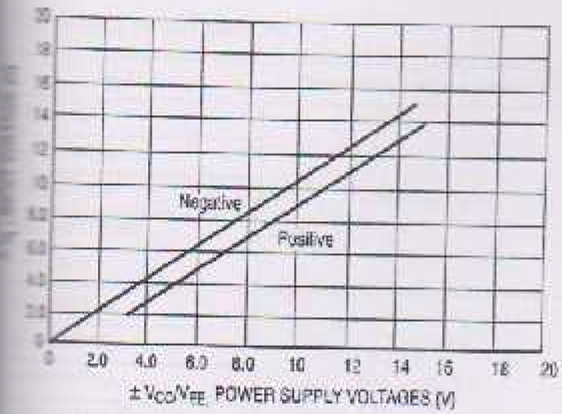


Figure 5. Input Voltage Range

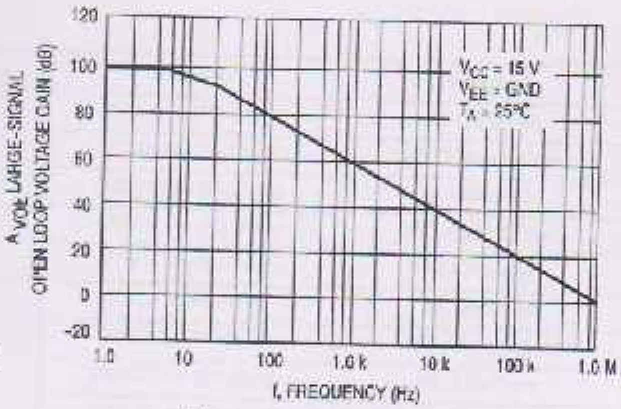


Figure 6. Open Loop Frequency

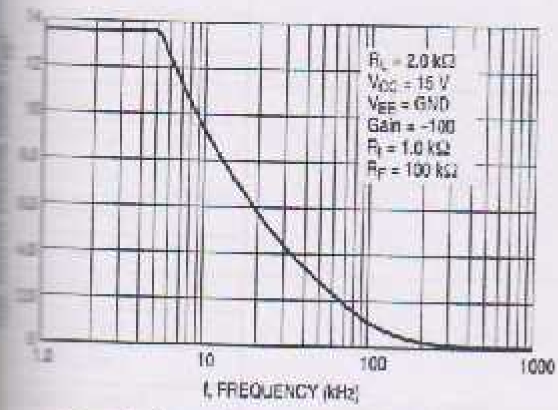


Figure 7. Large–Signal Frequency Response

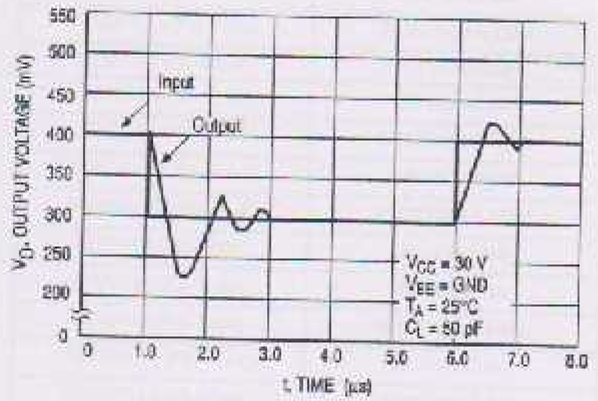


Figure 8. Small–Signal Voltage Follower Pulse Response (Noninverting)

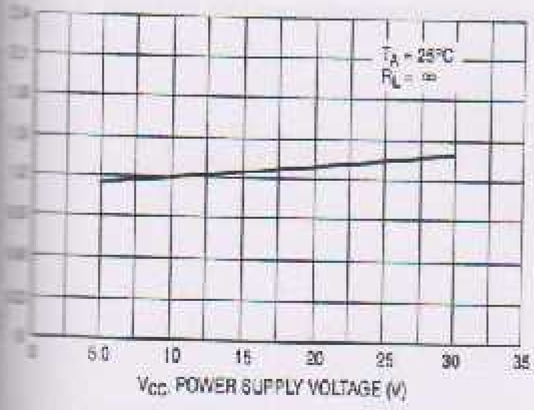


Figure 9. Power Supply Current versus Power Supply Voltage

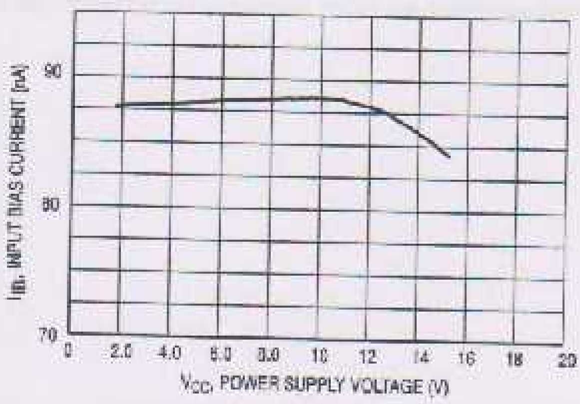


Figure 10. Input Bias Current versus Power Supply Voltage

ORDERING INFORMATION

Device	Operating Temperature Range	Package	Shipping†
LM224DG	−25°C to +85°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM224DR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM224DTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM224DTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM224NG		PDIP−14 (Pb−Free)	25 Units/Rail
LM324DG	0°C to +70°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM324DR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM324DTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM324DTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM324NG		PDIP−14 (Pb−Free)	25 Units/Rail
LM324ADG		SOIC−14 (Pb−Free)	55 Units/Rail
LM324ADR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM324ADTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM324ADTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM324ANG		PDIP−14 (Pb−Free)	25 Units/Rail
LM2902DG	−40°C to +105°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM2902DR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM2902DTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM2902DTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM2902NG		PDIP−14 (Pb−Free)	25 Units/Rail
LM2902VDG	−40°C to +125°C	SOIC−14 (Pb−Free)	55 Units/Rail
LM2902VDR2G		SOIC−14 (Pb−Free)	2500/Tape & Reel
LM2902VDTBG		TSSOP−14 (Pb−Free)	96 Units/Tube
LM2902VDTBR2G		TSSOP−14 (Pb−Free)	2500/Tape & Reel
LM2902VNG		PDIP−14 (Pb−Free)	25 Units/Rail
NCV2902DR2G*		SOIC−14 (Pb−Free)	2500/Tape & Reel
NCV2902DTBR2G*		TSSOP−14 (Pb−Free)	

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.
*NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC−Q100 Qualified and PPAP Capable.

APPENDIX C

Datasheet For 1N4733A Regulator .

Silicon Power Zener Diodes

Features

- Silicon Planar Power Zener Diodes
- For use in stabilizing and clipping circuits with high power rating.

- Standard Zener voltage tolerance suffix "A" for ± 5 % tolerance. Other Zener voltages and tolerances are available upon request.

Applications

Voltage stabilization

Mechanical Data

Case: DO-41 Glass Case
Weight: approx. 350 mg
Packaging Codes/Options:
TR / 5k per 13 " reel , 25k/box
TAP / 5k per Ammo mag. (52 mm tape), 25k/box

Absolute Maximum Ratings

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Power dissipation	$T_{amb} \le 50$ °C	P_{Diss}	1	W
Z-current		I_Z	P_V/V_Z	mA
Junction temperature		T_j	200	°C
Storage temperature range		T_{stg}	- 65 to + 200	°C
Junction ambient	l = 9.5 mm (3/8 "), T_L = constant	R_{thJA}	100	K/W

Electrical Characteristics

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Min	Typ.	Max	Unit
Forward voltage	I_F = 200 mA	V_F			1.2	V

ctrical Characteristics

A...1N4764A

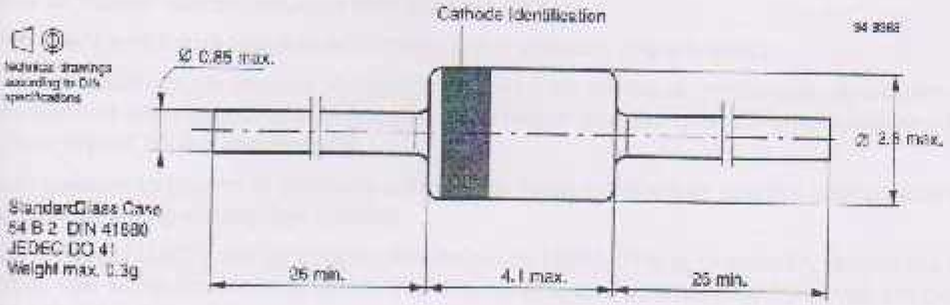
rtnumber	Nominal Zener Voltage[1)]	Test Current	Maximum Dynamic Impedance			Maximum Reverse Leakage Current		Surge curent	Maximum Regulator Current[2)]
	V_Z @ I_{ZT}	I_{ZT}	Z_{ZT} @ I_{ZT}	Z_{ZK} @ I_{ZK}	I_{ZK}	I_R	Test Voltage V_R	I_R @ T_{amb} = 25 °C	I_{ZM} @ T_{amb} = 60 °C
	V	mA	Ω	Ω	mA	µA	V	mA	mA
4728A	3.3	76	10	400	1	100	1	1380	276
4729A	3.6	69	10	400	1	100	1	1260	252
4730A	3.9	64	9	400	1	50	1	1190	234
4731A	4.3	58	9	400	1	10	1	1070	217
4732A	4.7	53	8	500	1	10	1	970	193
4733A	5.1	49	7	550	1	10	1	890	178
4734A	5.6	45	5	600	1	10	2	810	162
4735A	6.2	41	2	700	1	10	3	730	146
4736A	6.8	37	0.5	700	1	10	4	660	133
4737A	7.5	34	0	700	0.5	10	5	605	121
4738A	8.2	31	0.5	700	0.5	10	6	550	110
4739A *	9.1	28	0	700	0.5	10	7	500	100
4740A *	10	25	7	700	0.25	10	7.6	454	91
4741A *	11	23	8	700	0.25	5	8.4	414	83
4742A *	12	21	9	700	0.25	5	9.1	380	76
4743A *	13	19	10	100	0.25	5	9.9	344	69
4744A *	15	17	14	700	0.25	5	11.4	304	61
4745A *	16	15.5	16	700	0.25	5	12.2	285	57
4746A *	18	14	20	750	0.25	5	13.7	250	50
4747A *	20	12.5	22	750	0.25	5	15.2	225	45
4748A *	22	11.5	23	750	0.25	5	16.7	205	41
4749A *	24	10.5	25	750	0.25	5	18.2	190	38
4750A *	27	9.5	35	750	0.25	5	20.6	170	34
4751A *	30	8.5	40	1000	0.25	5	22.8	150	30
4752A *	33	7.5	45	1000	0.25	5	25.1	135	27
4753A *	36	7	50	1000	0.25	5	27.4	125	25
4754A *	39	6.5	60	1000	0.25	5	29.7	115	23
4755A *	43	6	70	1500	0.25	5	32.7	110	22
4756A *	47	5.5	80	1500	0.25	5	35.8	95	19
4757A *	51	5	95	1500	0.25	5	38.8	90	18
4758A *	56	4.5	110	2000	0.25	5	42.6	80	16
4759A *	62	4	125	2000	0.25	5	47.1	70	14
4760A *	68	3.7	150	2000	0.25	5	51.7	65	13
4761A *	75	3.3	175	2000	0.25	5	56	60	12
4762A *	82	3.0	200	3000	0.25	5	62.2	55	11
4763A *	91	2.8	250	3000	0.25	5	69.2	50	10
4764A *	100	2.5	350	3000	0.25	5	76.0	45	9

dc-measurement at theral equilibrium while maitaining the lead temperature (T_L) at 30 °C + 1 °C, 9.5 mm (3/8 ") from the diode

ovided that electrodes at a distance of 10 mm from case are kept at ambient temperature.

al measurement of Voltage group 9V1 to 75 at 95 % V_{zmin} ≤ 35 nA at T_j 25 °C

Package Dimensions in mm



ne Depleting Substances Policy Statement

e policy of **Vishay Semiconductor GmbH** to

et all present and future national and international statutory requirements.

gularly and continuously improve the performance of our products, processes, distribution and ratingsystems with respect to their impact on the health and safety of our employees and the public, as l as their impact on the environment.

rticular concern to control or eliminate releases of those substances into the atmosphere which are n as ozone depleting substances (ODSs).

ntreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs d their use within the next ten years. Various national and international initiatives are pressing for an an on these substances.

y **Semiconductor GmbH** has been able to use its policy of continuous improvements to eliminate the ODSs listed in the following documents.

ex A, B and list of transitional substances of the Montreal Protocol and the London Amendments ectively

s I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental ection Agency (EPA) in the USA

ncil Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

y **Semiconductor GmbH** can certify that our semiconductors are not manufactured with ozone depleting ces and do not contain such substances.

We reserve the right to make changes to improve technical design and may do so without further notice.

Parameters can vary in different applications. All operating parameters must be validated for each ustomer application by the customer. Should the buyer use Vishay Semiconductors products for any nintended or unauthorized application, the buyer shall indemnify Vishay Semiconductors against all claims, costs, damages, and expenses, arising out of, directly or indirectly, any claim of personal damage, injury or death associated with such unintended or unauthorized use.

Vishay Semiconductor GmbH, P.O.B. 3535, D-74025 Heilbronn, Germany
Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423

APPENDIX D

Project Software Code .

// initialize the state of switches to control treatment modes

```
int s0 = 40;
int s1 = 42;
int s2 = 44;
int s3 = 46;
int s0state =0;
int s1state = 0;
int s2state = 0;
int s3state = 0;
```

// initialize variables to control change in frequency for stimulating signal and pulse width

```
int d;
int c;
float n;
float t;
```

// initialize variables to control Applying tratment one time for each tigger

```
int treat=1;
int o=1;
int f=1;
int s=1;
int l=1;
int x;
```

// initialization to measure Right Side Voltage and its analogus Force

```
float voltforceR = 0;
float voltageR = 0;
float forceR = 0;
```

```
// initialization to measure Left Side Voltage and its analogus Force
float voltforceL = 0;
float voltageL = 0;
float forceL= 0 ;
// initialization to measure Average Voltage and its analogus Force
float voltforceS = 0;
float voltageS = 0;
float forceS = 0;
// initialization to measure Reference Voltage and its analogus Force
float voltRef = 0 ;
float voltageRef = 0;
float forceRef = 0;

#include <LiquidCrystal.h>
LiquidCrystal lcd(31, 33, 35, 37, 39, 41);

void setup() {
Serial.begin(9600);
pinMode(s0, INPUT); // sets the digital pin 7 as input
pinMode(s1, INPUT); // sets the digital pin 6 as input
pinMode(s2, INPUT); // sets the digital pin 5 as input
pinMode(s3, INPUT); // sets the digital pin 4 as input
lcd.begin(16,4);
lcd.clear();
```

```
void loop() {
// read  switches state to control reatment modes
s0state = digitalRead(s0); // read the input pin from switch
s1state = digitalRead(s1); // read the input pin from switch
s2state = digitalRead(s2); // read the input pin from switch
s3state = digitalRead(s3); // read the input pin from switch

//  Display Right Side Voltage and its analogus Force
voltforceR = analogRead(0); // force A0 R
voltageR =  voltforceR* (5.0/1023.0);
forceR = (23.522*voltageR - 1.948)*4.448;
lcd.setCursor(0,0);
lcd.print("R-V= ");
lcd.setCursor(5,0);
lcd.print(voltageR);
lcd.setCursor(10,0);
lcd.print("F=   N  ");
lcd.setCursor(13,0);
lcd.print(forceR);

//  Display Left Side Voltage and its analogus Force
voltforceL = analogRead(1); // force A1 L
voltageL =  voltforceL* (5.0/1023.0);
forceL= (23.522*voltageL - 1.948)*4.448;
lcd.setCursor(0,1);
lcd.print("L-V=");
```

```
lcd.setCursor(5,1);
lcd.print(voltageL);
lcd.setCursor(10,1);
lcd.print("F=   N");
lcd.setCursor(13,1);
lcd.print(forceL);
```

// **Display Average Voltage and its analogus Force**

```
voltforceS = analogRead(2); // force A2 SUM
voltageS =  voltforceS * (5.0/1023.0);
forceS= (23.522*voltageS - 1.9)*4.448;
lcd.setCursor(0,2);
lcd.print("SUM-V= ");
lcd.setCursor(6,2);
lcd.print(voltageS);
lcd.setCursor(10,2);
lcd.print("F=   N");
lcd.setCursor(13,2);
lcd.print(forceS);
```

// **Display Referance Voltage and its analogus Force**

```
voltRef = analogRead(3);
voltageRef =  voltRef * (5.0/1023.0);
lcd.setCursor(0,3);
lcd.print("REF-V= ");
lcd.setCursor(6,3);
lcd.print(voltageRef);
```

```
forceRef=(23.522*voltageRef - 1.9)*4.448;

lcd.setCursor(10,3);

lcd.print("F=    N ");

lcd.setCursor(13,3);

lcd.print(forceRef);


// chech if the patient is in Bruxism state or not

// if "YES" Start stimulating pulsed signal for treatment according to treatment mode


if(voltageS>=voltageRef)

{

switch(s0state&s1state)

{

// if switch(S0)is HIGH AND switch(S1) IS LOW :

// Start Modulation Mode for 15 minutes

// Display the STATE of person " Bruxist or not " , Mode of treatment

// Display Frequency & pulse , treatment period


case HIGH & LOW :

lcd.clear();

lcd.setCursor(0,1);

lcd.print("Mode:");

lcd.setCursor(12,1);

lcd.print("T:");

lcd.setCursor(0,2);

lcd.print("F:  Hz");
```

```
lcd.setCursor(9,2);
lcd.print("PW:   M");
lcd.setCursor(5,1);
lcd.print("Modu");
lcd.setCursor(14,1);
lcd.print("15");
lcd.setCursor(2,2);
lcd.print("150");
lcd.setCursor(12,2);
lcd.print("150");

for(x=0;x<=90;x++){
if(digitalRead(40) == HIGH && digitalRead(42) == LOW  ){
for(d=150;d>=60;d--){
if(digitalRead(40) == HIGH && digitalRead(42) ==LOW ){
delay(34);
t=0.1*d;
digitalWrite(9,HIGH);
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print("  ");
}
else
digitalWrite(9,LOW);
}
for(c=0;c<=156;c++){
```

```
if(digitalRead(40) == HIGH && digitalRead(42) == LOW){
d=60;
digitalWrite(9, HIGH);
t=0.1*d;
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print("  ");
}
else
digitalWrite(9,LOW);
}
for(d=60;d<=150;d++){
if(digitalRead(40) == HIGH && digitalRead(42) == LOW){
delay(34);
t=0.1*d;
digitalWrite(9,HIGH);
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print(" ");
}
else
digitalWrite(9,LOW);
}
for(c=0;c<=64;c++){
```

```
if(digitalRead(40) == HIGH && digitalRead(42) == LOW ){
d=150;
digitalWrite(9, HIGH);
t=0.1*d;
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print(" ");
}
else
digitalWrite(9,LOW);
}
}
else
digitalWrite(9,LOW);
}
o=0;
break;

case HIGH & HIGH :
```

// if switch(S0)is HIGH AND switch(S1) IS HIGH :

// Start Normal Mode for 15 minutes

// Display the STATE of person " Bruxist or not " , Mode of treatment

// Display Frequency & pulse , tratment periode

```
lcd.clear();
lcd.setCursor(0,1);
```

```
lcd.print("Mode:");
lcd.setCursor(12,1);
lcd.print("T:");
lcd.setCursor(0,2);
lcd.print("F:  Hz");
lcd.setCursor(9,2);
lcd.print("PW:  M");
lcd.setCursor(5,1);
lcd.print("Normal");
lcd.setCursor(14,1);
lcd.print("15");
lcd.setCursor(2,2);
lcd.print("90");
lcd.setCursor(12,2);
lcd.print("150");

for(x=0;x<=1585;x++){
if(digitalRead(40) == HIGH && digitalRead(42) == HIGH ){
for(c=0;c<=90;c++){
if(digitalRead(40) == HIGH && digitalRead(42) == HIGH ){
n=0.15;
digitalWrite(9, HIGH);
delay(n);
digitalWrite(9, LOW);
Serial.println(n);
}
else
```

```
digitalWrite(9,LOW);
}
}
else
digitalWrite(9,LOW);
}
f=0;
break;
}
switch(s2state&s3state)
{
case HIGH & LOW :
```

// if switch(S2)is HIGH AND switch(S3) IS LOW :

// Start Modulation Mode for 30 minutes

// Display the STATE of person " Bruxist or not " / Mode of treatment /

// Display Frequency & pulse / treatment period /

```
lcd.clear();
lcd.setCursor(0,1);
lcd.print("Mode:");
lcd.setCursor(12,1);
lcd.print("T:");
lcd.setCursor(0,2);
lcd.print("F:  Hz");
lcd.setCursor(9,2);
lcd.print("PW:  M");
lcd.setCursor(5,1);
```

```
lcd.print("Modu");
lcd.setCursor(14,1);
lcd.print("30");
lcd.setCursor(2,2);
lcd.print("150");
lcd.setCursor(12,2);
lcd.print("150");

for(x=0;x<=180;x++){
if(digitalRead(44) == HIGH && digitalRead(46) ==LOW ){
for(d=150;d>=60;d--){
if(digitalRead(44) == HIGH && digitalRead(46) ==LOW ){
delay(34);
t=0.1*d;
digitalWrite(9,HIGH);
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print("  ");
}
else
digitalWrite(9,LOW);
}
for(c=0;c<=156;c++){
if(digitalRead(44) == HIGH && digitalRead(46) ==LOW){
d=60;
digitalWrite(9, HIGH);
```

```
t=0.1*d;
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print("  ");
}
else
digitalWrite(9,LOW);
}
for(d=60;d<=150;d++){
if(digitalRead(44) == HIGH && digitalRead(46) ==LOW  ){
delay(34);
t=0.1*d;
digitalWrite(9,HIGH);
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print("  ");
}
else
digitalWrite(9,LOW);
}
for(c=0;c<=64;c++){
if(digitalRead(44) == HIGH && digitalRead(46) == LOW ){
d=150;
digitalWrite(9, HIGH);
t=0.1*d;
```

```
delay(t);
digitalWrite(9,LOW);
Serial.print(t);
Serial.print("  ");
} // inner if
else
digitalWrite(9,LOW);
} // inner for
} // if
else
digitalWrite(9,LOW);
}
s=0;
break;
case HIGH & HIGH :

// if switch(S2)is HIGH AND switch(S3) IS HIGH :
// Start Normal Mode for 30 minutes
// Display the STATE of person " Bruxist or not " / Mode of treatment /
// Display Frequency & pulse / treatment period /

lcd.setCursor(0,1);
lcd.print("Mode:");
lcd.setCursor(12,1);
lcd.print("T:");
lcd.setCursor(0,2);
lcd.print("F:   Hz");
```

```
lcd.setCursor(9,2);
lcd.print("PW:  M");
lcd.setCursor(5,1);
lcd.print("Normal");
lcd.setCursor(14,1);
lcd.print("30");
lcd.setCursor(2,2);
lcd.print("90");
lcd.setCursor(12,2);
lcd.print("150");

for(x=0;x<=3170;x++){
if(digitalRead(44) == HIGH && digitalRead(46) == HIGH ){
for(c=0;c<=90;c++){
if(digitalRead(44) == HIGH && digitalRead(46) == HIGH){
digitalWrite(9, HIGH);
n=0.15;
delay(n);
digitalWrite(9, LOW);
Serial.println(n);
}
else
digitalWrite(9,LOW);
}
}
else
digitalWrite(9,LOW);
```

```
}
l=0;
break;
}
}
treat=0;
lcd.clear();
lcd.setCursor(0,0);
lcd.print("STATE:No Bruxism");
}
```

APPENDIX E

Datasheet For AD822N Operational Amplifier .

![ANALOG DEVICES]

Single-Supply, Rail-to-Rail Low Power FET-Input Op Amp

AD822

EATURES

- ue single-supply operation
  - Output swings rail-to-rail
  - Input voltage range extends below ground
  - Single-supply capability from 5 V to 30 V
  - Dual-supply capability from ±2.5 V to ±15 V
- gh load drive
  - Capacitive load drive of 350 pF, G = +1
  - Minimum output current of 15 mA
- cellent ac performance for low power
  - 800 μA maximum quiescent current per amplifier
  - Unity-gain bandwidth: 1.8 MHz
  - Slew rate of 3 V/μs
- od dc performance
  - 800 μV maximum input offset voltage
  - 2 μV/°C typical offset voltage drift
  - 25 pA maximum input bias current
- w noise
  - 13 nV/√Hz @ 10 kHz
  - No phase inversion

PPLICATIONS

- ttery-powered precision instrumentation
- otodiode preamps
- tive filters
- -bit to 14-bit data acquisition systems
- dical instrumentation
- w power references and regulators

CONNECTION DIAGRAM

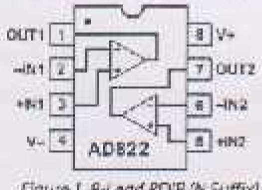


Figure 1. 8-Lead PDIP (N Suffix); 8-Lead MSOP (RM Suffix); and 8 Lead SOIC_N (R Suffix)

GENERAL DESCRIPTION

The AD822 is a dual precision, low power FET input op amp that can operate from a single supply of 5 V to 30 V or dual supplies of ±2.5 V to ±15 V. It has true single-supply capability with an input voltage range extending below the negative rail, allowing the AD822 to accommodate input signals below ground in the single-supply mode. Output voltage swing extends to within 10 mV of each rail, providing the maximum output dynamic range.

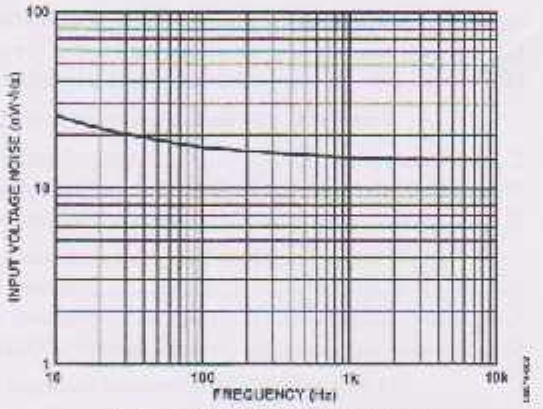


Figure 2. Input Voltage Noise vs. Frequency

Offset voltage of 800 μV maximum, offset voltage drift of 2 μV/°C, input bias currents below 25 pA, and low input voltage noise provide dc precision with source impedances up to a gigaohm. The 1.8 MHz unity-gain bandwidth, −93 dB THD at 10 kHz, and 3 V/μs slew rate are provided with a low supply current of 800 μA per amplifier.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.461.3113

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The AD822 drives up to 350 pF of direct capacitive load as a follower and provides a minimum output current of 15 mA. This allows the amplifier to handle a wide range of load conditions. Its combination of ac and dc performance, plus the outstanding load drive capability, results in an exceptionally versatile amplifier for the single-supply user.

The AD822 is available in two performance grades. The A grade and B grade are rated over the industrial temperature range of −40°C to +85°C.

The AD822 is offered in three varieties of 8-lead packages: PDIP, MSOP, and SOIC_N.

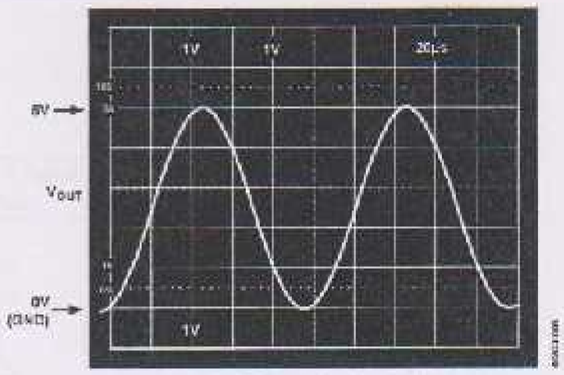


Figure 3. Gain-of-2 Amplifier; V_S = 5 V, 0 V, V_{IN} = 2.5 V Sine Centered at 1.25 V, R_L = 100 Ω

ECIFICATIONS

V, 5 V @ T_A = 25°C, V_{CM} = 0 V, V_{OUT} = 0.2 V, unless otherwise noted.

1.

meter	Conditions	A Grade Min	A Grade Typ	A Grade Max	B Grade Min	B Grade Typ	B Grade Max	Unit
FORMANCE								
al Offset			0.1	0.8		0.1	0.4	mV
mum Offset Over Temperature			0.5	1.2		0.5	0.9	mV
et Drift			2			2		μV/°C
t Bias Current	V_{CM} = 0 V to 4 V		2	25		2	10	pA
T_{MAX}			0.5	5		0.5	2.5	nA
t Offset Current			2	20		2	10	pA
T_{MAX}			0.5			0.5		nA
n-Loop Gain	V_{OUT} = 0.2 V to 4 V							
	R_L = 100 kΩ	500	1000		500	1000		V/mV
to T_{MAX}		400			400			V/mV
	R_L = 10 kΩ	80	150		80	150		V/mV
to T_{MAX}		80			80			V/mV
	R_L = 1 kΩ	15	30		15	30		V/mV
to T_{MAX}		10			10			V/mV
HARMONIC PERFORMANCE								
t Voltage Noise								
0.1 Hz to 10 Hz			2			2		μV p-p
10 Hz			25			25		nV/√Hz
100 Hz			21			21		nV/√Hz
1 kHz			16			16		nV/√Hz
10 kHz			13			13		nV/√Hz
t Current Noise								
0.1 Hz to 10 Hz			18			18		fA p-p
1 kHz			0.8			0.8		fA/√Hz
monic Distortion	R_L = 10 kΩ to 2.5 V							
10 kHz	V_{OUT} = 0.25 V to 4.75 V		−93			−93		dB
C PERFORMANCE								
-Gain Frequency			1.8			1.8		MHz
ower Response	V_{OUT} p-p = 4.5 V		210			210		kHz
Rate			3			3		V/μs
ng Time								
0.1%	V_{OUT} = 0.2 V to 4.5 V		1.4			1.4		μs
0.01%	V_{OUT} = 0.2 V to 4.5 V		1.8			1.8		μs
G CHARACTERISTICS								
Offset				1.0			0.5	mV
mum Offset Over Temperature				1.6			1.3	mV
et Drift			3			3		μV/°C
Bias Current				20			10	pA
alk @ f = 1 kHz	R_L = 5 kΩ		−130			−130		dB
alk @ f = 100 kHz	R_L = 5 kΩ		−93			−93		dB
ARACTERISTICS								
oltage Range[1], T_{MIN} to T_{MAX}		−0.2		+4	−0.2		+4	V
on-Mode Rejection Ratio (CMRR)	V_{CM} = 0 V to 2 V	56	80		69	80		dB
to T_{MAX}	V_{CM} = 0 V to 2 V	66			66			dB

Parameter	Conditions	A Grade Min	A Grade Typ	A Grade Max	B Grade Min	B Grade Typ	B Grade Max	Unit
Input Impedance								
Differential			$10^{13}\|\|0.5$			$10^{13}\|\|0.5$		Ω||pF
Common Mode			$10^{13}\|\|2.8$			$10^{13}\|\|2.8$		Ω||pF
OUTPUT CHARACTERISTICS								
Output Saturation Voltage[2]								
$V_{OL} - V_{EE}$	I_{SINK} = 20 μA		5	7		5	7	mV
T_{MIN} to T_{MAX}				10			10	mV
$V_{CC} - V_{OH}$	I_{SOURCE} = 20 μA		10	14		10	14	mV
T_{MIN} to T_{MAX}				20			20	mV
$V_{OL} - V_{EE}$	I_{SINK} = 2 mA		40	55		40	55	mV
T_{MIN} to T_{MAX}				80			80	mV
$V_{CC} - V_{OH}$	I_{SOURCE} = 2 mA		80	110		80	110	mV
T_{MIN} to T_{MAX}				160			160	mV
$V_{OL} - V_{EE}$	I_{SINK} = 15 mA		300	500		300	500	mV
T_{MIN} to T_{MAX}				1000			1000	mV
$V_{CC} - V_{OH}$	I_{SOURCE} = 15 mA		800	1500		800	1500	mV
T_{MIN} to T_{MAX}				1900			1900	mV
Operating Output Current		15			15			mA
T_{MIN} to T_{MAX}		12			12			mA
Capacitive Load Drive			350			350		pF
POWER SUPPLY								
Quiescent Current, T_{MIN} to T_{MAX}			1.24	1.6		1.24	1.6	mA
Power Supply Rejection	V+ = 5 V to 15 V	66	80		70	80		dB
T_{MIN} to T_{MAX}		66			70			dB

[1] This is a functional specification. Amplifier bandwidth decreases when the input common-mode voltage is driven in the range (V+ − 1 V) to V+. Common-mode error voltage is typically less than 5 mV with the common-mode voltage set at 1 V below the positive supply.

[2] $V_{OL} - V_{EE}$ is defined as the difference between the lowest possible output voltage (V_{OL}) and the negative voltage supply rail (V_{EE}). $V_{CC} - V_{OH}$ is defined as the difference between the highest possible output voltage (V_{OH}) and the positive supply voltage (V_{CC}).

± 5 V @ T_A = 25°C, V_{CM} = 0 V, V_{OUT} = 0 V, unless otherwise noted.

le 2.

meter	Conditions	A Grade Min	A Grade Typ	A Grade Max	B Grade Min	B Grade Typ	B Grade Max	Unit
RFORMANCE								
al Offset			0.1	0.8		0.1	0.4	mV
imum Offset Over Temperature			0.5	1.5		0.5	1	mV
set Drift			2			2		μV/°C
ut Bias Current	V_{CM} = −5 V to +4 V		2	25		2	10	pA
T_{MAX}			0.5	5		0.5	2.5	nA
ut Offset Current			2	20		2	10	pA
T_{MAX}			0.5			0.5		nA
en-Loop Gain	V_{OUT} = −4 V to +4 V							
	R_L = 100 kΩ	400	1000		400	1000		V/mV
to T_{MAX}		400			400			V/mV
	R_L = 10 kΩ	80	150		80	150		V/mV
to T_{MAX}		80			80			V/mV
	R_L = 1 kΩ	20	30		20	30		V/mV
to T_{MAX}		10			10			V/mV
HARMONIC PERFORMANCE								
t Voltage Noise								
0.1 Hz to 10 Hz			2			2		μV p-p
10 Hz			25			25		nV/√Hz
100 Hz			21			21		nV/√Hz
1 kHz			16			16		nV/√Hz
10 kHz			13			13		nV/√Hz
t Current Noise								
0.1 Hz to 10 Hz			18			18		fA p-p
1 kHz			0.8			0.8		fA/√Hz
monic Distortion	R_L = 10 kΩ							
10 kHz	V_{OUT} = ±4.5 V		−93			−93		dB
C PERFORMANCE								
Gain Frequency			1.9			1.9		MHz
Power Response	V_{OUT} p-p = 9 V		105			105		kHz
Rate			3			3		V/μs
ng Time								
0.1%	V_{OUT} = 0 V to ±4.5 V		1.4			1.4		μs
0.01%	V_{OUT} = 0 V to ±4.5 V		1.8			1.8		μs
NG CHARACTERISTICS								
Offset				1.0			0.5	mV
um Offset Over Temperature				3			2	mV
et Drift			3			3		μV/°C
Bias Current				25			10	pA
alk @ f = 1 kHz	R_L = 5 kΩ		−130			−130		dB
alk @ f = 100 kHz	R_L = 5 kΩ		−93			−93		dB
HARACTERISTICS								
oltage Range[1], T_{MIN} to T_{MAX}		−5.2		+4	−5.2		+4	V
on-Mode Rejection Ratio (CMRR)	V_{CM} = −5 V to +2 V	66	80		69	80		dB
to T_{MAX}	V_{CM} = −5 V to +2 V	66			66			dB
mpedance								
ential			10^{13}‖0.5			10^{13}‖0.5		Ω‖pF
mon Mode			10^{13}‖2.8			10^{13}‖2.8		Ω‖pF

...ameter	Conditions	A Grade Min	A Grade Typ	A Grade Max	B Grade Min	B Grade Typ	B Grade Max	Unit
...UTPUT CHARACTERISTICS								
Output Saturation Voltage[2]								
$V_{OL} - V_{EE}$	$I_{SINK} = 20\ \mu A$		5	7		5	7	mV
T_{MIN} to T_{MAX}				10			10	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 20\ \mu A$		10	14		10	14	mV
T_{MIN} to T_{MAX}				20			20	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 2$ mA		40	55		40	55	mV
T_{MIN} to T_{MAX}				80			80	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 2$ mA		80	110		80	110	mV
T_{MIN} to T_{MAX}				160			160	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 15$ mA		300	500		300	500	mV
T_{MIN} to T_{MAX}				1000			1000	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 15$ mA		800	1500		800	1500	mV
T_{MIN} to T_{MAX}				1900			1900	mV
Operating Output Current		15			15			mA
T_{MIN} to T_{MAX}		12			12			mA
Capacitive Load Drive			350			350		pF
...WER SUPPLY								
Quiescent Current, T_{MIN} to T_{MAX}			1.3	1.6		1.3	1.6	mA
Power Supply Rejection	$V_{SY} = \pm 5$ V to ± 15 V	66	80		70	80		dB
T_{MIN} to T_{MAX}		66			70			dB

...is a functional specification. Amplifier bandwidth decreases when the input common-mode voltage is driven in the range [V+ − 1 V] to V+. Common-mode error ...tage is typically less than 5 mV with the common-mode voltage set at 1 V below the positive supply.

... $- V_{EE}$ is defined as the difference between the lowest possible output voltage (V_{OL}) and the negative voltage supply rail (V_{EE}). $V_{CC} - V_{OH}$ is defined as the difference ...tween the highest possible output voltage (V_{OH}) and the positive supply voltage (V_{CC}).

±15 V @ T_A = 25°C, V_{CM} = 0 V, V_{OUT} = 0 V, unless otherwise noted.

e 3.

meter	Conditions	A Grade Min	Typ	Max	B Grade Min	Typ	Max	Unit
FORMANCE								
al Offset			0.4	2		0.3	1.5	mV
imum Offset Over Temperature			0.5	3		0.5	2.5	mV
et Drift			2			2		μV/°C
ut Bias Current	V_{CM} = 0 V		2	25		2	12	pA
	V_{CM} = −10 V		40			40		pA
T_{MAX}	V_{CM} = 0 V		0.5	5		0.5	2.5	nA
ut Offset Current			2	20		2	12	pA
T_{MAX}			0.5			0.5		nA
en-Loop Gain	V_{OUT} = −10 V to +10 V							
	R_L = 100 kΩ	500	2000		500	2000		V/mV
to T_{MAX}		500			500			V/mV
	R_L = 10 kΩ	100	500		100	500		V/mV
to T_{MAX}		100			100			V/mV
	R_L = 1 kΩ	30	45		30	45		V/mV
to T_{MAX}		20			20			V/mV
HARMONIC PERFORMANCE								
t Voltage Noise								
= 0.1 Hz to 10 Hz			2			2		μV p-p
= 10 Hz			25			25		nV/√Hz
= 100 Hz			21			21		nV/√Hz
= 1 kHz			16			16		nV/√Hz
= 10 kHz			13			13		nV/√Hz
t Current Noise								
= 0.1 Hz to 10 Hz			18			18		fA p-p
= 1 kHz			0.8			0.8		fA/√Hz
monic Distortion	R_L = 10 kΩ							
= 10 kHz	V_{OUT} = ±10 V		−85			−85		dB
C PERFORMANCE								
y-Gain Frequency			1.9			1.9		MHz
ower Response	V_{OUT} p-p = 20 V		45			45		kHz
Rate			3			3		V/μs
ing Time								
0.1%	V_{OUT} = 0 V to ±10 V		4.1			4.1		μs
0.01%	V_{OUT} = 0 V to ±10 V		4.5			4.5		μs
G CHARACTERISTICS								
Offset				3			2	mV
um Offset Over Temperature				4			2.5	mV
set Drift			3			3		μV/°C
Bias Current				25			12	pA
alk @ f = 1 kHz	R_L = 5 kΩ		−130			−130		dB
alk @ f = 100 kHz	R_L = 5 kΩ		−93			−93		dB
CHARACTERISTICS								
Voltage Range[1], T_{MIN} to T_{MAX}		−15.2		+14	−15.2		+14	V
on-Mode Rejection Ratio (CMRR)	V_{CM} = −15 V to +12 V	70	80		74	90		dB
to T_{MAX}	V_{CM} = −15 V to +12 V	70			74			dB
mpedance								
rential			10^{13}‖0.5			10^{13}‖0.5		Ω‖pF
mon Mode			10^{13}‖2.8			10^{13}‖2.8		Ω‖pF

Parameter	Conditions	A Grade Min	A Grade Typ	A Grade Max	B Grade Min	B Grade Typ	B Grade Max	Unit
OUTPUT CHARACTERISTICS								
Output Saturation Voltage[2]								
$V_{OL} - V_{EE}$	$I_{SINK} = 20\ \mu A$		5	7		5	7	mV
T_{MIN} to T_{MAX}				10			10	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 20\ \mu A$		10	14		10	14	mV
T_{MIN} to T_{MAX}				20			20	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 2$ mA		40	55		40	55	mV
T_{MIN} to T_{MAX}				80			80	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 2$ mA		80	110		80	110	mV
T_{MIN} to T_{MAX}				160			160	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 15$ mA		300	500		300	500	mV
T_{MIN} to T_{MAX}				1000			1000	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 15$ mA		800	1500		800	1500	mV
T_{MIN} to T_{MAX}				1900			1900	mV
Operating Output Current		20			20			mA
T_{MIN} to T_{MAX}		15			15			mA
Capacitive Load Drive			350			350		pF
POWER SUPPLY								
Quiescent Current, T_{MIN} to T_{MAX}			1.4	1.8		1.4	1.8	mA
Power Supply Rejection	$V_{S\pm} = \pm 5$ V to ± 15 V	70	80		70	80		dB
T_{MIN} to T_{MAX}		70			70			dB

[1] This is a functional specification. Amplifier bandwidth decreases when the input common-mode voltage is driven in the range (V+ − 1 V) to V+. Common-mode error voltage is typically less than 5 mV with the common-mode voltage set at 1 V below the positive supply.
[2] $V_{OL} - V_{EE}$ is defined as the difference between the lowest possible output voltage (V_{OL}) and the negative voltage supply rail (V_{EE}). $V_{CC} - V_{OH}$ is defined as the difference between the highest possible output voltage (V_{OH}) and the positive supply voltage (V_{CC}).

LUTE MAXIMUM RATINGS

meter	Rating
oltage	±18 V
Power Dissipation	
PDIP (N)	Observe derating curves
SOIC_N (R)	Observe derating curves
MSOP (RM)	Observe derating curves
oltage[1]	((V+) + 0.2 V) to ((V−) − 20 V)
Short-Circuit Duration	Indefinite
Input Voltage	±30 V
Temperature Range (N)	−65°C to +125°C
Temperature Range (R, RM)	−65°C to +150°C
Temperature Range	
and B Grade	−40°C to +85°C
perature	260°C
ing, 60 sec)	

Characteristics section.

above those listed under Absolute Maximum Ratings permanent damage to the device. This is a stress functional operation of the device at these or any ditions above those indicated in the operational this specification is not implied. Exposure to absolute rating conditions for extended periods may affect ability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 5. Thermal Resistance

Package Type	θ_{JA}	Unit
8-lead PDIP (N)	90	°C/W
8-lead SOIC_N (R)	160	°C/W
8-lead MSOP (RM)	190	°C/W

MAXIMUM POWER DISSIPATION

The maximum power that can be safely dissipated by the AD822 is limited by the associated rise in junction temperature. For plastic packages, the maximum safe junction temperature is 145°C. If these maximums are exceeded momentarily, proper circuit operation is restored as soon as the die temperature is reduced. Leaving the device in the overheated condition for an extended period can result in device burnout. To ensure proper operation, it is important to observe the derating curves shown in Figure 27.

While the AD822 is internally short-circuit protected, this may not be sufficient to guarantee that the maximum junction temperature is not exceeded under all conditions. With power supplies ±12 V (or less) at an ambient temperature of 25°C or less, if the output node is shorted to a supply rail, then the amplifier is not destroyed, even if this condition persists for an extended period.

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

TYPICAL PERFORMANCE CHARACTERISTICS

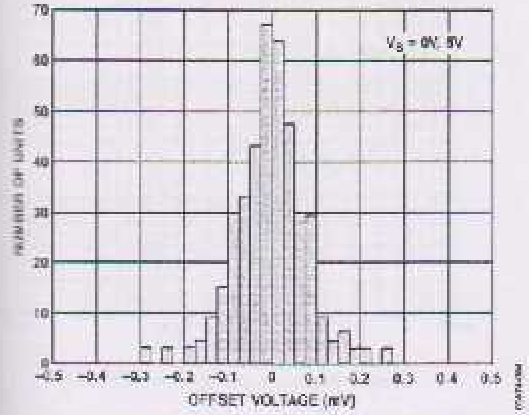


Figure 4. Typical Distribution of Offset Voltage (390 Units)

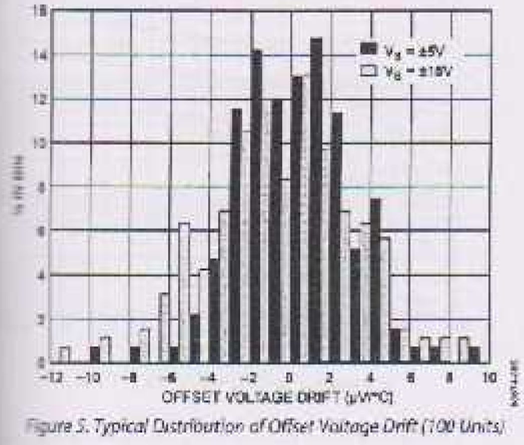


Figure 5. Typical Distribution of Offset Voltage Drift (100 Units)

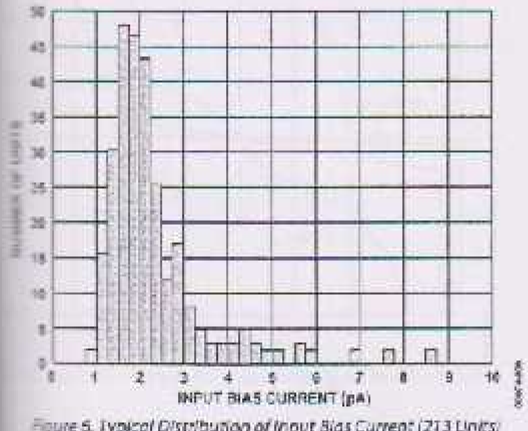


Figure 6. Typical Distribution of Input Bias Current (213 Units)

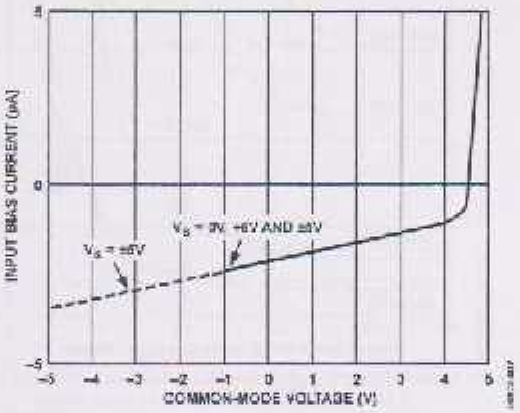


Figure 7. Input Bias Current vs. Common-Mode Voltage; $V_S = 5$ V, 0 V, and $V_S = \pm 5$ V

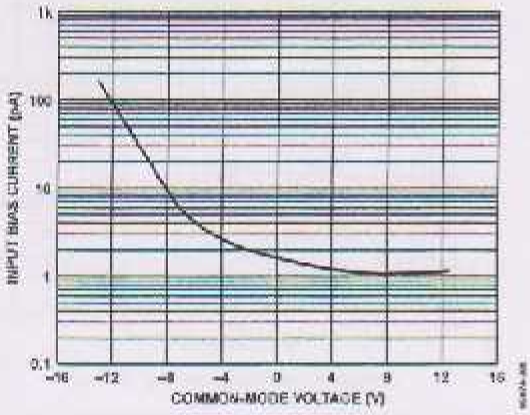


Figure 8. Input Bias Current vs. Common-Mode Voltage; $V_S = \pm 15$ V

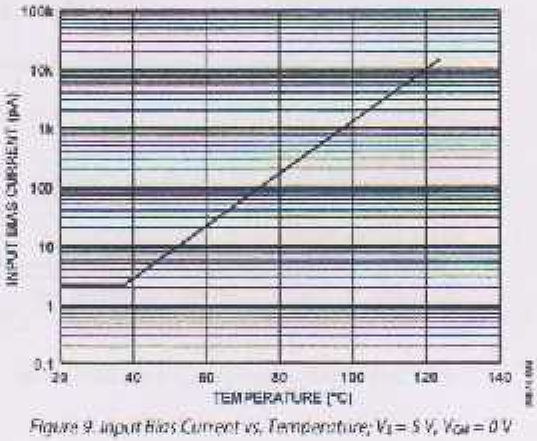


Figure 9. Input Bias Current vs. Temperature; $V_S = 5$ V, $V_{CM} = 0$ V

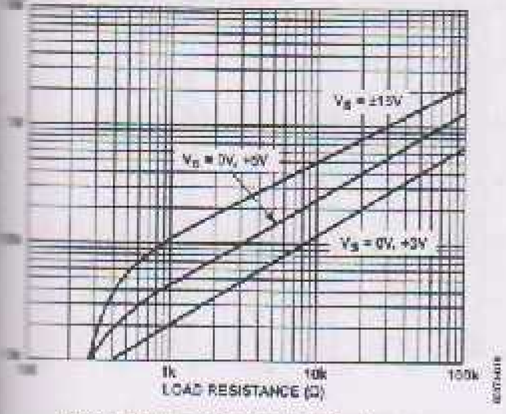


Figure 10. Open-Loop Gain vs. Load Resistance

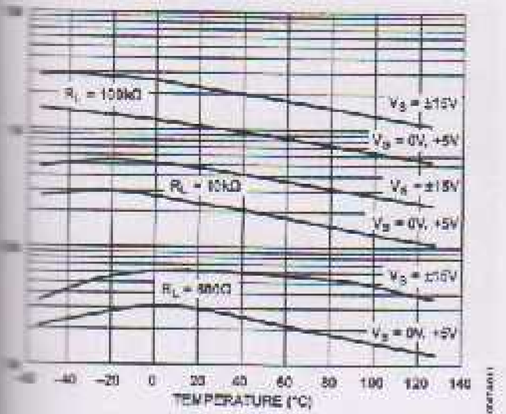
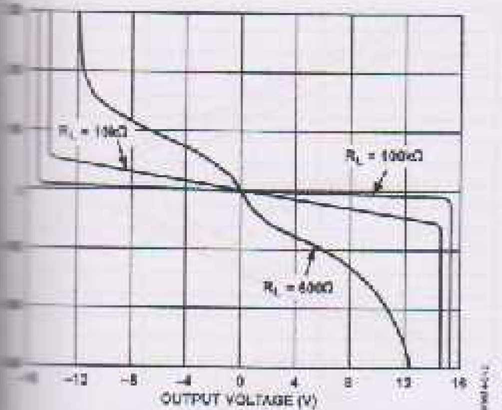


Figure 11. Open-Loop Gain vs. Temperature



2. Input Error Voltage vs. Output Voltage for Resistive Loads

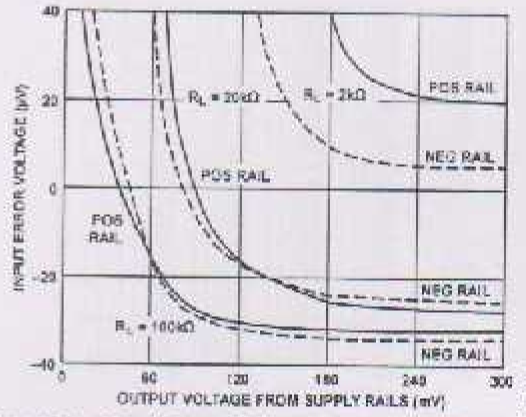


Figure 13. Input Error Voltage with Output Voltage Within 300 mV of Either Supply Rail for Various Resistive Loads; $V_S = \pm5$ V

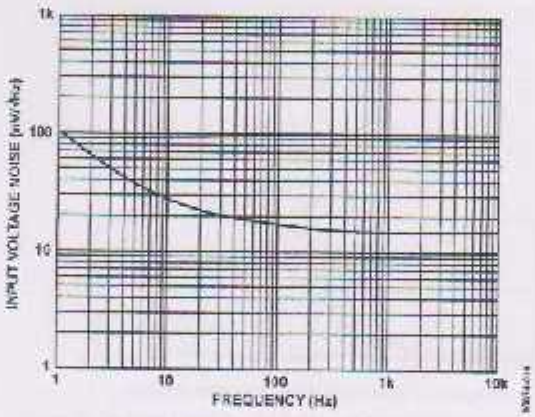


Figure 14. Input Voltage Noise vs. Frequency

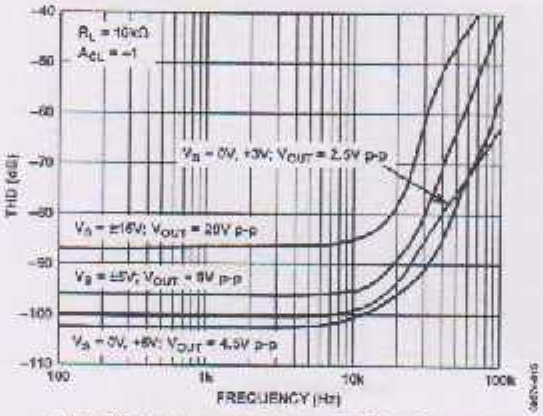


Figure 15. Total Harmonic Distortion (THD) vs. Frequency

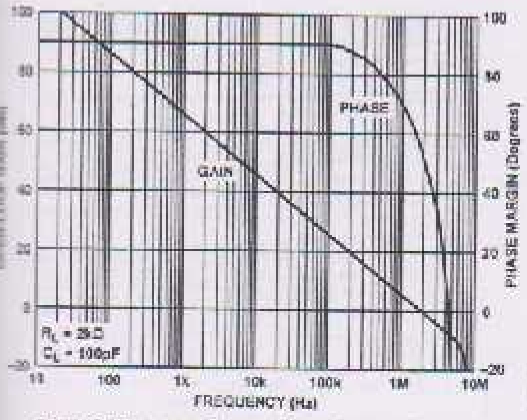


Figure 16. Open-Loop Gain and Phase Margin vs. Frequency

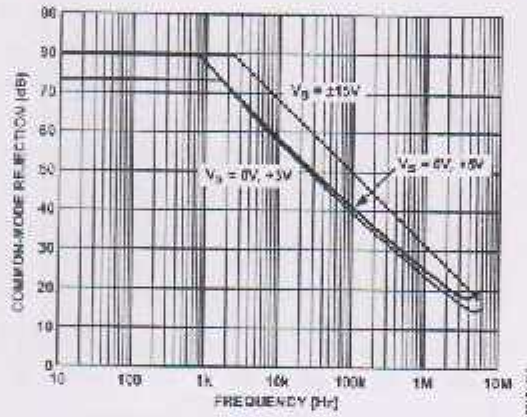


Figure 19. Common-Mode Rejection vs. Frequency

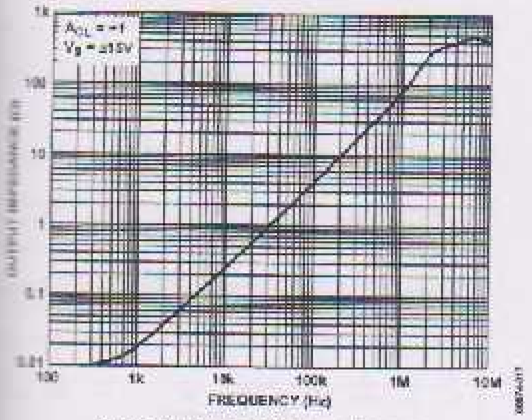


Figure 17. Output Impedance vs. Frequency

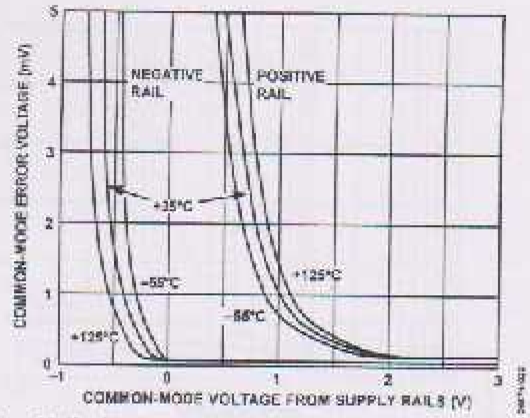


Figure 20. Absolute Common-Mode Error vs. Common-Mode Voltage from Supply Rails (V_S – V_{CM})

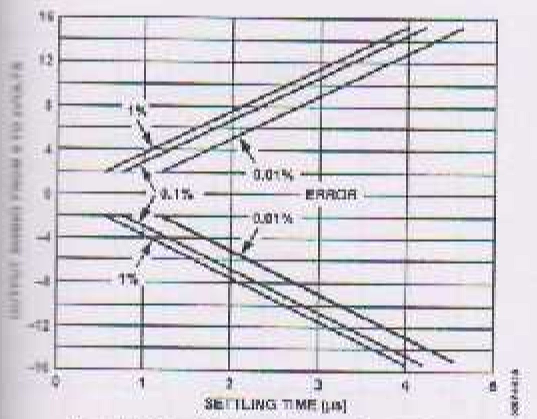


Figure 18. Output Swing and Error vs. Settling Time

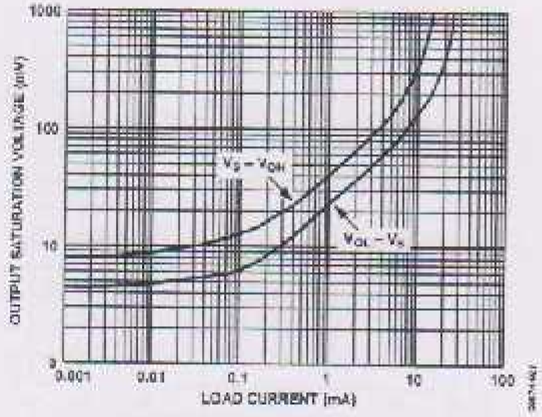


Figure 21. Output Saturation Voltage vs. Load Current

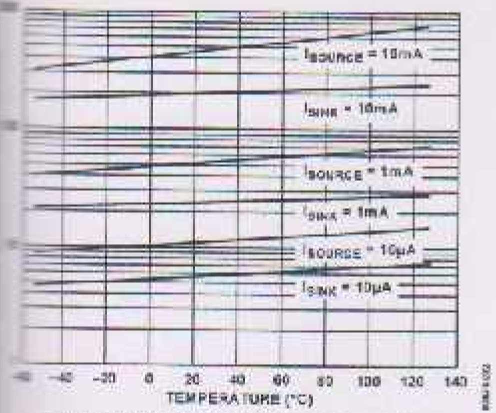


Figure 22. Output Saturation Voltage vs. Temperature

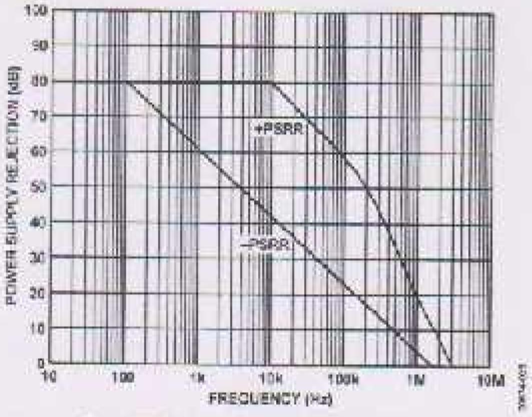


Figure 25. Power Supply Rejection vs. Frequency

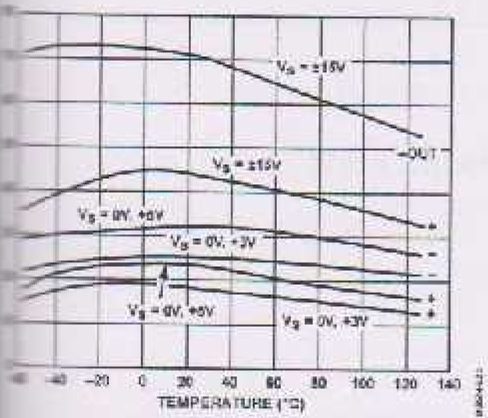


Figure 23. Short-Circuit Current Limit vs. Temperature

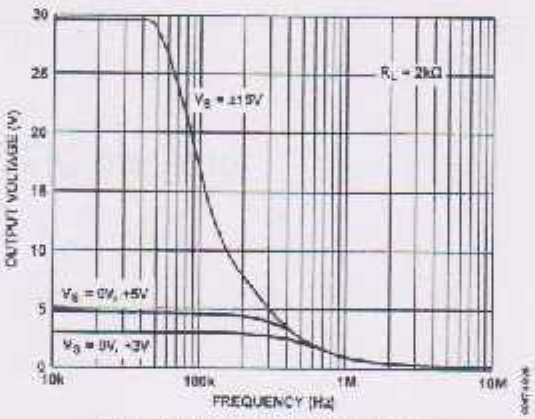


Figure 26. Large Signal Frequency Response

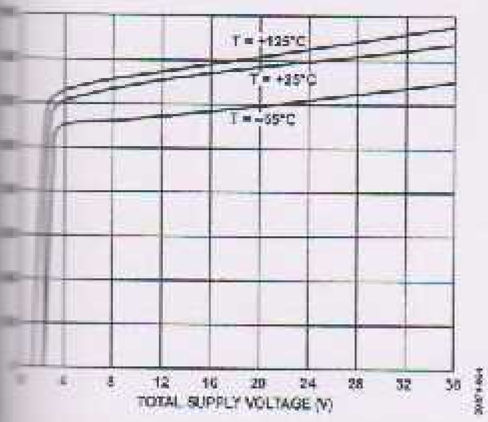


Figure 24. Quiescent Current vs. Supply Voltage vs. Temperature

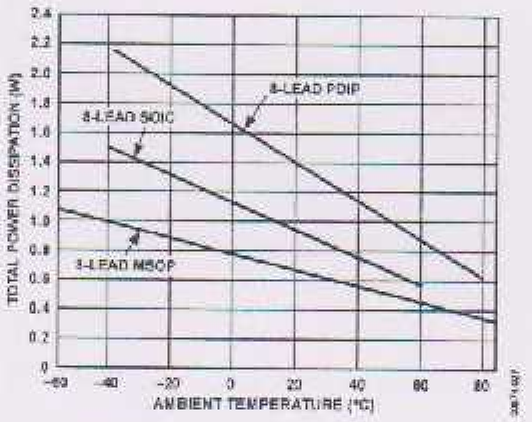


Figure 27. Maximum Power Dissipation vs. Temperature for Packages

APPENDIX F

Data Sheet For BC547C transistor .

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Order this document
by BC546/D

Amplifier Transistors
NPN Silicon

BC546, B
BC547, A, B, C
BC548, A, B, C

CASE 29–04, STYLE 17
TO–92 (TO–226AA)

MAXIMUM RATINGS

Rating	Symbol	BC 546	BC 547	BC 548	Unit
Collector–Emitter Voltage	V_{CEO}	65	45	30	Vdc
Collector–Base Voltage	V_{CBO}	80	50	30	Vdc
Emitter–Base Voltage	V_{EBO}		6.0		Vdc
Collector Current — Continuous	I_C		100		mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D		625 5.0		mW mW/°C
Total Device Dissipation @ T_C = 25°C Derate above 25°C	P_D		1.5 12		Watt mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}		–55 to +150		°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS						
Collector–Emitter Breakdown Voltage (I_C = 1.0 mA, I_B = 0)	BC546 BC547 BC548	$V_{(BR)CEO}$	65 45 30	— — —	— — —	V
Collector–Base Breakdown Voltage (I_C = 100 µAdc)	BC546 BC547 BC548	$V_{(BR)CBO}$	80 50 30	— — —	— — —	V
Emitter–Base Breakdown Voltage (I_E = 10 µA, I_C = 0)	BC546 BC547 BC548	$V_{(BR)EBO}$	6.0 6.0 6.0	— — —	— — —	V
Collector Cutoff Current (V_{CE} = 70 V, V_{BE} = 0) (V_{CE} = 50 V, V_{BE} = 0) (V_{CE} = 35 V, V_{BE} = 0) (V_{CE} = 30 V, T_A = 125°C)	BC546 BC547 BC548 BC546/547/548	I_{CES}	— — — —	0.2 0.2 0.2 —	15 15 15 4.0	nA µA

REV 1

MOTOROLA

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) (Continued)

Characteristic		Symbol	Min	Typ	Max	Unit
ON CHARACTERISTICS						
DC Current Gain (I_C = 10 μA, V_{CE} = 5.0 V)	BC547A/548A	h_{FE}	—	90	—	—
	BC546B/547B/548B		—	150	—	
	BC548C		—	270	—	
(I_C = 2.0 mA, V_{CE} = 5.0 V)	BC546		110	—	450	
	BC547		110	—	800	
	BC548		110	—	800	
	BC547A/548A		110	180	220	
	BC546B/547B/548B		200	290	450	
	BC547C/BC548C		420	520	800	
(I_C = 100 mA, V_{CE} = 5.0 V)	BC547A/548A		—	120	—	
	BC546B/547B/548B		—	180	—	
	BC548C		—	300	—	
Collector–Emitter Saturation Voltage (I_C = 10 mA, I_B = 0.5 mA)		$V_{CE(sat)}$	—	0.09	0.25	V
(I_C = 100 mA, I_B = 5.0 mA)			—	0.2	0.6	
(I_C = 10 mA, I_B = See Note 1)			—	0.3	0.6	
Base–Emitter Saturation Voltage (I_C = 10 mA, I_B = 0.5 mA)		$V_{BE(sat)}$	—	0.7	—	V
Base–Emitter On Voltage (I_C = 2.0 mA, V_{CE} = 5.0 V)		$V_{BE(on)}$	0.55	—	0.7	V
(I_C = 10 mA, V_{CE} = 5.0 V)			—	—	0.77	
SMALL–SIGNAL CHARACTERISTICS						
Current–Gain — Bandwidth Product (I_C = 10 mA, V_{CE} = 5.0 V, f = 100 MHz)	BC546	f_T	150	300	—	MHz
	BC547		150	300	—	
	BC548		150	300	—	
Output Capacitance (V_{CB} = 10 V, I_C = 0, f = 1.0 MHz)		C_{obo}	—	1.7	4.5	pF
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 1.0 MHz)		C_{ibo}	—	10	—	pF
Small–Signal Current Gain (I_C = 2.0 mA, V_{CE} = 5.0 V, f = 1.0 kHz)	BC546	h_{fe}	125	—	500	—
	BC547/548		125	—	900	
	BC547A/548A		125	220	260	
	BC546B/547B/548B		240	330	500	
	BC547C/548C		450	600	900	
Noise Figure (I_C = 0.2 mA, V_{CE} = 5.0 V, R_S = 2 kΩ, f = 1.0 kHz, Δf = 200 Hz)	BC546	NF	—	2.0	10	dB
	BC547		—	2.0	10	
	BC548		—	2.0	10	

Note 1: I_B is value for which I_C = 11 mA at V_{CE} = 1.0 V.

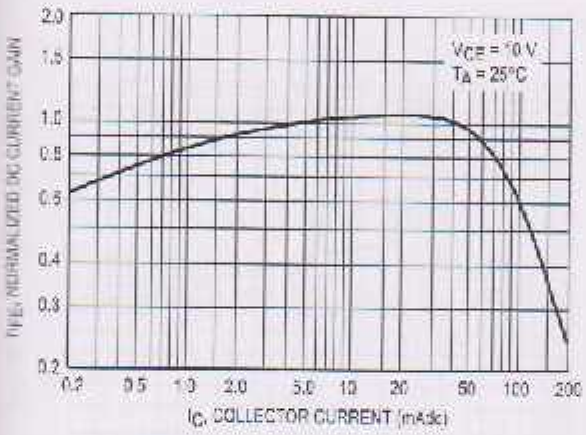


Figure 1. Normalized DC Current Gain

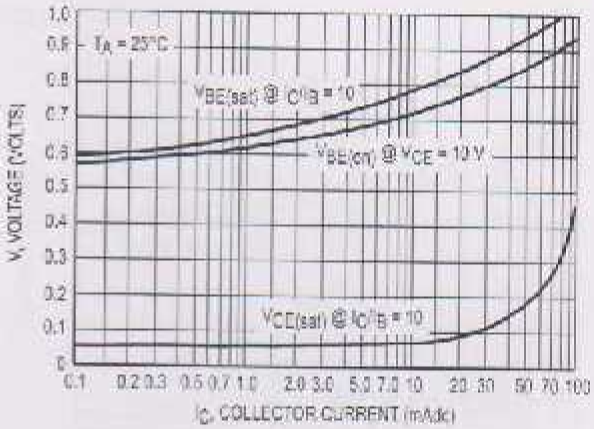


Figure 2. "Saturation" and "On" Voltages

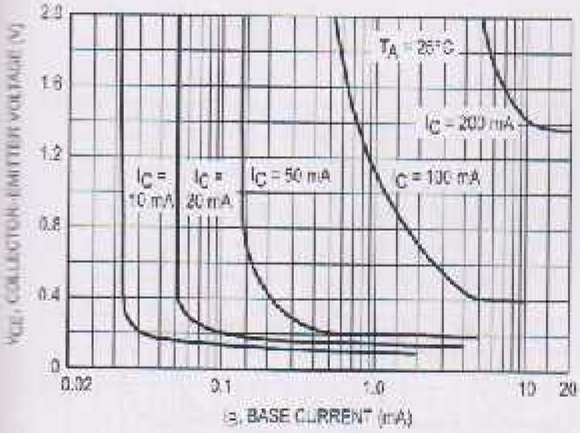


Figure 3. Collector Saturation Region

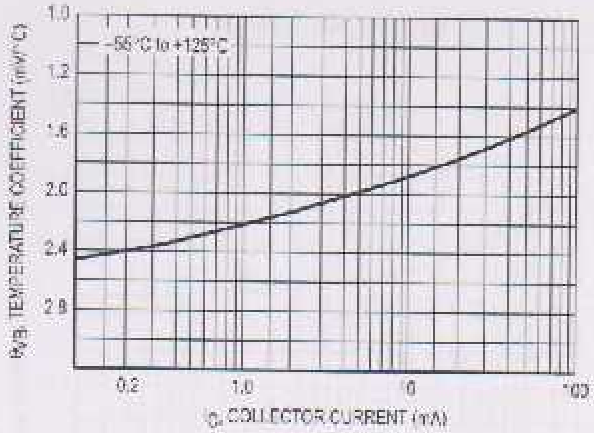


Figure 4. Base–Emitter Temperature Coefficient

BC547/BC548

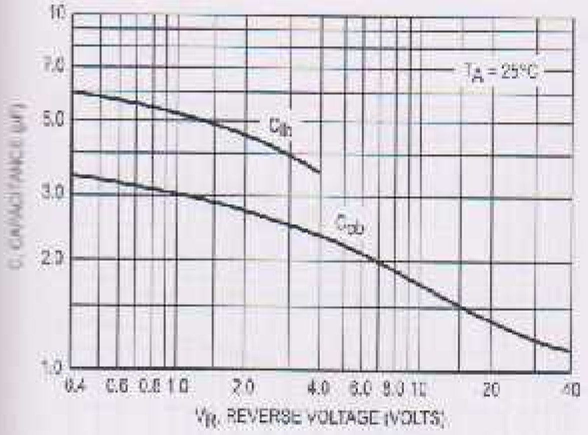


Figure 5. Capacitances

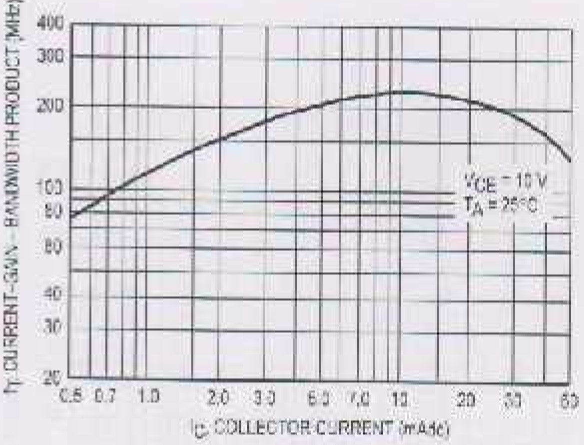


Figure 6. Current–Gain – Bandwidth Product

BC547/BC548

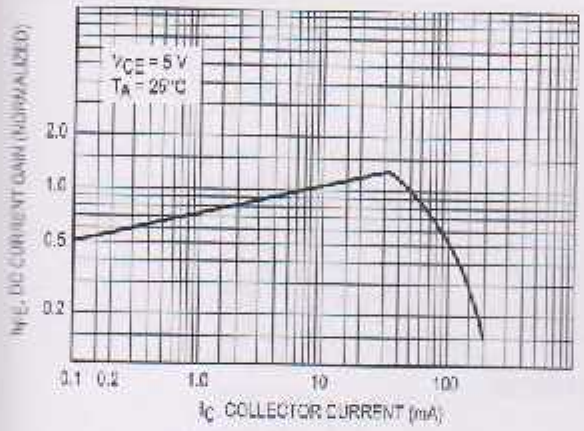


Figure 7. DC Current Gain

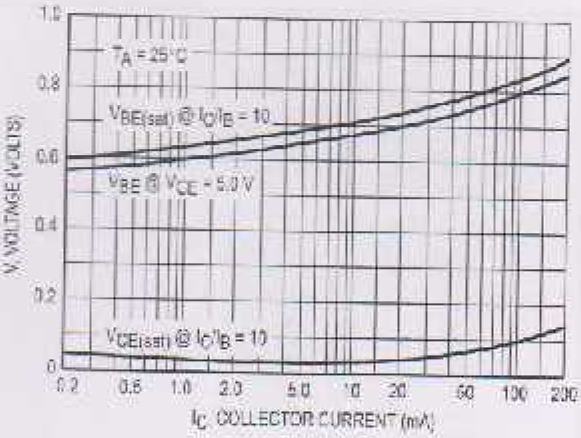


Figure 8. "On" Voltage

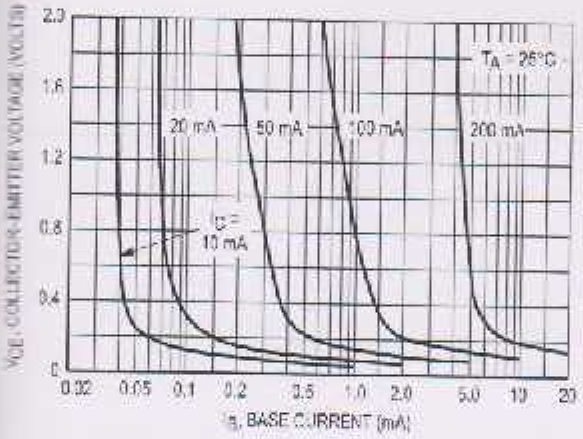


Figure 9. Collector Saturation Region

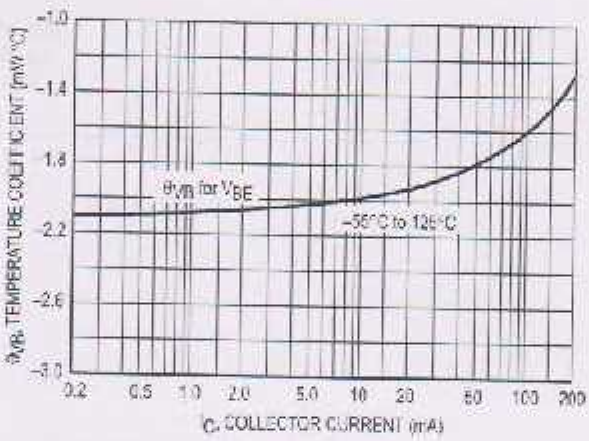


Figure 10. Base–Emitter Temperature Coefficient

BC546

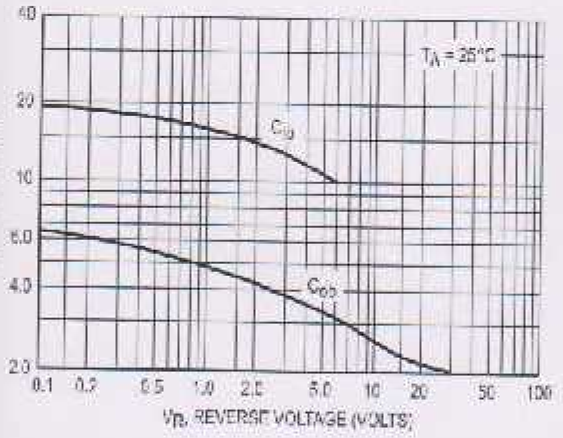


Figure 11. Capacitance

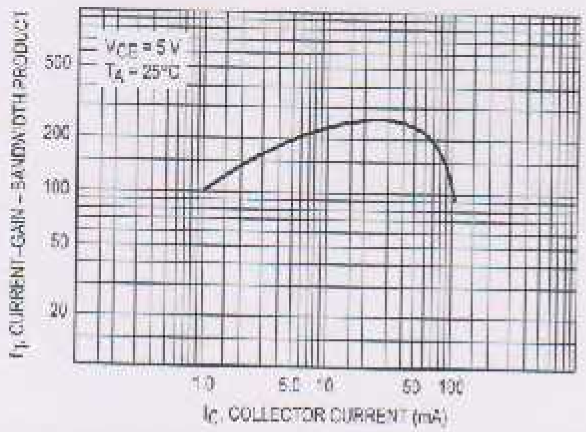
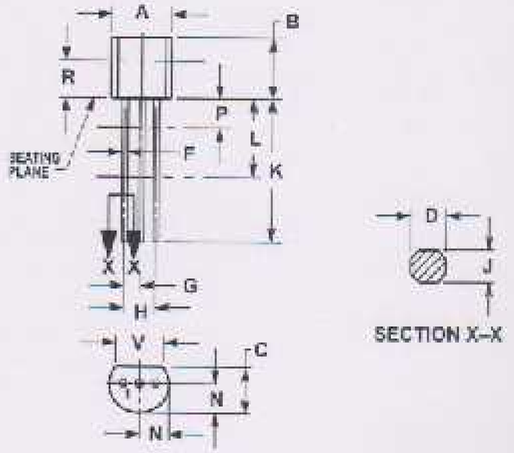


Figure 12. Current–Gain – Bandwidth Product

PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. CONTOUR OF PACKAGE BEYOND DIMENSION R IS UNCONTROLLED.
4. DIMENSION F APPLIES BETWEEN P AND L. DIMENSION D AND J APPLY BETWEEN L AND K MINIMUM. LEAD DIMENSION IS UNCONTROLLED IN P AND BEYOND DIMENSION K MINIMUM.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.175	0.205	4.45	5.20
B	0.170	0.210	4.32	5.33
C	0.125	0.165	3.18	4.19
D	0.016	0.022	0.41	0.55
F	0.016	0.019	0.41	0.48
G	0.045	0.055	1.15	1.39
H	0.095	0.105	2.42	2.66
J	0.015	0.020	0.39	0.50
K	0.500	—	12.70	—
L	0.250	—	6.35	—
N	0.080	0.105	2.04	2.66
P	—	0.100	—	2.54
R	0.115	—	2.93	—
V	0.135	—	3.43	—

CASE 029–04
(TO–226AA)
ISSUE AD

STYLE 17:
PIN 1. COLLECTOR
2. BASE
3. EMITTER

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MOTOROLA

APPENDIX G

Normal & Abnormal Teeth Force Recording .

Table 6.10 : Normal Biting Force For Male

#No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
1	4.2	96.84	99.24	4.7	108.61	111.01	**Male**	**Right** side is more used in normal life
2	4.1	94.49	96.89	3.4	78.03	80.43	**Male**	**Right** side is more used in normal life
3	3.6	82.73	85.13	2.5	56.85	59.25	**Male**	**Right** side is more used in normal life
4	2.9	66.26	68.66	2.4	54.50	56.9	**Male**	**Right** side is more used in normal life
5	2.4	54.50	56.9	3.6	82.73	85.13	**Male**	**Both Sides**
6	4.3	99.19	101.59	2.7	61.56	63.96	**Male**	**Left** side is more used in normal life
7	1.9	42.74	45.14	4.1	94.49	96.89	**Male**	**Right** side is more used in normal life
8	3.7	85.08	87.48	4.7	108.61	111.01	**Male**	**Left** side is more used in normal life
9	1.3	28.63	31.03	1.2	26.27	28.68	**Male**	**Right** side is more used in normal life
10	3.7	85.08	87.48	3.3	75.67	78.07	**Male**	**Right** side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
11	3.4	78.02	80.42	2.1	47.45	49.85	**Male**	**Right** side is more used in normal life
12	1.4	30.98	33.38	1.2	26.28	28.68	**Male**	**Both sides**
13	3.8	87.43	89.83	4.1	94.49	96.89	**Male**	**Right** side is more used in normal life
14	2.3	52.15	54.55	1.6	35.69	38.09	**Male**	**Left** side is more used in normal life
15	2.1	47.45	49.85	1.5	33.33	35.73	**Male**	**Right** side is more used in normal life
16	2.2	49.80	52.2	3.6	82.73	85.13	**Male**	**Right** side is more used in normal life
17	2.9	66.27	68.67	2.3	52.15	54.55	**Male**	**Right** side is more used in normal life
18	2.1	47.45	49.85	1.9	42.74	45.14	**Male**	**Right** side is more used in normal life
19	1.6	35.69	38.09	0.8	16.87	19.27	**Male**	**Right** side is more used in normal life
20	3	68.62	71.02	3.8	87.44	89.84	**Male**	**Right** side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
21	3.4	78.03	80.43	2.2	49.80	52.2	**Male**	**Right** side is more used in normal life
22	4.3	99.19	101.59	3.6	82.73	85.13	**Male**	**Left** side is more used in normal life
23	1.4	30.98	33.38	1.7	38.08	40.48	**Male**	**Right** side is more used in normal life
24	3.1	70.97	73.37	2.2	49.80	52.20	**Male**	**Right** side is more used in normal life
25	2.2	49.80	52.20	1.9	42.74	45.14	**Male**	**Left** side is more used in normal life
26	2.1	47.44	49.84	2.7	61.56	**63.96**	**Male**	**Right** side is more used in normal life
27	2.8	63.91	66.31	1.7	38.08	40.48	**Male**	**Right** side is more used in normal life
28	2.4	54.50	56.90	3.1	70.97	73.37	**Male**	**Right** side is more used in normal life
29	3.9	89.78	92.18	2.8	63.91	66.31	**Male**	**Left** side is more used in normal life
30	2.4	54.50	56.90	0.9	19.22	21.62	**Male**	**Left** side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
31	1.2	26.27	28.67	1.0	21.57	23.97	**Male**	**Right** side is more used in normal life
32	1.3	28.63	31.03	1.1	23.92	26.33	**Male**	**Right** side is more used in normal life
33	2.2	49.80	52.20	1.4	30.98	33.38	**Male**	**Both sides**
34	1.7	38.03	40.43	1.1	23.92	26.32	**Male**	**Right** side is more used in normal life
35	2.5	56.85	59.25	3.1	70.97	73.37	**Male**	**Both sides**
36	3.2	73.32	75.72	1.8	40.39	42.89	**Male**	**Right** side is more used in normal life
37	2.2	49.80	52.20	1.9	42.74	45.14	**Male**	**Both sides**
38	1.4	30.98	33.38	1.7	38.03	40.43	**Male**	**Right** side is more used in normal life
39	1.3	28.63	31.03	1.2	26.27	28.67	**Male**	**Right** side is more used in normal life
40	1.1	23.92	26.32	1.8	40.39	42.79	**Male**	**Right** side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
41	2.1	52.15	54.55	1.0	21.57	23.97	Male	**Right** side is more used in normal life
42	2.3	52.15	54.55	1.9	42.74	45.14	Male	**Right** side is more used in normal life
43	1.8	40.39	42.79	1.1	23.92	26.32	Male	**Right** side is more used in normal life
44	1.3	28.63	31.03	1.7	38.03	40.43	Male	**Left** side is more used in normal life
45	1.9	49.3	51.7	2.04	46.04	48.44	Male	**Right** side is more used in normal life

Table 6.11 : Normal Biting Force For Female

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
1	0.55	10.99	13.39	2.1	47.45	49.85	**Female**	**Left** side is more used in normal life
2	1.7	38.04	40.44	3.01	68.85	71.25	**Female**	**Left** side is more used in normal life
3	1.4	32.93	35.33	0.47	9.11	11.51	**Female**	**Right** side is more used in normal life
4	2.1	47.45	49.85	1.03	22.28	24.68	**Female**	**Right** side is more used in normal life
5	2.2	49.80	52.2	2.6	59.21	61.61	**Female**	**Right** side is more used in normal life
6	2.3	52.15	54.55	1.7	38.04	40.44	**Female**	**Left** side is more used in normal life
7	0.5	9.8	12.2	2.4	54.50	56.9	**Female**	**Both sides**
8	0.8	16.86	19.26	2.6	59.21	61.61	**Female**	**Right** side is more used in normal life
9	1.03	21.64	24.04	1.1	23.93	26.33	**Female**	**Both sides**
10	3.36	77.09	79.49	2.23	50.51	52.91	**Female**	**Right** side is more used in normal life

#No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
11	4.2	96.84	99.24	4.5	103.90	106.3	**Female**	**Right** side is more used in normal life
12	2.4	54.50	56.9	2.8	63.91	66.31	**Female**	**Right** side is more used in normal life
13	2.4	54.50	56.9	3.1	70.97	73.37	**Female**	**Right** side is more used in normal life

#No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
11	4.2	96.84	99.24	4.5	103.90	106.3	**Female**	**Right** side is more used in normal life
12	2.4	54.50	56.9	2.8	63.91	66.31	**Female**	**Right** side is more used in normal life
13	2.4	54.50	56.9	3.1	70.97	73.37	**Female**	**Right** side is more used in normal life
14	1.3	28.63	31.03	3.1	70.97	73.37	**Female**	**Right** side is more used in normal life
15	1.8	40.39	42.79	2.98	68.15	70.55	**Female**	**Left** side is more used in normal life
16	3.7	85.08	87.48	3.0	68.62	71.02	**Female**	**Right** side is more used in normal life
17	1.4	30.98	33.38	0.93	19.93	22.33	**Female**	**Left** side is more used in normal life
18	0.4	7.46	9.86	0.5	9.81	12.21	**Female**	**Both sides**
19	1.9	42.74	45.14	0.49	9.58	11.98	**Female**	**Right** side is more used in normal life
20	1.02	22.04	24.44	0.54	10.75	13.15	**Female**	Right side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
21	2.52	57.33	59.73	1.96	44.2	46.6	**Female**	**Right** side is more used in normal life
22	2.35	53.3	55.7	2.18	49.3	51.7	**Female**	**Right** side is more used in normal life
23	1.2	26.27	28.67	1.4	30.98	33.38	**Female**	**Left** side is more used in normal life
24	2.1	47.44	49.84	1.6	35.68	38.08	**Female**	**Right** side is more used in normal life
25	1.1	23.92	26.32	1.0	21.57	23.97	**Female**	**Right** side is more used in normal life
26	1.9	42.74	45.14	2.3	52.15	54.55	**Female**	**Right** side is more used in normal life
27	1.0	21.57	23.97	1.3	28.63	31.03	**Female**	**Right** side is more used in normal life
28	3.1	70.97	73.37	1.5	33.33	35.73	**Female**	**Right** side is more used in normal life
29	1.9	42.74	45.14	1.3	28.63	31.03	**Female**	**Both sides**
30	1.2	26.27	28.67	0.9	19.22	21.62	**Female**	**Right** side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
31	1.2	26.27	28.67	1.1	23.92	26.32	**Female**	**Left** side is more used in normal life
32	1.4	30.98	33.38	2.8	63.91	66.31	**Female**	**Right** side is more used in normal life
33	2.2	49.80	52.20	1.3	28.63	31.03	**Female**	**Left** side is more used in normal life
34	1.4	30.98	33.38	1.1	23.93	26.33	**Female**	**Right** side is more used in normal life
35	1.7	38.04	40.44	1.5	33.34	35.74	**Female**	**Right** side is more used in normal life
36	0.8	16.87	19.27	1.1	23.93	26.33	**Female**	**Right** side is more used in normal life
37	1.2	26.27	28.67	1.7	38.03	40.43	**Female**	**Left** side is more used in normal life
38	1.5	33.33	35.73	2.3	52.15	54.55	**Female**	**Right** side is more used in normal life
39	3.4	78.02	80.42	2.2	49.80	52.20	**Female**	**Left** side is more used in normal life
40	2.7	61.56	63.96	1.4	30.98	33.38	**Female**	**Right** side is more used in normal life

# No	Right side (v)	Right side (lb)	Wasted force on Si material (+2.4lb)	Left side force (v)	Left side force (lb)	Wasted force on Si material (+2.4lb)	Gender	Patient comment
41	3.1	70.97	73.37	2.5	56.85	59.25	**Female**	**Both sides**
42	1.1	23.92	26.32	1.8	40.93	43.33	**Female**	**Left** side is more used in normal life
43	3.6	82.73	85.13	2.1	47.44	49.84	**Female**	**Right** side is more used in normal life
44	2.4	54.50	56.90	2.1	47.44	49.84	**Female**	**Left** side is more used in normal life
45	1.84	41.3	43.7	2.12	47.9	50.3	**Female**	**Right** side is more used in normal life

Table 6.12 : Biting Force For Bruxsers Patient

# No	Right side (V)	Right Side (Ib)	Wasted force on si material (+2.4Ib)	Left side force (V)	Left side force (Ib)	Wasted force on si material (+2.4Ib)	Gender	Patient comment
1	3.8	87.43	89.83	4.2	96.84	99.24	**Male**	**Left** side is more used in normal life
2	6.5	150.94	153.34	6.1	141.53	143.93	**Male**	**Left** side is more used in normal life
3	4.0	92.14	94.54	6.5	150.94	153.34	**Male**	**Right** side is more used in normal life
4	5.3	122.71	125.11	6.1	141.53	143.93	**Female**	**Right** side is more used in normal life
5	5.8	134.47	136.87	6.5	150.09	153.34	**Female**	**Right** side is more used in normal life
6	6.2	143.88	146.28	6.5	150.94	153.34	**Male**	**Left** side is more used in normal life
7	7.1	165.05	167.45	5.1	118.01	120.41	**Female**	**Both side**
8	5.2	120.36	122.76	5.3	122.71	125.11	**Female**	**Right** side is more used in normal life
9	5	115.66	118.06	5.1	119.96	122.36	**Female**	**Both side**
10	5.0	115.66	118.06	4.5	103.90	106.30	**Male**	**Right** side is more used in normal life

11	4.7	108.60	111.00	4.8	110.95	113.35	**Female**	**Left** side is more used in normal life
12	5.2	120.36	122.76	5.5	127.42	129.82	**Male**	**Left** side is more used in normal life
13	5.4	125.07	127.47	4.8	110.95	113.35	**Female**	**Right** side is more used in normal life

11	4.7	108.60	111.00	4.8	110.95	113.35	**Female**	**Left** side is more used in normal life
12	5.2	120.36	122.76	5.5	127.42	129.82	**Male**	**Left** side is more used in normal life
13	5.4	125.07	127.47	4.8	110.95	113.35	**Female**	**Right** side is more used in normal life

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