Design of Portable Medical System for Monitoring and Treating Sleep Apnea

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List of Abbreviation :

DC : Direct Current .

AC : Alternate Current.

CPAP : continuous positive airway pressure

LPF: low pass filter

HPF: high pass filter

ECG: Electrocardiography

EMG: Electromyography

EOG: Electrooculography

EEG: electroencephalogram

OSA : obstructive sleep apnea

CSA: central sleep apnea

PSG:: polysomnography

HVPC: High Voltage Pulsed Current

الإهداء :

اذا كان الإهداء يعبر ولو بجزء من الوفاء فالإهداء

إلى معلم البشرية ومنبع العلم . . . نبينا محمد (صلى الله عليه وسلم)

إلى ينبوع العطاء الذي زرع في نفسي الطموح والمثابرة . . . والدي العزيز

إلى نبع الحنان الذي لا ينضب . . . أمي الغالية

إلى الذين رووا بدمائهم ثرى فلسطين إلى من هم أفضل منا جميعاً إلى الذين ارتقوا إلى السمو . . . شهداء فلسطين

إلى الذين عشقوا الحرية التي تفوح منها رائحة الليمون والبرتقال والنرجس . . . الأسرى والمعتقلين

إلى الذين هم رمز للاستبسال والشجاعة . . . أبطال غزة هاشم وأطفالها وأطفال أهل اليرموك

إلى أعمدة العلم والمعرفة الذين خطوا لي وللآخرين صفحات الإبداع

. . . المعلم والمربي الفاضل م. علي عمرو

إلى القلوب الطاهرة الرقيقة والنفوس البريئة إلى رياحين حياتي . . .

إخوتي

هديل واسراء و ربا

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Abstract

The idea of this project is to design a medical system which has the ability to diagnose sleep apnea, and help the patient to wake up by activating an alarm system, and apply reflexology therapy to patient simultaneously.

A pressure sensor will be used to monitor the air flow inside and outside the patient nose and mouth. The sensors signals will be processed and transferred to microprocessor; if the air flow is interrupted for more than 10 seconds, the controller will activate an alarm system to wake the patient, and activate a nerve stimulator connected to the sole of the foot to stimulate certain areas of the foot that affect the energy balance in the human body and activate blood circulation and respiratory system based on reflexology therapy.

الملخص

يهدف المشروع إلى تصميم نموذج الكتروني بسيط لجهاز تشخيص متلازمة انقطاع التنفس أثناء النوم، ليصبح به الحد الأدنى من القياسات اللازمة لتشخيص المرض، بالإضافة إلى ميزة إيقاظ المريض وتعزيز قدرته على شفاء نفسه بنفسه من خلال علم أل reflexology. يعتمد هذا التصميم على اقتباس تدفق الهواء الداخل والخارج من الأنف والفم بواسطة " pressure sensor" ، وبالتالي الحصول على اشاره تتضمن معلومات عن حاله التنفس لدى المريض ، ثم نقل هذه الإشارة لدارة متحكم صغري ومعالجة تغيرها، فإذا انقطع جريان الهواء لمده تزيد عن ١٠ ثواني ' يقوم بإرسال أمر إلى وحده التنبيه لإيقاظ المريض ، كما ترسل أمر إلى جهاز الكتروني أخر يعمل على تنبيه مناطق معينة أسفل القدم التي تؤثر على توازن الطاقة في جسم الإنسان وتعزز قدرة الجسم على شفاء نفسه بشكل طبيعي ، حيث يقوم هذا الجهاز بعمل مساج في باطن القدم بواسطه تيار كهربائي محفِز لهذه النقاط بظاهرة تدعى "reflexology" ، تعمل على تنشيط الدورة الدموية في كافه أعضاء الجسم .

Chapter One

Introduction

1.1 Overview.

1.2 Project Objectives.

1.3 Project Motivation.

1.4 The Importance Of The Project.

1.5 Literature Review And Related Work.

1.6 Economical Study.

1.7 Schedule Time.

1.1Overview.

According to several studies, obstructive sleep apnea (OSA) affects an estimated 15 million adult Americans and is present in a large proportion of patients with hypertension, and in those with other cardiovascular disorders, including coronary artery disease, stroke, and a trial fibrillation. In contrast, central sleep apnea (CSA) occurs mainly in patients with heart failure .[1],[2]

Research studies in the U.S. and around the world indicate positive benefits of reflexology for various conditions. In particular, there are several well-designed studies that indicate reflexologies promise as an intervention to reduce pain and enhance relaxation, sleep, and the reduction of psychological symptoms, such as anxiety and depression.

The final project is aimed to design and build a simple device for monitoring and treating sleep apnea . The device consists of two main circuit one for monitor the occurrence of breathing interruptions and the other for treat sleep apnea by using reflexology therapy .

Untreated sleep apnea can:

- Increase the risk of high blood pressure, heart attack, stroke, obesity, and diabetes.
- Increase the risk of, or worsen, heart failure.
- Make arrhythmias (ah-RITH-me-ahs), or irregular heartbeats, more likely.
- Increase the chance of having work-related or driving accidents.

Sleep apnea is a chronic condition that requires long-term management. Lifestyle changes, mouthpieces, surgery, and breathing devices can successfully treat sleep apnea in many people.[3]

1.2 Project Objectives.

The main objectives of the project are :

- To study the physiology of reflexology therapy and respiratory system.
- To show the benefit of electrical stimulation for sleep apnea cases .
- Design a medical system that has the ability to monitor the patient breathe to diagnose sleep apnea, and make treatment by reflexology therapy.

1.3 Project Motivation.

The motivation of this project is to minimize the challenges that facing the patient during treat this problem by current device . For example in sleep lap a lot of test records several body functions during sleep, including brain activity, eye movement, oxygen and carbon dioxide blood levels, heart rate and rhythm, breathing rate and rhythm, the flow of air through your mouth and nose, snoring, body muscle movements, and chest and belly movement., moreover the uncomfortable ,complexity continuous positive air pressure device Which it goes with patient everywhere. In the other hand , this project provide more facilities in diagnosis from other technique as polysomnogram which consist of more complex step to give indication of bio signal from heart , brain, ….etc, where the reflexology deal with it with no need to make measuring by activate the energy pathways of heart, brain,…..etc.

1.4 The Importance Of The Project.

- Non invasive method.
- Portable system which means it will be small and comfortable .
- Simple to use and safe .
- The implementation of this project depends on some sensor for diagnosis , so it is easier than previous methods which is depend on take a bio signal and deal with it, which means existence of wire, data acquisitions, and more complex steps to complete diagnosis of problem .

1.5 Literature Review And Related Works.

Sleep apnea is a sleep disorder characterized by pauses in breathing during sleep. There are three distinct forms of sleep apnea : central , obstructive , and complex (i.e., a combination of central and obstructive) constituting 0.4%, 84% and 15% of cases respectively .

- CPAP, or continuous positive airway pressure, is a treatment that uses mild air pressure to keep the airways open. CPAP typically is used by people who have breathing problems, such as sleep apnea.

CPAP treatment involves a CPAP machine, which has three main parts:

- A mask or other device that fits over the nose or the nose and mouth. Straps keep the mask in place while you're wearing it.
- A tube that connects the mask to the machine's motor.
- A motor that blows air into the tube.

CPAP is a method for treatment obstructive sleep apnea. Sleep apnea is a common disorder that causes pauses in breathing or shallow breaths while you sleep. As a result, not enough air reaches your lungs.[3]

In obstructive sleep apnea, your airway collapses or is blocked during sleep. When you try to breathe, any air that squeezes past the blockage can cause loud snoring. Your snoring may wake other people in the house.

The mild pressure from CPAP can prevent your airway from collapsing or becoming blocked.

But , this is method is not for treat , it is just for prevent occurrence of apnea , which that means the patient will use it everywhere, not just when he goes to sleep .

Figure 1.1: CPAP configuration[A]

- The Polysomnogram Test

Sleep centers use what’s known as polysomnogram to make a continuous record of your sleep. About two dozen small, thin electrodes and other sensors are pasted on specific body sites to take readings during the night.

If your doctor thinks you have a sleep disorder, he will send you to a sleep center for sleep investigations. The most common investigation in a sleep laboratory is polysomnography (PSG).[4]

In other words, the polysomnogram is used by sleep doctors and sleep technologists to:

- Record a person's sleep.
- To diagnose many sleep disorders, including sleep apnea.
- To investigate the differences between normal and abnormal sleep.

To collect all the signals from a sleeping person, the sleep doctors use sophisticated equipment, very expensive, called polysomnogram. This equipment is like a computer, with additional systems, such as:

- An electroencephalogram (EEG) - which records the brain wave activity.
- An electrooculogram (EOG) - which records the activity of the eyes.
- An electromyogram (EMG) - which records the muscles activity.
- An electrocardiogram (ECG) - monitors the heart rate and rhythm.
- Body movement detector - the patient will have a couple of electrodes placed on the muscles of the shins, together with a body position sensor around the waist.

During your sleep study, you will also have other equipment which collects signals related to breathing, and records the airflow through the nose and mouth, your oxygen and carbon dioxide levels, and how big is your effort to breathe.

Figure 1.2 : Polysomnogram Test[B]

1.6 Economical Study.

The estimated cost is :

Table 1.1 contains the main required hardware component of the project design, and it's cost .

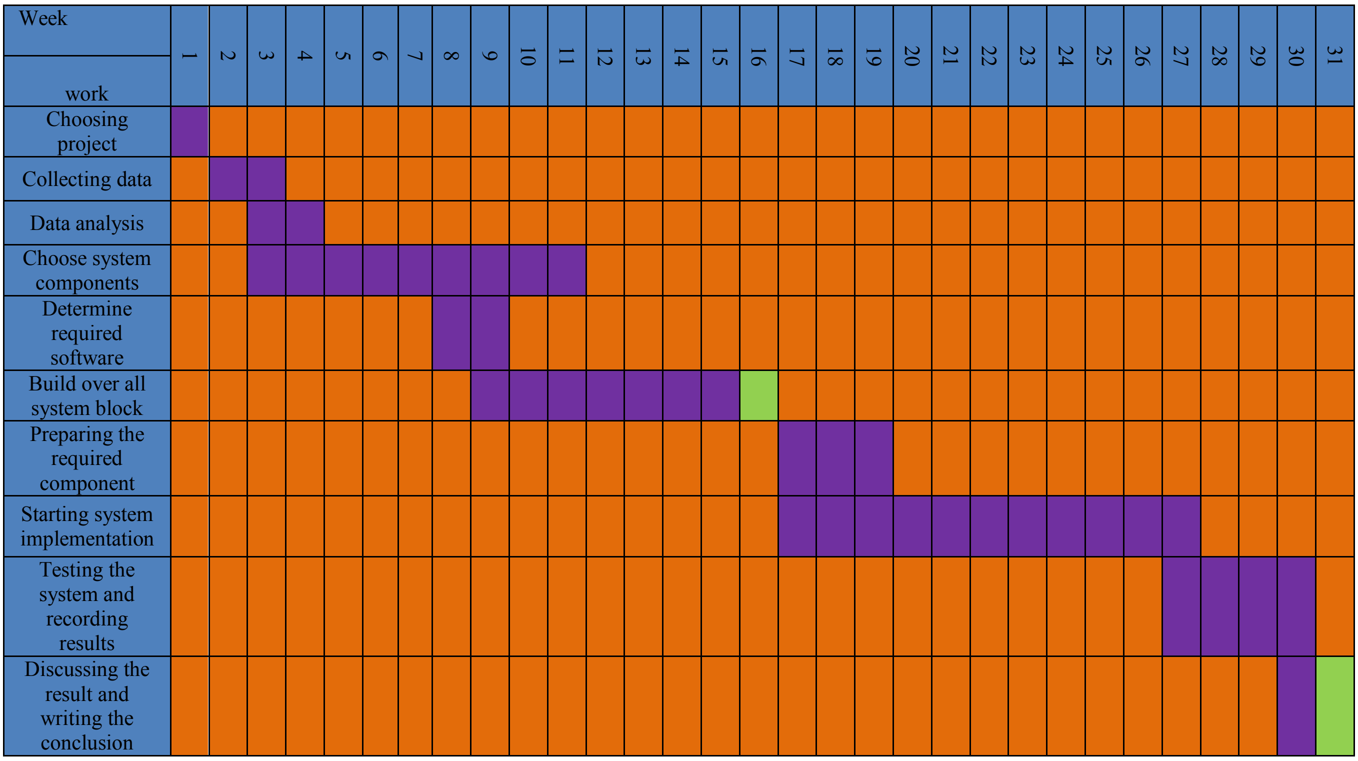
Table 1.1: Estimated Component Cost .

Components	Cost(JD)
Resistors	5
Capacitors	5
Inductors	5
Op-Amps	5
Filters	15
Voltages source "batteries"	10
Voltage regulator	20
Pressure sensor	50
Buzzer	5
MCU	20
Total price approximately	**140**

1.7 Schedule Time.

In this section we make a plan for the predictive project tasks due to the time zone of both lasting semesters , this time plan shown in the table 1.2 .

Table (1.2): Schedule Time .



Week work	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Choosing project	🟪	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Collecting data	🟧	🟪	🟪	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Data analysis	🟧	🟧	🟪	🟪	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Choose system components	🟧	🟧	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Determine required software	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟪	🟪	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Build over all system block	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Preparing the required component	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟪	🟪	🟪	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Starting system implementation	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟧	🟧	🟧	🟧
Testing the system and recording results	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟪	🟪	🟪	🟪	🟧
Discussing the result and writing the conclusion	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟪	🟩

Green square at 16 week represent the date of delivery of the introduction project respectively

Chapter Two

Physiological Background

2.1 The Respiratory System.

2.1.1 Airways

2.1.2 Lungs and Blood Vessels

2.1.3 Muscles Used for Breathing

2.2 Sleep Apnea.

2.3 Reflexology.

2.3.1 History

2.3.2 Reflexology For Respiratory Failure

2.4 Nerve Stimulators.

2.4.1 Electrical Stimulation

2.4.2 physiological Responses to Electricity

2.1 The Respiratory System

The respiratory system consists of organs that process air: the nose, throat, and lungs. Each lung is a network of tubes and sacs that remove oxygen from the air in exchange for carbon dioxide. Such lung functions are controlled by the respiratory center in the brain stem. Regulation is due to multiple factors including sensory impulses from the limbs and feet during electrical stimulation**.[5]**

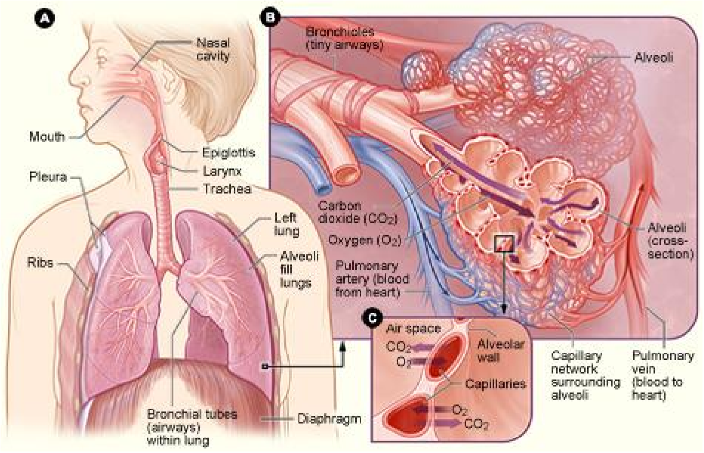


Figure 2.1 : Respiratory System[C]

2.1.1 Airways:

The airways are pipes that carry oxygen-rich air to your lungs. They also carry carbon dioxide, a waste gas, out of your lungs. The airways include your: nose and linked air passages (called nasal cavities), mouth, larynx, or voice box , trachea , or windpipe, tubes called bronchial tubes or bronchi, and their branches.

Air first enters to body through the nose or mouth, which wets and warms the air. (Cold, dry air can irritate your lungs.) The air then travels through your voice box and down your windpipe. The windpipe splits into two bronchial tubes that enter your lungs.

A thin flap of tissue called the epiglottis covers the windpipe when the person swallow. This prevents food and drink from entering the air passages that lead to the lungs.

Except for the mouth and some parts of the nose, all of the airways have special hairs called cilia that are coated with sticky mucus. The cilia trap germs and other foreign particles that enter your airways when you breathe in air.

These fine hairs then sweep the particles up to the nose or mouth. From there, they're swallowed, coughed, or sneezed out of the body. Nose hairs and mouth saliva also trap particles and germs.

2.1.2 Lungs and Blood Vessels :

The lungs and linked blood vessels deliver oxygen to your body and remove carbon dioxide from your body. The lungs lie on either side of your breastbone and fill the inside of your chest cavity. The left lung is slightly smaller than the right lung to allow room for the heart.

Within the lungs, the bronchi branch into thousands of smaller, thinner tubes called bronchioles. These tubes end in bunches of tiny round air sacs called alveoli.

Each of these air sacs is covered in a mesh of tiny blood vessels called capillaries. The capillaries connect to a network of arteries and veins that move blood through the body.

The pulmonary artery and its branches deliver blood rich in carbon dioxide (and lacking in oxygen) to the capillaries that surround the air sacs. Inside the air sacs, carbon dioxide moves from the blood into the air. At the same time, oxygen moves from the air into the blood in the capillaries.

The oxygen-rich blood then travels to the heart through the pulmonary vein and its branches. The heart pumps the oxygen-rich blood out to the body.

The lungs are divided into five main sections called lobes. Some people need to have a diseased lung lobe removed. However, they can still breathe well using the rest of their lung lobes.

2.1.3 Muscles Used for Breathing:

Muscles near the lungs help expand and contract (tighten) the lungs to allow breathing. These muscles include the:

- Diaphragm .
- Intercostals muscles.
- Abdominal muscles.
- Muscles in the neck and collarbone area.

The diaphragm is a dome-shaped muscle located below your lungs. It separates the chest cavity from the abdominal cavity. The diaphragm is the main muscle used for breathing.

The intercostals muscles are located between your ribs. They also play a major role in helping you breathe.

Beneath the diaphragm are abdominal muscles. They help the person breathe out when the person breathing fast (for example, during physical activity).

Muscles in the neck and collarbone area help the person breathe in when other muscles involved in breathing don't work well, or when lung disease impairs the person breathing.

2.2 Sleep Apnea

sleep apnea is a serious sleep disorder that occurs when a person's breathing is interrupted during sleep .

Typical breathing rates occur anywhere from 10-20 breathes per minute. During sleep apnea, the tongue blocks the airway and a 10-30 second pause in breathing occurs , causing the sufferer to miss one to two breathes.

There are three distinct forms of sleep apnea : central, obstructive, and complex (i.e., a combination of central and obstructive) constituting 0.4%,84%and 15% of cases respectively .[6]

- Central sleep apnea : causes pauses in breathing by the lack of effort in breathing . this is due to the failure of neurons in signals to indicate inhalation.
- Obstructive sleep apnea : is where the air path inside the throat is blocked by an object, such as the tongue. As the muscles relax during sleep , the tongue can block the airway, which causes the patient to enter a lighter sleep stage or possibly cause the patient to awaken . most patients suffering from obstructive apnea have trouble getting into a deep sleep state. Even though the light sleep time may be numerous , it is still not as effective as deep sleep .
- Mixed apnea : is the combination of central and obstructive sleep apnea. While obstructive sleep apnea takes place during sleep , central sleep apnea is often developed . patients experience problems breathing and constantly wake up from sleep because of long-term obstructive apnea .

Most people who have sleep apnea don’t know they have it because it only occurs during sleep. People who have small airway in their noses, throats, or mouths also are more likely to have sleep apnea . smaller airways may be due to the shape of these structures or allergies or other medical conditions that cause congestion in these areas .

Risk factors for sleep apnea are : smoking , high blood pressure , heart failure, overweigh , smaller airways , brain tamers , and Family history.

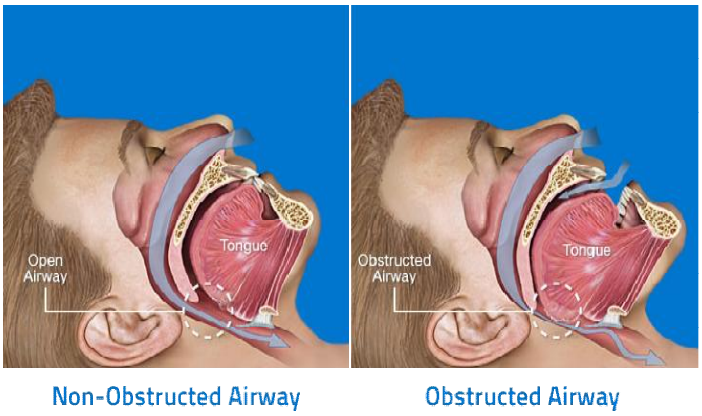


Figure 2.2 : case of sleep apnea , occurred because of muscle limpnesswhich led to the blockage of the airway.[D]

2.3 Reflexology

2.3.1 History

Practices resembling reflexology may have existed in previous historical periods. Similar practices have been documented in the histories of China and Egypt. Reflexology was introduced to the United States in 1913 by William H. Fitzgerald, M.D. (1872–1942), an ear, nose, and throat specialist, and Dr. Edwin Bowers. Fitzgerald claimed that applying pressure had an anesthetic effect on other areas of the body. It was modified in the 1930s and 1940s by Eunice D. Ingham (1889–1974), a nurse and physiotherapist. Ingham claimed that the feet and hands were especially sensitive, and mapped the entire body into "reflexes" on the feet renaming "zone therapy" to reflexology. "Modern reflexologists use Ingham's methods, or similar techniques developed by the reflexologist Laura Norman.

Reflexology is the art or science that according to Webster's Dictionary, is the "massage of the hands or feet based on the belief that pressure applied to specific points on these extremities benefits other parts of the body”. It is common knowledge that basic foot and hand massage promotes the circulation of your blood while loosening tense muscle tissues. Since ancient times in China, it has been believed that the bottoms of the feet and hands can be divided into 25 parts. Each part represents different glands, organs and parts of the body. Reflexology is the art or science of reprogramming the atoms, cells, and electrons of the body to their original state through the triggering of these signal points on the foot or hand. Reflexology offers a unique method of massage and benefits.[7]

Dr. Brent Bauer, MD stated that “Reflexology is generally relaxing and may be an effective way to alleviate stress.” Several studies have also been done indicating that reflexology may reduce pain and psychological symptoms associated with anxiety and depression and may have benefits in palliative care of people with cancer.[5]

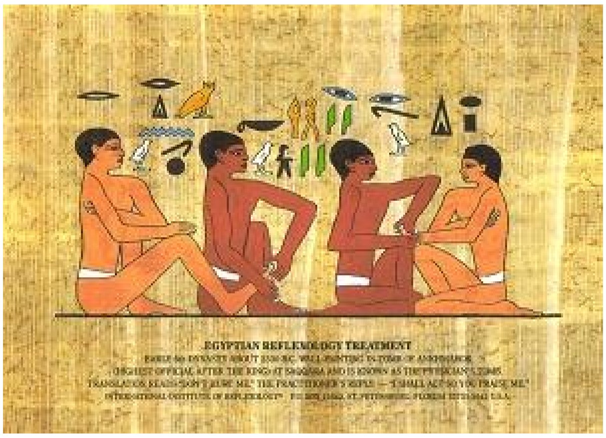


Figure 2.3 : ancient reflexology medical systems , based on apply pressure by the trainer hand on foot and hand of the patient .[E]

2.3.2 Reflexology For Respiratory Failure

Electrical stimulation is used to stimulate the skin to relieve pain. The signals received by the body through the skin are able to relieve the pain because the signals interfere with the neural transmission of signals from the underlying pain receptors of our body, so the pain signal gets cut off. These same signals our body receives through our skin via electrical stimulation also duplicates the signals from the cells that make up our nervous system which send messages to the muscles in our body causing our muscles to contact and allowing for the movement of certain body parts, like our hands or our feet.

Foot reflexology is the practice of stimulating points on the feet to improve health. An electrical foot reflexology stimulator has been developed on the basics of foot reflexology massage and electro acupuncture. The device consists of a battery and a boost converter, the control-electronic and n electrodes. It is developed for the application of a changing current flow through the human body within the range of the foot reflex zones. Because of various control possibilities the proposed device is very flexible. A software controls the user parameters and offers an independent current control mode. This is very important for the user's safety. The possibility to change frequency, current or waveform in a wide range is a good argument for medically skilled and technically unskilled persons to use this device. This helps to establish new alternative medicine methods which have no or less interaction to other medicines.[8]

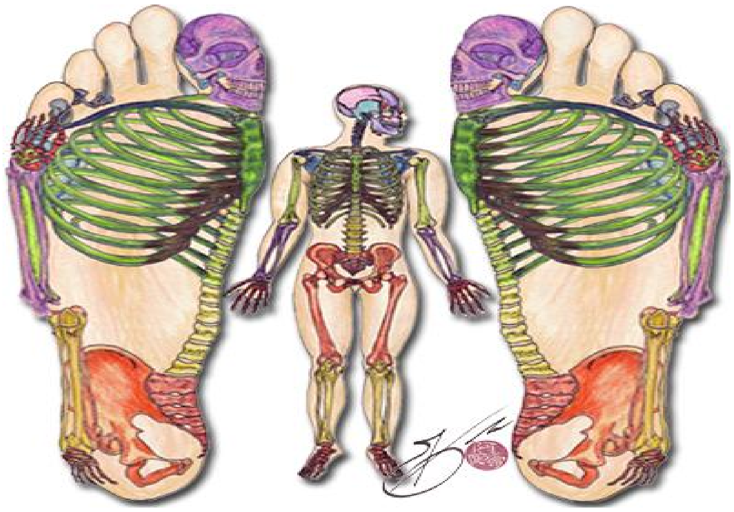


Figure 2.4 : Reflexology zone corresponding to the body organs .[F]

2.4 Nerve Stimulators

The nerves cells release messages from the brain to the muscles , they also carry messages from sensors back to the brain . The outside of the nerve is positively charged (polarized). When the nerve cell is stimulated – depolarization , the electrical pulse runs down from the brain to the muscle . The wave of depolarization runs over the muscle fiber and causes it to contract. A nerve stimulators supplies electrons to depolarize a nerve . The number of electrons supplied per stimulus equals the current . If negative electrons added to the outside they will neutralize the charge . This will cause that wave of depolarization to wash down the nerve . The negative electrode should be attached , as near as possible to a nerve .[9]

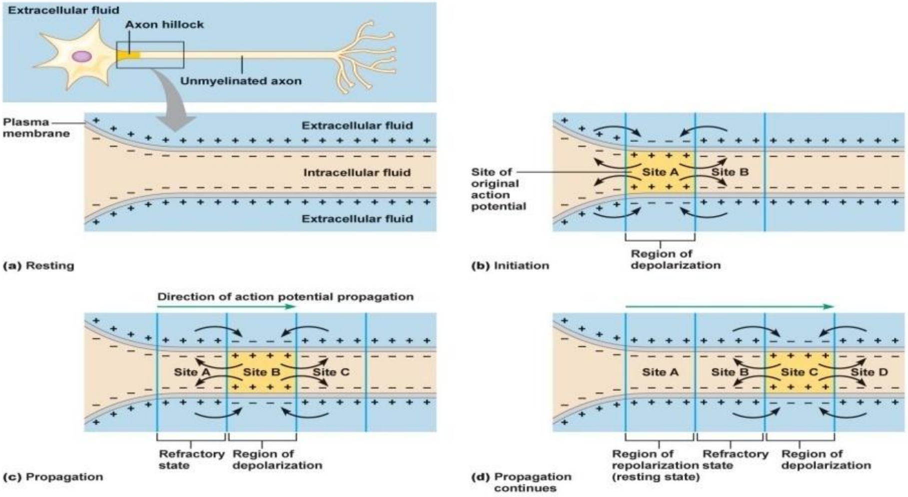


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Figure 2.5 : Action Potential of Nerve[G]

2.4.1 Electrical stimulation

Creating muscle contraction through nerve or muscle stimulation , Stimulating sensory nerves to help in treating pain , creating an electrical field in biologic tissues to stimulate or alter the healing process , and creating an electrical field on the skin surface to drive ions beneficial to the healing process into or through the skin.

As electricity moves through the body's conductive medium, changes in the physiologic functioning can occur at various levels : Cellular , Tissue , Segmental , and Systematic.And which are summarized in Excitation of nerve cells Skeletal muscle contraction ,smooth muscle contraction , Tissue regeneration , modification of joint mobility , muscle pumping action to change circulation and lymphatic activity , alteration of the micro vascular system not associated with muscle pumping , increased movement of charged proteins into the lymphatic channels , Analgesic effects as endogenous pain suppressors are released and act at different levels to control pain , and Analgesic effects from the stimulation of certain neurotransmitters to control neural activity in the presence of pain stimuli.[9]

Electrical stimulation uses an electrical current to cause a single muscle or a group of muscles to contract. By placing electrodes on the skin.

There tow type of electric current : Direct Current (DC) and Alternating Current (AC) . DC current represent continuous flow of electrons in one direction (Galvanic Current) . AC current represent flow of electrons in alternating direction .

Electricity Waveforms : Modulation Current which represent alternation of current magnitude and duration , and Pulsatile Current which represent interrupted current flow ("on" – "off" periods).

2.4.2 physiological Responses to Electricity

As electricity enters the body electrons flow is replaced by ion movement toward opposite poles . At the negative pole the +ion cause an alkaline rxn r protein breakdown (tissue softening). Alkaline rxn kills bacteria. A the positive pole the –ion cause an acidic rxn r protein coagulation (tissue hardening). Skin cells migration toward the pole (used in healing). Pulsing the current minimizes these effects.[9]

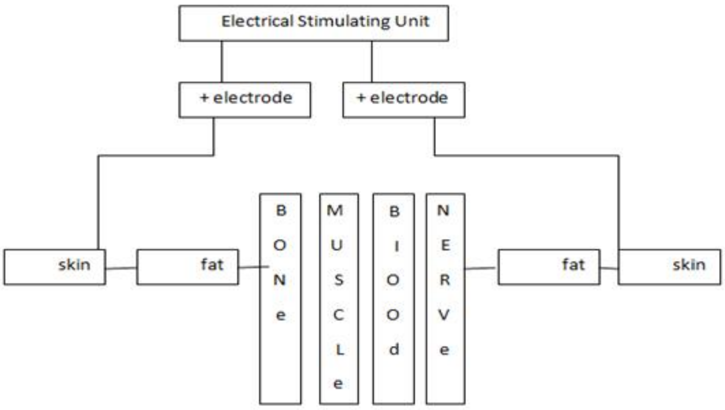


Figure 2.6 : Electrical Circuit in the Body[H]

Chapter Three

Technology Background

3.1 Sensors for Sleep Apnea Detection.

3.1.1 Pressure Sensor .

3.2Electrotherapy.

3.2.1High Voltage Pulsed Current (HVPC)

3.2.2 Type Of Electrode

3.3Microcontrollers.

3.4 Buzzer.

This chapter talks about sleep apnea and reflexology science background technologies , and new technologies that will be employed to achieve project aims, such as sensors for sleep apnea detection, buzzer, programmable micro controller, electronic circuit for current delivery to the patient , and study them to choose the best for the project design .

3.1 Sensors for Sleep Apnea Detection

Present sleep apnea monitoring involves the use of a bedside monitor with wires and patch electrodes which are placed on the patient’s chest and head. Monitoring devices of this sort monitor the muscle activity associated with breathing, heart rate, and oxygen levels via oximeters. Another sensing device that is used is known as the oral/nasal thermistor which covers the patient’s mouth and nose and detects the difference in air temperature during inhalation and exhalation. These however, are not reliable due to the inaccuracy associated with sensitive temperature differences in breathing air flows. [10]

3.1.1 Pressure sensor

In this project the chosen pressure sensor is NPC-1210 Low Pressure Sensor which is based on NovaSensor’s advanced SenStable piezoresistive sensing technology. Silicon micromachining techniques are used to ion implant piezoresistive strain gages into a Wheatstone bridge configuration ,and it is illustrate in figure (3.1)

The sensor was chosen because of its:

- High sensitivity
- High accuracy
- Interchangeable
- Temperature compensated 0°C to 60°C (32°F to 140°F)
- PCB mountable package
- DIP package
- Solid-state reliability
- Individual device traceability

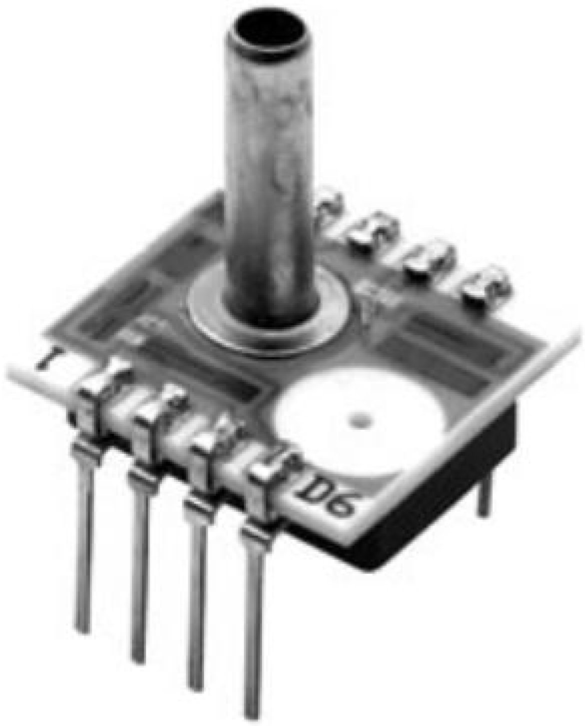


Figure 3.1: pressure sensor.[I]

The internal structure of the pressure sensor contains strain gauge in bridge and instrumentation amplifier and its illustrate in figure 3.2

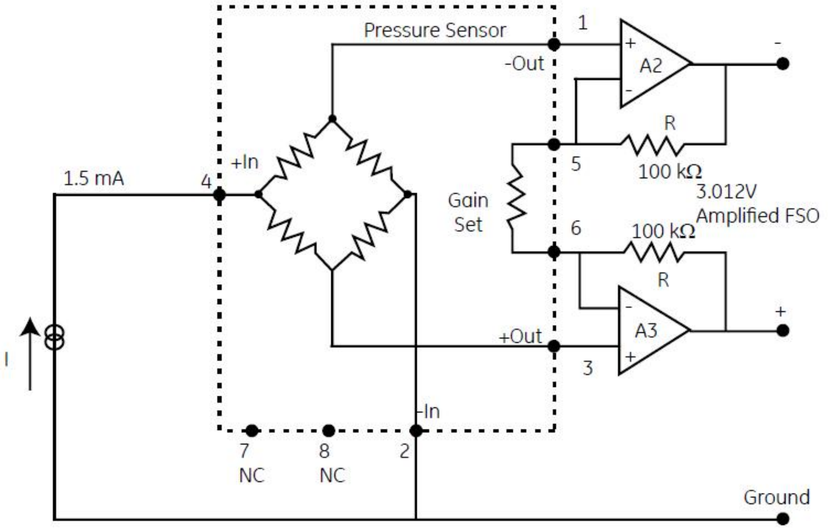


Figure 3.2: Internal structure of pressure sensor[J].

3.2Electrotherapy

There are tow type of electrotherapy stimulation, Low Frequency Stimulation Current, and Medium Frequency Stimulation Current.

- Low Frequency Stimulation Current: When using frequency in a range below 1000Hz, nerves and muscle fibers are able to follow this rhythm and respond to each single current pulse.

Example: TENS, Faradic, Biodynamic current, Pulsed Galvanic / HVPC (High Voltage Pulsed Current) [9]

- Medium Frequency Stimulation Current: When using frequency in the range of approximately 1kHz up to 100kHz it become impossible for excitable structures to react to every single pulse , only the summation of pulses achieves a single depolarization response .
- Interferential current is an alternating current of approximately 4000Hz. Therefore, it belongs into the group of medium frequency stimulation current.

The design apply "HVPC" with this features:

- Pulse Rate: 1to 20Hz.
- Output Voltage: 1 - 100volts .

3.2.1High Voltage Pulsed Current (HVPC)

HVPC is an electrical current with a monophasic waveform. Due to the lower impedance associated with high voltage, HVPC is able to penetrate the skin more easily. Because of this, the depth of tissue penetration is proportional to the current pulse amplitude. The dosage associated with HVPC requires specific parameters to be set according to the desired therapeutic effects, Pulse amplitudes 1- 500 V. Pulse duration range 5-10 microseconds (µsec). Pulse frequency range 2 – 100 pulses per second.[9]

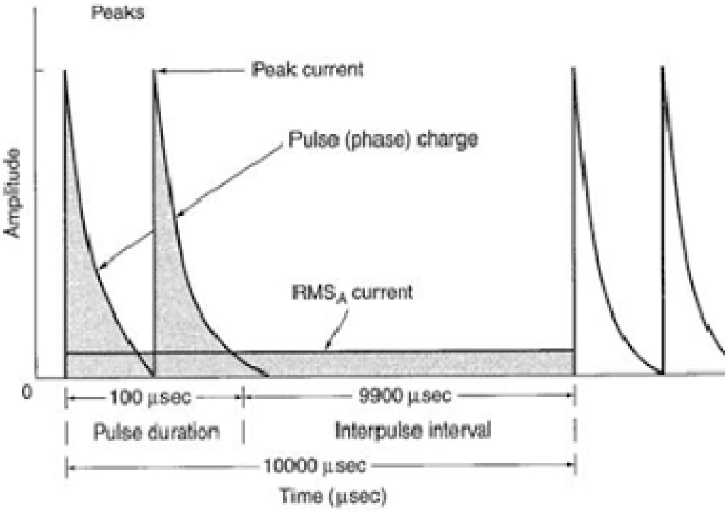


Figure 3.1: High voltage monophasic twin peak pulsed current.[K]

The HPVC waveform allows for a high peak voltage but a low average current, meaning the overall amount of current the patient receives is very low. [8]

3.2.2 Type of Electrode

There three type of Electrode: PLATE electrode, PAD electrode, and Suction electrode.

The most suitable electrode can apply in this design is plate electrode, to be fixed to the skin of the patient, and which have their features:

- It is metal or rubber which is covered by well moistened sponge pockets.
- Fixed to the skin of the by mean of straps.
- Plate electrode with spongs pocket are available in various size .
- electrode pocket have thicker and thiner wall always place the thicker wall to the skin .

Figure 3.2 : Type of Electrode , plate electrode , suction electrode and pad electrode , respectively.[L]

3.3Microcontrollers

A microcontroller is a highly integrated chip that contains all the components comprising a controller, this includes a CPU, RAM, some form of ROM, I/O ports, and timers, and a microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals.

As microcontroller is an integrated circuit, the cost of the total system decreases, a smaller and cheaper circuit board used, the labor required to assemble and test the circuit board reduces, and the number of chips and the amount of wiring reduces. Microcontrollers are designed for using in embedded systems, which mean that they are part of embedded systems, so they are sometimes called "embedded microcontrollers".

A microcontroller is designed for a very specific task to control a particular system and is used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, and toys. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes.[13]

Most microcontrollers deal with a digital data, so analog-to-digital converter (ADC) must be exist to convert analog data to digital, but in some microcontrollers there is a digital-to-analog converter (DAC) that allows the processor to output analog signals or voltage levels.

There are many microcontroller types and architectures different in length of register and instruction word. We can mention here the most known types of microcontrollers: PIC (8-bit PIC16, PIC18, 16-bit dsPIC33/PIC24), Intel 8051, MIPS, AT mega.

The microcontroller used in this project, is PIC18f4550.[Appendix B] which have these features :

- Low power consumption (nano watt Technology).
- Has different pin layout (40 and 44 pins).
- High performance and speed up to 12Mb/s in full speed mode and 1.5Mb/s in low speed mode .
- Accuracy of 10-bit to convert analog signal to digital number relatively.
- Up to 13 analog to digital converter model channels with programmable accusation
- 32k bytes of program memory .
- 2048 bytes of SRAM.
- 256 bytes of EEPROM data memory.

advantages of PIC microcontrollers:

- Inexpensive - PIC boards are relatively inexpensive compared to Arduino
- microcontroller platforms.
- Simple, clear programming environment - The PIC programming
- environment is easy-to-use for beginners, yet flexible enough for advanced
- users.
- Open source and extensible software- The PIC software and is published as
- open source tools, available for extension by experienced programmers.
- Open source and extensible hardware - The PIC is based on Atmel's
- ATMEGA8 and ATMEGA168 microcontrollers.

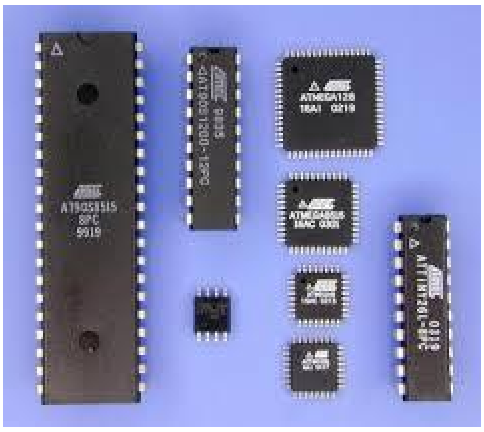


Figure 3.5 : Different type of Microcontroller[M]

3.4 Buzzer

Buzzer's function in this project is that called intermittent warning when apnea and stop signal from used sensors. If there is no breathing happen during the specific time of a seconds of sensitive optical and thermal work, then the buzzer makes alarm. The alarm stops working when the return of the patient's breathing in a natural way.

A buzzer is a mechanical, electromechanical, magnetic, electromagnetic, electro-acoustic or piezoelectric audio signaling device. A piezo electric buzzer can be driven by an oscillating electronic circuit or other audio signal source. A click, beep or ring can indicate that a button has been pressed.[14][Appendix E]

Specification :

- Voltage : 5v .
- Size : 32x15.5mm.
- Sound at 30cm : 70dB.

Features :

- Low pitch sound , medium sound output .
- Low current consumption.
- Externally duration , long life.
- Ultra small size , easy to install.

Figure 3.8: Buzzer Configuration[N]

Chapter Four

System Design

4.1Introduction.

4.2 Sleep Apnea Circuit Design.

4.2.1 Low Pressure Sensor Circuit Design.
4.2.2 Low Pass Filter.
4.2.3 Amplifier Design Using Non Inverting Amplifier .

4.3 Reflexology Stimulator Unit.

4.3.1 Muscle Stimulator Circuit.

4.4 Controller Unit.

4.4.1 PIC 18F4550.
4.4.2 The Programing Code

4.5 Power Design.

4.6 System Flowchart.

4.1 Introduction

This chapter gives a detail description of the system operation; a general block diagram that illustrates the intended operation of the project will be explained. A sequence of project steps flow is included to explain the logical secessions of the project tasks to achieve the desired requirements. The general block diagram is divided into a sub-blocks to briefly clarify the function of each step alone. Furthermore, the needs of each stage, either hardware or software, to accomplish its function is determined. Finally, the alternative parts, according to their functions and the availability, are mentioned.

The system composed of three main parts shown in figure 4.1; sleep apnea unit which measures the respiratory signal and exploits it to detect sleep apnea, reflexology stimulator unit which applies an alternating current flow through the human body, and control unit which gets the data from sleep apnea, processes the data, and give the appropriate order to the reflexology stimulator unit to treat the patient.

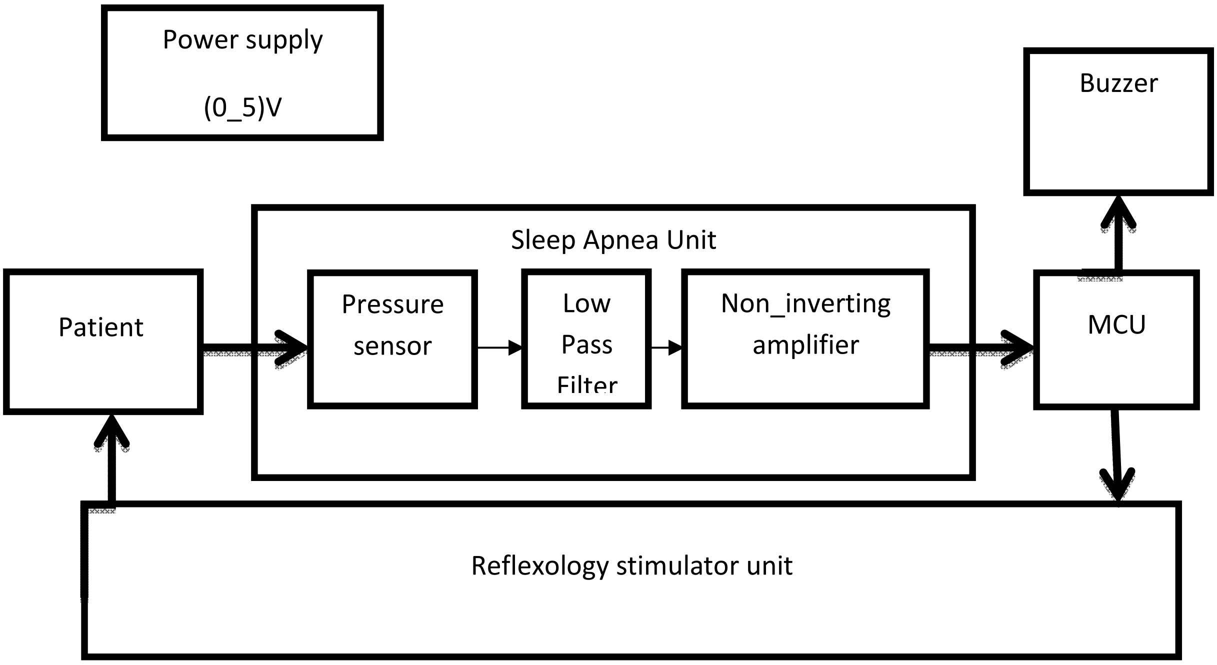


Figure 4.1: Main block diagram of the system.

The following sections describe the principle of operation of each stage.

4.2 Sleep Apnea Circuit Design

This section describes the design of sleep apnea circuit used to acquire the breathing signal from pressure transducer and process it to detect the sleep apnea. The circuit consists of low pressure sensor, low pass filter, and Non-inverting amplifier as shown in figure 4.2.

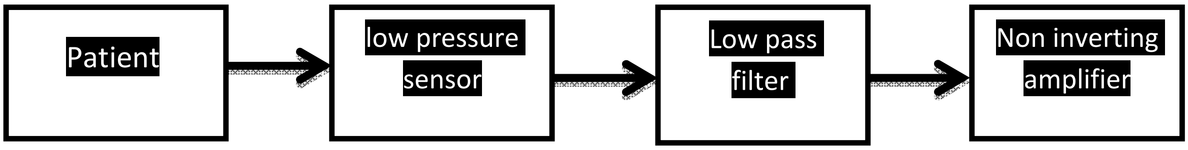


Figure 4.2: Main Block Diagram For Sleep Apnea Circuit Design

More details of each block and its function in the circuit is provided in the following sections.

4.2.1 Low Pressure sensor Circuit Design

In this project a NPC-1210 Series low pressure sensor is used to measure the air flow inside and outside the mouth and nose non-invasively. According to pressure sensor specifications, the output signal from the pressure transducer sensor is a low amplitude superimposed noise voltage signal with a peak to peak of around(50mV to 110mV) when the sensor is unamplified. To increase the voltage to noise ratio the set gain resistor which illustrate in figure (4.3) was controlled using equation (4.1) and the gain set to be 5.

The gain of instrumentation amplifier in the internal structure of the sensor is given by:

$$\text{Gain} = 1 + 2\left(\frac{100K\Omega}{Set\ gain}\right) \tag{4.1}$$

To set the gain 5: Set gain resistor is 200KΩ.

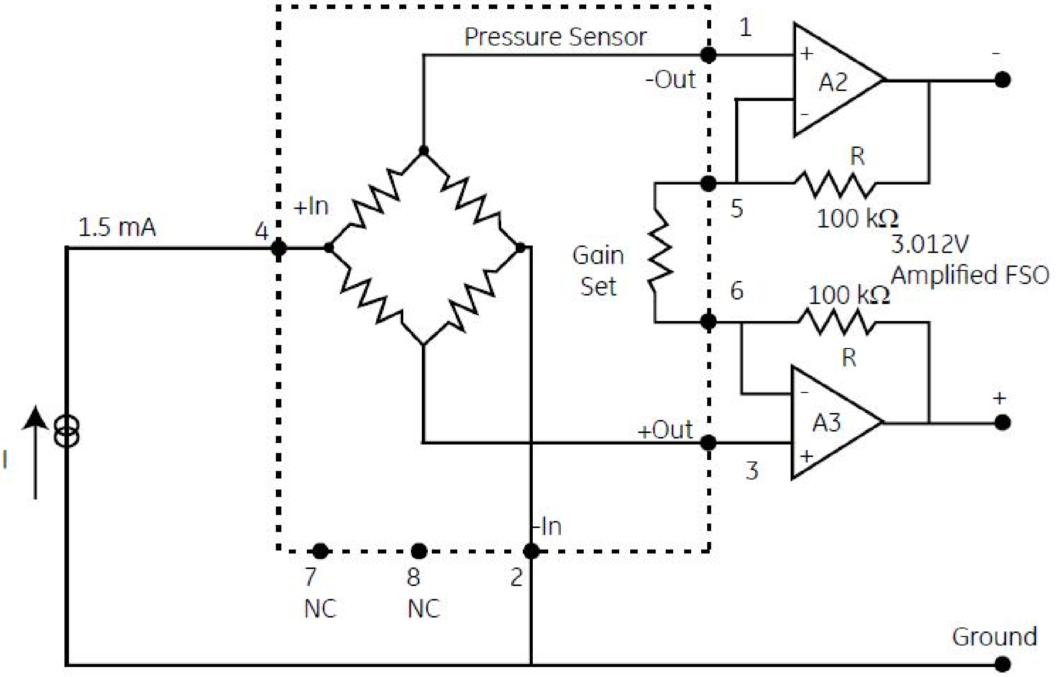


Figure 4.3: Internal Structure of Low Pressure Sensor.

According to the datasheet of NPC-1210 Series low pressure sensor the sensor require1.5 mA as a minimum current to operate, and its maximum value is 2mA.Its input impedance is approximately 3KΩ.

Required power of the sensor was determined using equation (4.2):

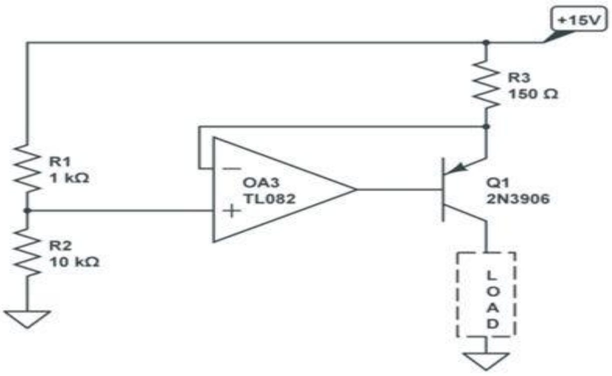
$$V= I*R \tag{4.2}$$

$$V_{max} = 2mA*3k\Omega =6 \text{ volt}$$

$$V_{min} =1.5*3K\Omega =4.5 \text{ volt}$$

So the value of the voltage must be between 4.5volt and 6 volt. In this project the chosen value is 5volt.

Constant current source :



4.2.2 Low Pass Filter

A low pass filter is used to attenuate high frequency noise from the initial voltage readings, where the range of frequency of the desired signal Noise is mostly attributed to 50Hz from other equipment, outlets, and wirings in an indoor atmosphere as well as noise contributed from the sensor unit. A 7Hz cut-off, 2nd order, 0.5dB ripple, Chebyshev low-pass filter is used in a sallen-key configuration to effectively attenuates noise. The cut-off frequency was chosen to be low enough to pass low frequencies associated with breathing and attenuate higher frequency noise. Although the Chebyshev filter has the poorest time-domain performance amongst the Bessel and Butterworth filters, it provides the best frequency domain characteristics, with a sharp cut-off (2nd order) and a low 0.5dB ripple. Figure (4.4) illustrate low pass filter.

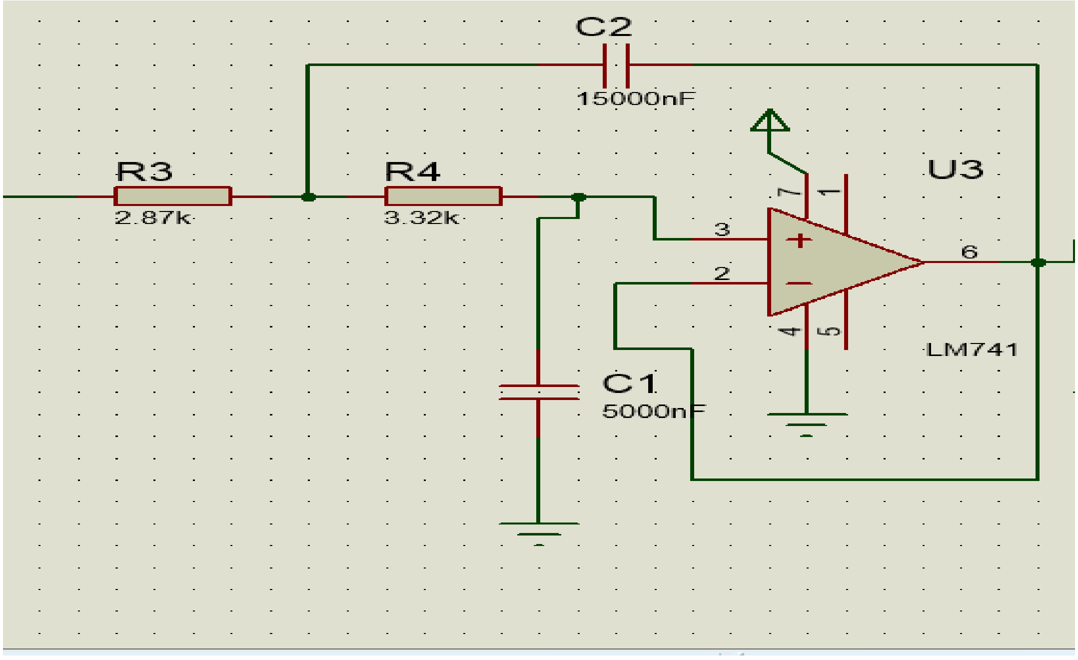


Figure 4.4: Low Pass Filter

To determine the values of capacitors and resistance:

According to appendix c (the Tschebyscheff coefficients for 0.5-dB ripple), obtain the coefficients a1 and b1 for a second-order filter with:

a_1 = 1.3614 and b1 = 1.3827
f=7 Hz.

Specifying C1 as 5 µF yields in a C_2 of:

$$C2 \geq \frac{4b1}{a1^2}$$

$$C1 \geq 15\mu$$

R_1 and R_2 are according this equation:

$$R1, R2 = \frac{a1 * c2 \pm \sqrt{a1^2 * c2^2 - 4 * b1 * c1 * c2}}{4\pi \, f \, c1 \, c2}$$

Yields R1= 2.87 KΩ and R2 3.32 KΩ

4.2.3 Amplifier Design using Non Inverting Amplifier

In this stage the signal is amplify again before entering the microcontroller, the saturation point and microcontroller specifications are considerable in amplification design; figure 4.5 illustrate Non_ inverting Op-amp design.

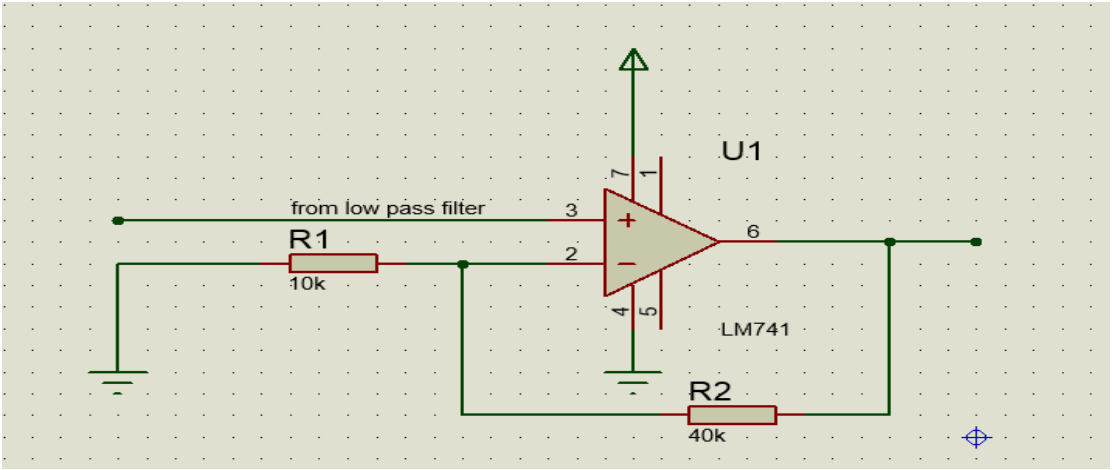


Figure 4.5 : Non_inverting Amplifier

The microcontroller input channel accepts a maximum voltage of 5V p. Hence, the gain of the amplifier is set to 5 to bring the output range to 400mV for normal breathing and 5V for heavy breathing, .This value was chosen for no saturation case happened and to prevent amplify the noise to high value . The gain is determined by and using equation (4.3).

$$G = 1 + \frac{R2}{R1} = 1 + (40K/10K) = 5. \quad (4.3)$$

The non_inverting configuration was used due to its simplicity and allows for precise control of gain using R1 and R2. The gain of the op-amp is low enough to ensure the output does not saturate.

4.3 Reflexology Stimulator Unit

Fig (4.6) shows the design component of electronic muscle stimulator circuit that stimulates nerves in particular places in the patient's body where electrodes are attached.

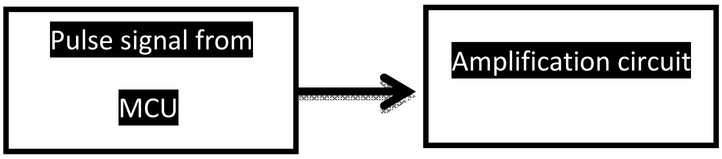


Fig 4.6: The block diagram for muscle stimulator circuit

4.3.1 Muscle Stimulator Circuit

PIC18F4550 is programmed to generate about 20Hz pulses (it will discuss in section 4.4 deeply). The output of PIC18F4550 is fed to transistor T_1, whose emitter is further connected to the base of transistor T_2 through VR_1 and R_2. The collector of transistor T2 is connected to one end of the secondary winding of transformer X1. The other end of the secondary winding of the transformer is connected to ground. Transformer X1 is driven by the pulse frequencies generated to produce high voltage at its primary terminals. Separate electrodes are connected to each end of the primary winding of transformer X1. The RV2 potentiometer used to control the value of the output voltage of the circuit. Diode 1N4007 (D1) protects transistor T2 against high-voltage pulses generated by the transformer as shown in figure (4.7).

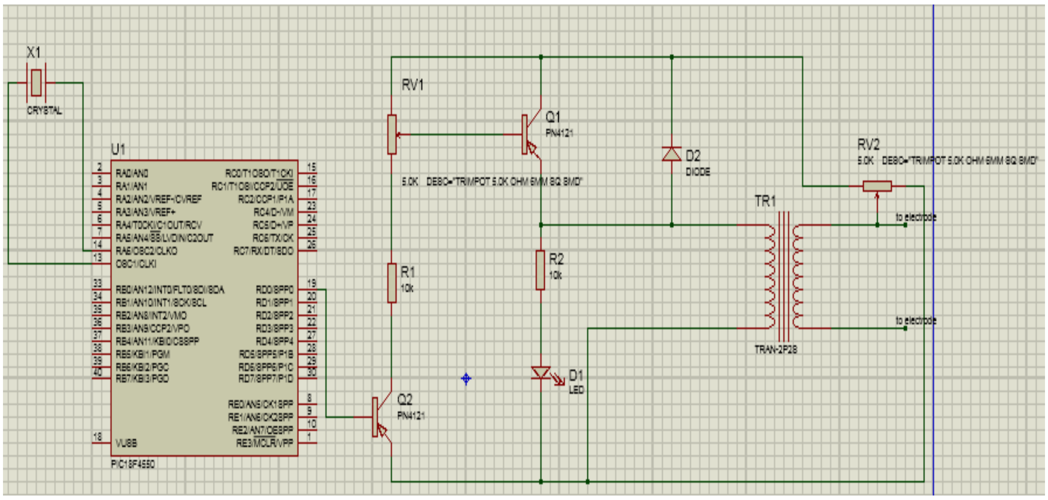


Figure 4.7: Muscle Stimulator Circuit.

The potentiometer is implemented to the circuit to vary V_{R1}, hence, control the intensity of current sensing at the electrodes. The brightness level of LED1 indicates the amplitude of the pulses. In order to increase the intensity level, replace the 1.8-kilo-ohm resistor with 5.6 kilo-ohms or higher value up to 10 kilo-ohms. X1 is a small mains transformer with 220V primary to 12V, 100/150M secondary. It must be reverse connected, i.e., connect the secondary winding to the collector of T2 and ground, and primary winding to the output electrodes. The output voltage is about 60V, but the output current is so small that there is no threat of electric shock.

Darlington transistor shown in Fig (4.8) is used for current amplification and controlling. According Darlington Transistor Configuration, the collectors of two transistors are connected together, and the emitter of TR1 drives the base of TR2. This configuration achieves β multiplication because for a base current i_b, the collector current is $\beta.i_b$ where the current gain is greater than one as equation (4.4):

$$\mathbf{IC=\beta1.IB+\beta2.\beta1.IB+\beta2.IB} \tag{4.4}$$

Where β_1 and β_2 are the gains of the individual transistors.

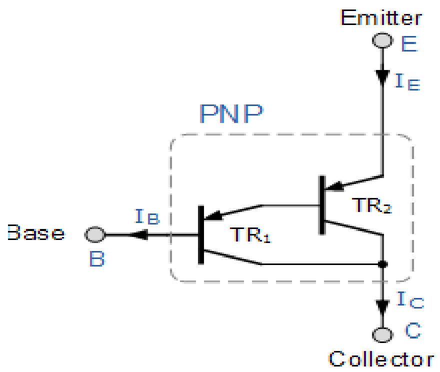


Figure 4.8: Darlington Transistor Configuration[P]

This means that the overall current gain, β is given by the gain of the first transistor multiplied by the gain of the second transistor as the current gains of the two transistors multiply. In other words, a pair of bipolar transistors combined together to make a single Darlington transistor pair can be regarded as a single transistor with a very high value of β and consequently a high input resistance.

4.4 Control Unit

4.4.1 PIC 18F4550

A PIC18f4550 microcontroller is chosen in this project to acquire the signals from the pressure transducer circuit, process them, and activate alarm system and reflexology circuit when sleep apnea occurs. The pressure sensor circuit is connected to PIC via analog input pin, Reflexology circuit, and alarm system are connected to PIC via "digital " pins on the PIC board. This PIC has 33 digital input/output pins and 8 analog input pins and powered by 5V pressure sensor output, reflexology system input and buzzer are connected to the PIC Microcontroller through the serial data line ANALOG RB0, ANALOGRA1 & ANALOGRA2 pin on the PIC board respectively as shown in Figure (4.9).PIC was programed to generate pulse signal whit 20Hz and 5 volt peak to peak.

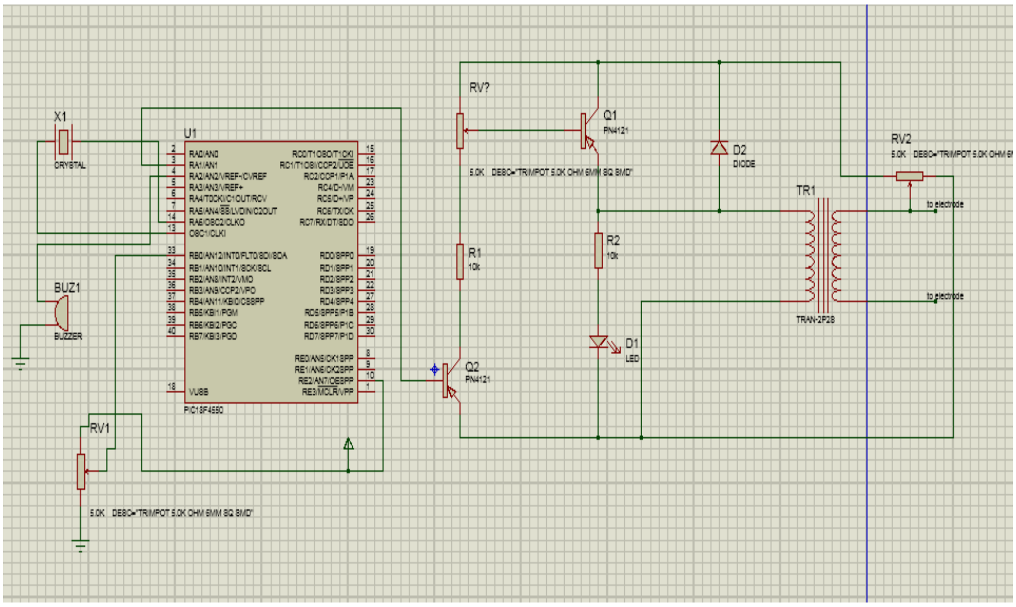


Figure 4.9:the interfacing of PIC and the system

4.4.2 The programing code .

The using code in this project is:

```
} ()void main
؛int x,c,i
؛porta =0
؛portd=0
؛trisd.rd0=0
؛trisa=0b11000000
```

```
؛adcon0=5
؛adcon1=13
؛adcon2=0b10010101
؛x=0

}(while(1

؛go_done_bit =1
؛(while(  go_done_bit
؛i=adresL
(if(i>=0
}
؛x=x+1
(if (x==50*10^10
؛porta=0b1100000000
{
else
؛x=0


{
{
```

4.5 Power Design.

The device needs power supply to power up the entire hardware. However as the system is supposed to be portable a battery that has the following characteristics is required:

- Lightweight.
- Provide required system power.
- Has relatively long life.

The system intended to operate using a rechargeable (9- volt) battery, but all stages need to operate within a voltage supply of (5) volt. This stage use voltage regulator (LM317) to obtain these voltage values from the battery.

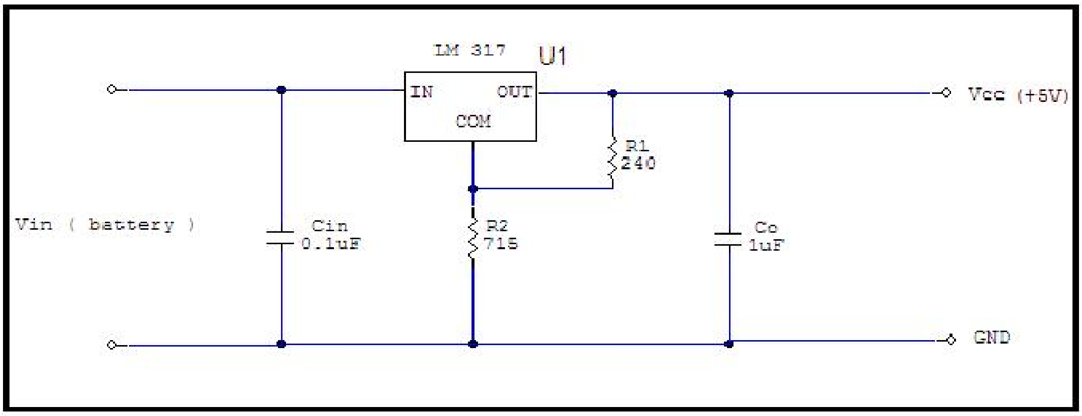


Figure 4.10 : shows the schematic electrical connection of voltage regulator to obtain (+5v).

LM317 (U1) was chosen as positive voltage regulator due to its relatively high output current capability (1.5A), adjustable output voltage, and low cost features. Desired output voltage can be computed according to the following equation.

$$\mathrm{Vout} = 1.25\left(1 + \frac{\mathrm{R2}}{\mathrm{R1}}\right) + \mathrm{Iadj} * \mathrm{R2} \qquad (4.5)$$

According to U1 datasheet [Appendix-G], R1, Cin, and Co equal 240Ω, 0.1μF, and 1μF respectively. R2 was adjusted to obtain 5v output voltage, also Iadj is controlled to less than 100μA, and the error associated with this term is negligible inmost applications. Hence, substituting Iadj by 100μA :

$$5 = 1.25\left(1 + \frac{\mathrm{R2}}{240}\right) + 100\mu * \mathrm{R2}$$

By Solving equation above for R2, obtaining R2 = 715 Ω.

4.6 System Flowchart

The desirable system operation flowchart is described in the figure (4.11).This flowchart explains the sequence of function that the system intended to pass through it to achieve project objectives.

It's clearly shown in this flowchart that the system will detect the air flow inside and outside the body through pressure sensor which located on the nose of the patient .After this stage we used the amplification and filtration stage to get the desired values, these values will analyze by PIC Microcontroller to diagnose the condition.

According to analyzing data, the device can diagnose the condition. If there is stop air flow for 10 second so the alarm and reflexology system will be active else, the device will detect the air flow another time until turn off the device.

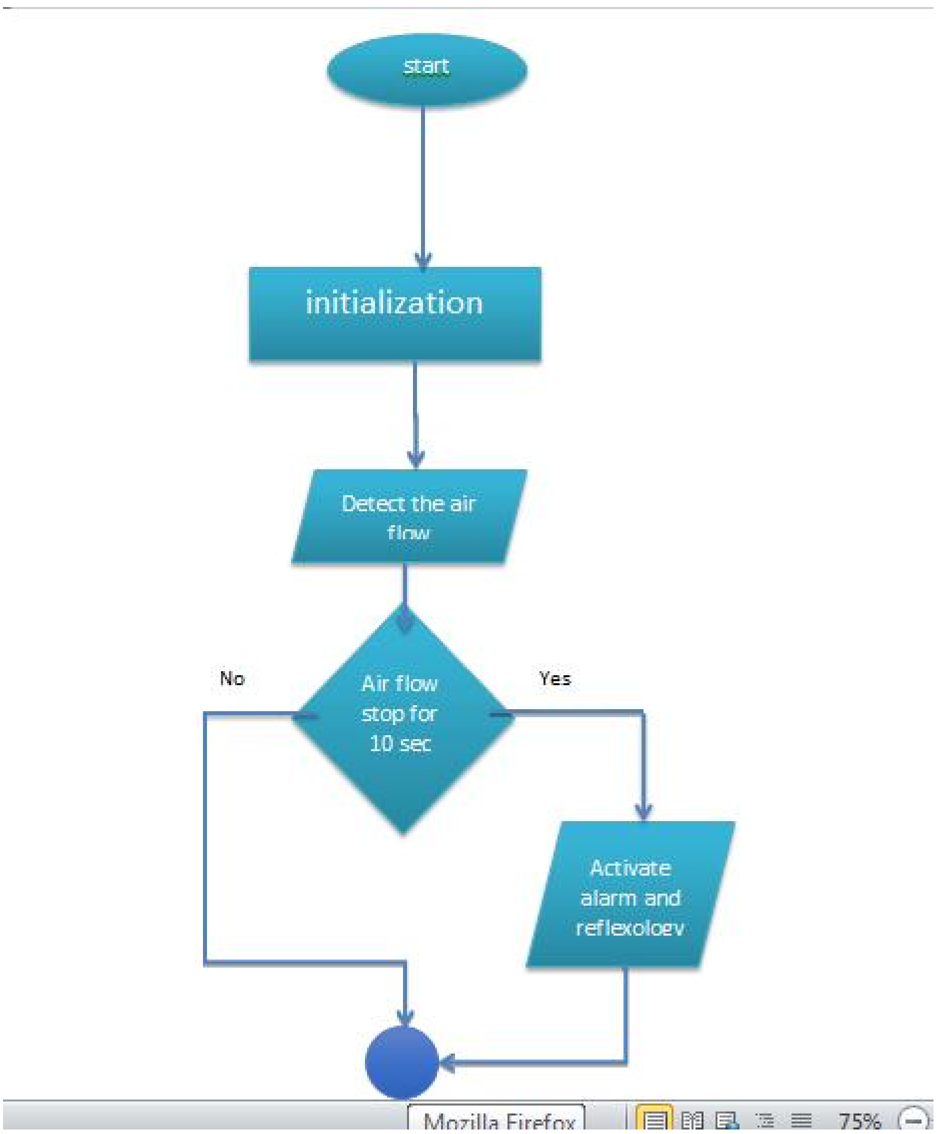


Figure 4.11: System Flow Chart

Chapter Five

System Implementation And Testing

5.1 Project Implementation.

5.1.1 Sleep Apnea Circuit.

5.1.2 Muscle Stimulator Circuit.

5.1.3 Overall System Circuit

5.2 Project Testing.

5.2.1 Air flow sensor circuit:

5.2.2 Muscle Stimulator Circuit:

After designing the project in the preceding chapter, the system is implemented and tested as will be discussed in this chapter. An implementation of each stage in the system is performed according to the system requirements. The hardware and software components are then examined by doing the appropriate test for each stage as will be discussed in the following sections.

5.1 Project Implementation

Practical implementation of the project have been done in the second semester, and this started by implementing each individual subsystem and after completing this implementation, the individual subsystems are connected together to accomplish the project as one unit.

5.1.1 Sleep Apnea Circuit

As mentioned before, the sleep apnea circuit consists of low pressure sensor, amplification circuit, and low pass filter. Low pressure sensor has to be close enough to the patient's breath; therefore this sensor was located in a mask. The used mask is made from a reinforced rubber material which is suitable for the patient's face. The mask used in this project is shown in figure (5.1).

Figure 5.1: Mask &The Low Pressure Sensor.

The NPC-1210 Low Pressure sensor is located in the mask to be close to patient’s breath, where its processing circuit is located in the system box. It is composed of amplification circuit and filter as depicted in figure (5.2).

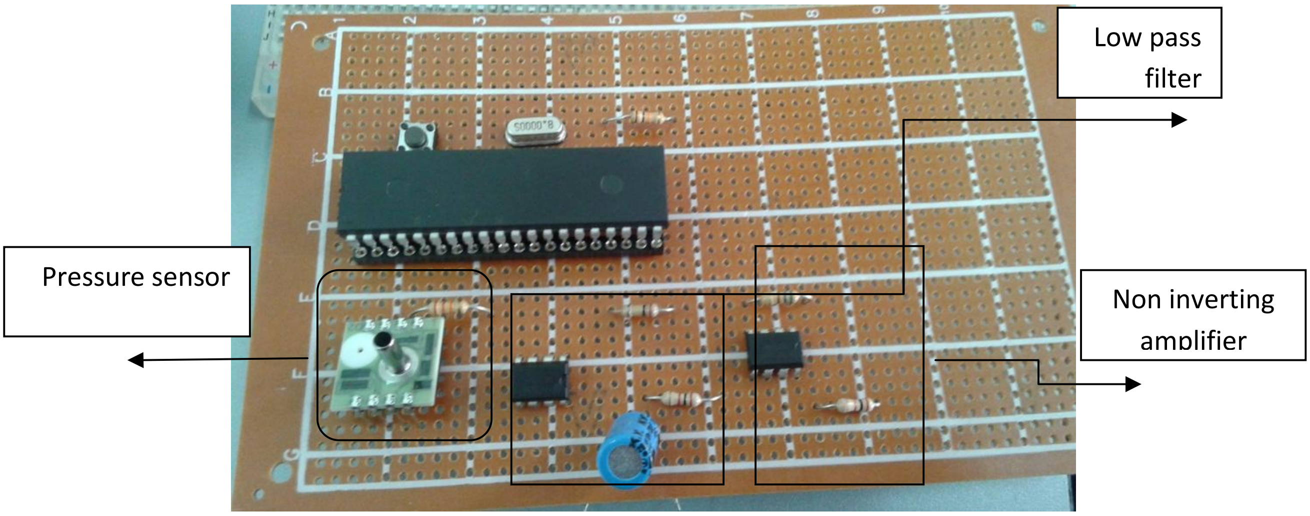


Figure 5.2: Sleep Apnea Circuit

The sensor fixed on the mask and connected to the pic microcontroller to detect of the patient’s breath as discussed in the previous chapter.

5.1.2 Muscle Stimulator Circuit

The Muscle Stimulator Circuit consists of deriving transistor circuit and step up transformer.it is implemented as shown in figure (5.3).

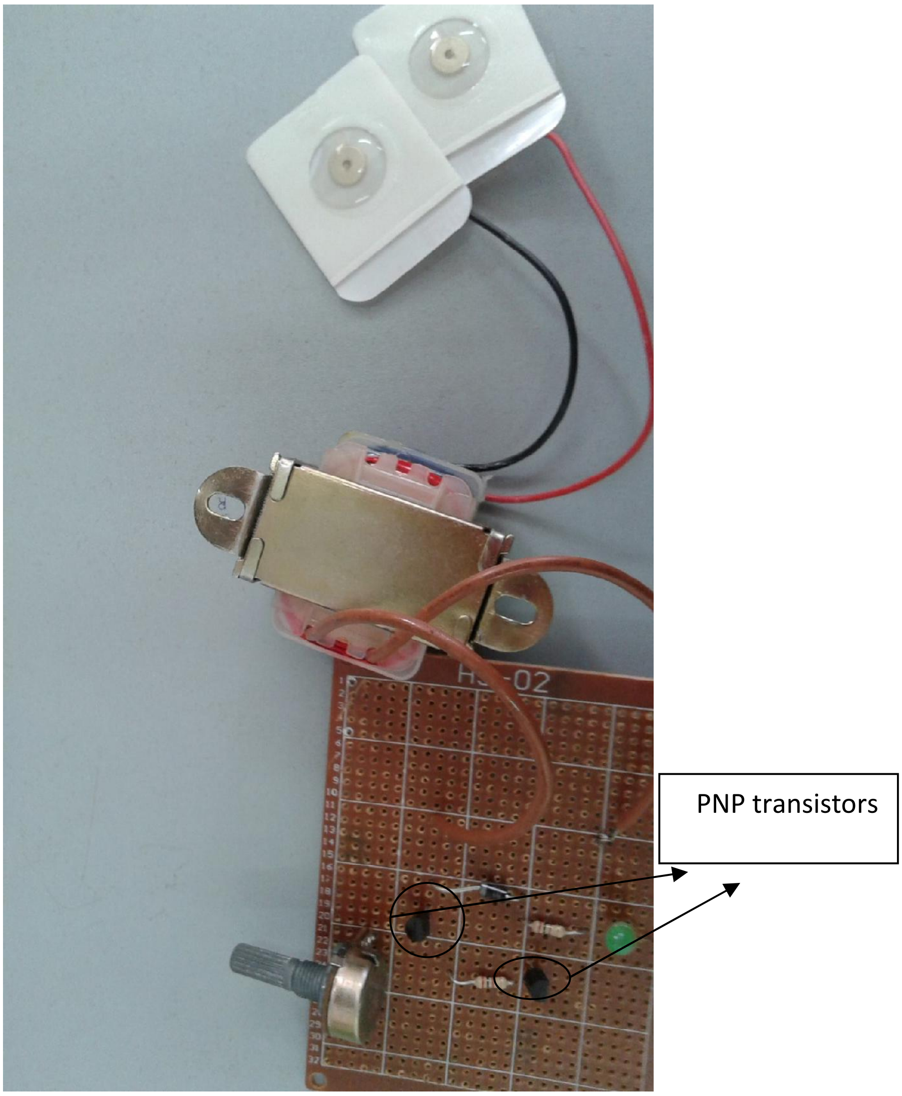


Figure 5.3: Muscle Stimulator Circuit.

5.1.3 Overall System Circuit

The overall circuit of the system is shown in the following figure (5.4).

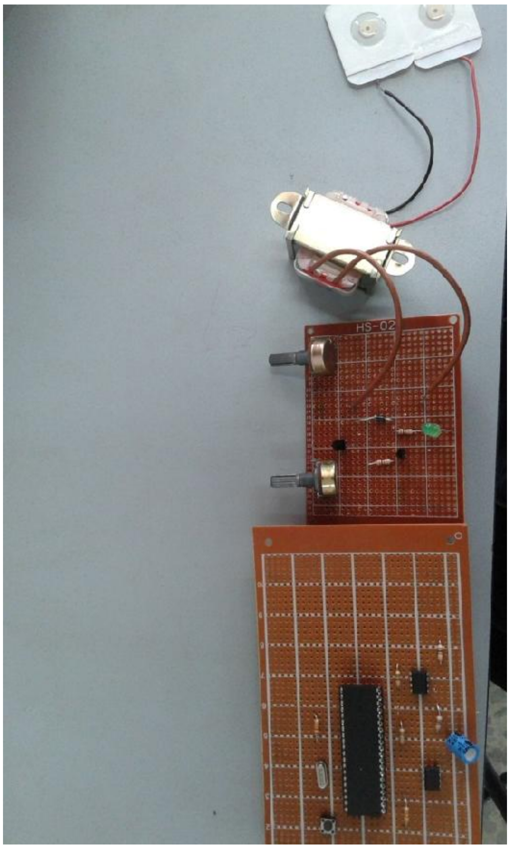


Figure 5.4: Overall System Circuit

5.2Project Testing

After implementing all individual subsystems and connecting them together, testing operation is done to get the result of each effective subsystem. According to the project objectives, the system is supposed to detect the sleep apnea and provide alarm system when it occur , and provide electrical pulses that applied on the patient foots to achieve reflexology treatment. And the following results appear as follows:

5.2.1 Air flow sensor circuit:

The output voltage of this circuit is change when the tested person was breathing because of pressure change through inspiration and expiration and so the output voltage didn't change when the tested person stopped his breathing.

5.2.2 Muscle Stimulator Circuit:

Generating of square wave with the desired frequency with 5 volt amplitude value is the important function of the microcontroller in this project so the microcontroller was programed to generate this signal when the patient stops breathing for ten second. This section will show the output signal of PIC18F4550 when the sleep apnea occur in the following figure (5.5).

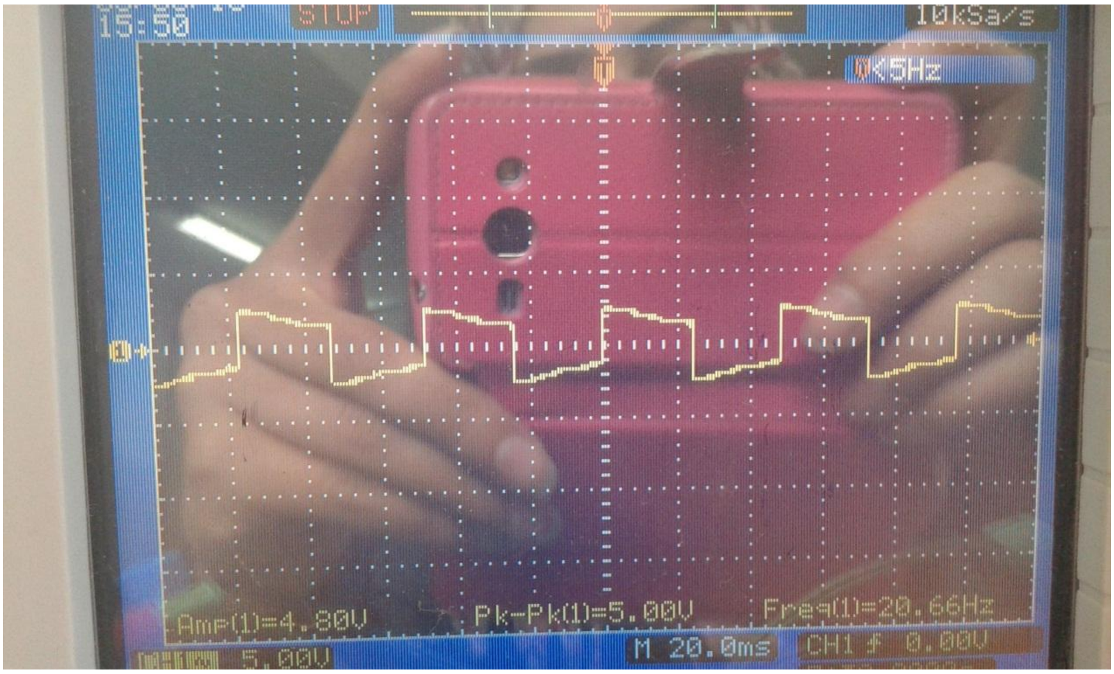


Figure 5.5 The output Signal of PIC

Figure 5.6 display the final output signal of the system (which is applied on the patient foots) when the breath stop for ten seconds and synchronously the alarm activate,the output of this stage square wave of 20 HZ and 30V, Step_up transformer was used to amplify the signal **.**

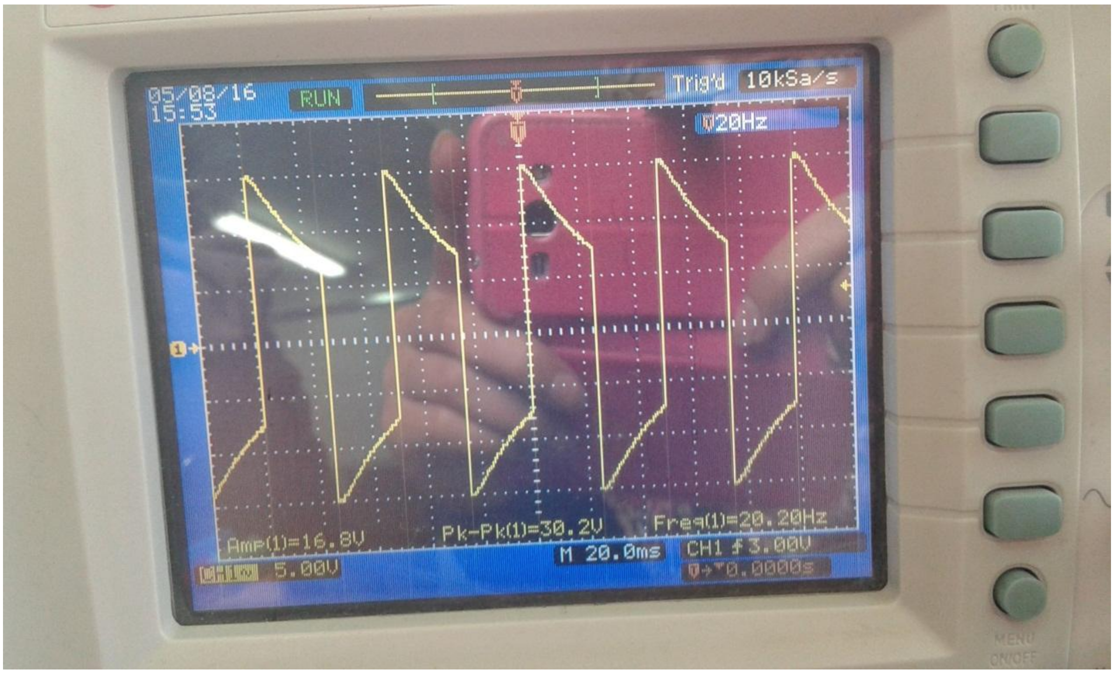


Figure (5.6): Final Output Signal of the Reflexology Stimulator

Chapter Six

Results And Conclusions

6.1 Sensor Unit Results

6.2 Reflexology Operation Results

6.3 Conclusion

Results that obtained due to system implementation and testing are observed and recorded in this chapter. These results are recorded according to test procedures and give a good impact about the system behavior. The results are studied and analyzed providing important conclusions mentioned in this chapter.

6.1 Sensor Unit Results

Due to testing of the air flow sensor unit the following results are obtained:

1- In this project a diagnostic system has been built using a NPC-1210 Series low pressure sensor, which is pressure sensor to detect the sleep apnea, when happened interrupt in breathing more than 10s an alarm system activate.

2- NPC-1210 is designed to measure continuously.

6.2 Reflexology Operation Results

All system components are combined to get whole project and then activated. The system operates as expected and gives good results that can be summarized as follow:

1-We obtain a 5v , 20Hz square wave after pic18f4550.

2-The current of the square wave adjust by Darlington transistor to reach 10mA.

3-The voltage reach to 30v by using a step-up transformer .

6.3 Conclusion

In this project thanks to Allah, there had been accomplished a design and implementation of a Portable Medical System for Monitoring and Treating Sleep Apnea, which is used to diagnostic the sleep apnea and so it treat it when its occur by activate sound alarm and applied special electrical pulses using special electrodes that is fastened on the patient skin.

This documentation include the detailed design of the project and stages which were followed in order to reach to the desired goals of the project, those are represented as designing and studying each practical stage of whole project's stages each one side, then to collect or assemble these stages as one integrated unit. After designing, processing, implementing and testing these sensors, the overall system can provide the following features:

1- There are a proximally linearly proportional relation between the change of the air flow and the output voltage.
2- Sensor response is very sensitive to the ambient vibration, so shielding mechanisms is important and is implemented by mask.
3- Low pressure sensor, is easy used device, so we recommended using it in graduated projects.
4-The project shows that this unit gives signal that can be used as reflexology treatment.
5-PIC18F4550, easy used device. So it used to control the frequency of the output signal.
6-To use this device of the project, no additional complicity steps needed.

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LM317 3-Terminal Adjustable Regulator

1 Features

- Output Voltage Range Adjustable From 1.25 V to 37 V
- Output Current Greater Than 1.5 A
- Internal Short-Circuit Current Limiting
- Thermal Overload Protection
- Output Safe-Area Compensation

2 Applications

- ATCA Solutions
- DLP: 3D Biometrics, Hyperspectral Imaging, Optical Networking, and Spectroscopy
- DVR and DVS
- Desktop PC
- Digital Signage and Still Camera
- ECG Electrocardiogram
- EV HEV Charger: Level 1, 2, and 3
- Electronic Shelf Label
- Energy Harvesting
- Ethernet Switch
- Femto Base Station
- Fingerprint and Iris Biometrics
- HVAC: Heating, Ventilating, and Air Conditioning
- High-Speed Data Acquisition and Generation
- Hydraulic Valve
- IP Phone: Wired and Wireless
- Infusion Pump
- Intelligent Occupancy Sensing
- Motor Control: Brushed DC, Brushless DC, Low-Voltage, Permanent Magnet, and Stepper Motor
- Point-to-Point Microwave Backhaul
- Power Bank Solutions
- Power Line Communication Modem
- Power Over Ethernet (PoE)
- Power Quality Meter
- Power Substation Control
- Private Branch Exchange (PBX)
- Programmable Logic Controller
- RFID Reader
- Refrigerator
- Signal or Waveform Generator
- Software Defined Radio (SDR)
- Washing Machine: High-End and Low-End
- X-ray: Baggage Scanner, Medical, and Dental

3 Description

The LM317 device is an adjustable three-terminal positive-voltage regulator capable of supplying more than 1.5 A over an output-voltage range of 1.25 V to 37 V. It requires only two external resistors to set the output voltage. The device features a typical line regulation of 0.01% and typical load regulation of 0.1%. It includes current limiting, thermal overload protection, and safe operating area protection. Overload protection remains functional even if the ADJUST terminal is disconnected.

Device Information(1)

PART NUMBER	PACKAGE (PIN)	BODY SIZE (NOM)
LM317	SOT (4)	6.50 mm × 3.50 mm
	TO-220 (3)	10.16 mm × 8.70 mm
	TO-220 (3)	10.16 mm × 8.59 mm
	TO-263 (3)	10.18 mm × 8.41 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

4 Battery-Charger Circuit

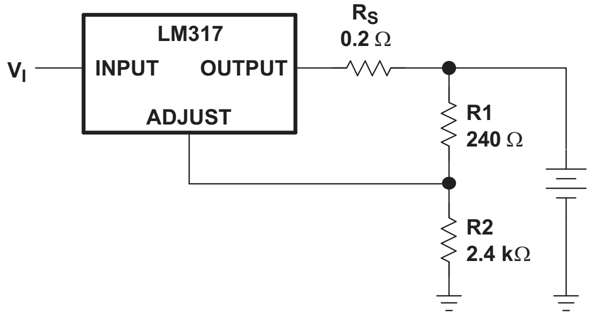


Table of Contents

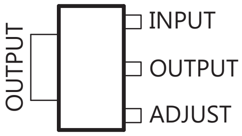
5 Revision History

Changes from Revision V (February 2013) to Revision W **Page**

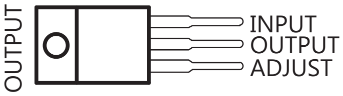
- Added *Applications*, *Device Information* table, *Pin Functions* table, *ESD Ratings* table, *Thermal Information* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section. 1
- Deleted *Ordering Information* table. 1

6 Pin Configuration and Functions

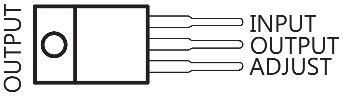
**DCY (SOT-223) PACKAGE
(TOP VIEW)**



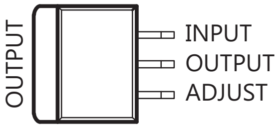
**KC (TO-220) PACKAGE
(TOP VIEW)**



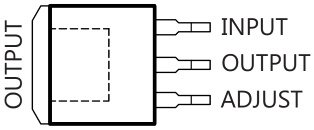
**KCS / KCT (TO-220) PACKAGE
(TOP VIEW)**



**KTE PACKAGE
(TOP VIEW)**



**KTT (TO-263) PACKAGE
(TOP VIEW)**



Pin Functions

PIN		TYPE	DESCRIPTION
NAME	DCY, KCS, KCT, KTT		
ADJUST	1	I	Output voltage adjustment pin. Connect to a resistor divider to set V_O
INPUT	3	I	Supply input pin
OUTPUT	2	O	Voltage output pin

7 Specifications

7.1 Absolute Maximum Ratings

over virtual junction temperature range (unless otherwise noted)(1)

		MIN	MAX	UNIT
$V_I - V_O$	Input-to-output differential voltage		40	V
T_J	Operating virtual junction temperature		150	°C
	Lead temperature 1,6 mm (1/16 in) from case for 10 s		260	°C
T_{stg}	Storage temperature range	–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

7.2 ESD Ratings

			MAX	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1)	2500	V
		Charged device model (CDM), per JEDEC specification JESD22-C101, all pins(2)	1000	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

7.3 Recommended Operating Conditions

		MIN	MAX	UNIT
V_O	Output voltage	1.25	7	V
$V_I - V_O$	Input-to-output differential voltage	3	40	V
I_O	Output current		1.5	A
T_J	Operating virtual junction temperature	0	125	°C

7.4 Thermal Information

THERMAL METRIC(1)		LM317			UNIT
		DCY	KCS	KTT	
		4 PINS	4 PINS	4 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	53	19	25.3	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	30.6	17	18	
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	—	3	1.94	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report (SPRA953).

7.5 Electrical Characteristics

over recommended ranges of operating virtual junction temperature (unless otherwise noted)

PARAMETER	TEST CONDITIONS[1]			MIN	TYP	MAX	UNIT
Line regulation[2]	$V_I - V_O$ = 3 V to 40 V		T_J = 25°C		0.01	0.04	%/V
			T_J = 0°C to 125°C		0.02	0.07	
Load regulation	I_O = 10 mA to 1500 mA	C_{ADJ}[3] = 10 μF, T_J = 25°C	$V_O \le 5$ V			25	mV
			$V_O \ge 5$ V		0.1	0.5	%V_O
		T_J = 0°C to 125°C	$V_O \le 5$ V		20	70	mV
			$V_O \ge 5$ V		0.3	1.5	%V_O
Thermal regulation	20-ms pulse,	T_J = 25°C			0.03	0.07	%V_O/W
ADJUST terminal current					50	100	μA
Change in ADJUST terminal current	$V_I - V_O$ = 2.5 V to 40 V, $P_D \le 20$ W, I_O = 10 mA to 1500 mA				0.2	5	μA
Reference voltage	$V_I - V_O$ = 3 V to 40 V, $P_D \le 20$ W, I_O = 10 mA to 1500 mA			1.2	1.25	1.3	V
Output-voltage temperature stability	T_J = 0°C to 125°C				0.7		%V_O
Minimum load current to maintain regulation	$V_I - V_O$ = 40 V				3.5	10	mA
Maximum output current	$V_I - V_O \le 15$ V,	$P_D < P_{MAX}$[4]		1.5	2.2		A
	$V_I - V_O \le 40$ V,	$P_D < P_{MAX}$[4],	T_J = 25°C	0.15	0.4		
RMS output noise voltage (% of V_O)	f = 10 Hz to 10 kHz,	T_J = 25°C			0.003		%V_O
Ripple rejection	V_O = 10 V,	f = 120 Hz	C_{ADJ} = 0 μF[3]		57		dB
			C_{ADJ} = 10 μF[3]	62	64		
Long-term stability	T_J = 25°C				0.3	1	%/1k hr

(1) Unless otherwise noted, the following test conditions apply: $|V_I - V_O|$ = 5 V and I_{OMAX} = 1.5 A, T_J = 0°C to 125°C. Pulse testing techniques are used to maintain the junction temperature as close to the ambient temperature as possible.

(2) Line regulation is expressed here as the percentage change in output voltage per 1-V change at the input.

(3) C_{ADJ} is connected between the ADJUST terminal and GND.

(4) Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A) / \theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.

7.6 Typical Characteristics

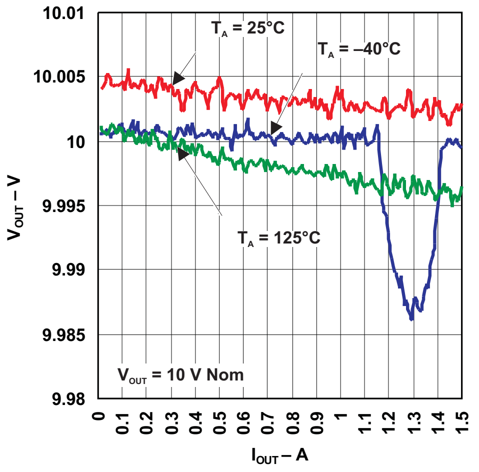


Figure 1. Load Regulation

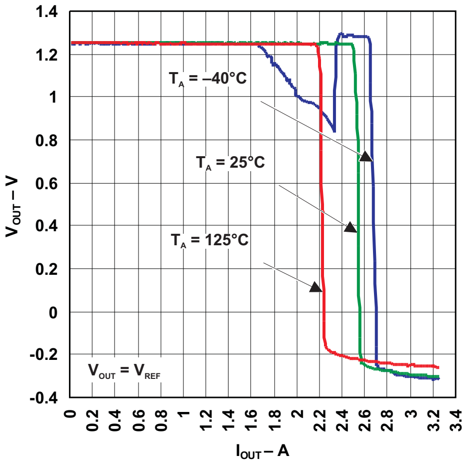


Figure 2. Load Regulation

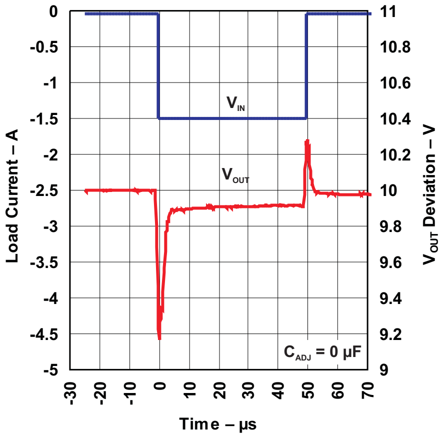


Figure 3. Load Transient Response

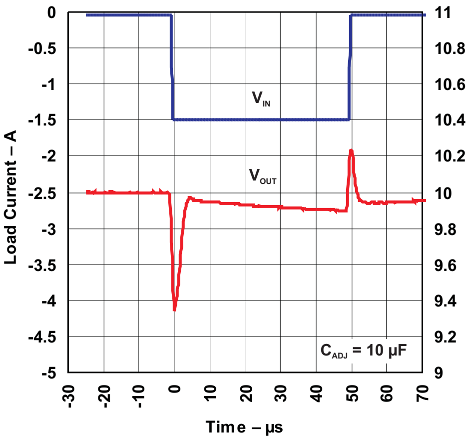


Figure 4. Load Transient Response

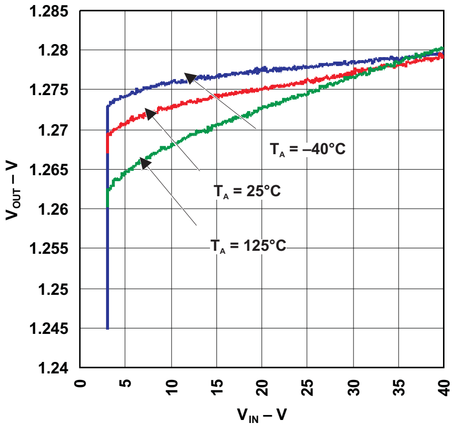


Figure 5. Line Regulation

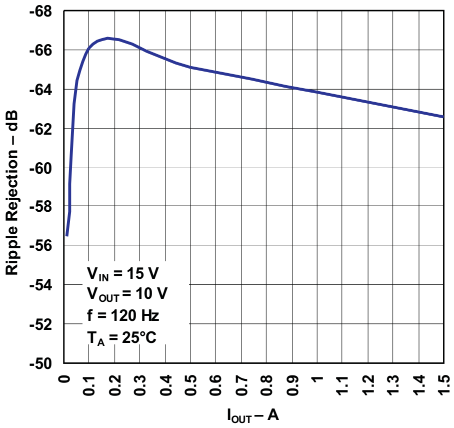


Figure 6. Ripple Rejection vs Output Current

Typical Characteristics (continued)

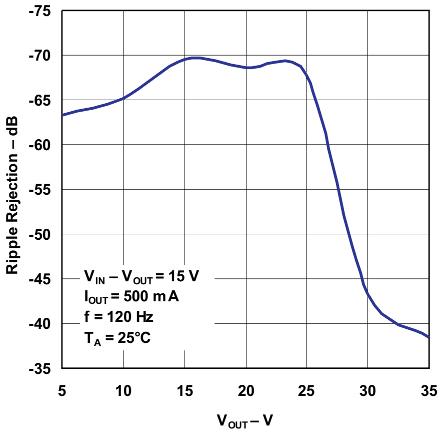


Figure 7. Ripple Rejection vs Output Voltage

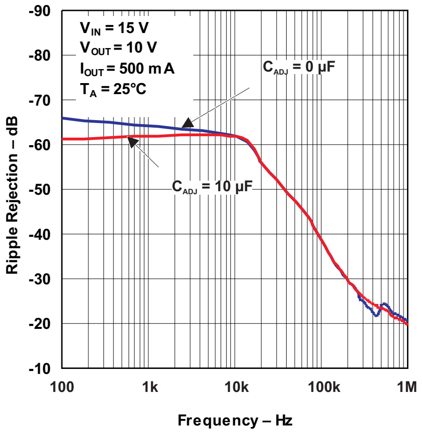


Figure 8. Ripple Rejection vs Frequency

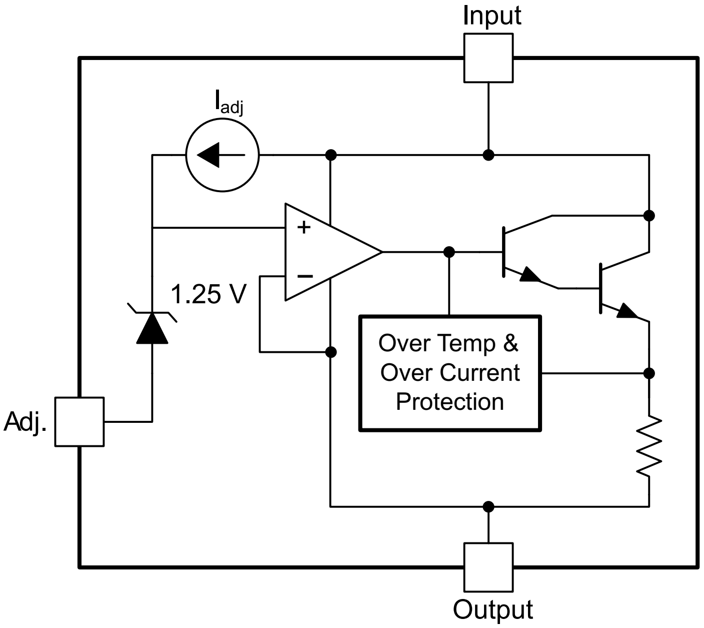
8 Detailed Description

8.1 Overview

The LM317 device is an adjustable three-terminal positive-voltage regulator capable of supplying more than 1.5 A over an output-voltage range of 1.25 V to 37 V. It requires only two external resistors to set the output voltage. The device features a typical line regulation of 0.01% and typical load regulation of 0.1%. It includes current limiting, thermal overload protection, and safe operating area protection. Overload protection remains functional even if the ADJUST terminal is disconnected.

The LM317 device is versatile in its applications, including uses in programmable output regulation and local on-card regulation. Or, by connecting a fixed resistor between the ADJUST and OUTPUT terminals, the LM317 device can function as a precision current regulator. An optional output capacitor can be added to improve transient response. The ADJUST terminal can be bypassed to achieve very high ripple-rejection ratios, which are difficult to achieve with standard three-terminal regulators.

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 NPN Darlington Output Drive

NPN Darlington output topology provides naturally low output impedance and an output capacitor is optional. To support maximum current and lowest temperature, 3-V headroom is recommended ($V_I – V_O$).

8.3.2 Overload Block

Over-current and over-temperature shutdown protects the device against overload or damage from operating in excessive heat.

8.3.3 Programmable Feedback

Op amp with 1.25-V offset input at the ADJUST terminal provides easy output voltage or current (not both) programming. For current regulation applications, a single resistor whose resistance value is 1.25 V/I_O and power rating is greater than $(1.25\ V)^2/R$ should be used. For voltage regulation applications, two resistors set the output voltage.

8.4 Device Functional Modes

8.4.1 Normal Operation

The device OUTPUT pin will source current necessary to make OUTPUT pin 1.25 V greater than ADJUST terminal to provide output regulation.

8.4.2 Operation With Low Input Voltage

The device requires up to 3-V headroom (V_I – V_O) to operate in regulation. With less headroom, the device may drop out and OUTPUT voltage will be INPUT voltage minus drop out voltage.

8.4.3 Operation at Light Loads

The device passes its bias current to the OUTPUT pin. The load or feedback must consume this minimum current for regulation or the output may be too high.

8.4.4 Operation In Self Protection

When an overload occurs the device will shut down Darlington NPN output stage or reduce the output current to prevent device damage. The device will automatically reset from the overload. The output may be reduced or alternate between on and off until the overload is removed.

9 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

9.1 Application Information

The flexibility of the LM317 allows it to be configured to take on many different functions in DC power applications.

9.2 Typical Application

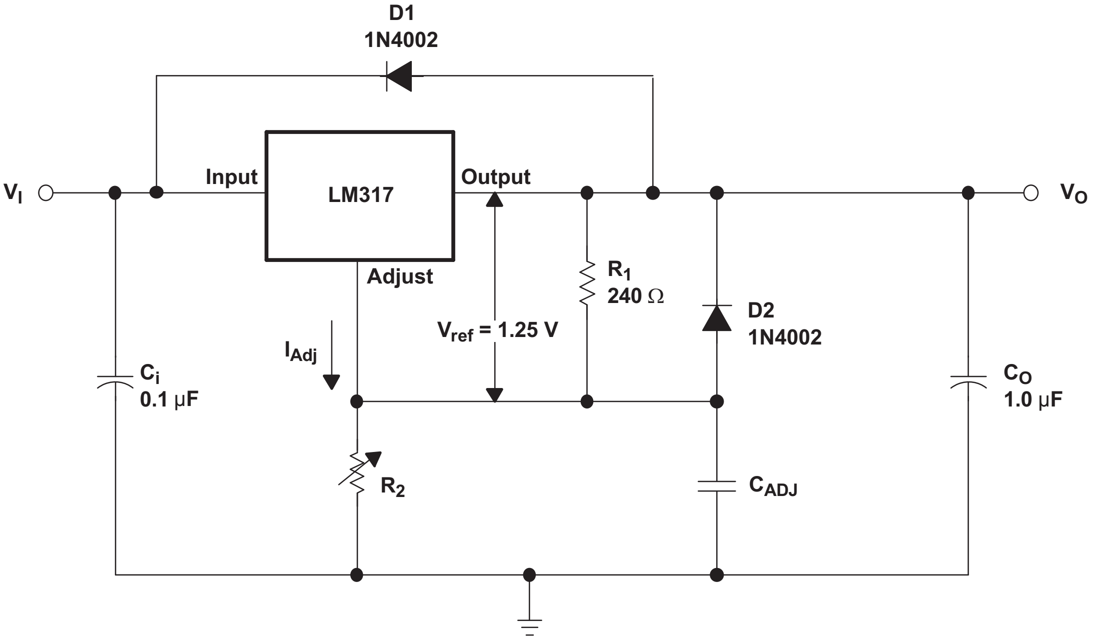


Figure 9. Adjustable Voltage Regulator

9.2.1 Design Requirements

- R1 and R2 are required to set the output voltage.
- C_{ADJ} is recommended to improve ripple rejection. It prevents amplification of the ripple as the output voltage is adjusted higher.
- C_i is recommended, particularly if the regulator is not in close proximity to the power-supply filter capacitors. A 0.1-µF disc or 1-µF tantalum capacitor provides sufficient bypassing for most applications, especially when adjustment and output capacitors are used.
- C_O improves transient response, but is not needed for stability.
- Protection diode D2 is recommended if C_{ADJ} is used. The diode provides a low-impedance discharge path to prevent the capacitor from discharging into the output of the regulator.
- Protection diode D1 is recommended if C_O is used. The diode provides a low-impedance discharge path to prevent the capacitor from discharging into the output of the regulator.

9.2.2 Detailed Design Procedure

V_O is calculated as shown in Equation 1. I_{ADJ} is typically 50 µA and negligible in most applications.

$$V_O = V_{REF} (1 + R2 / R1) + (I_{ADJ} \times R2) \tag{1}$$

Typical Application (continued)

9.2.3 Application Curves

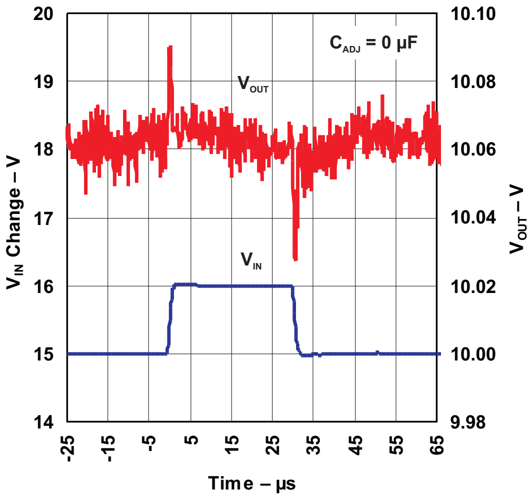


Figure 10. Line-Transient Response

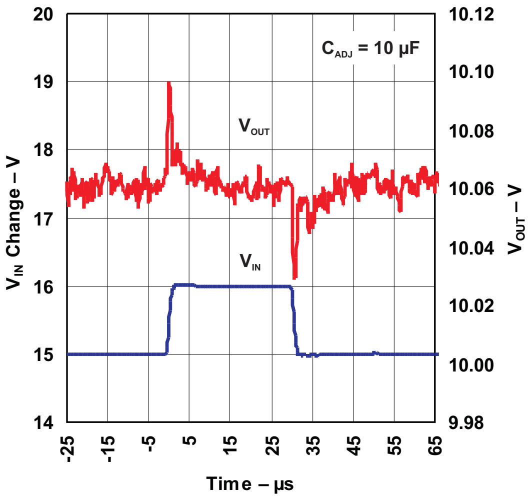


Figure 11. Line-Transient Response

9.3 System Examples

9.3.1 0-V to 30-V Regulator Circuit

Here, the voltage is determined by

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2 + R_3}{R_1}\right) - 10\,V$$

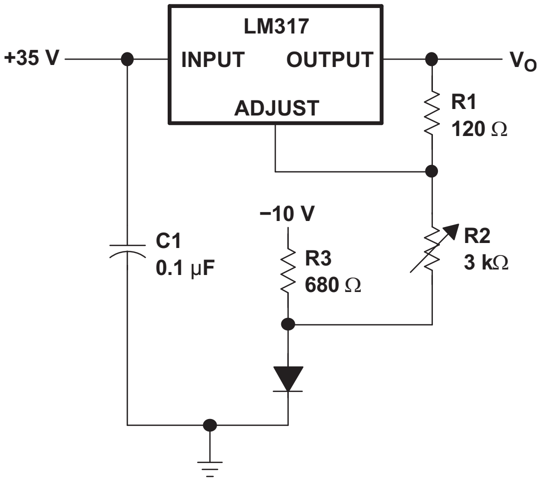


Figure 12. 0-V to 30-V Regulator Circuit

System Examples (continued)

9.3.2 Adjustable Regulator Circuit With Improved Ripple Rejection

C2 helps to stabilize the voltage at the adjustment pin, which will help reject noise. Diode D1 exists to discharge C2 in case the output is shorted to ground.

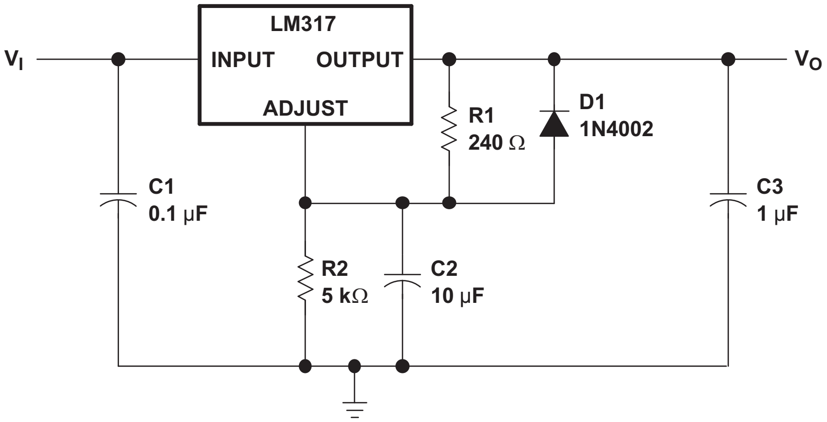


Figure 13. Adjustable Regulator Circuit with Improved Ripple Rejection

9.3.3 Precision Current-Limiter Circuit

This application will limit the output current to the I_{LIMIT} in the diagram.

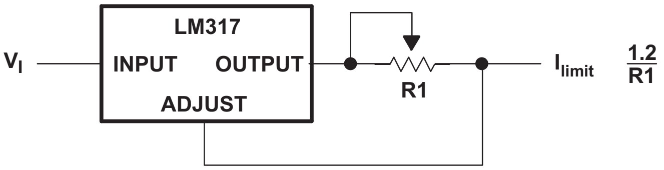


Figure 14. Precision Current-Limiter Circuit

9.3.4 Tracking Preregulator Circuit

This application keeps a constant voltage across the second LM317 in the circuit.

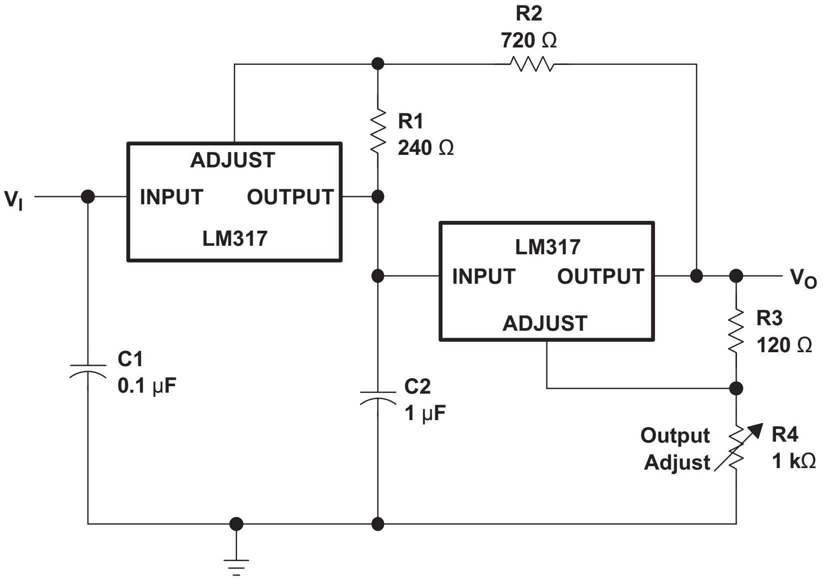


Figure 15. Tracking Preregulator Circuit

System Examples (continued)

9.3.5 1.25-V to 20-V Regulator Circuit With Minimum Program Current

Since the value of V_{REF} is constant, the value of R1 determines the amount of current that flows through R1 and R2. The size of R2 determines the IR drop from ADJUSTMENT to GND. Higher values of R2 translate to higher V_{OUT}.

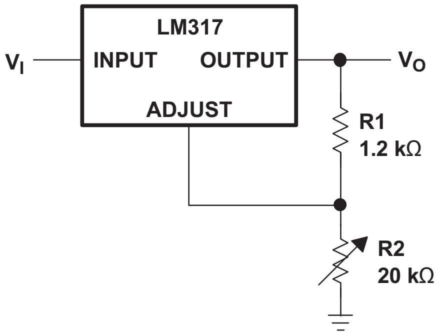


Figure 16. 1.25-V to 20-V Regulator Circuit With Minimum Program Current

9.3.6 Adjusting Multiple On-Card Regulators With a Single Control

With different values of R1 for each LM317, R2 can be chosen such that each LM317 outputs a different voltage.

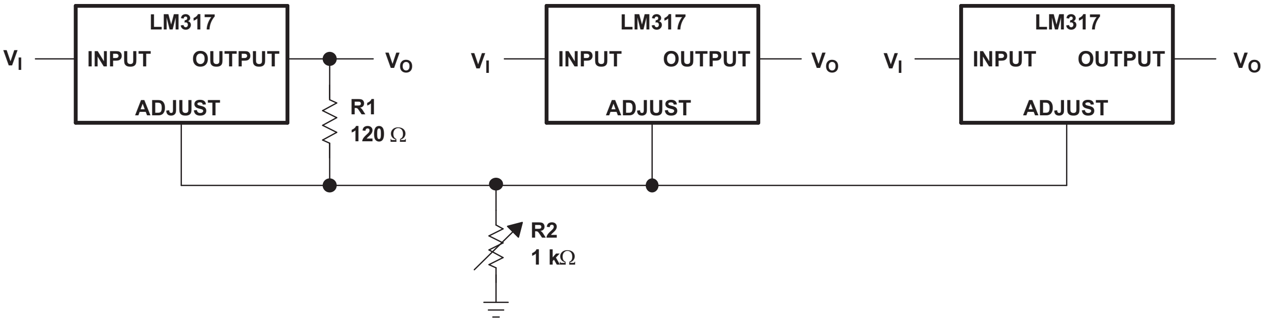


Figure 17. Adjusting Multiple On-Card Regulators With a Single Control

9.3.7 Battery-Charger Circuit

The series resistor limits the current output of the LM317, minimizing damage to the battery cell.

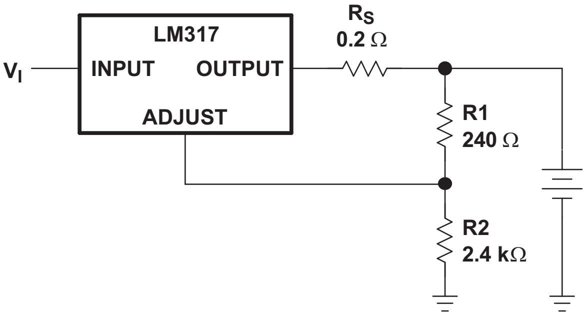


Figure 18. Battery-Charger Circuit

System Examples (continued)

9.3.8 50-mA Constant-Current Battery-Charger Circuit

The current limit operation mode can be used to trickle charge a battery at a fixed current. I_{CHG} = 1.25V÷24Ω. V_I should be greater than V_{BAT} + 4.25 V. (1.25V [V_{REF}]+ 3V [headroom])

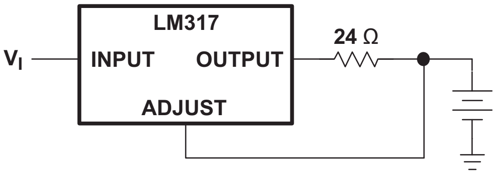


Figure 19. 50-mA Constant-Current Battery-Charger Circuit

9.3.9 Slow Turn-On 15-V Regulator Circuit

The capacitor C1, in combination with the PNP transistor, helps the circuit to slowly start supplying voltage. In the beginning, the capacitor is not charged. Therefore output voltage will start at V_{C1}+ V_{BE} + 1.25V = 0V + 0.65V + 1.25V = 1.9V. As the capacitor voltage rises, V_{OUT} will as rise at the same rate. When the output voltage reaches the value determined by R1 and R2, the PNP will be turned off.

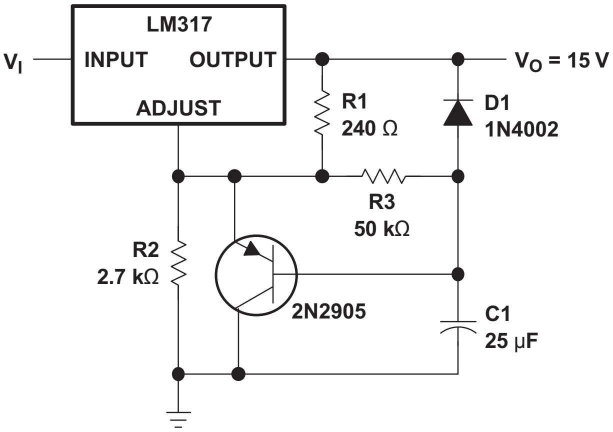


Figure 20. Slow Turn-On 15-V Regulator Circuit

9.3.10 AC Voltage-Regulator Circuit

These two LM317s can regulate both the positive and negative swings of a sinusoidal AC input.

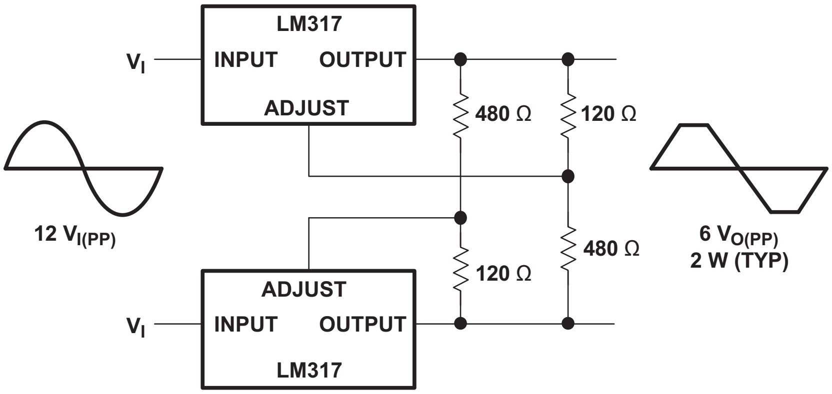


Figure 21. AC Voltage-Regulator Circuit

System Examples (continued)

9.3.11 Current-Limited 6-V Charger Circuit

As the charge current increases, the voltage at the bottom resistor increases until the NPN starts sinking current from the adjustment pin. The voltage at the adjustment pin will drop, and consequently the output voltage will decrease until the NPN stops conducting.

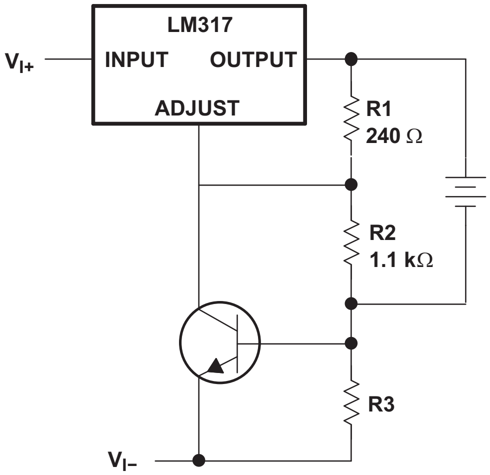


Figure 22. Current-Limited 6-V Charger Circuit

9.3.12 Adjustable 4-A Regulator Circuit

This application keeps the output current at 4 A while having the ability to adjust the output voltage using the adjustable (1.5 kΩ in schematic) resistor.

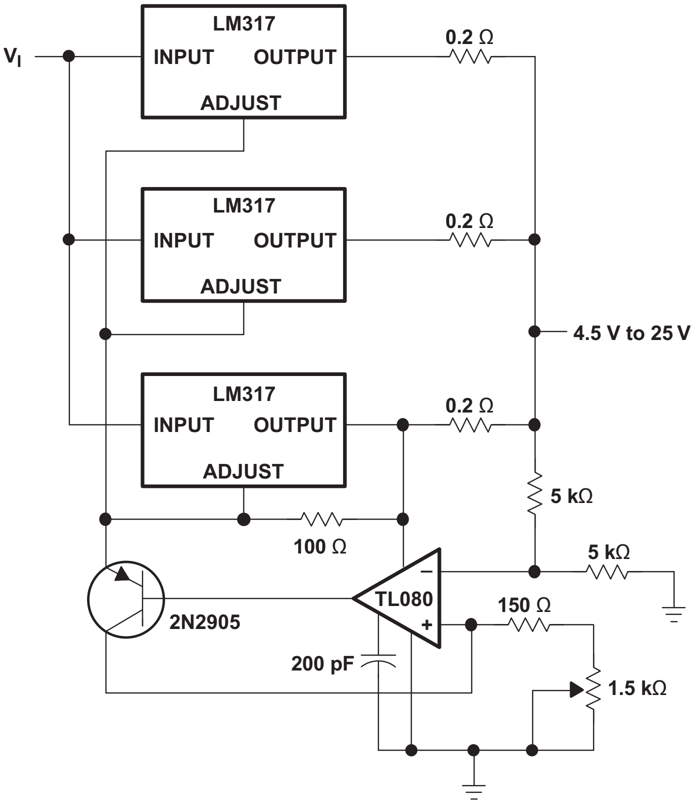


Figure 23. Adjustable 4-A Regulator Circuit

System Examples (continued)

9.3.13 High-Current Adjustable Regulator Circuit

The NPNs at the top of the schematic allow higher currents at V_{OUT} than the LM317 can provide, while still keeping the output voltage at levels determined by the adjustment pin resistor divider of the LM317.

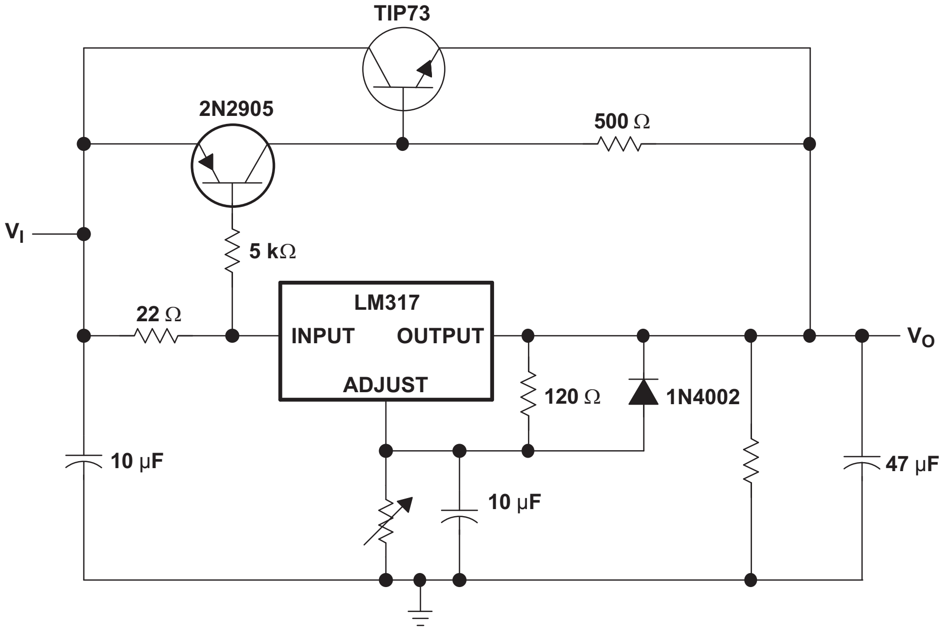


Figure 24. High-Current Adjustable Regulator Circuit

10 Power Supply Recommendations

The LM317 is designed to operate from an input voltage supply range between 1.25 V to 37 V greater than the output voltage. If the device is more than six inches from the input filter capacitors, an input bypass capacitor, 0.1 μF or greater, of any type is needed for stability.

11 Layout

11.1 Layout Guidelines

- It is recommended that the input terminal be bypassed to ground with a bypass capacitor.
- The optimum placement is closest to the input terminal of the device and the system GND. Care must be taken to minimize the loop area formed by the bypass-capacitor connection, the input terminal, and the system GND.
- For operation at full rated load, it is recommended to use wide trace lengths to eliminate I × R drop and heat dissipation.

11.2 Layout Example

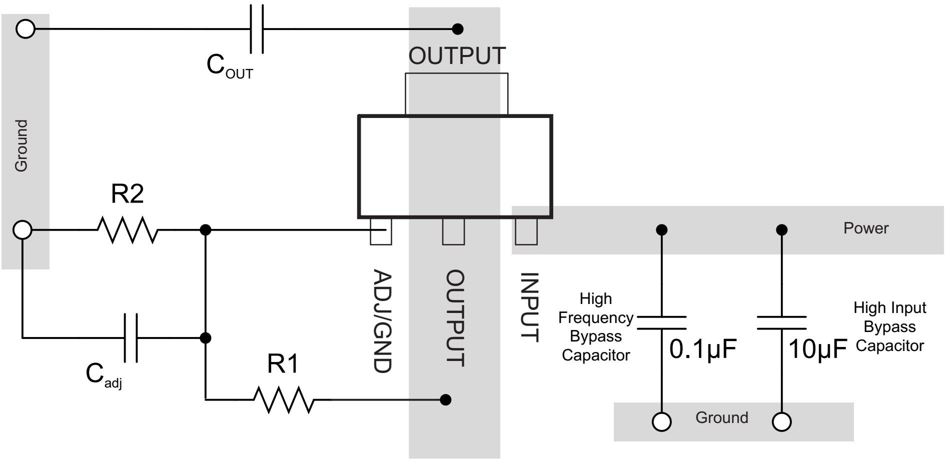


Figure 25. Layout Example

12 Device and Documentation Support

12.1 Trademarks

All trademarks are the property of their respective owners.

12.2 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

12.3 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM317DCY	ACTIVE	SOT-223	DCY	4	80	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	0 to 125	L3	Samples
LM317DCYG3	ACTIVE	SOT-223	DCY	4	80	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	0 to 125	L3	Samples
LM317DCYR	ACTIVE	SOT-223	DCY	4	2500	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	0 to 125	L3	Samples
LM317DCYRG3	ACTIVE	SOT-223	DCY	4	2500	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	0 to 125	L3	Samples
LM317KC	OBSOLETE	TO-220	KC	3		TBD	Call TI	Call TI	0 to 125	LM317	
LM317KCE3	OBSOLETE	TO-220	KC	3		TBD	Call TI	Call TI	0 to 125	LM317	
LM317KCS	ACTIVE	TO-220	KCS	3	50	Pb-Free (RoHS)	CU SN	N / A for Pkg Type	0 to 125	LM317	Samples
LM317KCSE3	ACTIVE	TO-220	KCS	3	50	Pb-Free (RoHS)	CU SN	N / A for Pkg Type	0 to 125	LM317	Samples
LM317KCT	ACTIVE	TO-220	KCT	3	50	Pb-Free (RoHS)	CU SN	N / A for Pkg Type	0 to 125	LM317	Samples
LM317KTER	OBSOLETE	PFM	KTE	3		TBD	Call TI	Call TI	0 to 125	LM317	
LM317KTTR	ACTIVE	DDPAK/ TO-263	KTT	3	500	Green (RoHS & no Sb/Br)	CU SN	Level-3-245C-168 HR	0 to 125	LM317	Samples
LM317KTTRG3	ACTIVE	DDPAK/ TO-263	KTT	3	500	Green (RoHS & no Sb/Br)	CU SN	Level-3-245C-168 HR	0 to 125	LM317	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

[3] MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

[4] There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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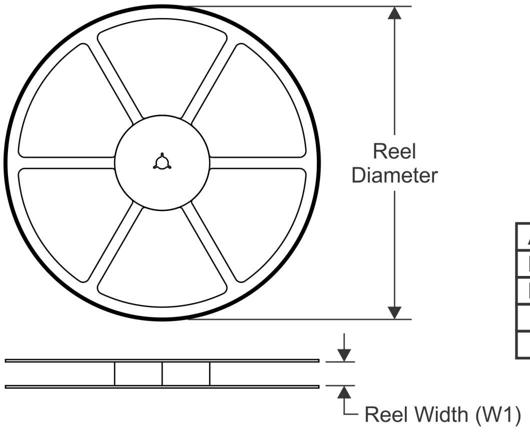
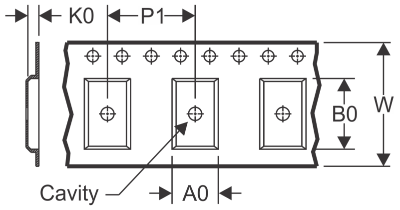
TAPE AND REEL INFORMATION

REEL DIMENSIONS

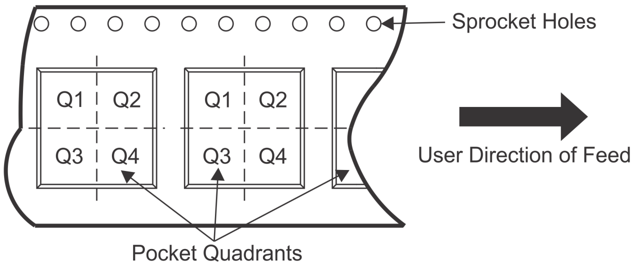


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

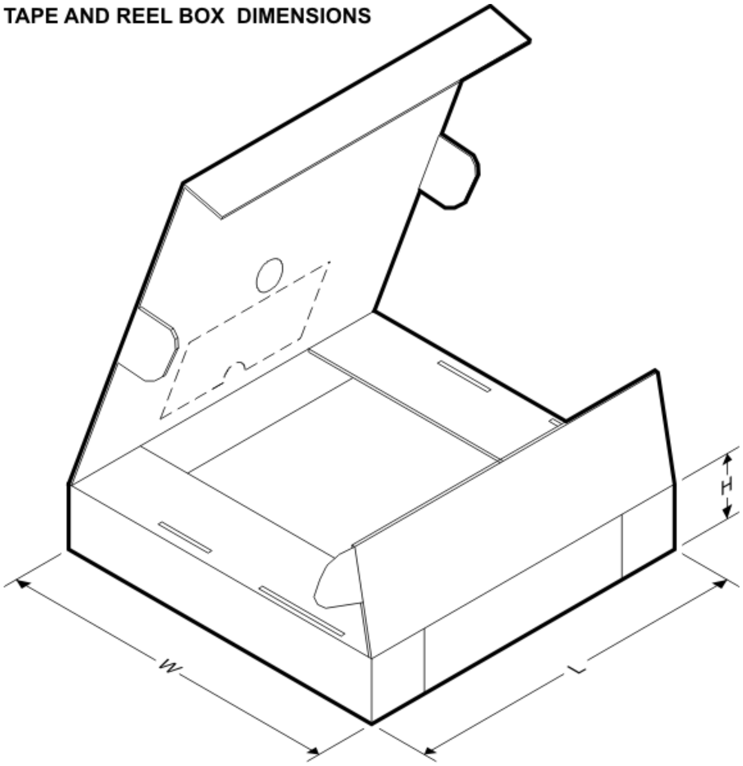
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM317DCYR	SOT-223	DCY	4	2500	330.0	12.4	7.05	7.4	1.9	8.0	12.0	Q3
LM317DCYR	SOT-223	DCY	4	2500	330.0	12.4	6.55	7.25	1.9	1.5	12.0	Q3
LM317KTTR	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.8	16.1	4.9	16.0	24.0	Q2
LM317KTTR	DDPAK/ TO-263	KTT	3	500	330.0	24.4	10.8	16.3	5.11	16.0	24.0	Q2

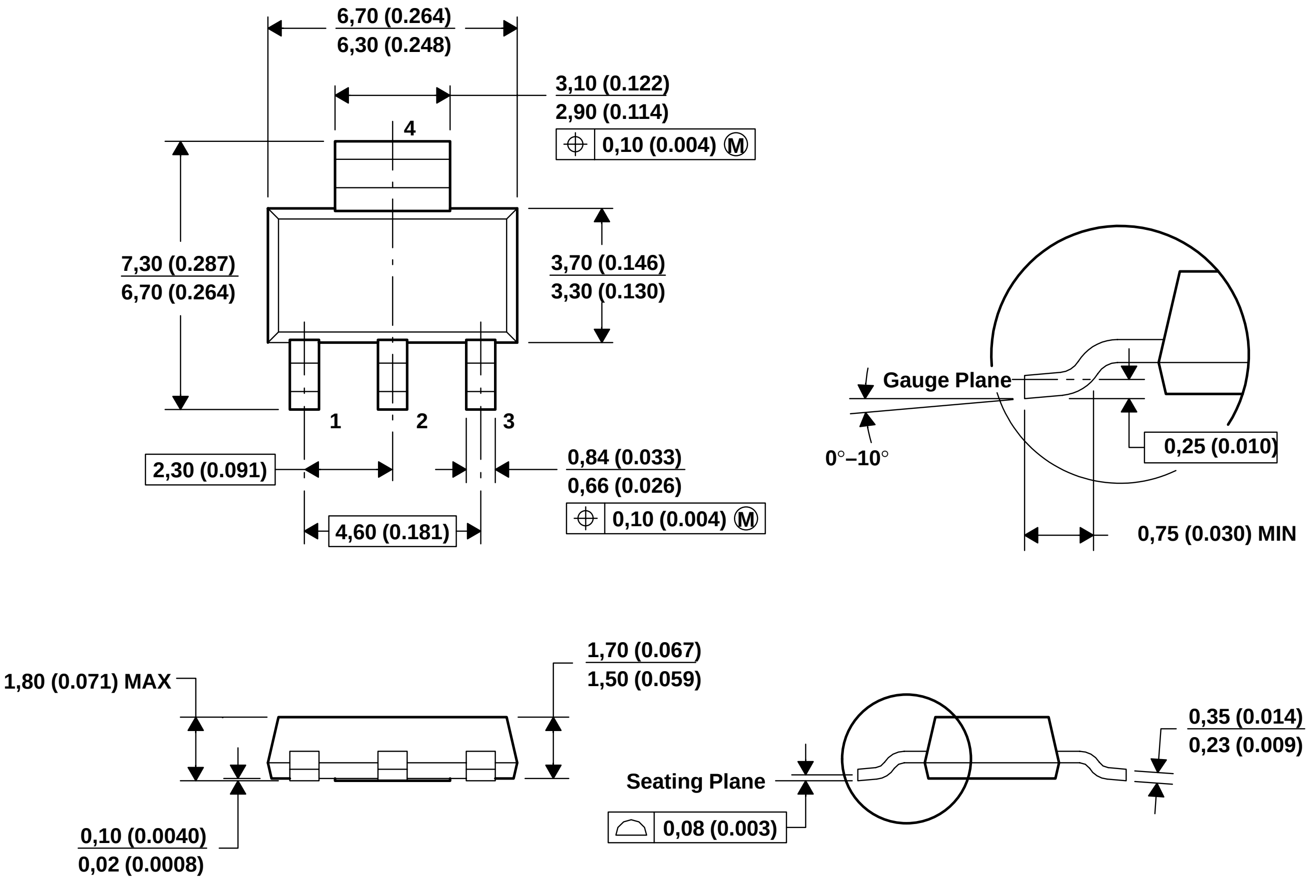
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM317DCYR	SOT-223	DCY	4	2500	340.0	340.0	38.0
LM317DCYR	SOT-223	DCY	4	2500	336.0	336.0	48.0
LM317KTTR	DDPAK/TO-263	KTT	3	500	350.0	334.0	47.0
LM317KTTR	DDPAK/TO-263	KTT	3	500	340.0	340.0	38.0

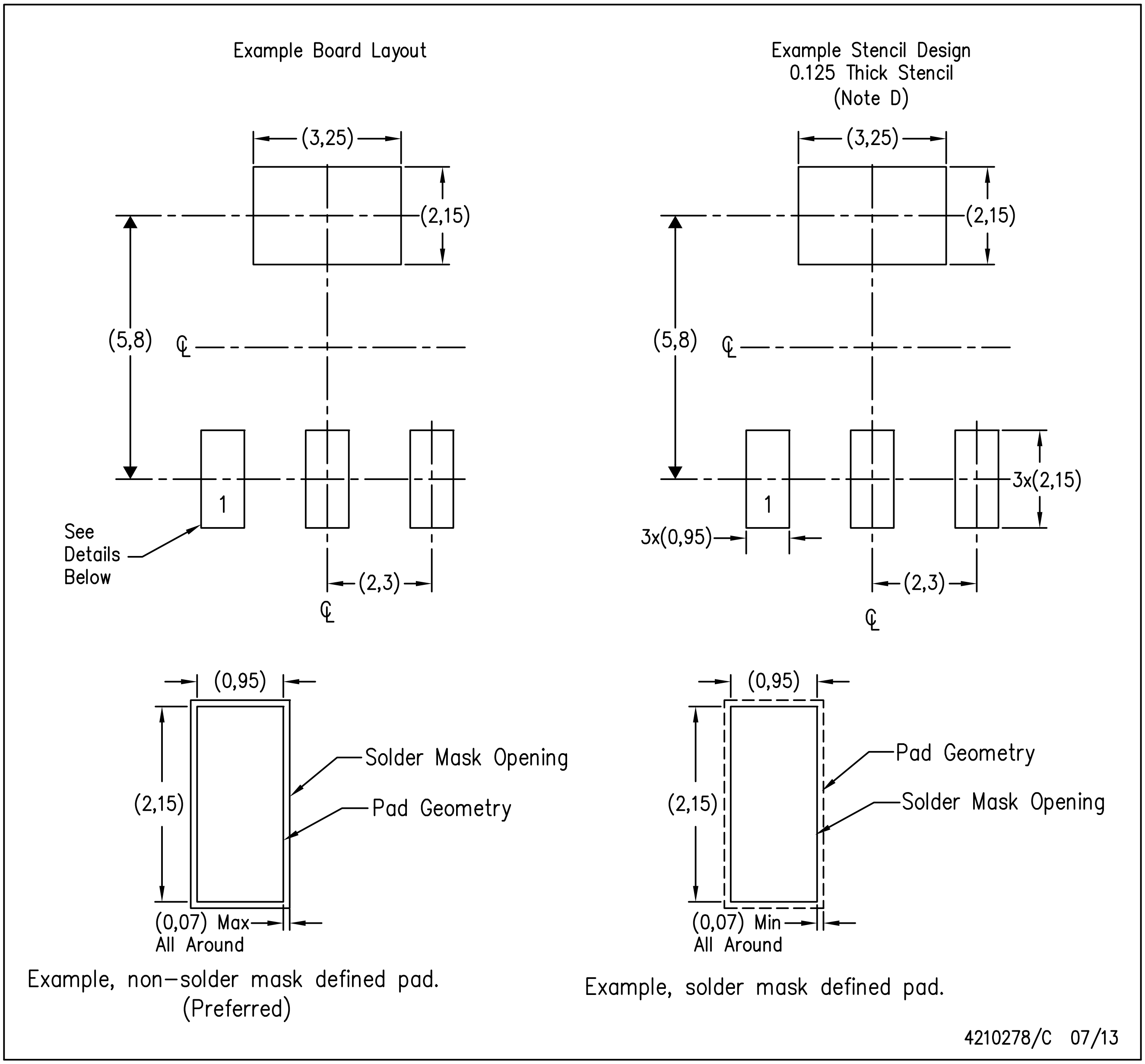
DCY (R-PDSO-G4) **PLASTIC SMALL-OUTLINE**



4202506/B 06/2002

NOTES:
- A. All linear dimensions are in millimeters (inches).
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion.
- D. Falls within JEDEC TO-261 Variation AA.

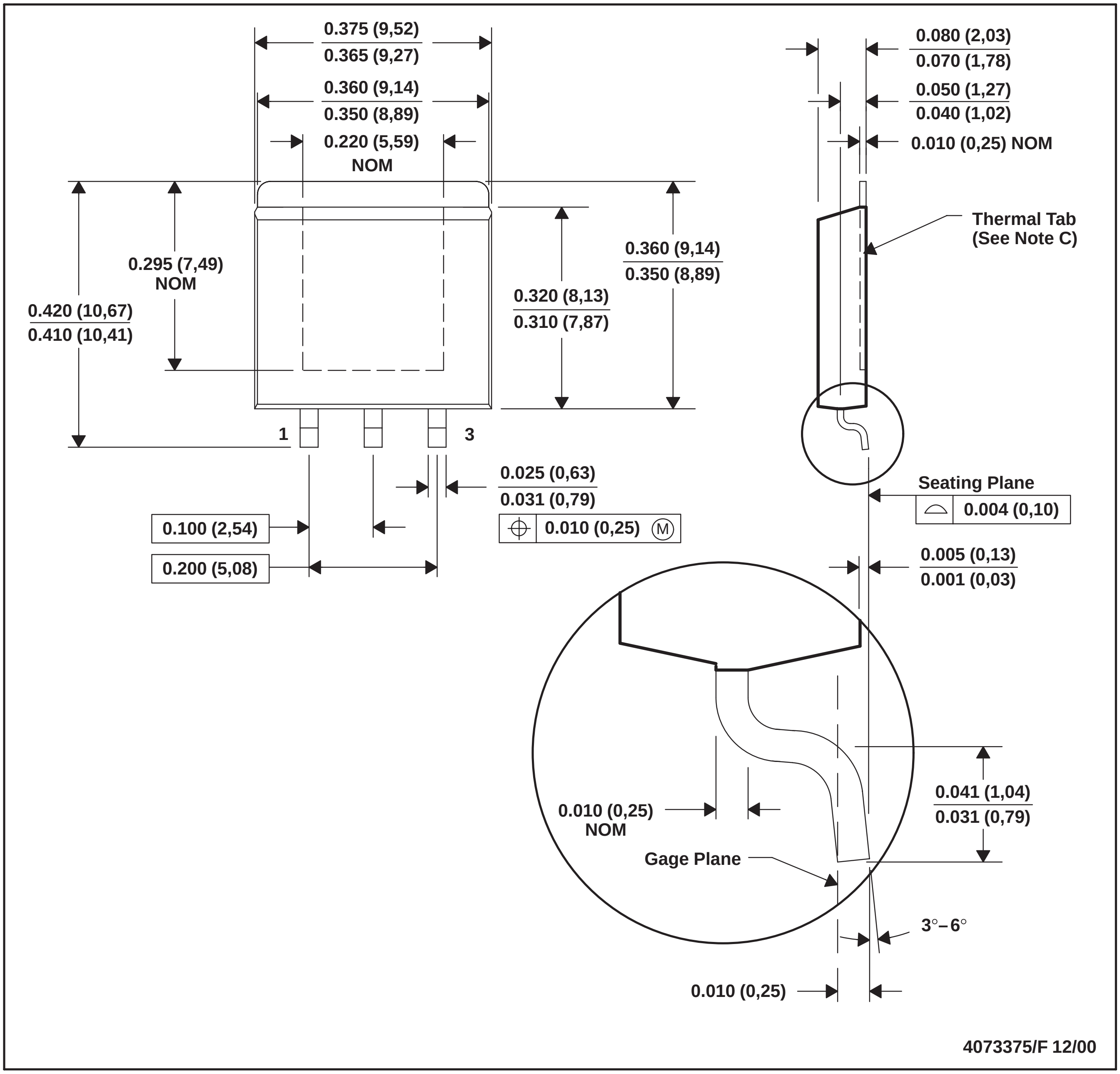
DCY (R–PDSO–G4) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC–7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil recommendations. Refer to IPC 7525 for stencil design considerations.

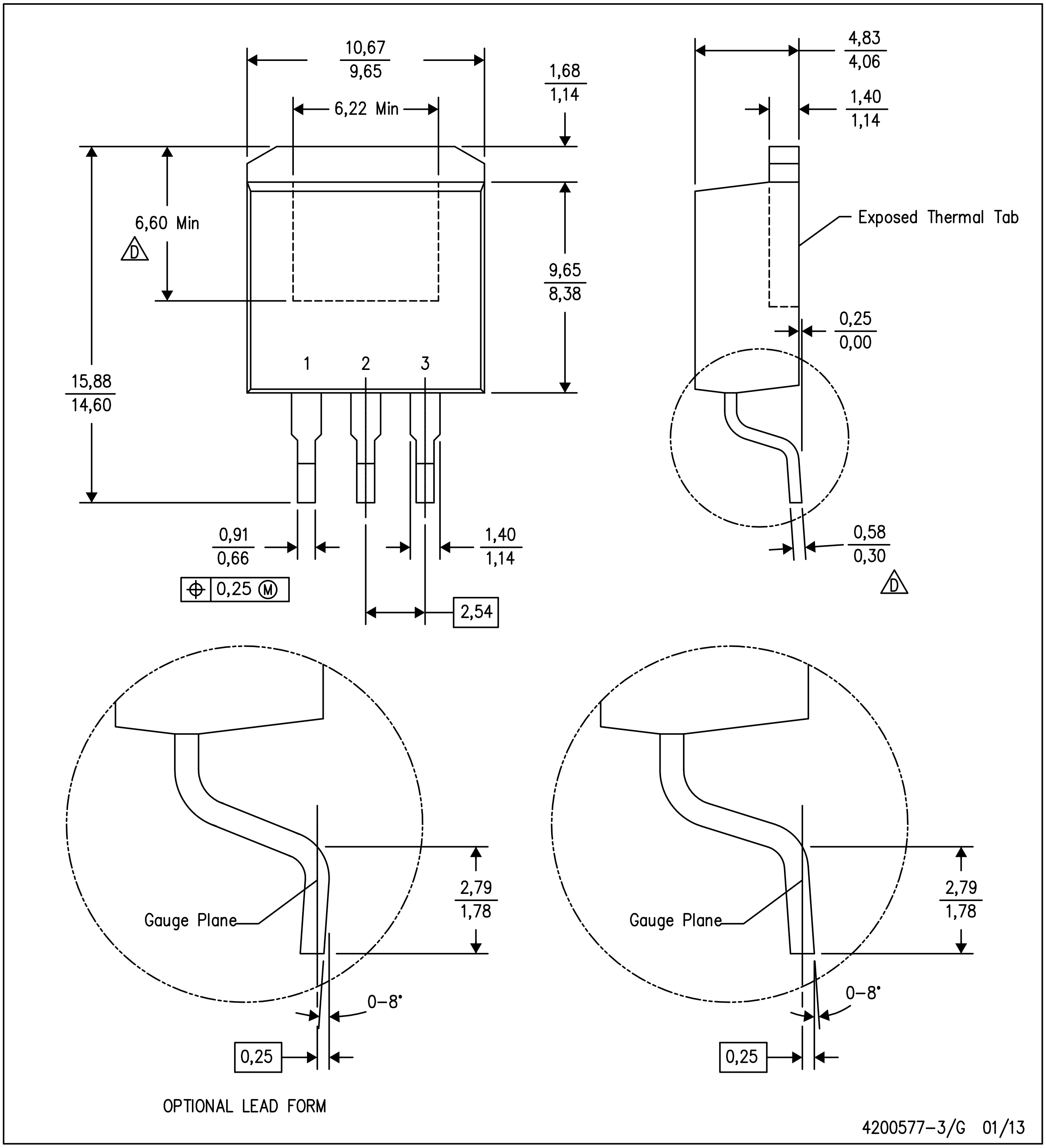
KTE (R-PSFM-G3)

PowerFLEX™ PLASTIC FLANGE-MOUNT



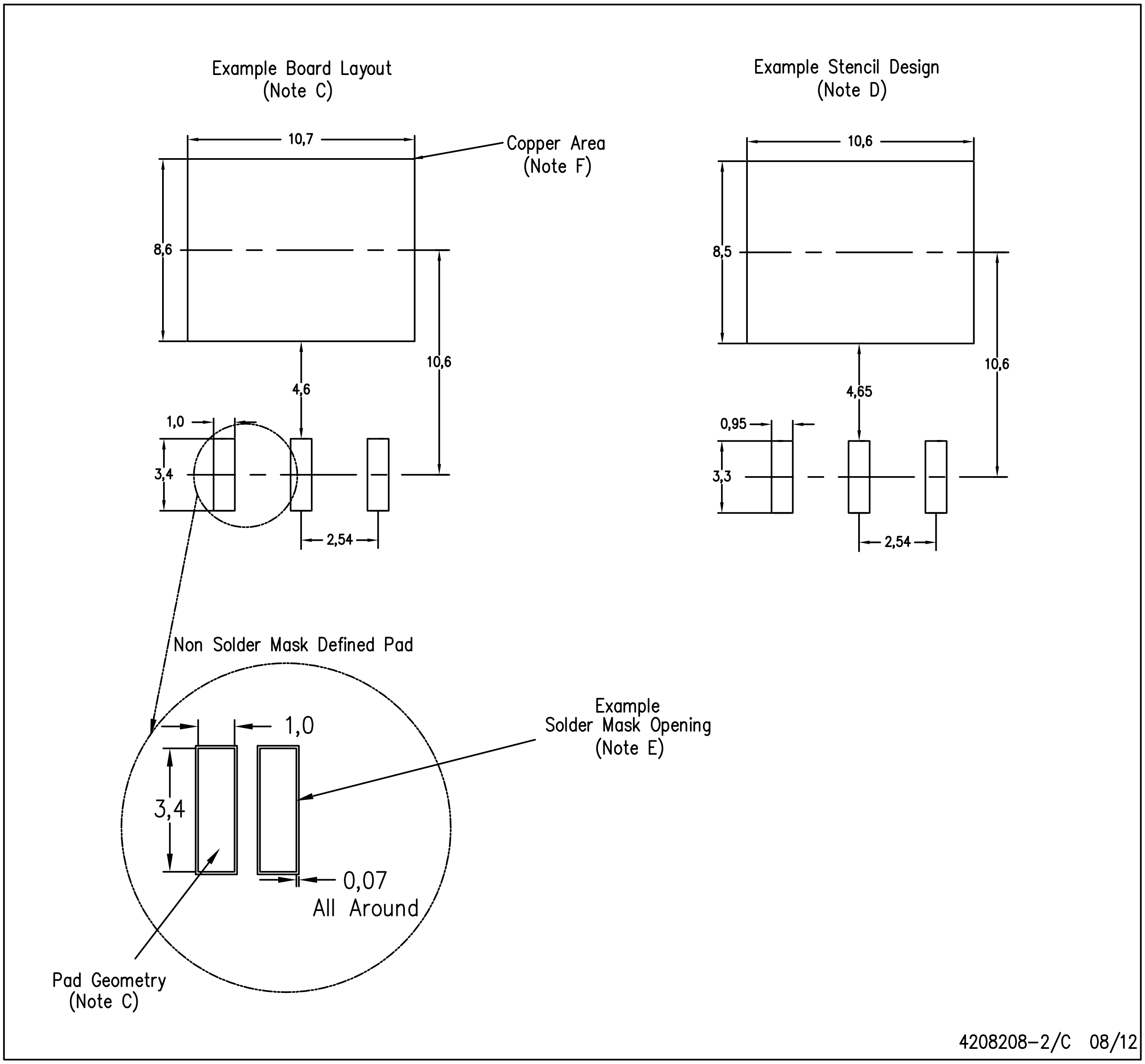
NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. The center lead is in electrical contact with the thermal tab.
- D. Dimensions do not include mold protrusions, not to exceed 0.006 (0,15).
- E. Falls within JEDEC MO-169

KTT (R–PSFM–G3) PLASTIC FLANGE–MOUNT PACKAGE



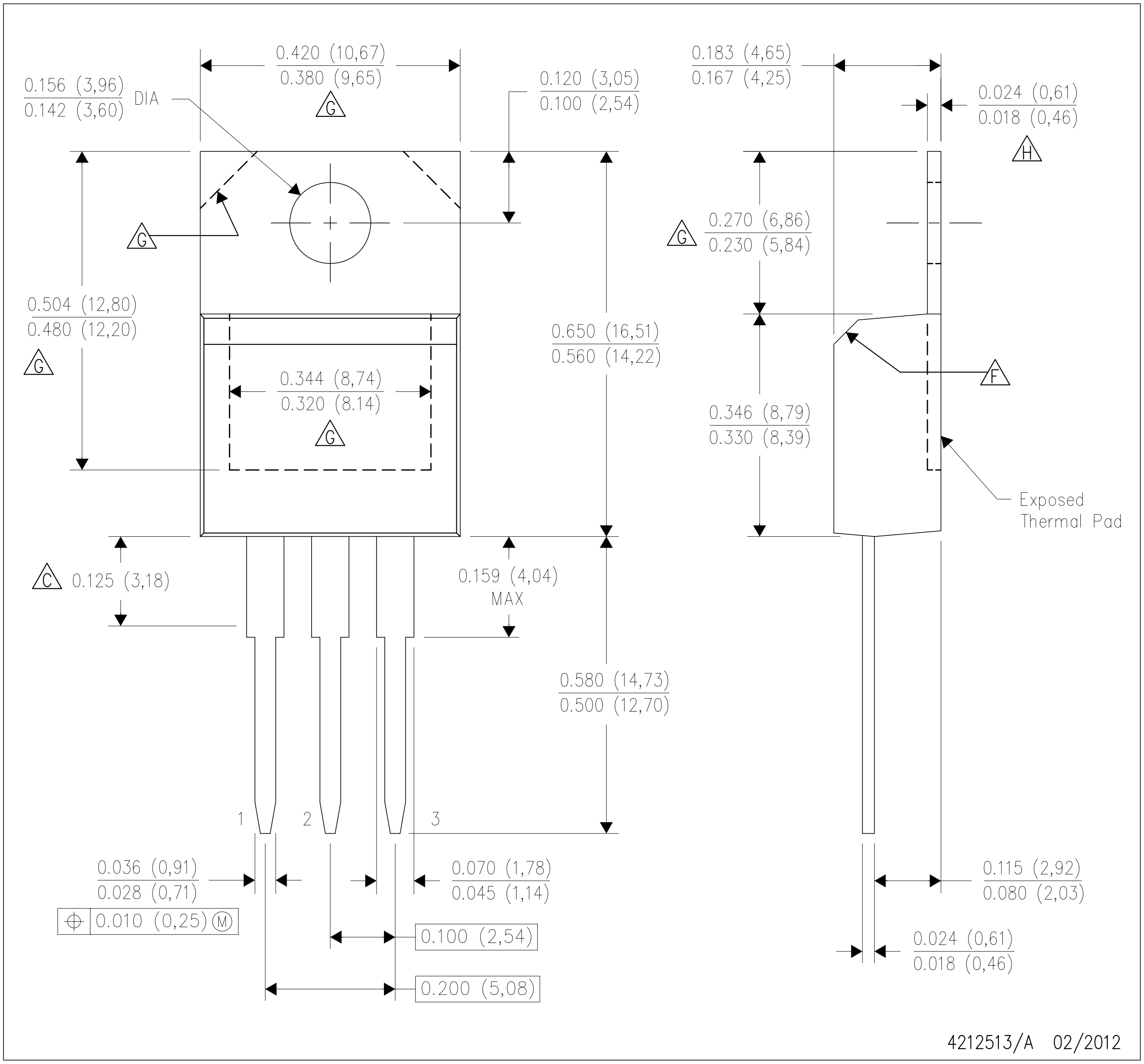
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion. Mold flash or protrusion not to exceed 0.005 (0,13) per side.
- D Falls within JEDEC TO–263 variation AA, except minimum lead thickness and minimum exposed pad length.

KTT (R–PSFM–G3) PLASTIC FLANGE–MOUNT PACKAGE

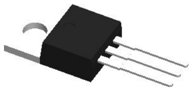


NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC–SM–782 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.
- F. This package is designed to be soldered to a thermal pad on the board. Refer to the Product Datasheet for specific thermal information, via requirements, and recommended thermal pad size. For thermal pad sizes larger than shown a solder mask defined pad is recommended in order to maintain the solderable pad geometry while increasing copper area.

KCT (R–PSFM–T3) PLASTIC FLANGE–MOUNT PACKAGE



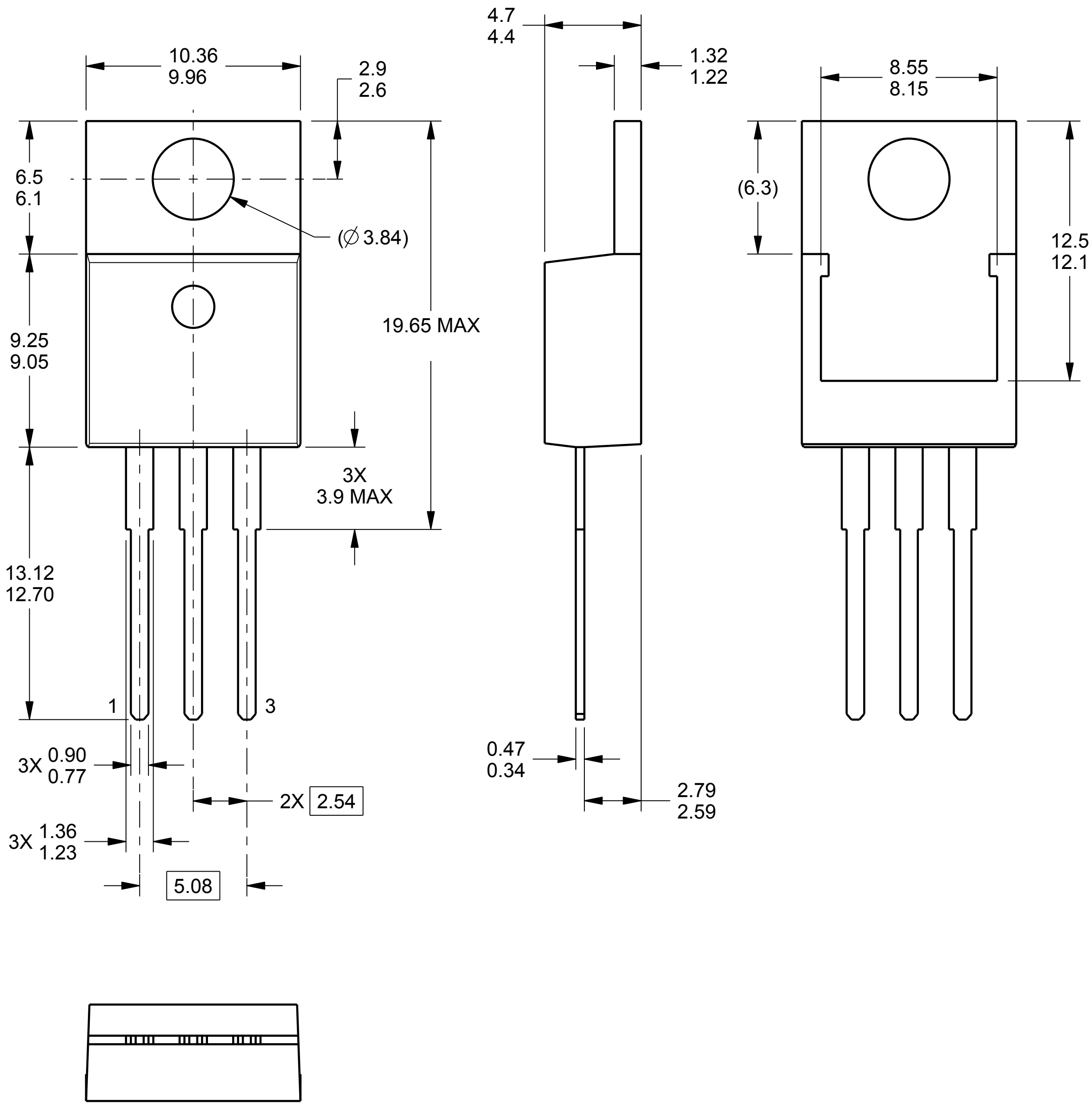
NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Lead dimensions are not controlled within this area.
- D. All lead dimensions apply before solder dip.
- E. The center lead is in electrical contact with the mounting tab.
- F. The chamfer is optional.
- G. Thermal pad contour optional within these dimensions.
- H. Falls within JEDEC TO–220 variation AB, except minimum tab thickness.



KCS0003B

TO-220 - 19.65 mm max height

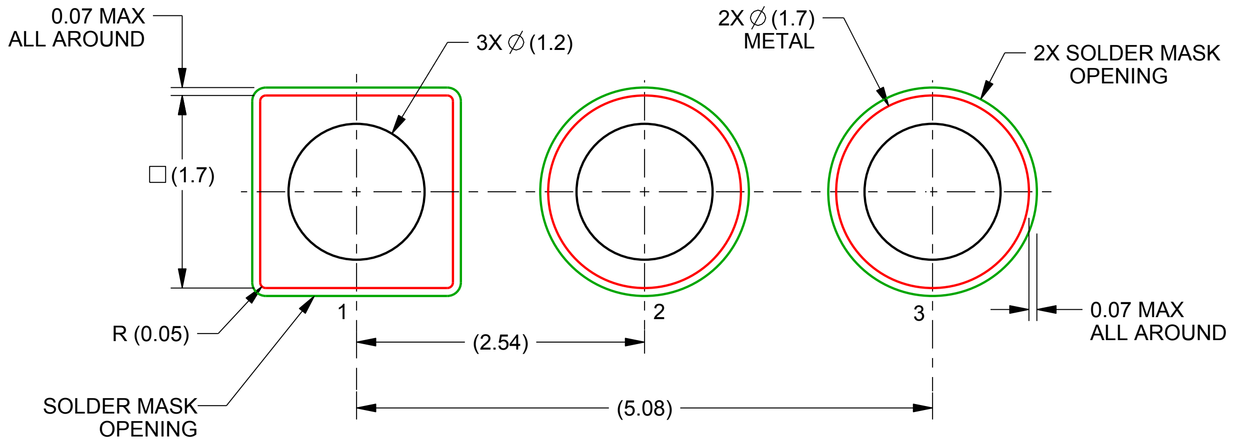
TO-220



4222214/A 10/2015

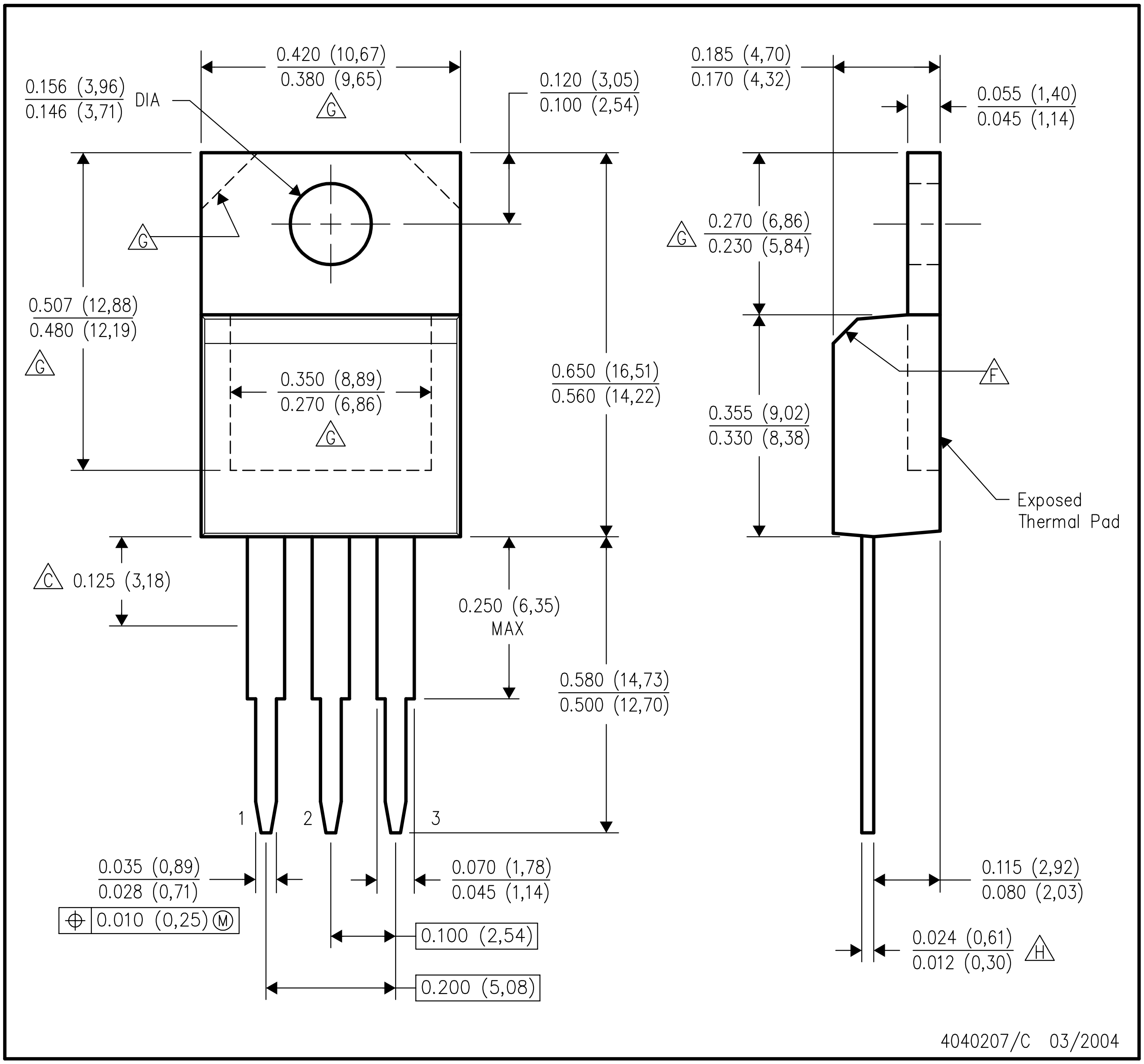
NOTES:

1. All controlling linear dimensions are in inches. Dimensions in brackets are in millimeters. Any dimension in brackets or parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC registration TO-220.



LAND PATTERN EXAMPLE
NON-SOLDER MASK DEFINED
SCALE:15X

KC (R–PSFM–T3) PLASTIC FLANGE–MOUNT PACKAGE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Lead dimensions are not controlled within this area.
- D. All lead dimensions apply before solder dip.
- E. The center lead is in electrical contact with the mounting tab.
- F. The chamfer is optional.
- G. Thermal pad contour optional within these dimensions.
- H. Falls within JEDEC TO–220 variation AB, except minimum lead thickness.

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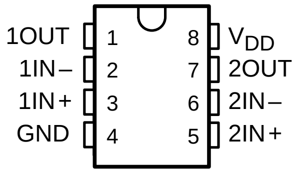
TLC272, TLC272A, TLC272B, TLC272Y, TLC277
LinCMOS™ PRECISION DUAL OPERATIONAL AMPLIFIERS

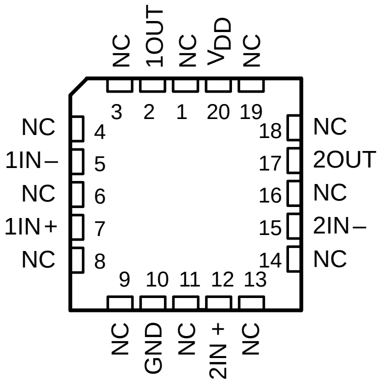
SLOS091E – OCTOBER 1987 – REVISED FEBRUARY 2002

- **Trimmed Offset Voltage:**
  TLC277 . . . 500 µV Max at 25°C,
  V_{DD} = 5 V
- **Input Offset Voltage Drift . . . Typically 0.1 µV/Month, Including the First 30 Days**
- **Wide Range of Supply Voltages Over Specified Temperature Range:**
  0°C to 70°C . . . 3 V to 16 V
  −40°C to 85°C . . . 4 V to 16 V
  −55°C to 125°C . . . 4 V to 16 V
- **Single-Supply Operation**
- **Common-Mode Input Voltage Range Extends Below the Negative Rail (C-Suffix, I-Suffix types)**
- **Low Noise . . . Typically 25 nV/$\sqrt{Hz}$ at f = 1 kHz**
- **Output Voltage Range Includes Negative Rail**
- **High Input impedance . . . 10^{12} Ω Typ**
- **ESD-Protection Circuitry**
- **Small-Outline Package Option Also Available in Tape and Reel**
- **Designed-In Latch-Up Immunity**

D, JG, P, OR PW PACKAGE
(TOP VIEW)



FK PACKAGE
(TOP VIEW)



NC – No internal connection

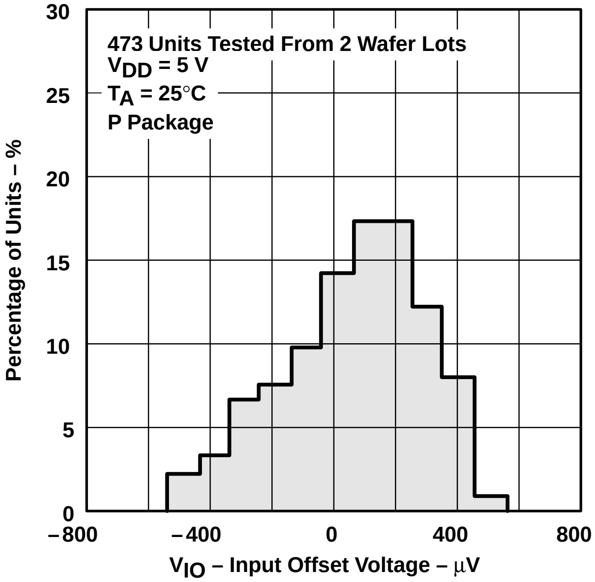
description

The TLC272 and TLC277 precision dual operational amplifiers combine a wide range of input offset voltage grades with low offset voltage drift, high input impedance, low noise, and speeds approaching those of general-purpose BiFET devices.

These devices use Texas Instruments silicon-gate LinCMOS™ technology, which provides offset voltage stability far exceeding the stability available with conventional metal-gate processes.

The extremely high input impedance, low bias currents, and high slew rates make these cost-effective devices ideal for applications previously reserved for BiFET and NFET products. Four offset voltage grades are available (C-suffix and I-suffix types), ranging from the low-cost TLC272 (10 mV) to the high-precision TLC277 (500 µV). These advantages, in combination with good common-mode rejection and supply voltage rejection, make these devices a good choice for new state-of-the-art designs as well as for upgrading existing designs.

DISTRIBUTION OF TLC277
INPUT OFFSET VOLTAGE



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description (continued)

AVAILABLE OPTIONS

T_A	V_{IO}max AT 25°C	PACKAGED DEVICES					CHIP FORM (Y)
		SMALL OUTLINE (D)	CHIP CARRIER (FK)	CERAMIC DIP (JG)	PLASTIC DIP (P)	TSSOP (PW)	
0°C to 70°c	500 μV	TLC277CD	—	—	TLC277CP	—	—
	2 mV	TLC272BCD	—	—	TLC272BCP	—	—
	5 mV	TLC272ACD	—	—	TLC272ACP	—	—
	10mV	TLC272CD	—	—	TLC272CP	TLC272CPW	TLC272Y
–40°C to 85°C	500 μV	TLC277ID	—	—	TLC277IP	—	—
	2 mV	TLC272BID	—	—	TLC272BIP	—	—
	5 mV	TLC272AID	—	—	TLC272AIP	—	—
	10 mV	TLC272ID	—	—	TLC272IP	—	—

The D package is available taped and reeled. Add R suffix to the device type (e.g., TLC277CDR).

In general, many features associated with bipolar technology are available on LinCMOS™ operational amplifiers without the power penalties of bipolar technology. General applications such as transducer interfacing, analog calculations, amplifier blocks, active filters, and signal buffering are easily designed with the TLC272 and TLC277. The devices also exhibit low voltage single-supply operation, making them ideally suited for remote and inaccessible battery-powered applications. The common-mode input voltage range includes the negative rail.

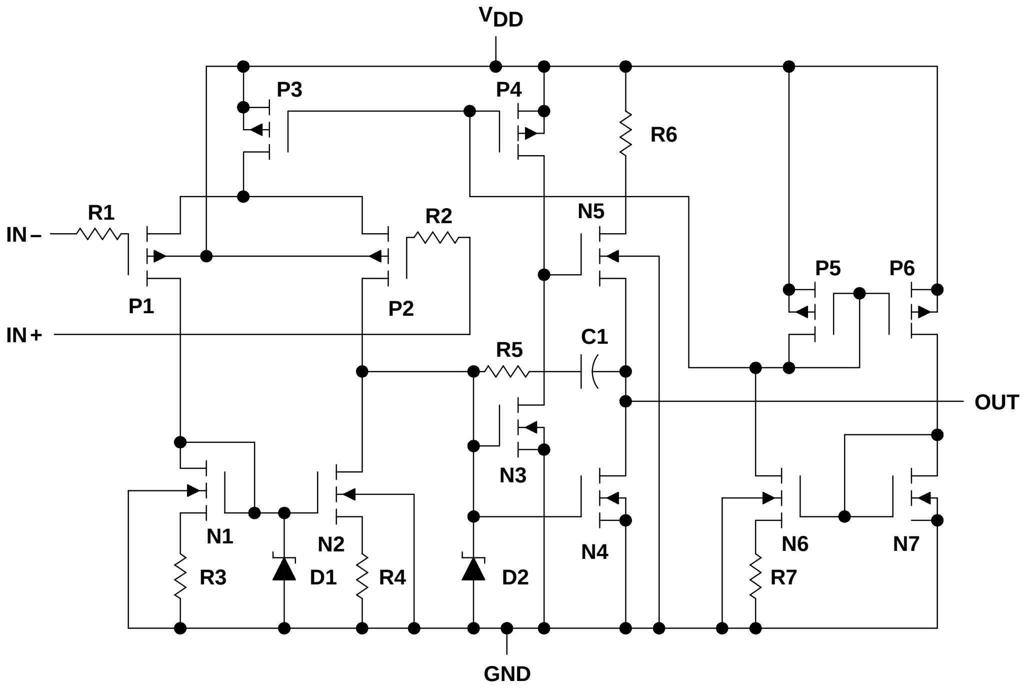
A wide range of packaging options is available, including small-outline and chip carrier versions for high-density system applications.

The device inputs and outputs are designed to withstand –100-mA surge currents without sustaining latch-up.

The TLC272 and TLC277 incorporate internal ESD-protection circuits that prevent functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2; however, care should be exercised in handling these devices as exposure to ESD may result in the degradation of the device parametric performance.

The C-suffix devices are characterized for operation from 0°C to 70°C. The I-suffix devices are characterized for operation from –40°C to 85°C. The M-suffix devices are characterized for operation over the full military temperature range of –55°C to 125°C.

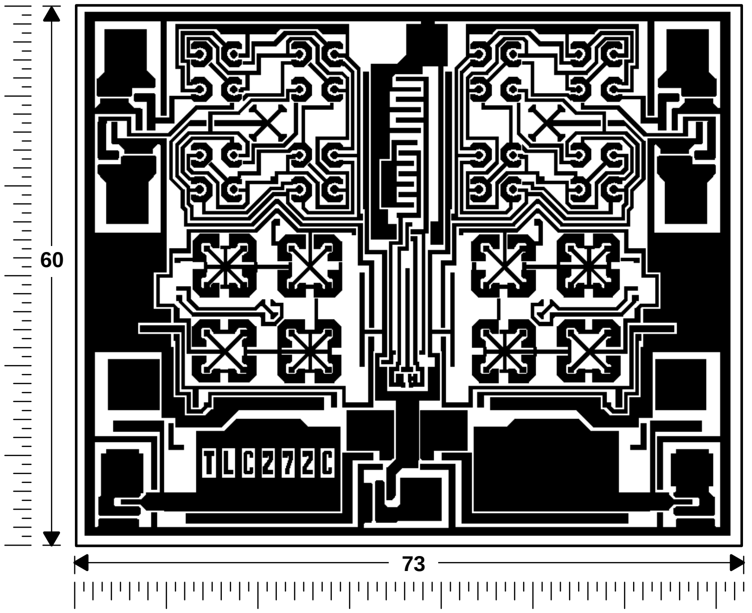
equivalent schematic (each amplifier)

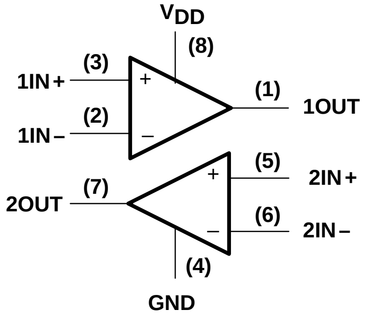


TLC272Y chip information

This chip, when properly assembled, displays characteristics similar to the TLC272C. Thermal compression or ultrasonic bonding may be used on the doped-aluminum bonding pads. Chips may be mounted with conductive epoxy or a gold-silicon preform.

BONDING PAD ASSIGNMENTS





CHIP THICKNESS: 15 TYPICAL

BONDING PADS: 4 × 4 MINIMUM

$T_J$max = 150°C

TOLERANCES ARE ±10%.

ALL DIMENSIONS ARE IN MILS.

PIN (4) IS INTERNALLY CONNECTED TO BACKSIDE OF CHIP.

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

Supply voltage, V_{DD} (see Note 1)	18 V
Differential input voltage, V_{ID} (see Note 2)	$\pm V_{DD}$
Input voltage range, V_I (any input)	-0.3 V to V_{DD}
Input current, I_I	±5 mA
output current, I_O (each output)	±30 mA
Total current into V_{DD}	45 mA
Total current out of GND	45 mA
Duration of short-circuit current at (or below) 25°C (see Note 3)	unlimited
Continuous total dissipation	See Dissipation Rating Table
Operating free-air temperature, T_A: C suffix	0°C to 70°C
I suffix	−40°C to 85°C
M suffix	−55°C to 125°C
Storage temperature range	−65°C to 150°C
Case temperature for 60 seconds: FK package	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D, P, or PW package	260°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: JG package	300°C

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

NOTES: 1. All voltage values, except differential voltages, are with respect to network ground.
2. Differential voltages are at IN+ with respect to IN−.
3. The output may be shorted to either supply. Temperature and/or supply voltages must be limited to ensure that the maximum dissipation rating is not exceeded (see application section).

DISSIPATION RATING TABLE

PACKAGE	$T_A \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ POWER RATING
D	725 mW	5.8 mW/°C	464 mW	377 mW	N/A
FK	1375 mW	11 mW/°C	880 mW	715 mW	275 mW
JG	1050 mW	8.4 mW/°C	672 mW	546 mW	210 mW
P	1000 mW	8.0 mW/°C	640 mW	520 mW	N/A
PW	525 mW	4.2 mW/°C	336 mW	N/A	N/A

recommended operating conditions

		C SUFFIX		I SUFFIX		M SUFFIX		UNIT
		MIN	MAX	MIN	MAX	MIN	MAX	
Supply voltage, V_{DD}		3	16	4	16	4	16	V
Common-mode input voltage, V_{IC}	V_{DD} = 5 V	−0.2	3.5	−0.2	3.5	0	3.5	V
	V_{DD} = 10 V	−0.2	8.5	−0.2	8.5	0	8.5	
Operating free-air temperature, T_A		0	70	−40	85	−55	125	°C

electrical characteristics at specified free-air temperature, V_{DD} = 5 V (unless otherwise noted)

PARAMETER			TEST CONDITIONS	T_A†	TLC272C, TLC272AC, TLC272BC, TLC277C			UNIT
					MIN	TYP	MAX	
V_{IO}	Input offset voltage	TLC272C	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		1.1	10	mV
				Full range			12	
		TLC272AC	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		0.9	5	
				Full range			6.5	
		TLC272BC	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		230	2000	µV
				Full range			3000	
		TLC277C	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		200	500	
				Full range			1500	
α_{VIO}	Temperature coefficient of input offset voltage			25°C to 70°C		1.8		µV/°C
I_{IO}	Input offset current (see Note 4)		V_O = 2.5 V, V_{IC} = 2.5 V	25°C		0.1	60	pA
				70°C		7	300	
I_{IB}	Input bias current (see Note 4)			25°C		0.6	60	pA
				70°C		40	600	
V_{ICR}	Common-mode input voltage range (see Note 5)			25°C	−0.2 to 4	−0.3 to 4.2		V
				Full range	−0.2 to 3.5			V
V_{OH}	High-level output voltage		V_{ID} = 100 mV, R_L = 10 kΩ	25°C	3.2	3.8		V
				0°C	3	3.8		
				70°C	3	3.8		
V_{OL}	Low-level output voltage		V_{ID} = –100 mV, I_{OL} = 0	25°C		0	50	mV
				0°C		0	50	
				70°C		0	50	
A_{VD}	Large-signal differential voltage amplification		V_O = 0.25 V to 2 V, R_L = 10 kΩ	25°C	5	23		V/mV
				0°C	4	27		
				70°C	4	20		
CMRR	Common-mode rejection ratio		V_{IC} = V_{ICR}min	25°C	65	80		dB
				0°C	60	84		
				70°C	60	85		
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)		V_{DD} = 5 V to 10 V, V_O = 1.4 V	25°C	65	95		dB
				0°C	60	94		
				70°C	60	96		
I_{DD}	Supply current (two amplifiers)		V_O = 2.5 V, V_{IC} = 2.5 V, No load	25°C		1.4	3.2	mA
				0°C		1.6	3.6	
				70°C		1.2	2.6	

† Full range is 0°C to 70°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.

5. This range also applies to each input individually.

electrical characteristics at specified free-air temperature, V_{DD} = 10 V (unless otherwise noted)

PARAMETER			TEST CONDITIONS		T_A†	TLC272C, TLC272AC, TLC272BC, TLC277C			UNIT
						MIN	TYP	MAX	
V_{IO}	Input offset voltage	TLC272C	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ	25°C		1.1	10	mV
					Full range			12	
		TLC272AC	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ	25°C		0.9	5	
					Full range			6.5	
		TLC272BC	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ	25°C		290	2000	µV
					Full range			3000	
		TLC277C	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ	25°C		250	800	
					Full range			1900	
α_{VIO}	Temperature coefficient of input offset voltage				25°C to 70°C		2		µV/°C
I_{IO}	Input offset current (see Note 4)		V_O = 5 V,	V_{IC} = 5 V	25°C		0.1	60	pA
					70°C		7	300	
I_{IB}	Input bias current (see Note 4)				25°C		0.7	60	pA
					70°C		50	600	
V_{ICR}	Common-mode input voltage range (see Note 5)				25°C	−0.2 to 9	−0.3 to 9.2		V
					Full range	−0.2 to 8.5			V
V_{OH}	High-level output voltage		V_{ID} = 100 mV,	R_L = 10 kΩ	25°C	8	8.5		V
					0°C	7.8	8.5		
					70°C	7.8	8.4		
V_{OL}	Low-level output voltage		V_{ID} = –100 mV,	I_{OL} = 0	25°C		0	50	mV
					0°C		0	50	
					70°C		0	50	
A_{VD}	Large-signal differential voltage amplification		V_O = 1 V to 6 V,	R_L = 10 kΩ	25°C	10	36		V/mV
					0°C	7.5	42		
					70°C	7.5	32		
CMRR	Common-mode rejection ratio		$V_{IC} = V_{ICR}$min		25°C	65	85		dB
					0°C	60	88		
					70°C	60	88		
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)		V_{DD} = 5 V to 10 V,	V_O = 1.4 V	25°C	65	95		dB
					0°C	60	94		
					70°C	60	96		
I_{DD}	Supply current (two amplifiers)		V_O = 5 V, No load	V_{IC} = 5 V,	25°C		1.9	4	mA
					0°C		2.3	4.4	
					70°C		1.6	3.4	

† Full range is 0°C to 70°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

electrical characteristics at specified free-air temperature, V_{DD} = 5 V (unless otherwise noted)

PARAMETER			TEST CONDITIONS	T_A†	TLC272I, TLC272AI, TLC272BI, TLC277I			UNIT
					MIN	TYP	MAX	
V_{IO}	Input offset voltage	TLC272I	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		1.1	10	mV
				Full range			13	
		TLC272AI	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		0.9	5	
				Full range			7	
		TLC272BI	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		230	2000	µV
				Full range			3500	
		TLC277I	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		200	500	
				Full range			2000	
α_{VIO}	Temperature coefficient of input offset voltage			25°C to 85°C		1.8		µV/°C
I_{IO}	Input offset current (see Note 4)		V_O = 2.5 V, V_{IC} = 2.5 V	25°C		0.1	60	pA
				85°C		24	15	
I_{IB}	Input bias current (see Note 4)			25°C		0.6	60	pA
				85°C		200	35	
V_{ICR}	Common-mode input voltage range (see Note 5)			25°C	−0.2 to 4	−0.3 to 4.2		V
				Full range	−0.2 to 3.5			V
V_{OH}	High-level output voltage		V_{ID} = 100 mV, R_L = 10 kΩ	25°C	3.2	3.8		V
				−40°C	3	3.8		
				85°C	3	3.8		
V_{OL}	Low-level output voltage		V_{ID} = –100 mV, I_{OL} = 0	25°C		0	50	mV
				−40°C		0	50	
				85°C		0	50	
A_{VD}	Large-signal differential voltage amplification		V_O = 1 V to 6 V, R_L = 10 kΩ	25°C	5	23		V/mV
				−40°C	3.5	32		
				85°C	3.5	19		
CMRR	Common-mode rejection ratio		$V_{IC} = V_{ICR}\text{min}$	25°C	65	80		dB
				−40°C	60	81		
				85°C	60	86		
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)		V_{DD} = 5 V to 10 V, V_O = 1.4 V	25°C	65	95		dB
				−40°C	60	92		
				85°C	60	96		
I_{DD}	Supply current (two amplifiers)		V_O = 2.5 V, V_{IC} = 2.5 V, No load	25°C		1.4	3.2	mA
				−40°C		1.9	4.4	
				85°C		1.1	2.4	

† Full range is −40°C to 85°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.

5. This range also applies to each input individually.

electrical characteristics at specified free-air temperature, V_{DD} = 10 V (unless otherwise noted)

PARAMETER			TEST CONDITIONS	T_A†	TLC272I, TLC272AI, TLC272BI, TLC277I			UNIT
					MIN	TYP	MAX	
V_{IO}	Input offset voltage	TLC272I	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		1.1	10	mV
				Full range			13	
		TLC272AI	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		0.9	5	
				Full range			7	
		TLC272BI	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		290	2000	µV
				Full range			3500	
		TLC277I	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		250	800	
				Full range			2900	
α_{VIO}	Temperature coefficient of input offset voltage			25°C to 85°C		2		µV/°C
I_{IO}	Input offset current (see Note 4)		V_O = 5 V, V_{IC} = 5 V	25°C		0.1	60	pA
				85°C		26	1000	
I_{IB}	Input bias current (see Note 4)			25°C		0.7	60	pA
				85°C		220	2000	
V_{ICR}	Common-mode input voltage range (see Note 5)			25°C	−0.2 to 9	−0.3 to 9.2		V
				Full range	−0.2 to 8.5			V
V_{OH}	High-level output voltage		V_{ID} = 100 mV, R_L = 10 kΩ	25°C	8	8.5		V
				−40°C	7.8	8.5		
				85°C	7.8	8.5		
V_{OL}	Low-level output voltage		V_{ID} = −100 mV, I_{OL} = 0	25°C		0	50	mV
				−40°C		0	50	
				85°C		0	50	
A_{VD}	Large-signal differential voltage amplification		V_O = 1 V to 6 V, R_L = 10 kΩ	25°C	10	36		V/mV
				−40°C	7	46		
				85°C	7	31		
CMRR	Common-mode rejection ratio		V_{IC} = V_{ICR}min	25°C	65	85		dB
				−40°C	60	87		
				85°C	60	88		
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)		V_{DD} = 5 V to 10 V, V_O = 1.4 V	25°C	65	95		dB
				−40°C	60	92		
				85°C	60	96		
I_{DD}	Supply current (two amplifiers)		V_O = 5 V, V_{IC} = 5 V, No load	25°C		1.4	4	mA
				−40°C		2.8	5	
				85°C		1.5	3.2	

† Full range is −40°C to 85°C.

NOTES:
4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

electrical characteristics at specified free-air temperature, V_{DD} = 5 V (unless otherwise noted)

PARAMETER			TEST CONDITIONS	T_A†	TLC272M, TLC277M			UNIT
					MIN	TYP	MAX	
V_{IO}	Input offset voltage	TLC272M	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		1.1	10	mV
				Full range			12	
		TLC277M	V_O = 1.4 V, V_{IC} = 0, R_S = 50 Ω, R_L = 10 kΩ	25°C		200	500	µV
				Full range			3750	
α_{VIO}	Temperature coefficient of input offset voltage			25°C to 125°C		2.1		µV/°C
I_{IO}	Input offset current (see Note 4)		V_O = 2.5 V, V_{IC} = 2.5 V	25°C		0.1	60	pA
				125°C		1.4	15	nA
I_{IB}	Input bias current (see Note 4)			25°C		0.6	60	pA
				125°C		9	35	nA
V_{ICR}	Common-mode input voltage range (see Note 5)			25°C	0 to 4	−0.3 to 4.2		V
				Full range	0 to 3.5			V
V_{OH}	High-level output voltage		V_{ID} = 100 mV, R_L = 10 kΩ	25°C	3.2	3.8		V
				−55°C	3	3.8		
				125°C	3	3.8		
V_{OL}	Low-level output voltage		V_{ID} = −100 mV, I_{OL} = 0	25°C		0	50	mV
				−55°C		0	50	
				125°C		0	50	
A_{VD}	Large-signal differential voltage amplification		V_O = 0.25 V to 2 V, R_L = 10 kΩ	25°C	5	23		V/mV
				−55°C	3.5	35		
				125°C	3.5	16		
CMRR	Common-mode rejection ratio		$V_{IC} = V_{ICR}$min	25°C	65	80		dB
				−55°C	60	81		
				125°C	60	84		
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)		V_{DD} = 5 V to 10 V, V_O = 1.4 V	25°C	65	95		dB
				−55°C	60	90		
				125°C	60	97		
I_{DD}	Supply current (two amplifiers)		V_O = 2.5 V, V_{IC} = 2.5 V, No load	25°C		1.4	3.2	mA
				−55°C		2	5	
				125°C		1	2.2	

† Full range is −55°C to 125°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

electrical characteristics at specified free-air temperature, V_{DD} = 10 V (unless otherwise noted)

PARAMETER			TEST CONDITIONS		T_A†	TLC272M, TLC277M MIN	TYP	MAX	UNIT
V_{IO}	Input offset voltage	TLC272M	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ	25°C		1.1	10	mV
					Full range			12	
		TLC277M	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ	25°C		250	800	µV
					Full range			4300	
α_{VIO}	Temperature coefficient of input offset voltage				25°C to 125°C		2.2		µV/°C
I_{IO}	Input offset current (see Note 4)		V_O = 5 V,	V_{IC} = 5 V	25°C		0.1	60	pA
					125°C		1.8	15	nA
I_{IB}	Input bias current (see Note 4)				25°C		0.7	60	pA
					125°C		10	35	nA
V_{ICR}	Common-mode input voltage range (see Note 5)				25°C	0 to 9	−0.3 to 9.2		V
					Full range	0 to 8.5			V
V_{OH}	High-level output voltage		V_{ID} = 100 mV,	R_L = 10 kΩ	25°C	8	8.5		V
					−55°C	7.8	8.5		
					125°C	7.8	8.4		
V_{OL}	Low-level output voltage		V_{ID} = −100 mV,	I_{OL} = 0	25°C		0	50	mV
					−55°C		0	50	
					125°C		0	50	
A_{VD}	Large-signal differential voltage amplification		V_O = 1 V to 6 V,	R_L = 10 kΩ	25°C	10	36		V/mV
					−55°C	7	50		
					125°C	7	27		
CMRR	Common-mode rejection ratio		$V_{IC} = V_{ICR}\text{min}$		25°C	65	85		dB
					−55°C	60	87		
					125°C	60	86		
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)		V_{DD} = 5 V to 10 V,	V_O = 1.4 V	25°C	65	95		dB
					−55°C	60	90		
					125°C	60	97		
I_{DD}	Supply current (two amplifiers)		V_O = 5 V, No load	V_{IC} = 5 V,	25°C		1.9	4	mA
					−55°C		3	6	
					125°C		1.3	2.8	

† Full range is −55°C to 125°C.

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

electrical characteristics, V_{DD} = 5 V, T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		TLC272Y			UNIT
				MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ		1.1	10	mV
α_{VIO}	Temperature coefficient of input offset voltage				1.8		µV/°C
I_{IO}	Input offset current (see Note 4)	V_O = 2.5 V,	V_{IC} = 2.5 V		0.1		pA
I_{IB}	Input bias current (see Note 4)				0.6		pA
V_{ICR}	Common-mode input voltage range (see Note 5)			–0.2 to 4	–0.3 to 4.2		V
V_{OH}	High-level output voltage	V_{ID} = 100 mV,	R_L = 10 kΩ	3.2	3.8		V
V_{OL}	Low-level output voltage	V_{ID} = –100 mV,	I_{OL} = 0		0	50	mV
A_{VD}	Large-signal differential voltage amplification	V_O = 0.25 V to 2 V	R_L = 10 kΩ	5	23		V/mV
CMRR	Common-mode rejection ratio	V_{IC} = V_{ICR}min		65	80		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)	V_{DD} = 5 V to 10 V,	V_O = 1.4 V	65	95		dB
I_{DD}	Supply current (two amplifiers)	V_O = 2.5 V, No load	V_{IC} = 2.5 V,		1.4	3.2	mA

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

electrical characteristics, V_{DD} = 10 V, T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		TLC272Y			UNIT
				MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 1.4 V, R_S = 50 Ω,	V_{IC} = 0, R_L = 10 kΩ		1.1	10	mV
α_{VIO}	Temperature coefficient of input offset voltage				1.8		µV/°C
I_{IO}	Input offset current (see Note 4)	V_O = 5 V,	V_{IC} = 5 V		0.1		pA
I_{IB}	Input bias current (see Note 4)				0.7		pA
V_{ICR}	Common-mode input voltage range (see Note 5)			–0.2 to 9	–0.3 to 9.2		V
V_{OH}	High-level output voltage	V_{ID} = 100 mV,	R_L = 10 kΩ	8	8.5		V
V_{OL}	Low-level output voltage	V_{ID} = –100 mV,	I_{OL} = 0		0	50	mV
A_{VD}	Large-signal differential voltage amplification	V_O = 1 V to 6 V,	R_L = 10 kΩ	10	36		V/mV
CMRR	Common-mode rejection ratio	V_{IC} = V_{ICR}min		65	85		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{DD}/\Delta V_{IO}$)	V_{DD} = 5 V to 10 V,	V_O = 1.4 V	65	95		dB
I_{DD}	Supply current (two amplifiers)	V_O = 5 V, No load	V_{IC} = 5 V,		1.9	4	mA

NOTES: 4. The typical values of input bias current and input offset current below 5 pA were determined mathematically.
5. This range also applies to each input individually.

operating characteristics at specified free-air temperature, V_{DD} = 5 V

PARAMETER		TEST CONDITIONS		T_A	TLC272C, TLC272AC, TLC272BC, TLC277C			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	R_L = 10 kΩ, C_L = 20 pF, See Figure 1	V_{IPP} = 1 V	25°C		3.6		V/µs
				0°C		4		
				70°C		3		
			V_{IPP} = 2.5 V	25°C		2.9		
				0°C		3.1		
				70°C		2.5		
V_n	Equivalent input noise voltage	f = 1 kHz, See Figure 2	R_S = 20 Ω,	25°C		25		nV/√Hz
B_{OM}	Maximum output-swing bandwidth	$V_O = V_{OH}$, R_L = 10 kΩ,	C_L = 20 pF, See Figure 1	25°C		320		kHz
				0°C		340		
				70°C		260		
B_1	Unity-gain bandwidth	V_I = 10 mV, See Figure 3	C_L = 20 pF,	25°C		1.7		MHz
				0°C		2		
				70°C		1.3		
ϕ_m	Phase margin	V_I = 10 mV, C_L = 20 pF,	f = B_1, See Figure 3	25°C		46°		
				0°C		47°		
				70°C		43°		

operating characteristics at specified free-air temperature, V_{DD} = 10 V

PARAMETER		TEST CONDITIONS		T_A	TLC272C, TLC272AC, TLC272BC, TLC277C			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	R_L = 10 kΩ, C_L = 20 pF, See Figure 1	V_{IPP} = 1 V	25°C		5.3		V/µs
				0°C		5.9		
				70°C		4.3		
			V_{IPP} = 5.5 V	25°C		4.6		
				0°C		5.1		
				70°C		3.8		
V_n	Equivalent input noise voltage	f = 1 kHz, See Figure 2	R_S = 20 Ω,	25°C		25		nV/√Hz
B_{OM}	Maximum output-swing bandwidth	$V_O = V_{OH}$, R_L = 10 kΩ,	C_L = 20 pF, See Figure 1	25°C		200		kHz
				0°C		220		
				70°C		140		
B_1	Unity-gain bandwidth	V_I = 10 mV, See Figure 3	C_L = 20 pF,	25°C		2.2		MHz
				0°C		2.5		
				70°C		1.8		
ϕ_m	Phase margin	V_I = 10 mV, C_L = 20 pF,	f = B_1, See Figure 3	25°C		49°		
				0°C		50°		
				70°C		46°		

operating characteristics at specified free-air temperature, V_{DD} = 5 V

PARAMETER		TEST CONDITIONS		T_A	TLC272I, TLC272AI, TLC272BI, TLC277I			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	R_L = 10 kΩ, C_L = 20 pF, See Figure 1	V_{IPP} = 1 V	25°C		3.6		V/μs
				–40°C		4.5		
				85°C		2.8		
			V_{IPP} = 2.5 V	25°C		2.9		
				–40°C		3.5		
				85°C		2.3		
V_n	Equivalent input noise voltage	f = 1 kHz, See Figure 2	R_S = 20 Ω,	25°C		25		nV/$\sqrt{Hz}$
B_{OM}	Maximum output-swing bandwidth	$V_O = V_{OH}$, R_L = 10 kΩ,	C_L = 20 pF, See Figure 1	25°C		320		kHz
				–40°C		380		
				85°C		250		
B_1	Unity-gain bandwidth	V_I = 10 mV, See Figure 3	C_L = 20 pF,	25°C		1.7		MHz
				–40°C		2.6		
				85°C		1.2		
ϕ_m	Phase margin	V_I = 10 mV, C_L = 20 pF,	f = B_1, See Figure 3	25°C		46°		
				–40°C		49°		
				85°C		43°		

operating characteristics at specified free-air temperature, V_{DD} = 10 V

PARAMETER		TEST CONDITIONS		T_A	TLC272I, TLC272AI, TLC272BI, TLC277I			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	R_L = 10 kΩ, C_L = 20 pF, See Figure 1	V_{IPP} = 1 V	25°C		5.3		V/μs
				–40°C		6.8		
				85°C		4		
			V_{IPP} = 5.5 V	25°C		4.6		
				–40°C		5.8		
				85°C		3.5		
V_n	Equivalent input noise voltage	f = 1 kHz, See Figure 2	R_S = 20 Ω,	25°C		25		nV/$\sqrt{Hz}$
B_{OM}	Maximum output-swing bandwidth	$V_O = V_{OH}$, R_L = 10 kΩ,	C_L = 20 pF, See Figure 1	25°C		200		kHz
				–40°C		260		
				85°C		130		
B_1	Unity-gain bandwidth	V_I = 10 mV, See Figure 3	C_L = 20 pF,	25°C		2.2		MHz
				–40°C		3.1		
				85°C		1.7		
ϕ_m	Phase margin	V_I = 10 mV, C_L = 20 pF,	f = B_1, See Figure 3	25°C		49°		
				–40°C		52°		
				85°C		46°		

operating characteristics at specified free-air temperature, V_{DD} = 5 V

PARAMETER		TEST CONDITIONS		T_A	TLC272M, TLC277M MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	R_L = 10 kΩ, C_L = 20 pF, See Figure 1	V_{IPP} = 1 V	25°C		3.6		V/µs
				–55°C		4.7		
				125°C		2.3		
			V_{IPP} = 2.5 V	25°C		2.9		
				–55°C		3.7		
				125°C		2		
V_n	Equivalent input noise voltage	f = 1 kHz, See Figure 2	R_S = 20 Ω,	25°C		25		nV/$\sqrt{Hz}$
B_{OM}	Maximum output-swing bandwidth	V_O = V_{OH}, R_L = 10 kΩ,	C_L = 20 pF, See Figure 1	25°C		320		kHz
				–55°C		400		
				125°C		230		
B_1	Unity-gain bandwidth	V_I = 10 mV, See Figure 3	C_L = 20 pF,	25°C		1.7		MHz
				–55°C		2.9		
				125°C		1.1		
ϕ_m	Phase margin	V_I = 10 mV, C_L = 20 pF,	f = B_1, See Figure 3	25°C		46°		
				–55°C		49°		
				125°C		41°		

operating characteristics at specified free-air temperature, V_{DD} = 10 V

PARAMETER		TEST CONDITIONS		T_A	TLC272M, TLC277M MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	R_L = 10 kΩ, C_L = 20 pF, See Figure 1	V_{IPP} = 1 V	25°C		5.3		V/µs
				–55°C		7.1		
				125°C		3.1		
			V_{IPP} = 5.5 V	25°C		4.6		
				–55°C		6.1		
				125°C		2.7		
V_n	Equivalent input noise voltage	f = 1 kHz, See Figure 2	R_S = 20 Ω,	25°C		25		nV/$\sqrt{Hz}$
B_{OM}	Maximum output-swing bandwidth	V_O = V_{OH}, R_L = 10 kΩ,	C_L = 20 pF, See Figure 1	25°C		200		kHz
				–55°C		280		
				125°C		110		
B_1	Unity-gain bandwidth	V_I = 10 mV, See Figure 3	C_L = 20 pF,	25°C		2.2		MHz
				–55°C		3.4		
				125°C		1.6		
ϕ_m	Phase margin	V_I = 10 mV, C_L = 20 pF,	f = B_1, See Figure 3	25°C		49°		
				–55°C		52°		
				125°C		44°		

operating characteristics, V_{DD} = 5 V, T_A = 25°C

PARAMETER		TEST CONDITIONS			TLC272Y			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	R_L = 10 kΩ, See Figure 1	C_L = 20 pF,	V_{IPP} = 1 V		3.6		V/µs
				V_{IPP} = 2.5 V		2.9		
V_n	Equivalent input noise voltage	f = 1 kHz,	R_S = 20 Ω,	See Figure 2		25		$nV/\sqrt{Hz}$
B_{OM}	Maximum output-swing bandwidth	$V_O = V_{OH}$, See Figure 1	C_L = 20 pF,	R_L = 10 kΩ,		320		kHz
B_1	Unity-gain bandwidth	V_I = 10 mV,	C_L = 20 pF,	See Figure 3		1.7		MHz
ϕ_m	Phase margin	V_I = 10 mV, See Figure 3	f = B_1,	C_L = 20 pF,		46°		

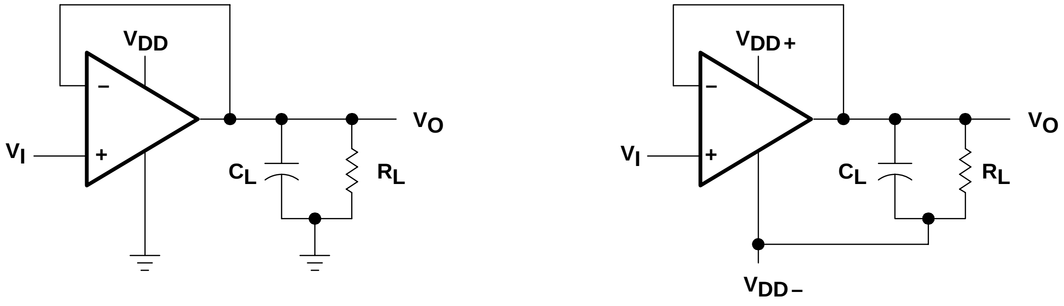
operating characteristics, V_{DD} = 10 V, T_A = 25°C

PARAMETER		TEST CONDITIONS			TLC272Y			UNIT
					MIN	TYP	MAX	
SR	Slew rate at unity gain	R_L = 10 kΩ, See Figure 1	C_L = 20 pF,	V_{IPP} = 1 V		5.3		V/µs
				V_{IPP} = 5.5 V		4.6		
V_n	Equivalent input noise voltage	f = 1 kHz,	R_S = 20 Ω,	See Figure 2		25		$nV/\sqrt{Hz}$
B_{OM}	Maximum output-swing bandwidth	$V_O = V_{OH}$, See Figure 1	C_L = 20 pF,	R_L = 10 kΩ,		200		kHz
B_1	Unity-gain bandwidth	V_I = 10 mV,	C_L = 20 pF,	See Figure 3		2.2		MHz
ϕ_m	Phase margin	V_I = 10 mV, See Figure 3	f = B_1,	C_L = 20 pF,		49°		

PARAMETER MEASUREMENT INFORMATION

single-supply versus split-supply test circuits

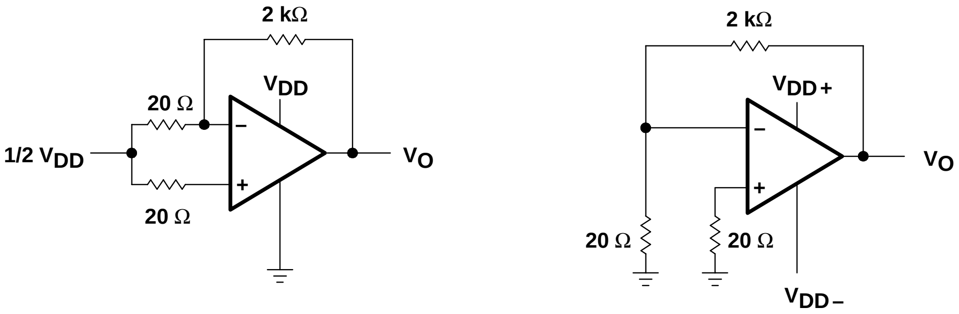
Because the TLC272 and TLC277 are optimized for single-supply operation, circuit configurations used for the various tests often present some inconvenience since the input signal, in many cases, must be offset from ground. This inconvenience can be avoided by testing the device with split supplies and the output load tied to the negative rail. A comparison of single-supply versus split-supply test circuits is shown below. The use of either circuit gives the same result.



(a) SINGLE SUPPLY

(b) SPLIT SUPPLY

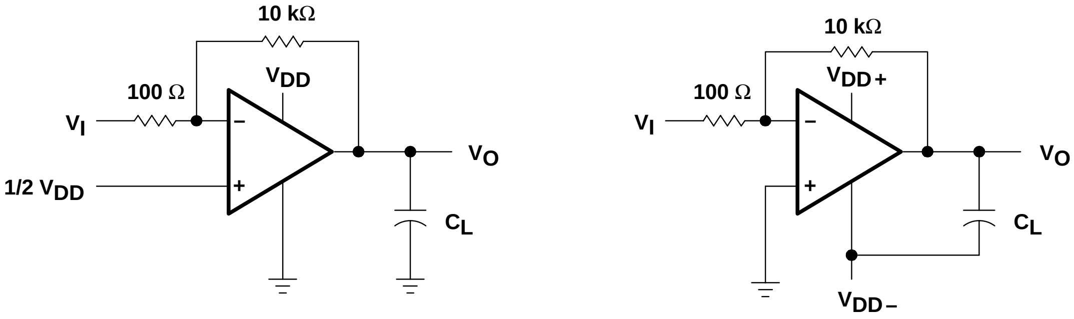
Figure 1. Unity-Gain Amplifier



(a) SINGLE SUPPLY

(b) SPLIT SUPPLY

Figure 2. Noise-Test Circuit



(a) SINGLE SUPPLY

(b) SPLIT SUPPLY

Figure 3. Gain-of-100 Inverting Amplifier

PARAMETER MEASUREMENT INFORMATION

input bias current

Because of the high input impedance of the TLC272 and TLC277 operational amplifiers, attempts to measure the input bias current can result in erroneous readings. The bias current at normal room ambient temperature is typically less than 1 pA, a value that is easily exceeded by leakages on the test socket. Two suggestions are offered to avoid erroneous measurements:

1. Isolate the device from other potential leakage sources. Use a grounded shield around and between the device inputs (see Figure 4). Leakages that would otherwise flow to the inputs are shunted away.
2. Compensate for the leakage of the test socket by actually performing an input bias current test (using a picoammeter) with no device in the test socket. The actual input bias current can then be calculated by subtracting the open-socket leakage readings from the readings obtained with a device in the test socket.

One word of caution: many automatic testers as well as some bench-top operational amplifier testers use the servo-loop technique with a resistor in series with the device input to measure the input bias current (the voltage drop across the series resistor is measured and the bias current is calculated). This method requires that a device be inserted into the test socket to obtain a correct reading; therefore, an open-socket reading is not feasible using this method.

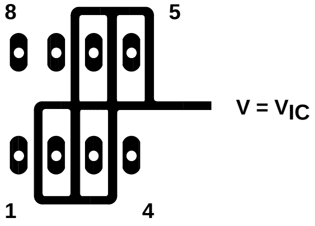


Figure 4. Isolation Metal Around Device Inputs (JG and P packages)

low-level output voltage

To obtain low-supply-voltage operation, some compromise was necessary in the input stage. This compromise results in the device low-level output being dependent on the common-mode input voltage level as well as the differential input voltage level. When attempting to correlate low-level output readings with those quoted in the electrical specifications, these two conditions should be observed. If conditions other than these are to be used, please refer to Figures 14 through 19 in the Typical Characteristics of this data sheet.

input offset voltage temperature coefficient

Erroneous readings often result from attempts to measure temperature coefficient of input offset voltage. This parameter is actually a calculation using input offset voltage measurements obtained at two different temperatures. When one (or both) of the temperatures is below freezing, moisture can collect on both the device and the test socket. This moisture results in leakage and contact resistance, which can cause erroneous input offset voltage readings. The isolation techniques previously mentioned have no effect on the leakage since the moisture also covers the isolation metal itself, thereby rendering it useless. It is suggested that these measurements be performed at temperatures above freezing to minimize error.

PARAMETER MEASUREMENT INFORMATION

full-power response

Full-power response, the frequency above which the operational amplifier slew rate limits the output voltage swing, is often specified two ways: full-linear response and full-peak response. The full-linear response is generally measured by monitoring the distortion level of the output while increasing the frequency of a sinusoidal input signal until the maximum frequency is found above which the output contains significant distortion. The full-peak response is defined as the maximum output frequency, without regard to distortion, above which full peak-to-peak output swing cannot be maintained.

Because there is no industry-wide accepted value for significant distortion, the full-peak response is specified in this data sheet and is measured using the circuit of Figure 1. The initial setup involves the use of a sinusoidal input to determine the maximum peak-to-peak output of the device (the amplitude of the sinusoidal wave is increased until clipping occurs). The sinusoidal wave is then replaced with a square wave of the same amplitude. The frequency is then increased until the maximum peak-to-peak output can no longer be maintained (Figure 5). A square wave is used to allow a more accurate determination of the point at which the maximum peak-to-peak output is reached.

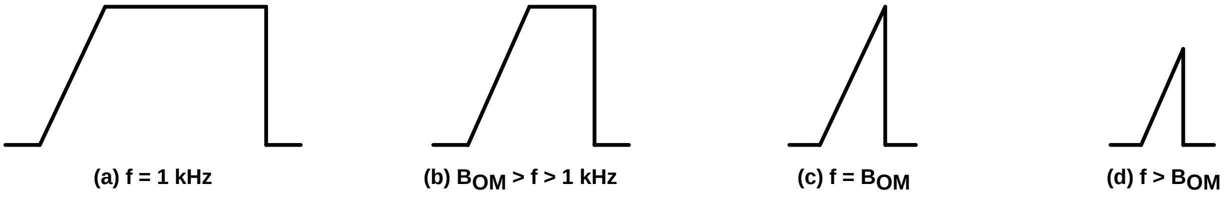

(a) f = 1 kHz (b) B_{OM} > f > 1 kHz (c) f = B_{OM} (d) f > B_{OM}

Figure 5. Full-Power-Response Output Signal

test time

Inadequate test time is a frequent problem, especially when testing CMOS devices in a high-volume, short-test-time environment. Internal capacitances are inherently higher in CMOS than in bipolar and BiFET devices and require longer test times than their bipolar and BiFET counterparts. The problem becomes more pronounced with reduced supply levels and lower temperatures.

TYPICAL CHARACTERISTICS

Table of Graphs

			FIGURE
V_{IO}	Input offset voltage	Distribution	6, 7
α_{VIO}	Temperature coefficient of input offset voltage	Distribution	8, 9
V_{OH}	High-level output voltage	vs High-level output current vs Supply voltage vs Free-air temperature	10, 11 12 13
V_{OL}	Low-level output voltage	vs Common-mode input voltage vs Differential input voltage vs Free-air temperature vs Low-level output current	14, 15 16 17 18, 19
A_{VD}	Large-signal differential voltage amplification	vs Supply voltage vs Free-air temperature vs Frequency	20 21 32, 33
I_{IB}	Input bias current	vs Free-air temperature	22
I_{IO}	Input offset current	vs Free-air temperature	22
V_{IC}	Common-mode input voltage	vs Supply voltage	23
I_{DD}	Supply current	vs Supply voltage vs Free-air temperature	24 25
SR	Slew rate	vs Supply voltage vs Free-air temperature	26 27
	Normalized slew rate	vs Free-air temperature	28
$V_{O(PP)}$	Maximum peak-to-peak output voltage	vs Frequency	29
B_1	Unity-gain bandwidth	vs Free-air temperature vs Supply voltage	30 31
ϕ_m	Phase margin	vs Supply voltage vs Free-air temperature vs Load capacitance	34 35 36
V_n	Equivalent input noise voltage	vs Frequency	37
	Phase shift	vs Frequency	32, 33

TYPICAL CHARACTERISTICS

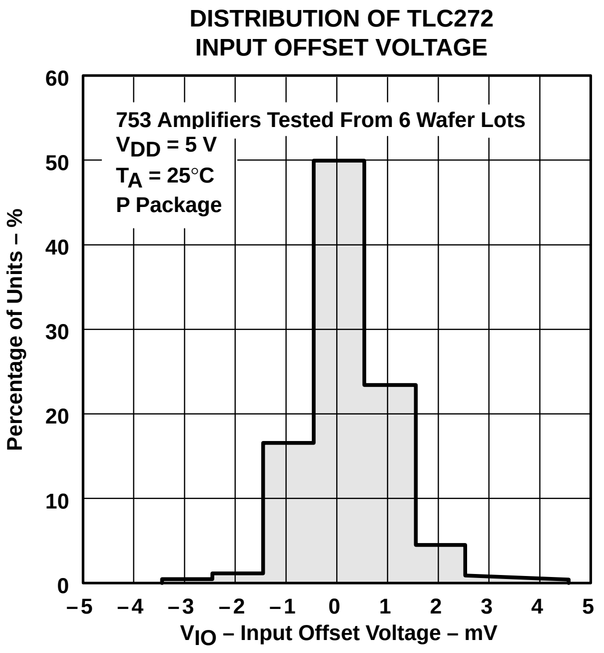


Figure 6

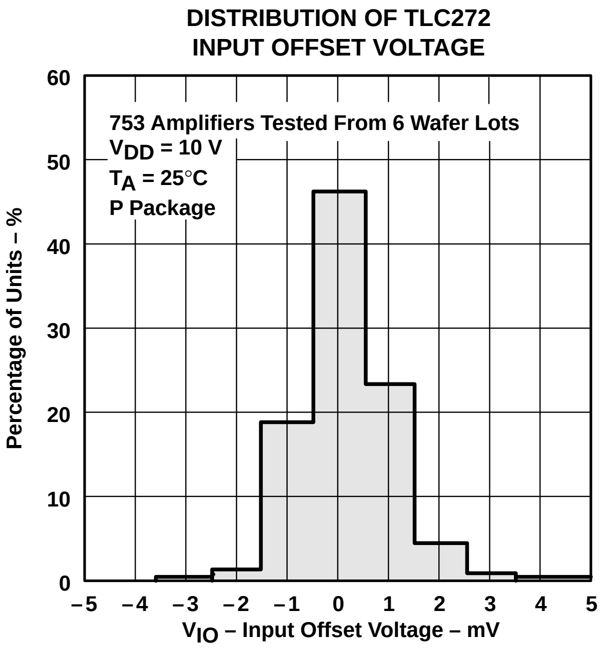


Figure 7

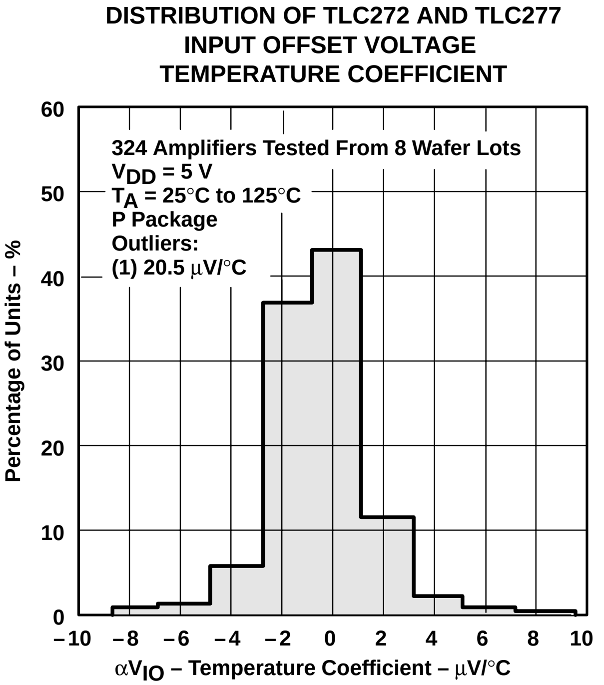


Figure 8

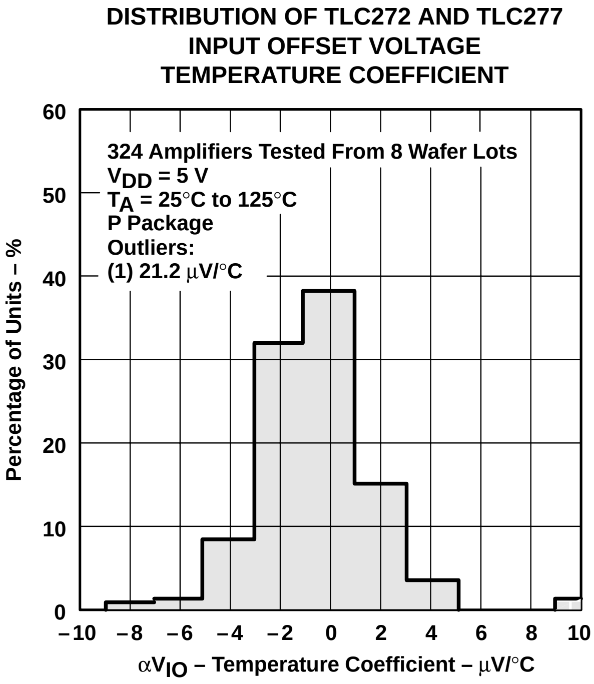
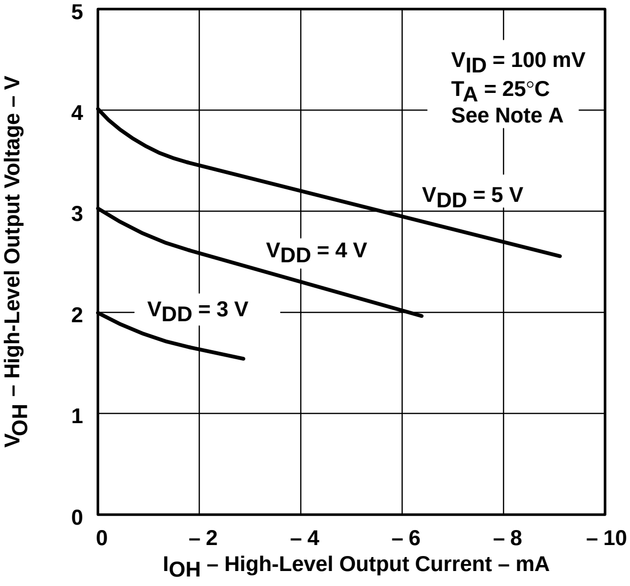


Figure 9

TYPICAL CHARACTERISTICS†


HIGH-LEVEL OUTPUT VOLTAGE
vs
HIGH-LEVEL OUTPUT CURRENT

NOTE A: The 3-V curve only applies to the C version.

Figure 10

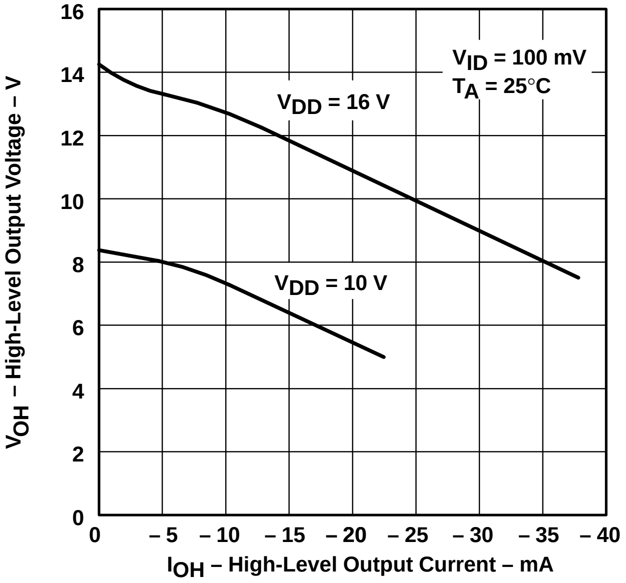

HIGH-LEVEL OUTPUT VOLTAGE
vs
HIGH-LEVEL OUTPUT CURRENT

Figure 11

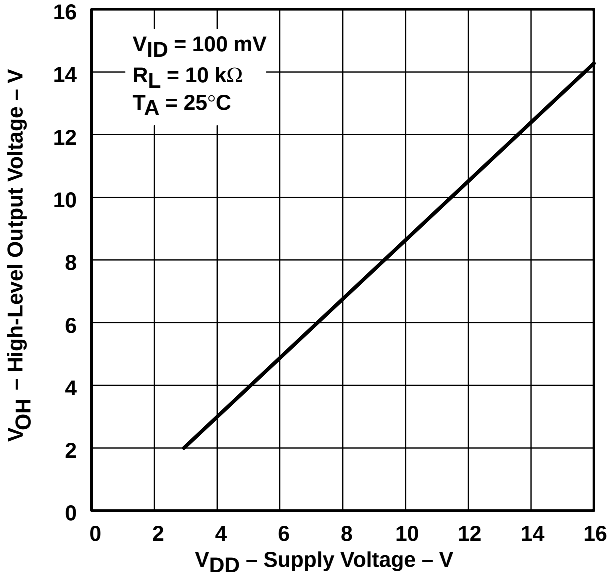

HIGH-LEVEL OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

Figure 12

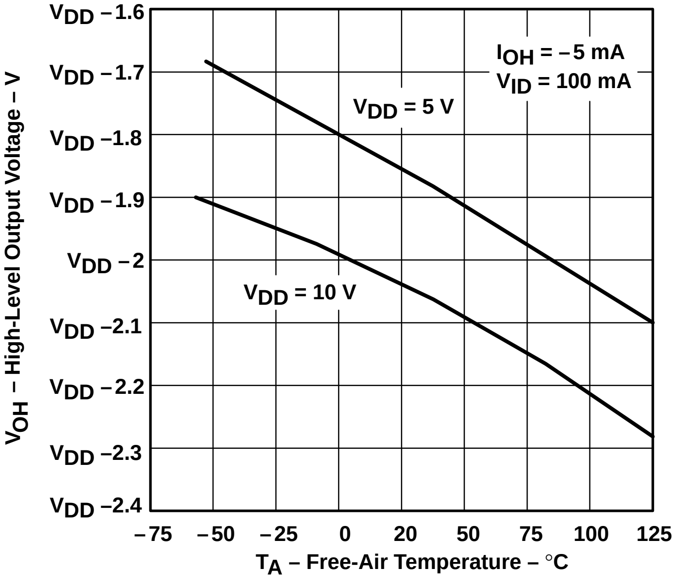

HIGH-LEVEL OUTPUT VOLTAGE
vs
FREE-AIR TEMPERATURE

Figure 13

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† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

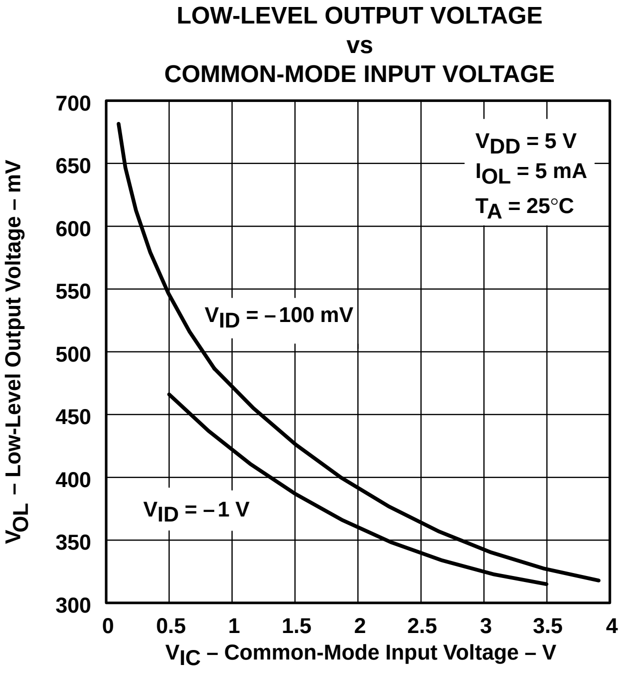

Figure 14

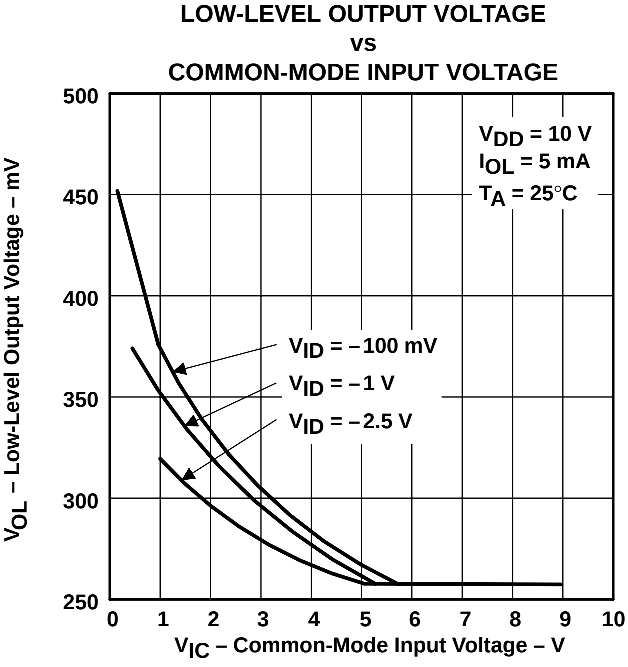

Figure 15

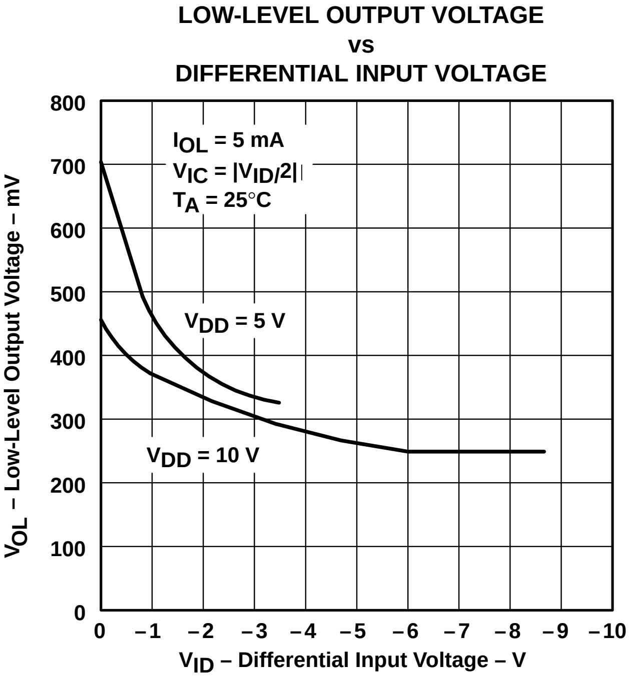

Figure 16

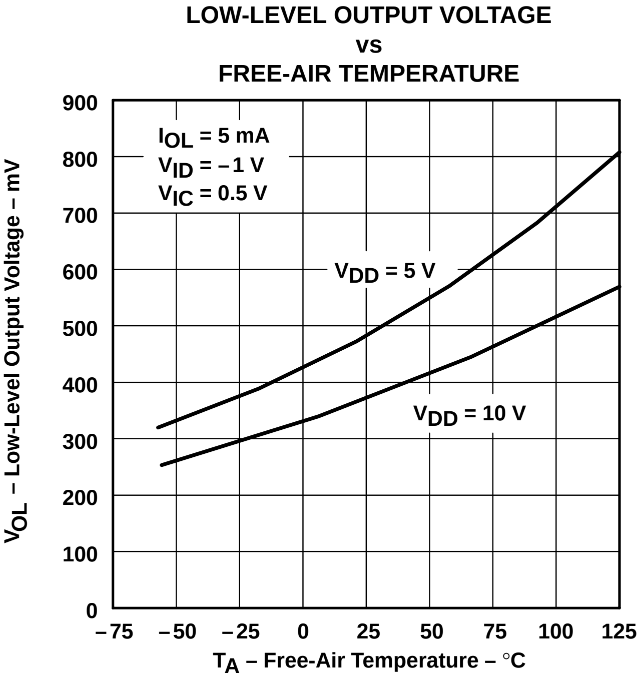

Figure 17

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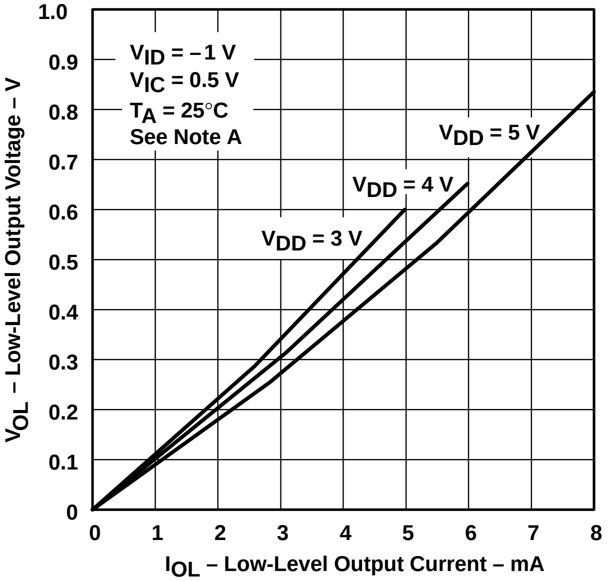
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

LOW-LEVEL OUTPUT VOLTAGE vs LOW-LEVEL OUTPUT CURRENT



NOTE A: The 3-V curve only applies to the C version.

Figure 18

LOW-LEVEL OUTPUT VOLTAGE vs LOW-LEVEL OUTPUT CURRENT

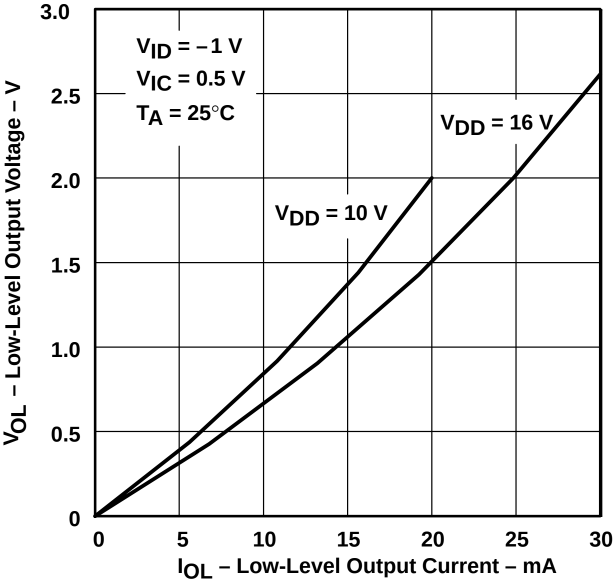


Figure 19

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION vs SUPPLY VOLTAGE

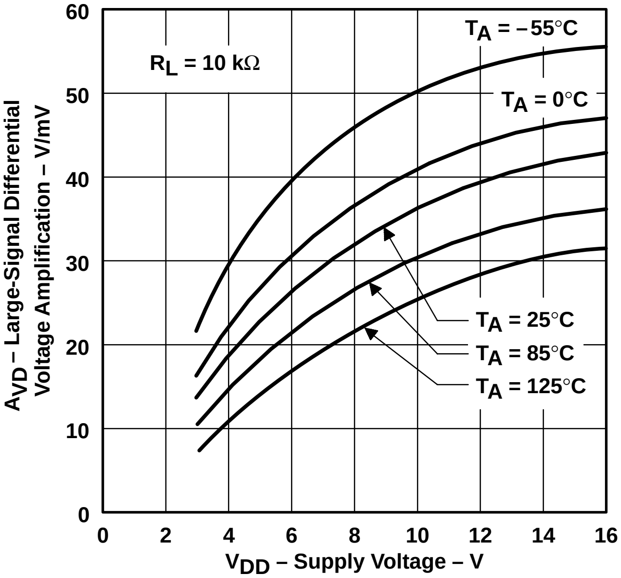


Figure 20

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION vs FREE-AIR TEMPERATURE

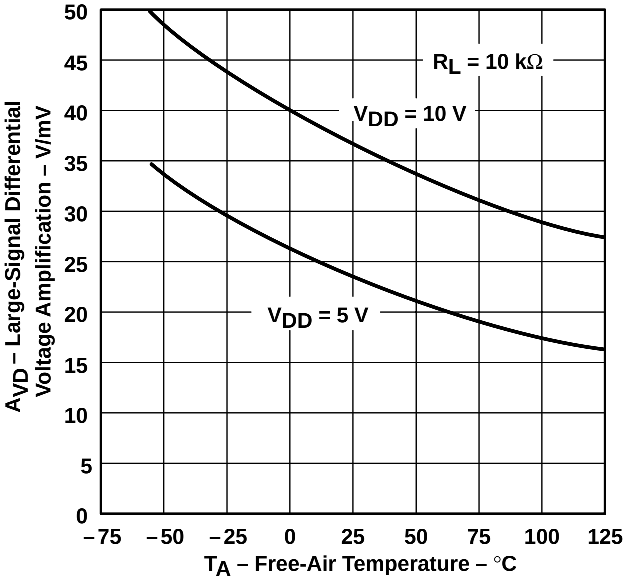


Figure 21

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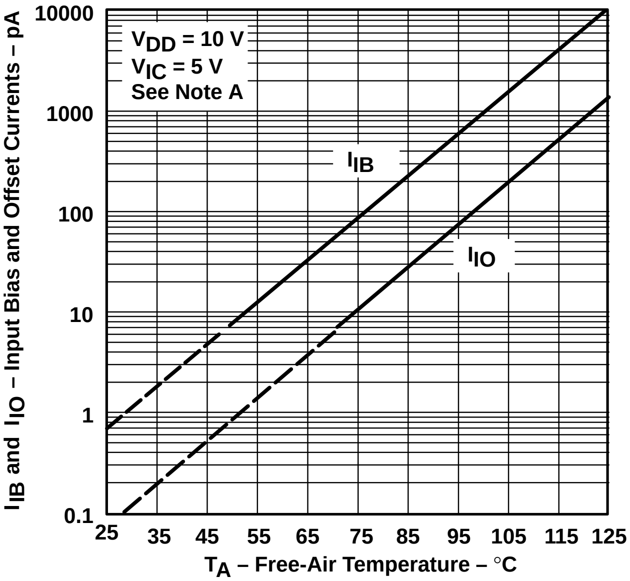
† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

INPUT BIAS CURRENT AND INPUT OFFSET CURRENT vs FREE-AIR TEMPERATURE



NOTE A: The typical values of input bias current and input offset current below 5 pA were determined mathematically.

Figure 22

COMMON-MODE INPUT VOLTAGE POSITIVE LIMIT vs SUPPLY VOLTAGE

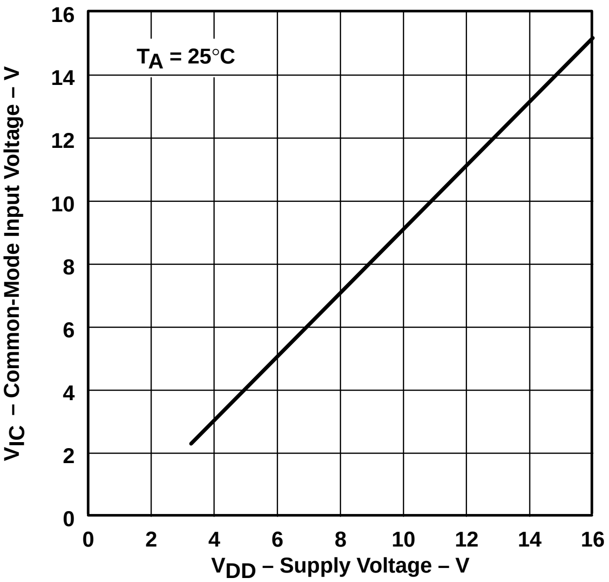


Figure 23

SUPPLY CURRENT vs SUPPLY VOLTAGE

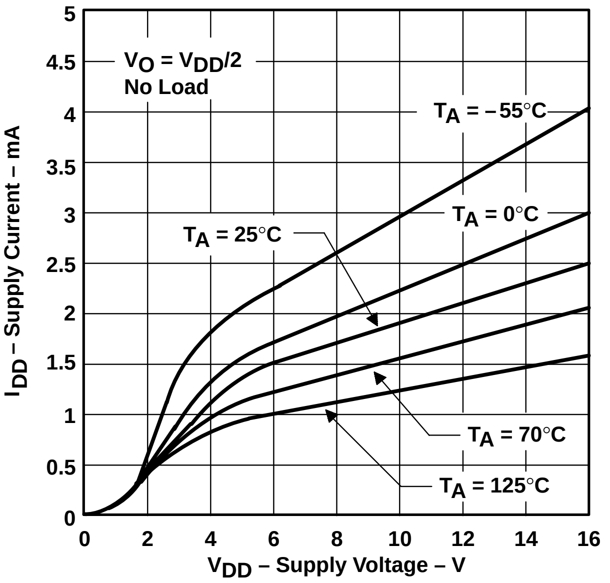


Figure 24

SUPPLY CURRENT vs FREE-AIR TEMPERATURE

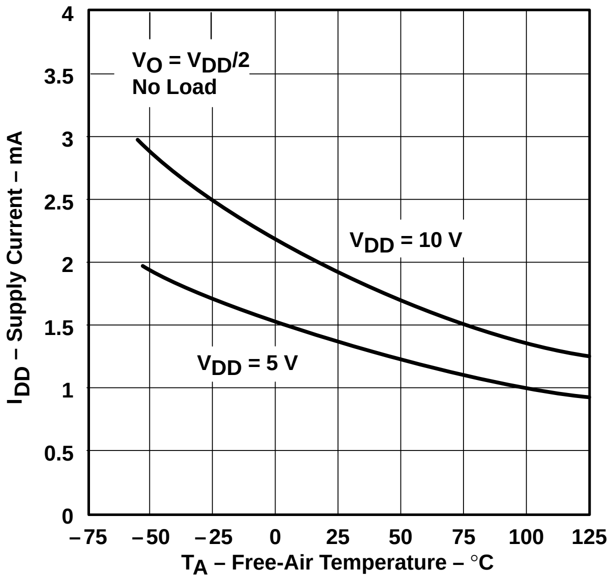


Figure 25

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† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

SLEW RATE vs SUPPLY VOLTAGE

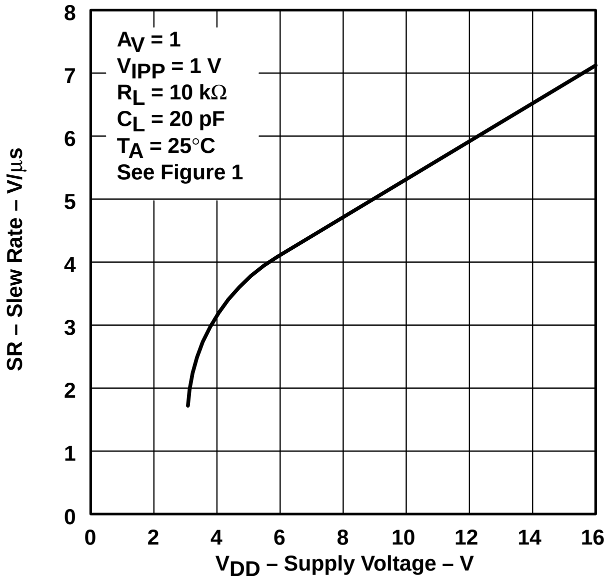

Figure 26

SLEW RATE vs FREE-AIR TEMPERATURE

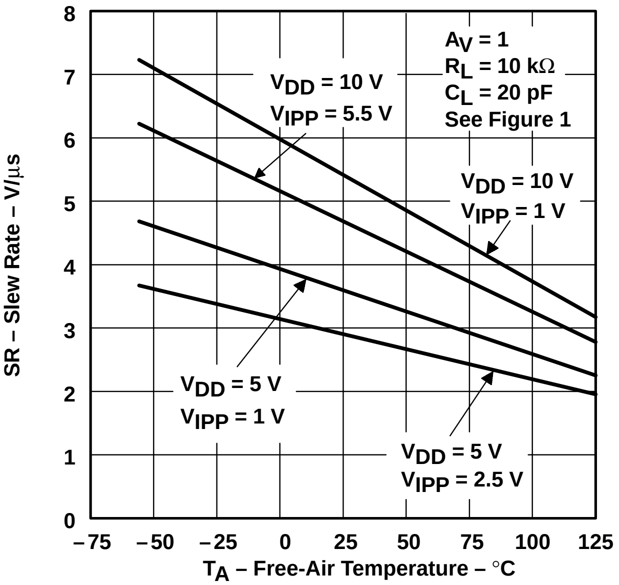

Figure 27

NORMALIZED SLEW RATE vs FREE-AIR TEMPERATURE

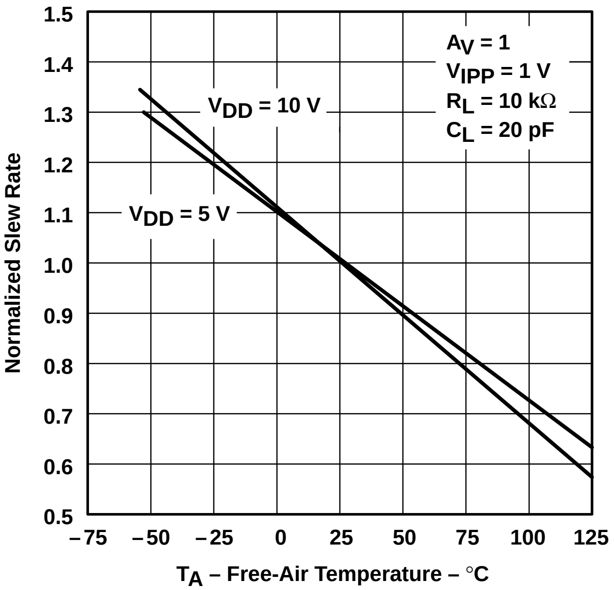

Figure 28

MAXIMUM PEAK OUTPUT VOLTAGE vs FREQUENCY

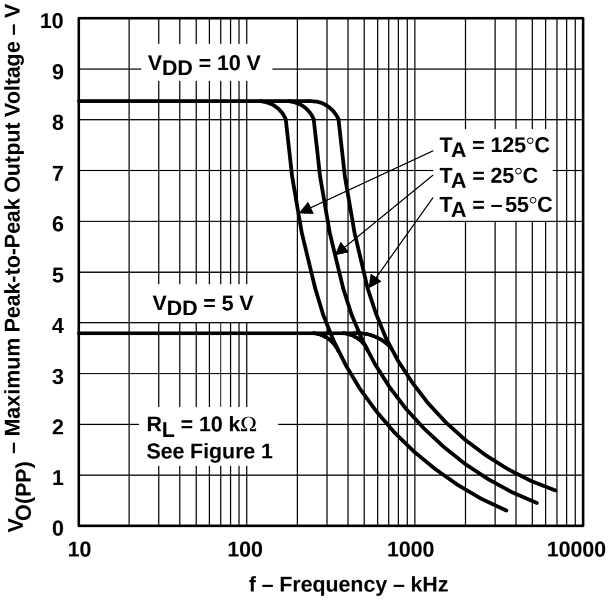

Figure 29

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† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

UNITY-GAIN BANDWIDTH
vs
FREE-AIR TEMPERATURE

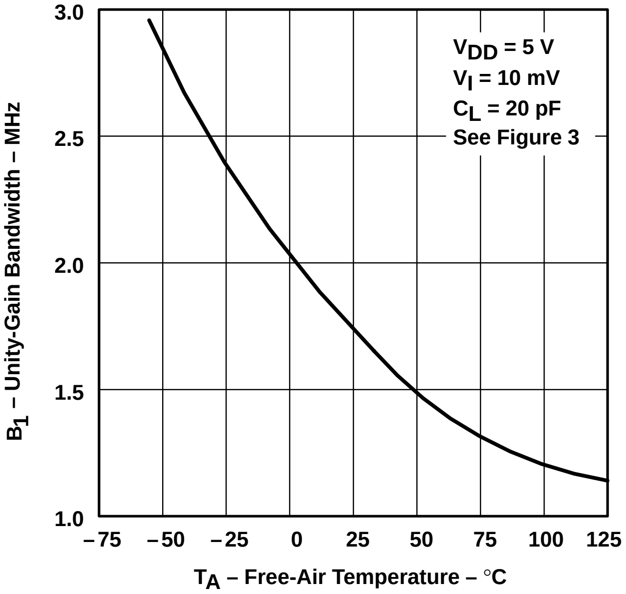

Figure 30

UNITY-GAIN BANDWIDTH
vs
SUPPLY VOLTAGE

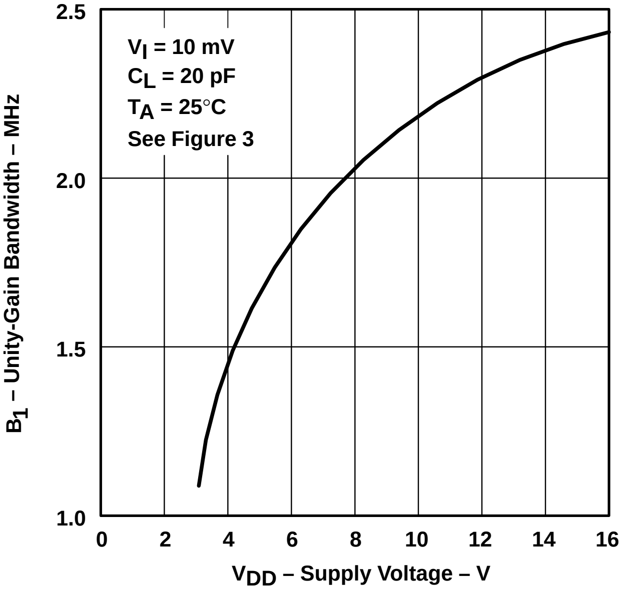

Figure 31

LARGE-SIGNAL DIFFERENTIAL VOLTAGE
AMPLIFICATION AND PHASE SHIFT
vs
FREQUENCY

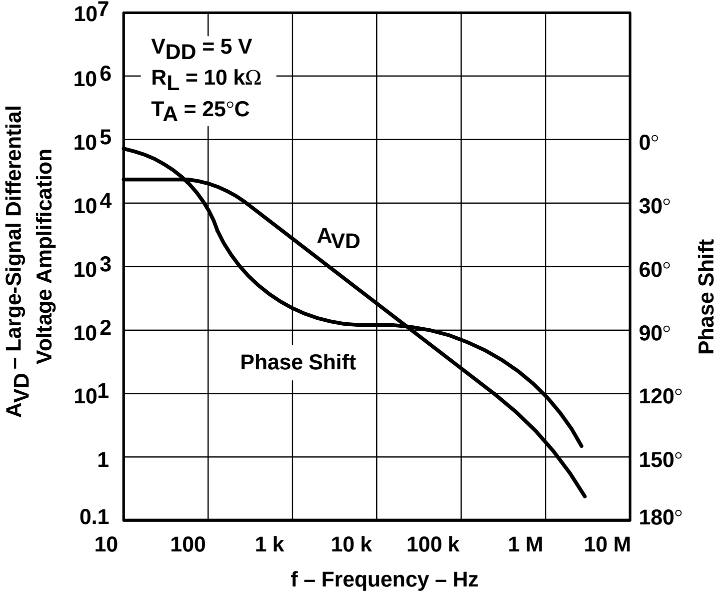

Figure 32

---

† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION AND PHASE SHIFT
vs
FREQUENCY

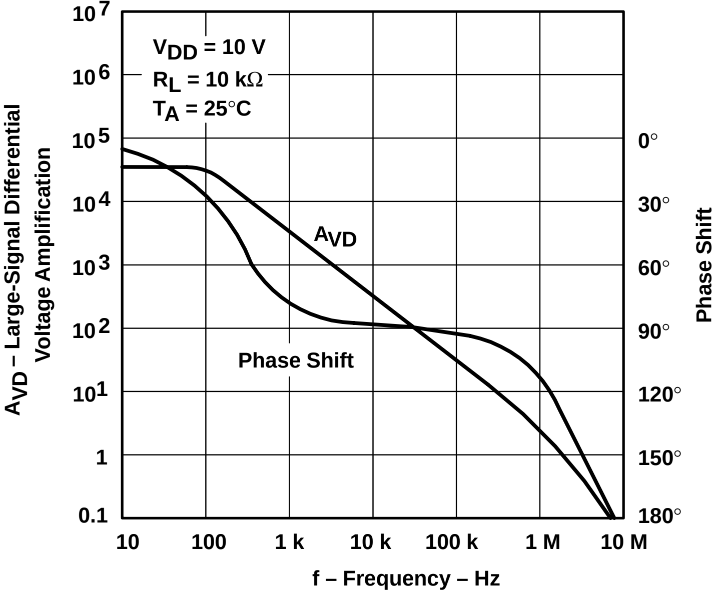

Figure 33

PHASE MARGIN
vs
SUPPLY VOLTAGE

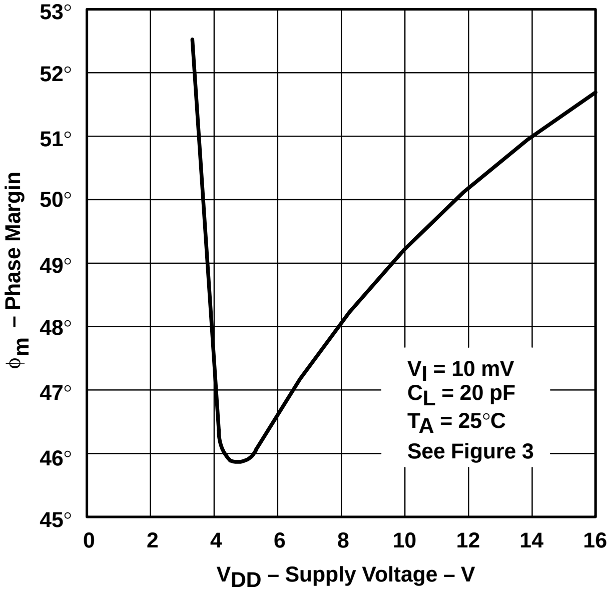

Figure 34

PHASE MARGIN
vs
FREE-AIR TEMPERATURE

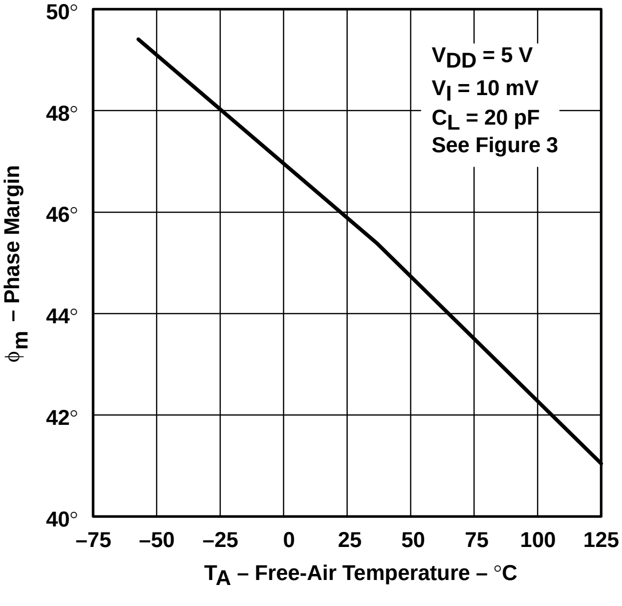

Figure 35

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† Data at high and low temperatures are applicable only within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS

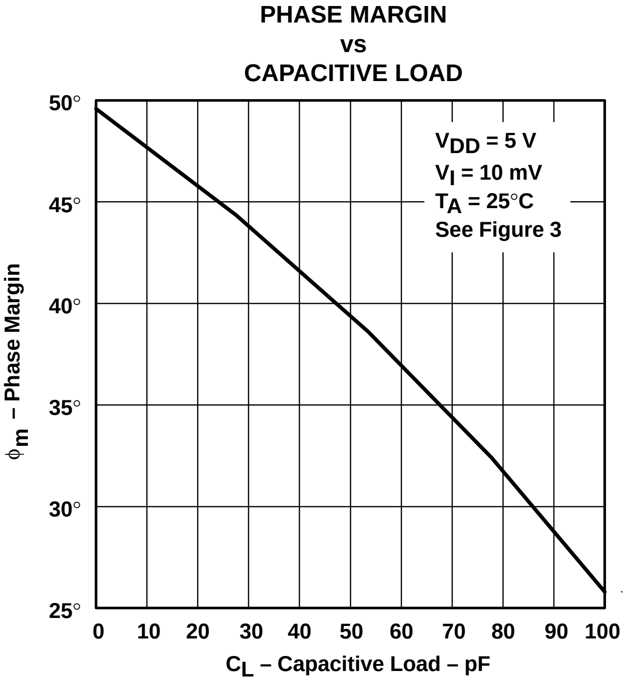


Figure 36

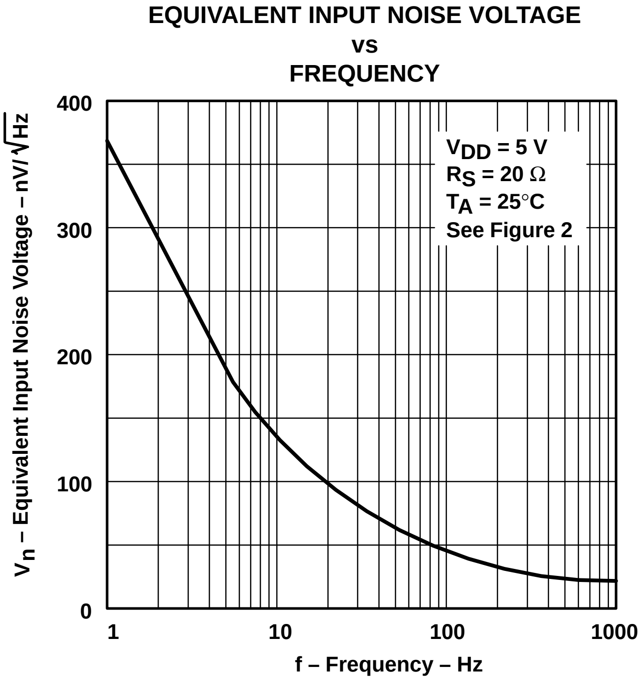


Figure 37

APPLICATION INFORMATION

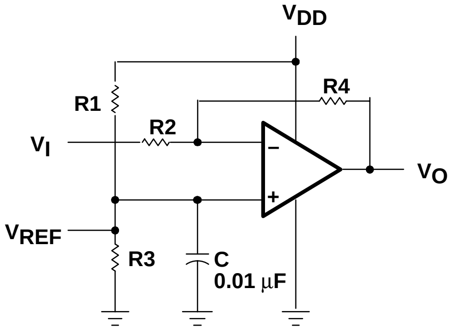
single-supply operation

While the TLC272 and TLC277 perform well using dual power supplies (also called balanced or split supplies), the design is optimized for single-supply operation. This design includes an input common-mode voltage range that encompasses ground as well as an output voltage range that pulls down to ground. The supply voltage range extends down to 3 V (C-suffix types), thus allowing operation with supply levels commonly available for TTL and HCMOS; however, for maximum dynamic range, 16-V single-supply operation is recommended.

Many single-supply applications require that a voltage be applied to one input to establish a reference level that is above ground. A resistive voltage divider is usually sufficient to establish this reference level (see Figure 38). The low input bias current of the TLC272 and TLC277 permits the use of very large resistive values to implement the voltage divider, thus minimizing power consumption.

The TLC272 and TLC277 work well in conjunction with digital logic; however, when powering both linear devices and digital logic from the same power supply, the following precautions are recommended:

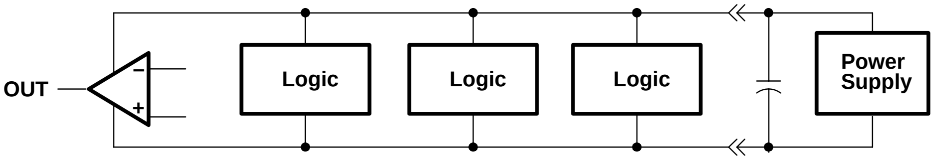
1. Power the linear devices from separate bypassed supply lines (see Figure 39); otherwise, the linear device supply rails can fluctuate due to voltage drops caused by high switching currents in the digital logic.
2. Use proper bypass techniques to reduce the probability of noise-induced errors. Single capacitive decoupling is often adequate; however, high-frequency applications may require RC decoupling.



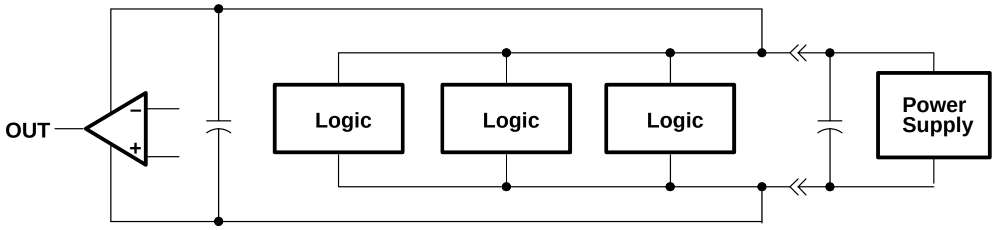
$$V_{REF} = V_{DD}\frac{R3}{R1 + R3}$$

$$V_O = (V_{REF} - V_I)\frac{R4}{R2} + V_{REF}$$

Figure 38. Inverting Amplifier With Voltage Reference



(a) COMMON SUPPLY RAILS



(b) SEPARATE BYPASSED SUPPLY RAILS (preferred)

Figure 39. Common vs Separate Supply Rails

APPLICATION INFORMATION

input characteristics

The TLC272 and TLC277 are specified with a minimum and a maximum input voltage that, if exceeded at either input, could cause the device to malfunction. Exceeding this specified range is a common problem, especially in single-supply operation. Note that the lower range limit includes the negative rail, while the upper range limit is specified at V_{DD} – 1 V at T_A = 25°C and at V_{DD} – 1.5 V at all other temperatures.

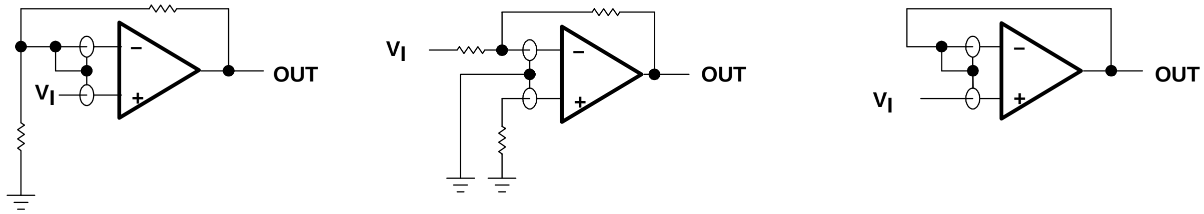
The use of the polysilicon-gate process and the careful input circuit design gives the TLC272 and TLC277 very good input offset voltage drift characteristics relative to conventional metal-gate processes. Offset voltage drift in CMOS devices is highly influenced by threshold voltage shifts caused by polarization of the phosphorus dopant implanted in the oxide. Placing the phosphorus dopant in a conductor (such as a polysilicon gate) alleviates the polarization problem, thus reducing threshold voltage shifts by more than an order of magnitude. The offset voltage drift with time has been calculated to be typically 0.1 μV/month, including the first month of operation.

Because of the extremely high input impedance and resulting low bias current requirements, the TLC272 and TLC277 are well suited for low-level signal processing; however, leakage currents on printed-circuit boards and sockets can easily exceed bias current requirements and cause a degradation in device performance. It is good practice to include guard rings around inputs (similar to those of Figure 4 in the Parameter Measurement Information section). These guards should be driven from a low-impedance source at the same voltage level as the common-mode input (see Figure 40).

Unused amplifiers should be connected as grounded unity-gain followers to avoid possible oscillation.

noise performance

The noise specifications in operational amplifier circuits are greatly dependent on the current in the first-stage differential amplifier. The low input bias current requirements of the TLC272 and TLC277 result in a very low noise current, which is insignificant in most applications. This feature makes the devices especially favorable over bipolar devices when using values of circuit impedance greater than 50 kΩ, since bipolar devices exhibit greater noise currents.



(a) NONINVERTING AMPLIFIER **(b) INVERTING AMPLIFIER** **(c) UNITY-GAIN AMPLIFIER**

Figure 40. Guard-Ring Schemes

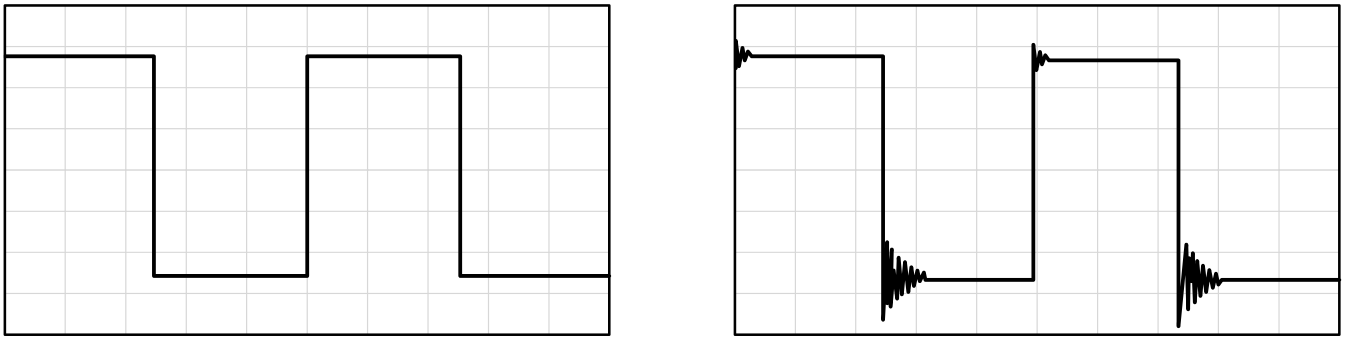
output characteristics

The output stage of the TLC272 and TLC277 is designed to sink and source relatively high amounts of current (see typical characteristics). If the output is subjected to a short-circuit condition, this high current capability can cause device damage under certain conditions. Output current capability increases with supply voltage.

All operating characteristics of the TLC272 and TLC277 are measured using a 20-pF load. The devices can drive higher capacitive loads; however, as output load capacitance increases, the resulting response pole occurs at lower frequencies, thereby causing ringing, peaking, or even oscillation (see Figure 41). In many cases, adding a small amount of resistance in series with the load capacitance alleviates the problem.

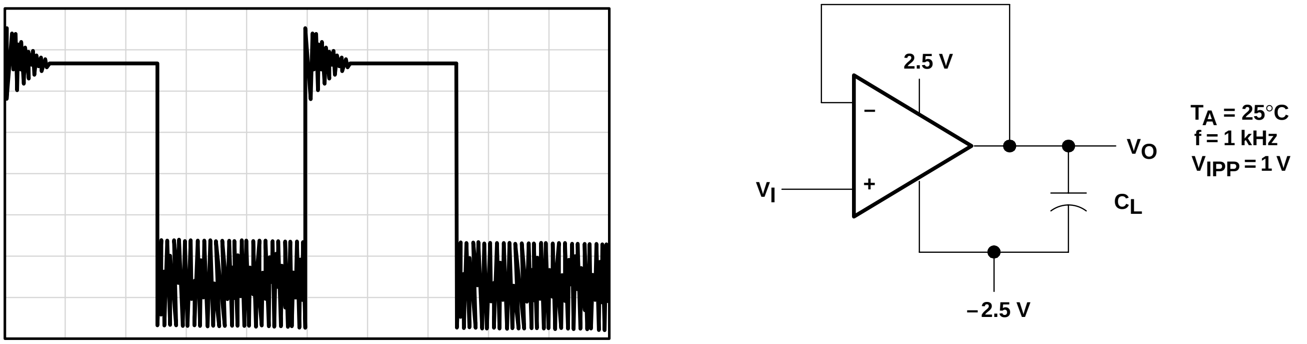
APPLICATION INFORMATION

output characteristics (continued)



(a) C_L = 20 pF, R_L = NO LOAD

(b) C_L = 130 pF, R_L = NO LOAD



(c) C_L = 150 pF, R_L = NO LOAD

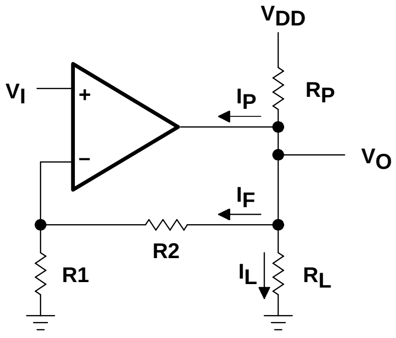
(d) TEST CIRCUIT

Figure 41. Effect of Capacitive Loads and Test Circuit

Although the TLC272 and TLC277 possess excellent high-level output voltage and current capability, methods for boosting this capability are available, if needed. The simplest method involves the use of a pullup resistor (R_P) connected from the output to the positive supply rail (see Figure 42). There are two disadvantages to the use of this circuit. First, the NMOS pulldown transistor N4 (see equivalent schematic) must sink a comparatively large amount of current. In this circuit, N4 behaves like a linear resistor with an on resistance between approximately 60 Ω and 180 Ω, depending on how hard the operational amplifier input is driven. With very low values of R_P, a voltage offset from 0 V at the output occurs. Second, pullup resistor R_P acts as a drain load to N4 and the gain of the operational amplifier is reduced at output voltage levels where N5 is not supplying the output current.

APPLICATION INFORMATION

output characteristics (continued)



$$R_p = \frac{V_{DD} - V_O}{I_F + I_L + I_P}$$

I_p = Pullup current required by the operational amplifier (typically 500 μA)

Figure 42. Resistive Pullup to Increase V_{OH}

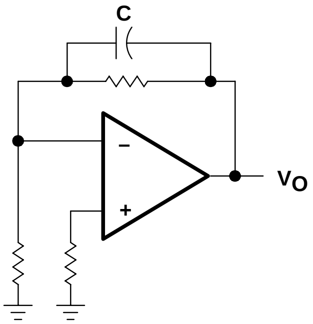


Figure 43. Compensation for Input Capacitance

feedback

Operational amplifier circuits almost always employ feedback, and since feedback is the first prerequisite for oscillation, some caution is appropriate. Most oscillation problems result from driving capacitive loads (discussed previously) and ignoring stray input capacitance. A small-value capacitor connected in parallel with the feedback resistor is an effective remedy (see Figure 43). The value of this capacitor is optimized empirically.

electrostatic discharge protection

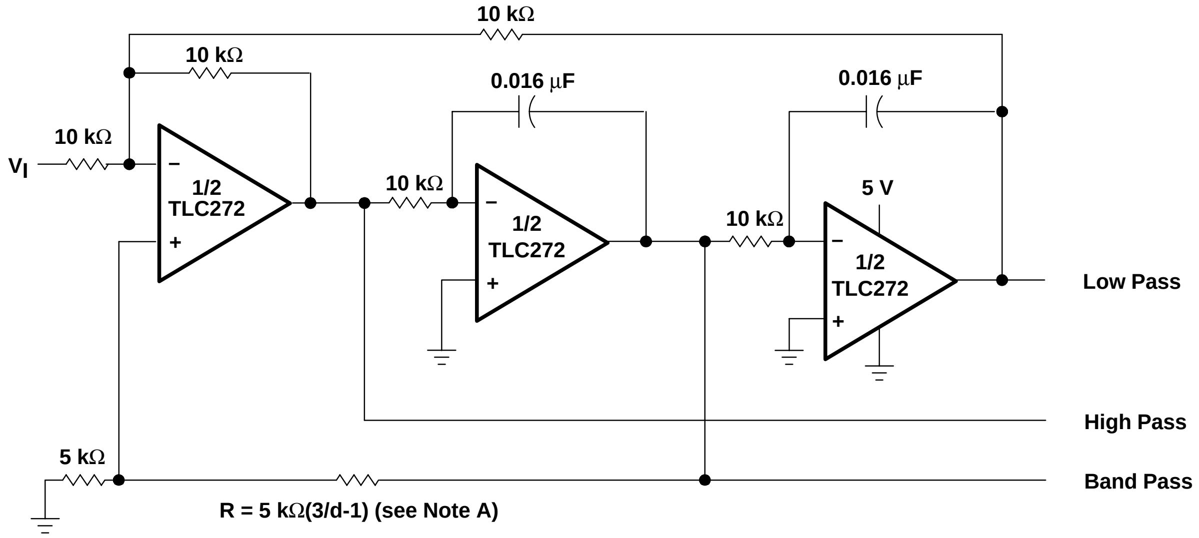
The TLC272 and TLC277 incorporate an internal electrostatic discharge (ESD) protection circuit that prevents functional failures at voltages up to 2000 V as tested under MIL-STD-883C, Method 3015.2. Care should be exercised, however, when handling these devices as exposure to ESD may result in the degradation of the device parametric performance. The protection circuit also causes the input bias currents to be temperature dependent and have the characteristics of a reverse-biased diode.

latch-up

Because CMOS devices are susceptible to latch-up due to their inherent parasitic thyristors, the TLC272 and TLC277 inputs and outputs were designed to withstand –100-mA surge currents without sustaining latch-up; however, techniques should be used to reduce the chance of latch-up whenever possible. Internal protection diodes should not, by design, be forward biased. Applied input and output voltage should not exceed the supply voltage by more than 300 mV. Care should be exercised when using capacitive coupling on pulse generators. Supply transients should be shunted by the use of decoupling capacitors (0.1 μF typical) located across the supply rails as close to the device as possible.

The current path established if latch-up occurs is usually between the positive supply rail and ground and can be triggered by surges on the supply lines and/or voltages on either the output or inputs that exceed the supply voltage. Once latch-up occurs, the current flow is limited only by the impedance of the power supply and the forward resistance of the parasitic thyristor and usually results in the destruction of the device. The chance of latch-up occurring increases with increasing temperature and supply voltages.

APPLICATION INFORMATION



NOTE A: d = damping factor, 1/Q

Figure 44. State-Variable Filter

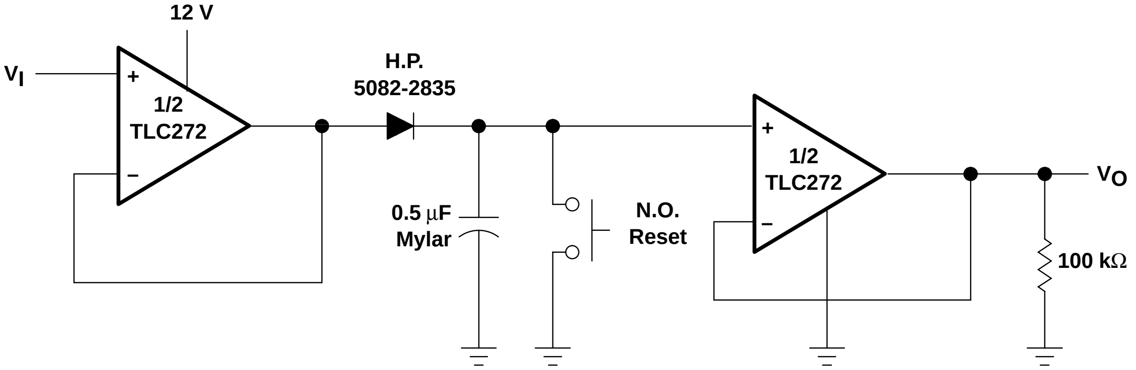
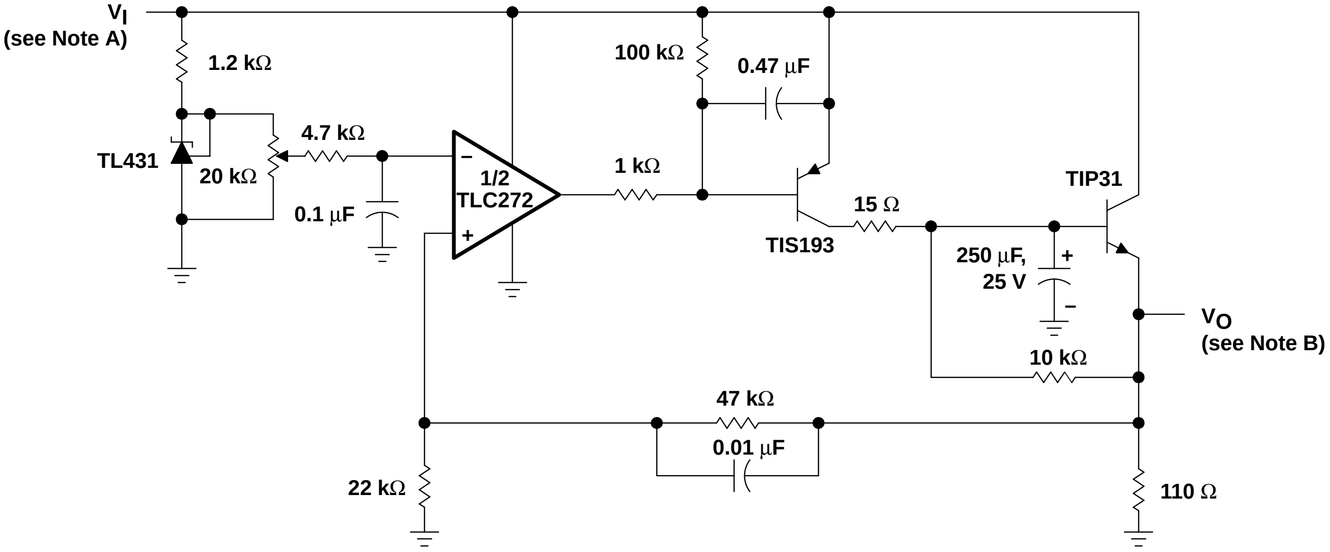


Figure 45. Positive-Peak Detector

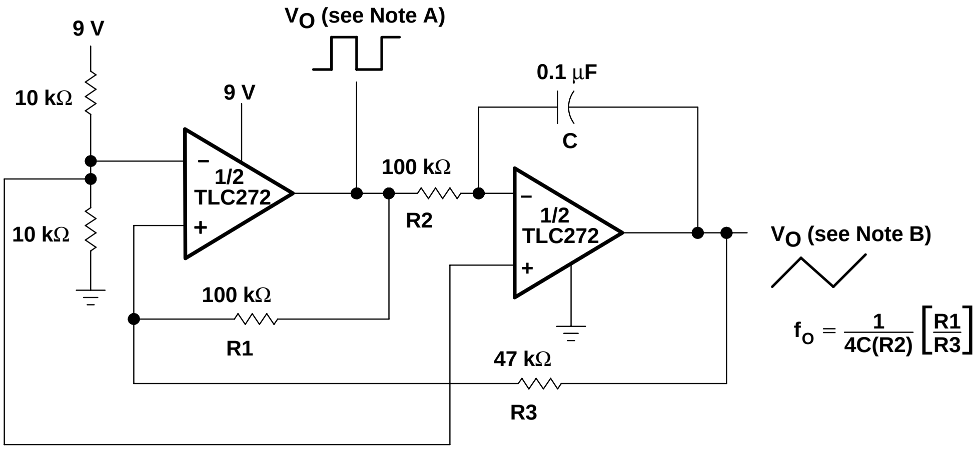
APPLICATION INFORMATION



NOTES: A. V_I = 3.5 to 15 V

B. V_O = 2 V, 0 to 1 A

Figure 46. Logic-Array Power Supply



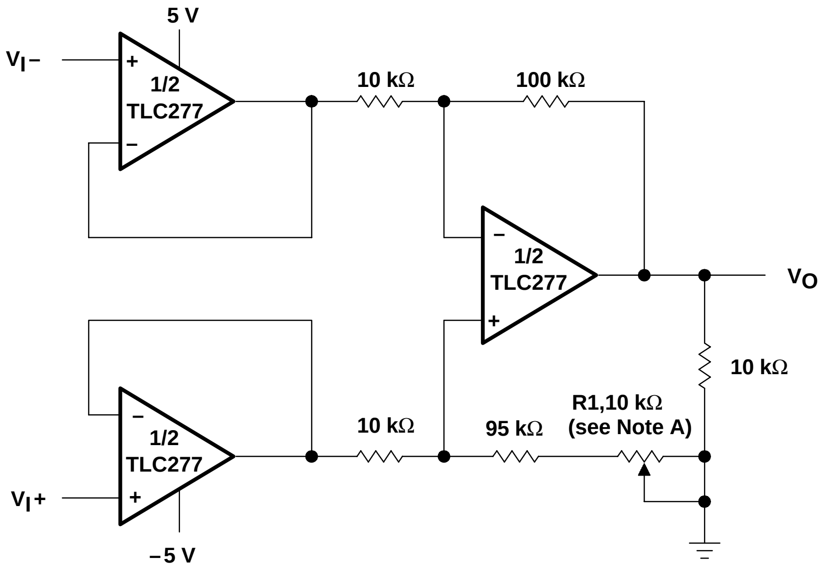
$$f_O = \frac{1}{4C(R2)}\left[\frac{R1}{R3}\right]$$

NOTES: A. $V_{O(PP)}$ = 8 V

B. $V_{O(PP)}$ = 4 V

Figure 47. Single-Supply Function Generator

APPLICATION INFORMATION



NOTE B: CMRR adjustment must be noninductive.

Figure 48. Low-Power Instrumentation Amplifier

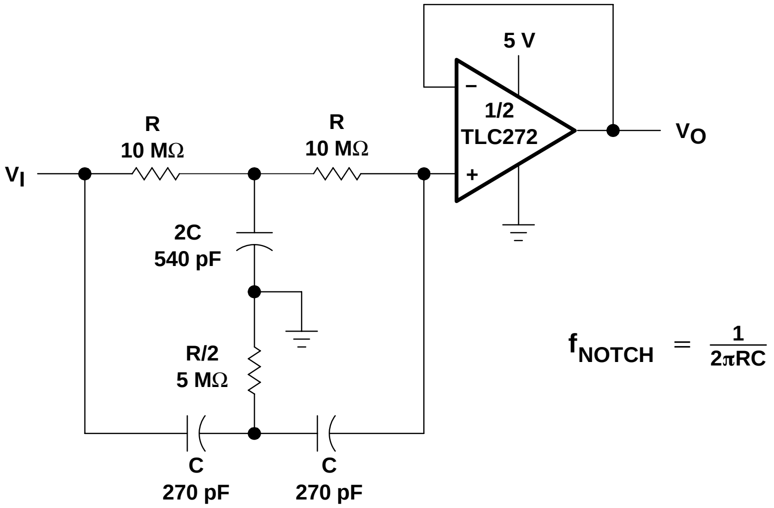


Figure 49. Single-Supply Twin-T Notch Filter

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
5962-89494022A	OBSOLETE	LCCC	FK	20		TBD	Call TI	Call TI	-55 to 125		
TLC272ACD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272AC	Samples
TLC272ACDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272AC	Samples
TLC272ACDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272AC	Samples
TLC272ACDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272AC	Samples
TLC272ACP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	TLC272ACP	Samples
TLC272ACPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	TLC272ACP	Samples
TLC272AID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272AI	Samples
TLC272AIDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272AI	Samples
TLC272AIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272AI	Samples
TLC272AIDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272AI	Samples
TLC272AIP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	TLC272AIP	Samples
TLC272AIPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	TLC272AIP	Samples
TLC272BCD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272BC	Samples
TLC272BCDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272BC	Samples
TLC272BCDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272BC	Samples
TLC272BCDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272BC	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLC272BCP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	TLC272BCP	Samples
TLC272BCPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	TLC272BCP	Samples
TLC272BID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272BI	Samples
TLC272BIDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272BI	Samples
TLC272BIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272BI	Samples
TLC272BIDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272BI	Samples
TLC272BIP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	TLC272BIP	Samples
TLC272CD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272C	Samples
TLC272CDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272C	Samples
TLC272CDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272C	Samples
TLC272CDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	272C	Samples
TLC272CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	TLC272CP	Samples
TLC272CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	0 to 70	TLC272CP	Samples
TLC272CPSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	P272	Samples
TLC272CPSRG4	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	P272	Samples
TLC272CPW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	P272C	Samples
TLC272CPWG4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	P272C	Samples
TLC272CPWLE	OBSOLETE	TSSOP	PW	8		TBD	Call TI	Call TI	0 to 70		

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLC272CPWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	P272C	Samples
TLC272CPWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	0 to 70	P272C	Samples
TLC272ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272I	Samples
TLC272IDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272I	Samples
TLC272IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272I	Samples
TLC272IDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 85	272I	Samples
TLC272IP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	TLC272IP	Samples
TLC272IPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	-40 to 85	TLC272IP	Samples
TLC272MFKB	OBSOLETE	LCCC	FK	20		TBD	Call TI	Call TI	-55 to 125		
TLC272MJG	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	-55 to 125		
TLC272MJGB	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	-55 to 125		
TLC272P-M	PREVIEW	PDIP	P	8		TBD	Call TI	Call TI			
TLC277CD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277C	Samples
TLC277CDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277C	Samples
TLC277CDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277C	Samples
TLC277CDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277C	Samples
TLC277CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type		TLC277CP	Samples
TLC277CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type		TLC277CP	Samples
TLC277CPSR	ACTIVE	SO	PS	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		P277	Samples
TLC277ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277I	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLC277IDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277I	Samples
TLC277IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277I	Samples
TLC277IDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM		277I	Samples
TLC277IP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type		TLC277IP	Samples
TLC277IPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type		TLC277IP	Samples
TLC277MFKB	OBSOLETE	LCCC	FK	20		TBD	Call TI	Call TI	-55 to 125		
TLC277MJG	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	-55 to 125		
TLC277MJGB	OBSOLETE	CDIP	JG	8		TBD	Call TI	Call TI	-55 to 125		

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

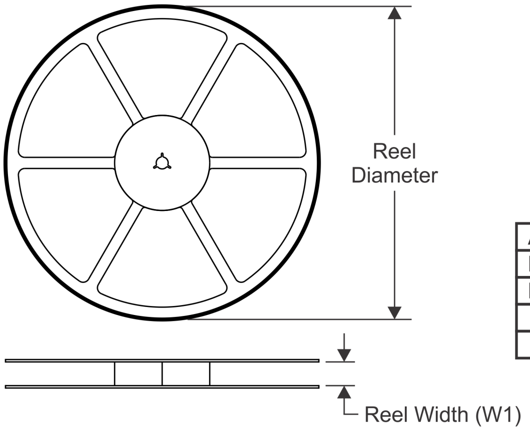
(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

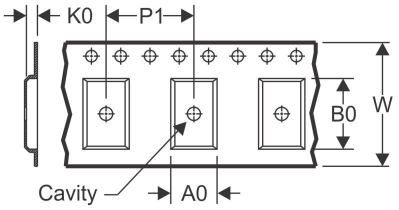
[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

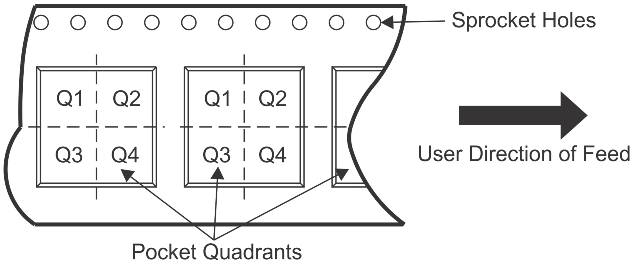


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

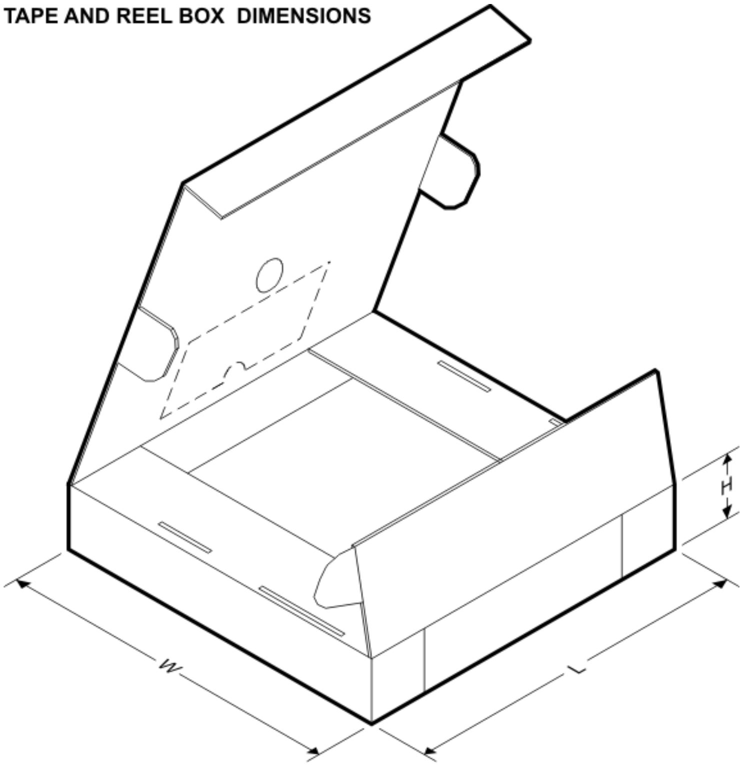
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TLC272ACDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272BCDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272BCDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272BIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272BIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272CDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC272CPWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
TLC272IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC277CDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC277CPSR	SO	PS	8	2000	330.0	16.4	8.2	6.6	2.5	12.0	16.0	Q1
TLC277IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
TLC277IDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

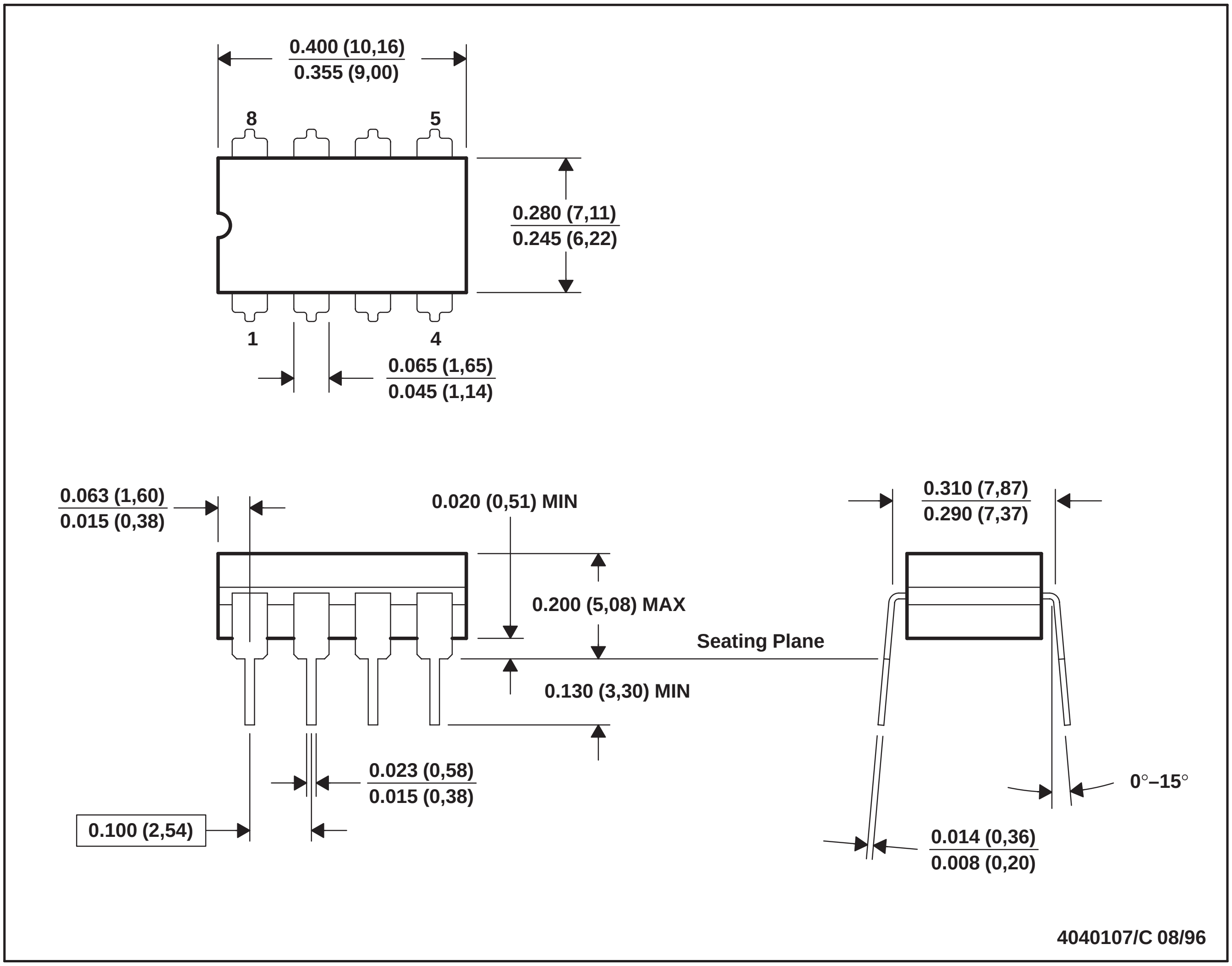
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TLC272ACDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC272AIDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC272BCDR	SOIC	D	8	2500	367.0	367.0	38.0
TLC272BCDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC272BIDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC272BIDR	SOIC	D	8	2500	367.0	367.0	38.0
TLC272CDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC272CPWR	TSSOP	PW	8	2000	367.0	367.0	35.0
TLC272IDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC277CDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC277CPSR	SO	PS	8	2000	367.0	367.0	38.0
TLC277IDR	SOIC	D	8	2500	340.5	338.1	20.6
TLC277IDR	SOIC	D	8	2500	367.0	367.0	38.0

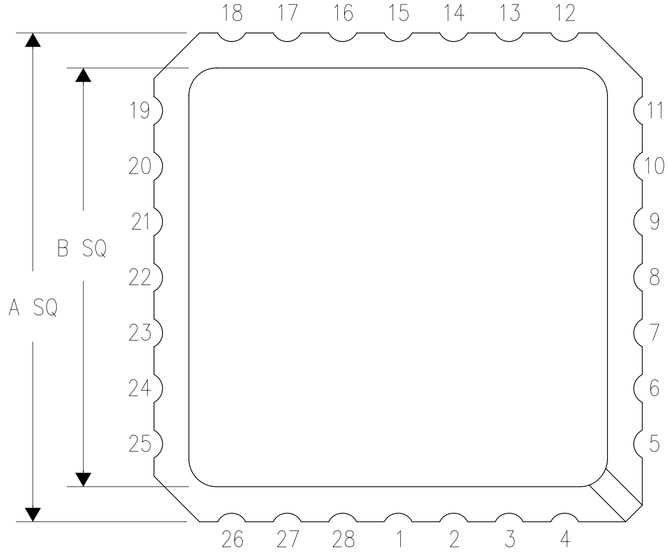
JG (R-GDIP-T8) **CERAMIC DUAL-IN-LINE**



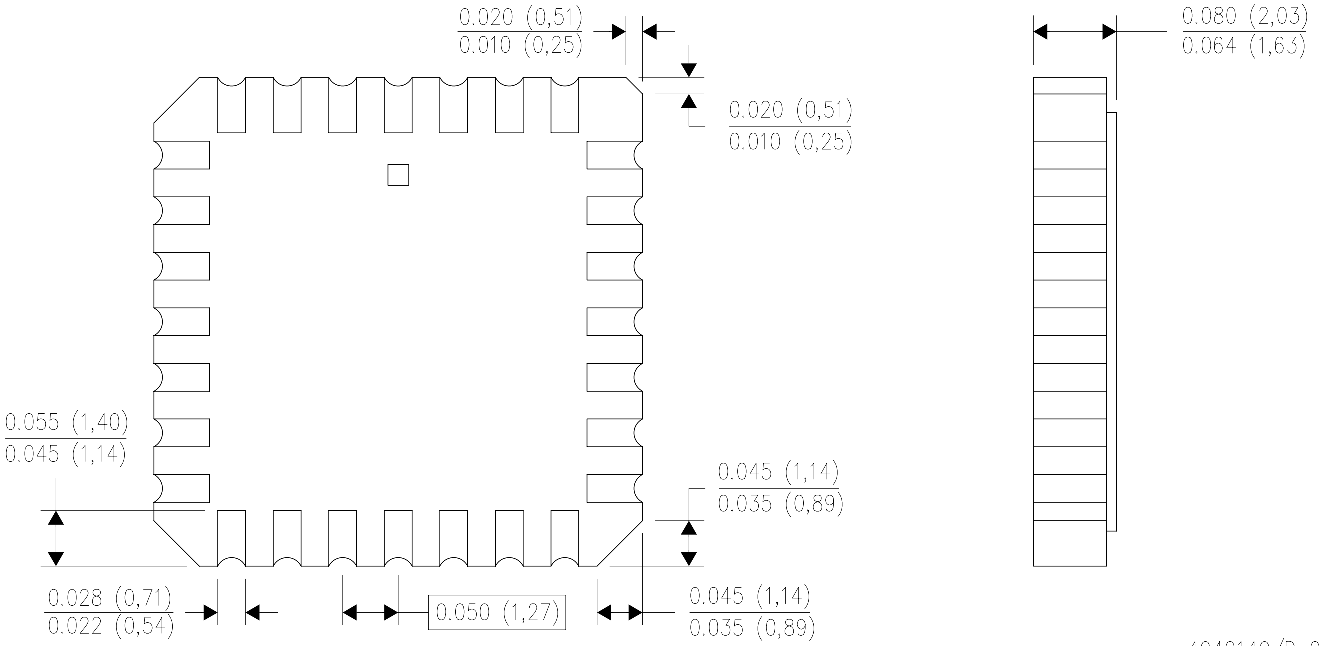
NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. This package can be hermetically sealed with a ceramic lid using glass frit.
- D. Index point is provided on cap for terminal identification.
- E. Falls within MIL STD 1835 GDIP1-T8

FK (S–CQCC–N**) LEADLESS CERAMIC CHIP CARRIER

28 TERMINAL SHOWN



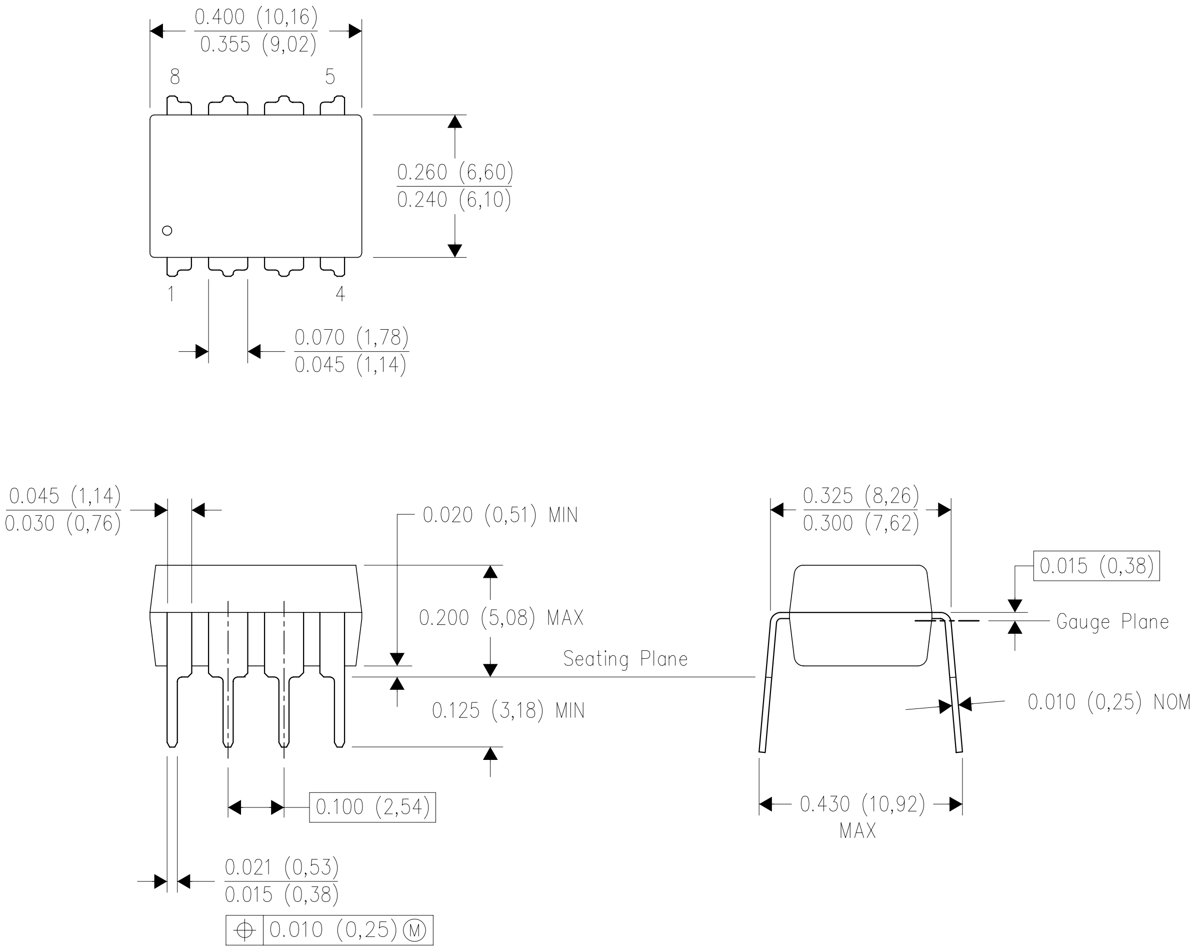
NO. OF TERMINALS **	A		B	
	MIN	MAX	MIN	MAX
20	0.342 (8,69)	0.358 (9,09)	0.307 (7,80)	0.358 (9,09)
28	0.442 (11,23)	0.458 (11,63)	0.406 (10,31)	0.458 (11,63)
44	0.640 (16,26)	0.660 (16,76)	0.495 (12,58)	0.560 (14,22)
52	0.740 (18,78)	0.761 (19,32)	0.495 (12,58)	0.560 (14,22)
68	0.938 (23,83)	0.962 (24,43)	0.850 (21,6)	0.858 (21,8)
84	1.141 (28,99)	1.165 (29,59)	1.047 (26,6)	1.063 (27,0)



4040140/D 01/11

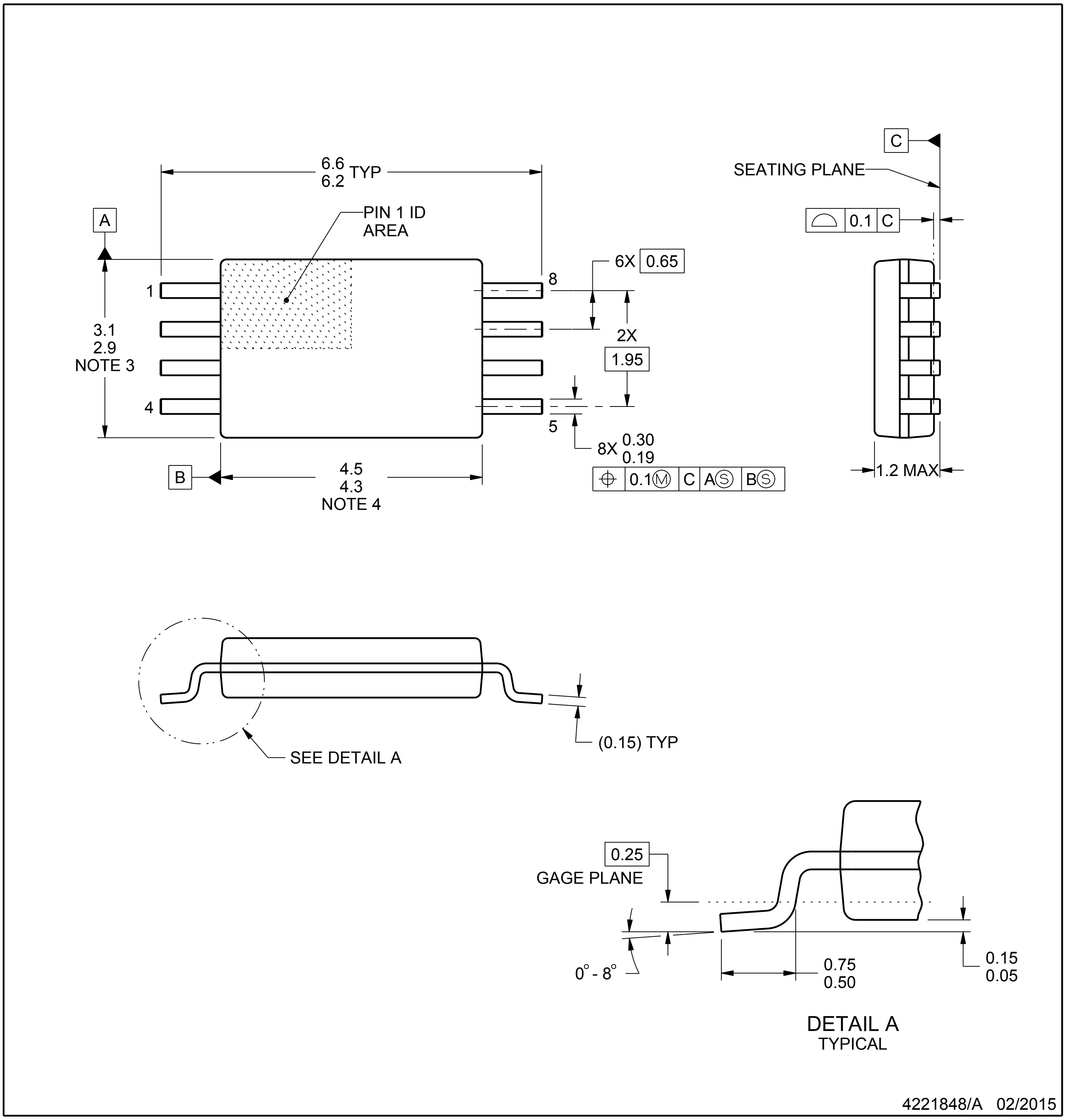
NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. This package can be hermetically sealed with a metal lid.
- D. Falls within JEDEC MS–004

P (R-PDIP-T8) PLASTIC DUAL-IN-LINE PACKAGE



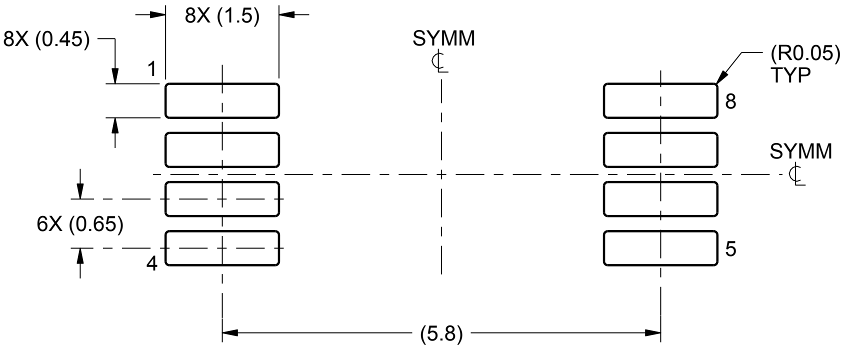
4040082/E 04/2010

NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Falls within JEDEC MS-001 variation BA.

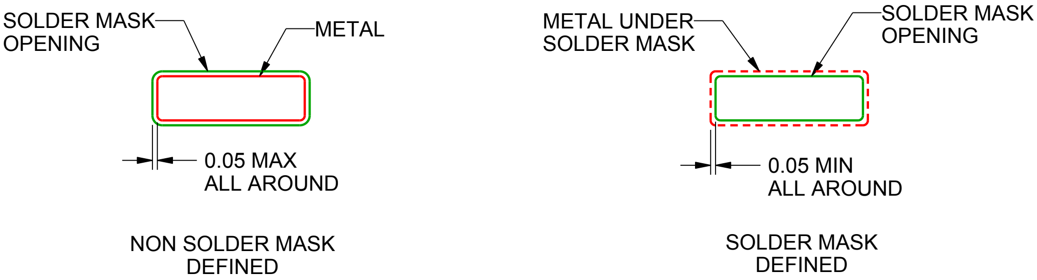


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153, variation AA.



LAND PATTERN EXAMPLE
SCALE:10X

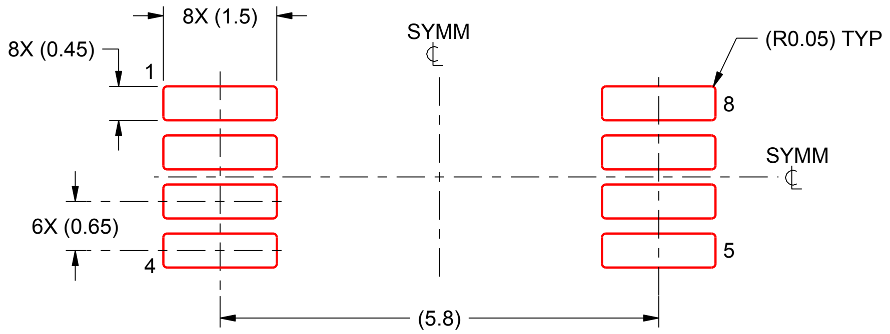


SOLDER MASK DETAILS
NOT TO SCALE

4221848/A 02/2015

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



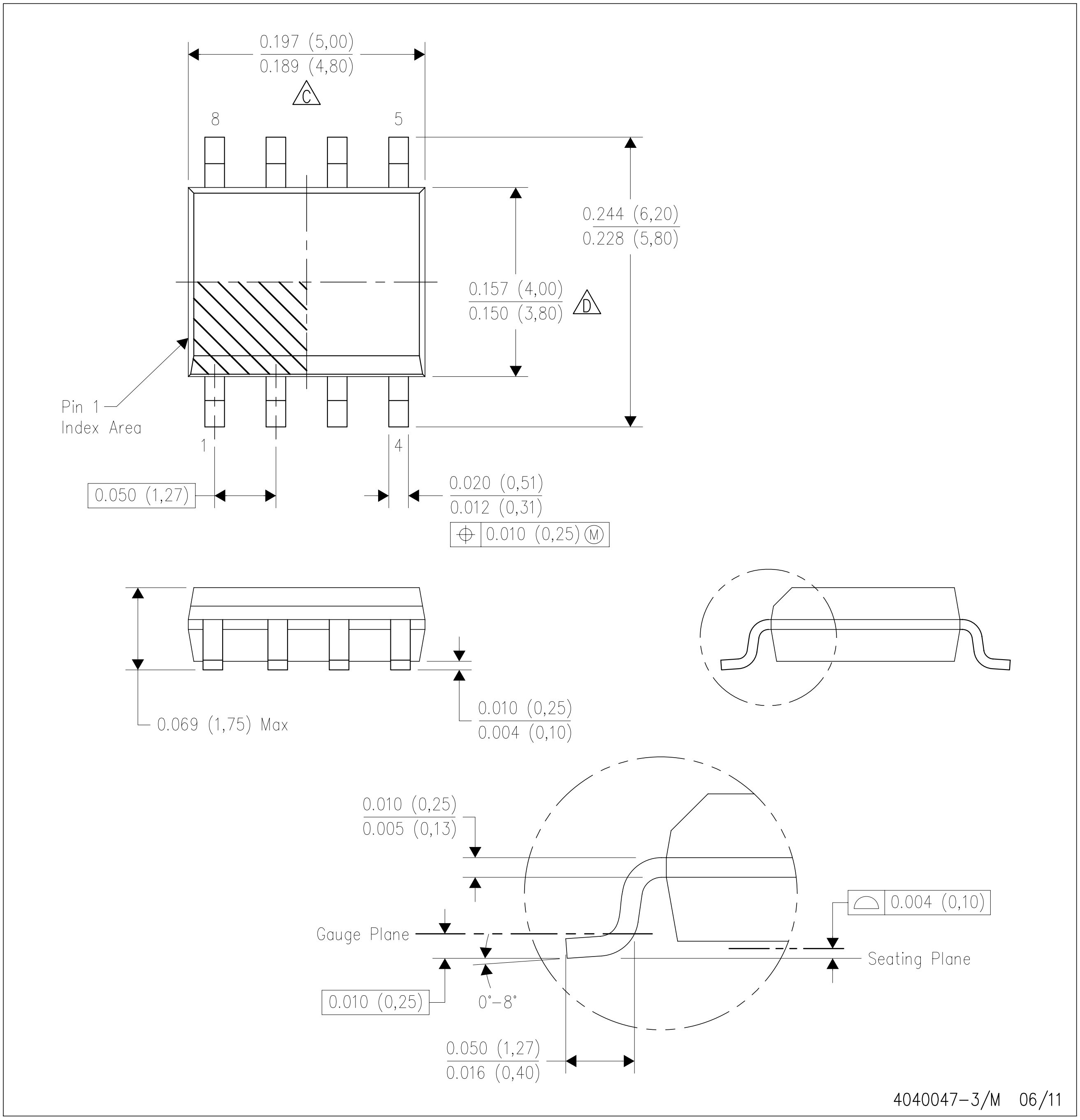
SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:10X

4221848/A 02/2015

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:

A. All linear dimensions are in inches (millimeters).

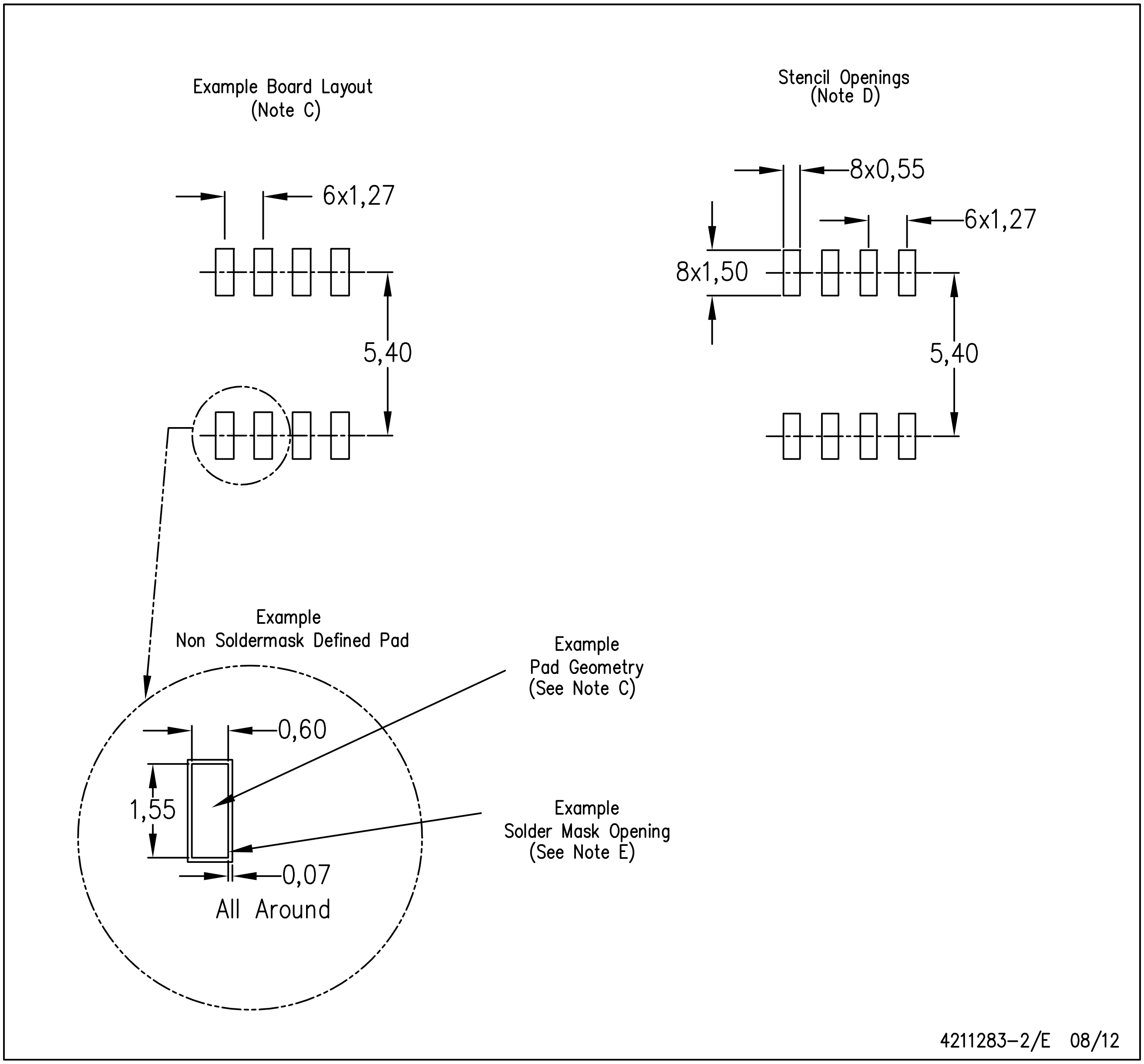
B. This drawing is subject to change without notice.

C Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.

D Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.

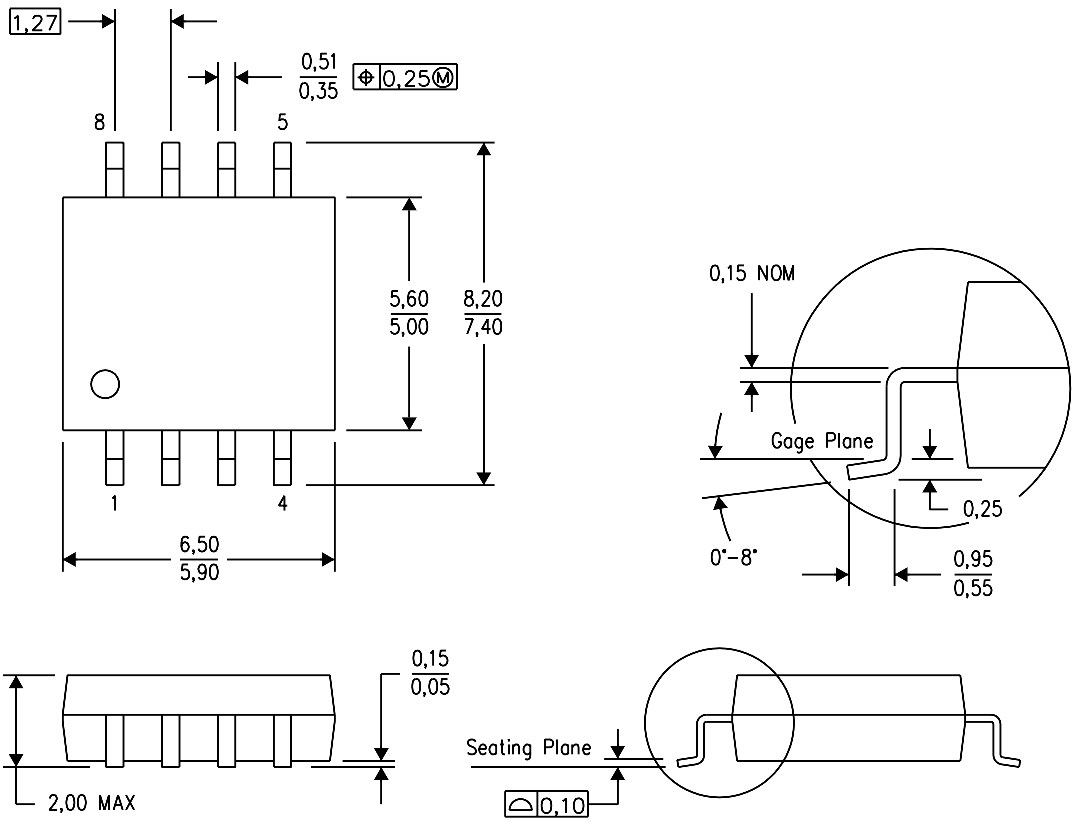
E. Reference JEDEC MS–012 variation AA.

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC–7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

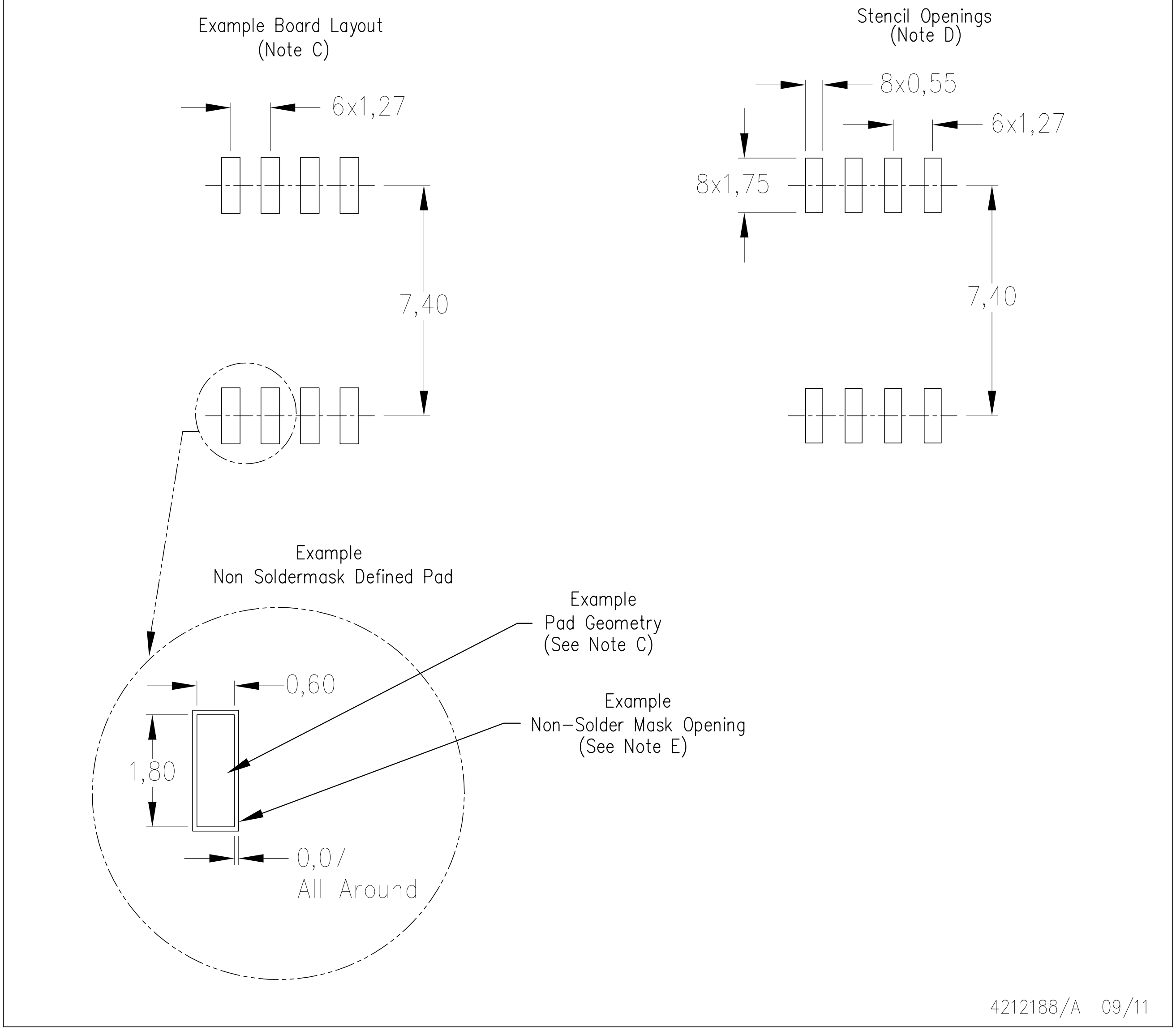
PS (R-PDSO-G8) **PLASTIC SMALL-OUTLINE PACKAGE**



4040063/C 03/03

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion, not to exceed 0,15.

PS (R-PDSO-G8) PLASTIC SMALL OUTLINE



4212188/A 09/11

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Publication IPC-7351 is recommended for alternate designs.
- D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
- E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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