COLLEGE OF ENGINEERING AND TECHNOLOGY
Electrical Engineering Department

Industrial Automation Engineering Program

GRADUATION PROJECT REPORT

EXOSKELETON FOR PERIPHERAL PARALYSIS CONTROLLED BY EMG SIGNALS

Project Team

Hamza R. AL-Ajouri **Mohammad H. Mohsen**

Tareq Z. Al-Qwasmeh

Project Supervisor
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Graduation Project Evaluation

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According to the orientations of the supervisor on the project and the examined committee is by the agreement of a staffers all, sending in this project to the Electrical and Computer Engineering Department are in the College of the Engineering and the Technology by the requirements of the department for the step of the bachelor's degree.

Project Supervisor Signature

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Committee Signature

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Department Headmaster Signature

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الإهداء

إلى الذي قال تعالى فيهما (و أخفض لهما جناح الذل من **الرحمة وقل رب** ارحمهما **كما** ربياني صغيرا).

الماس الذي لا ينكسر، **نبع العطاء الذي زرع الأخلاق بداخلي و علمني طرق الارتقاء** .... إلى أبي الطيب.

الزهرة **التي لا تذبل** ...... **نبع الحنان** ...... التي ساندتني بدعواتها و وقفت معي حتى وصلت لهذه **المرحلة من التقدم والنجاح** .... إلى من تعجز الكلمات عن وصفها و تسكن أمواج البحر لسماع إسمها.......... **إلى أمي**.

ملائكة الأرض.........شقائق النعمان.......... إلى أشقائي.

رفاق الدرب ...... بناة المستقبل ...... إلى أروع و أصدق و أنبل البشر........... إلى أصدقائي المخلصين.

الذين رفعوا رايات العلم و التعليم و أخمدوا رايات الجهل و التجهيل **إلى أساتذتي الأفاضل.**

أهدي هذا الجهد المتواضع إلى شهدائنا و أسرانا الأبطال و مغتربينا و كل حر فلسطيني .... إلى كل من قال لا إله إلا الله محمد رسول الله.

سائلاً المولى عز وجل أن يوفقني لما يحب و يرضى
لكم جميعا أهدي سهري و تعبي و جهدي

Dedication

This Project is dedicated to our parents who have been the source of inspiration and motivation all lifelong, and all people who help us.

And forever we should give our thanks, obedience and gratitude to our appreciation to:

Palestine Polytechnic University

College of Engineering & Technology

Electrical & Engineering Department

Our supervisor Dr. Sameer Khader

ABSTRACT

Spinal cordinjuries and other local injuries often lead to peripheral paralysis, while the brain stays fully functional. When this peripheral paralysis occurs in the hand, these individual are not able to execute daily activities on their own even if their arms are functional.

To remedy this problem, design an exoskeleton needs to assist paralyzed individuals. The exoskeleton's movements are controlled by the user's available electromyography(EMG) signals, a new control technique will developments to allow for a natural reaching and facilitator sequence by the natural residual muscle activation patterns.

But the signal need to purity and enlarge before entering to microcontroller, then run the motor to controlling exoskeleton.

الملخص

اصابات الحبل الشوكي و إصابات محلية أخرى غالبا ما تؤدي إلى الشلل الطرفي، في حين أن الدماغ يبقى تعمل بكامل طاقتها. عندما يحدث هذا الشلل الطرفي في اليد، فإن تلك اليد تصبح غير قادرة على تنفيذ الأنشطة اليومية من تلقاء نفسها حتى لو كانت الأذرع موجوده.

لمعالجة هذه **المشكلة**, **تم** تصميم بيت خارجي يتم توظيفه **لمساعدة** المشلولين طرفيا, حيث **ان حركات** اليد **المتمثلة في حركة** البيت الخارجي يتم التحكم بها من خلال الإشارة كهربائية **العضلة** (EMG signals), تقنية **التحكم** الجديد **سوف** يتم بناؤها **وتطويرها لتسمح بوصول الاشارات بشكل** طبيعي و تسلسل ميسر **باستخدام أجزاء العضلات** الطبيعية الفعالة المتبقية.

ولكن الإشارة تحتاج الى تنقية و تكبير قبل الدخول الى المتحكم الدقيق، **ومن** ثم تشغيل المحركات التي تقوم بالتحكم في البيت الخارجي لليد.

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Abbreviation Table

Description	Abbreviations
Electromyography	EMG
International Society of Electrophysiological Kinesiology	ISEK
Peripheral Nervous System	PNS
Central Nervous System	CNS
Biceps Muscle	BI
Triceps Muscle	TRI
Fast Oxidative Glycol tic	FOG
Fast Glycol tic	FG
Motor Unit Action Potential	MUAP
Chlorine Ions	Cl-
Silver Ions	Ag+
Common Mode Rejection Ratio	CMRR
Lower Frequency	FL
Higher Frequency	FH
Low Pass Filter	LPF
High Pass Filter	HPF
Digital to Analog Converter	DAC
Variable Reluctance	VR
Permanent Magnet	PM
Hybrid	HB
Microcontroller Family from Renesas Electronics	RX
Microcontroller Family from Tenesas Electronics	TX
Printed Circuit Board	PCB

1

Chapter One

General Background

1.1 Introduction

1.2 Project Aim

1.3 Literature Review

1.4 Project main component

1.5 Project cost

1.6 Time diagram

1.1 Introduction

Not a small Percentage of people out of our Palestinian society have a weakness in one of limbs that happened by some congenital reasons or kind of accidents or was done on the hand Israeli occupation in what it does against our Palestinian nation, and out of this case it is a part of our duty in order to help them doing their daily actions normally, and now we will go to the mechanization of doing this project.

Electromyography is a technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an electromyography, to produce a record called an electromyography.

An electromyography detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, and recruitment order or to analyze the biomechanics of human or animal movement.

EMG signals are not easily observed as they are weak signals in range of 1-100mV,so an EMG signal needs to be amplified by an amplifier specifically designed to measure it in order to be observed. The EMG signal is picked up by electrodes and then amplified. Generally more than one amplification stages as necessary in order to eliminate the low and high frequency noises or the other factors that can affect the output data.

EMG signal accuracy is dependent on many parameters such as electrodes number electrode placement, electrode orientation, electrode type, inter-electrode distance, skin preparation, skin and electrode gel temperature, subcutaneous fat between the electrode and muscle. The EMG signal is used for much application such as control computers and other devices.

In our project the EMG signals are tried to use for controlling of a simple hand-shaped gripper with a microcontroller interface, as shown in figure (1.1).

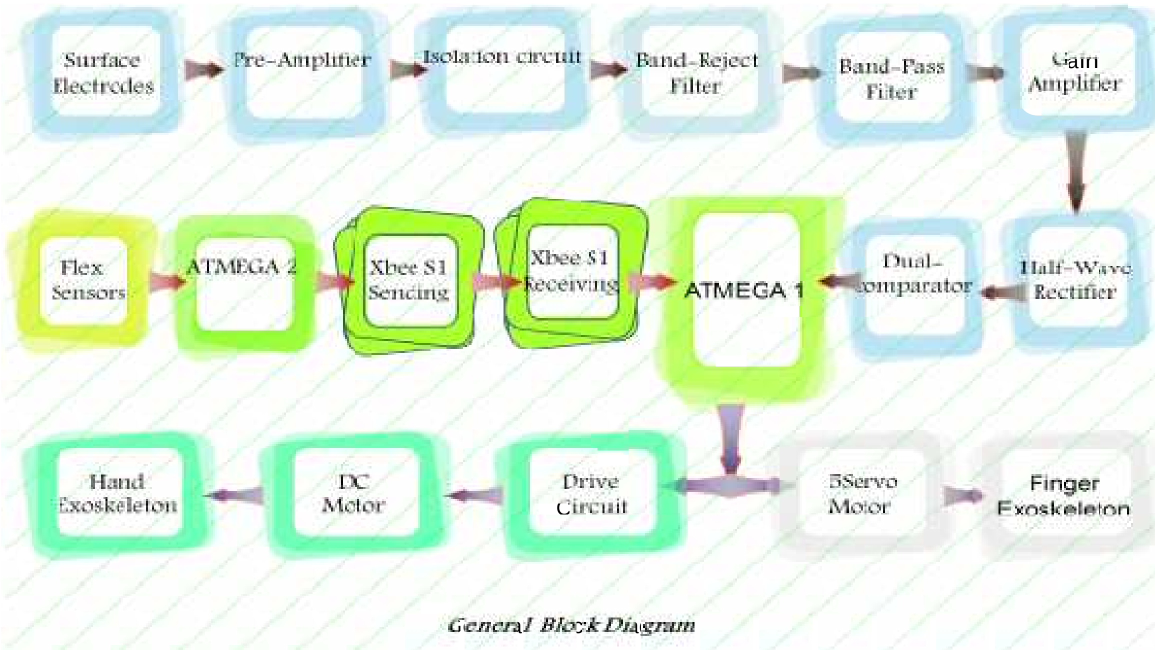


Figure (1.1):- The General Block Diagram.

1.2 Project Aim

The proposed project aims at design an artificial hand (limb) by using and processing muscle signals…

1.3 Literature Review

Francesco Redi (1626-1698)

First to recognize connection between muscles and generation of electric 1666—documented that electric ray fish used a highly-specialized muscle. [1]

Alessandro Volta (1745-1827)

Developed a device which produced electricity,which could be used to stimulate muscles, invented the first electric battery. [1]

Luigi Galvani

Credited as the father of neurophysiology for his similar work with frogs' legs-1791.

Showed that "electrical stimulation of muscular tissue produces contraction and force. [1]

Carlo Matteucci (1820-1845)

In 1838, Matteucci used one to show that bioelectricity is connected with muscular contraction.

1842 – Demonstrated the existence of the action potential accompanying a frog's muscle. [2]

Guillaume Duchenne (1806-1875)

1850 – Applied electric stimulation to intact skeletal muscles Interested in medical electricity for therapeutic purposes. Systematically mapped out functions of nearly every facial muscle Knowledge of EMG developed as fast as technology could keep up. [2]

The term electromyography comes from Etienne Marey, who modified Lippman's capillary electrometer (1876) as one of his many contributions to kinesiology. [2]

John Bas 1962

Basmajian compiles all of the known information about EMG. Also created fine - wire electrodes that were more comfortable than needles and could be used longer. The book Muscles Alive becomes an invaluable tool in the field and is updated through five editions, the last Carlo De Luca. Founded International Society of Electrophysiological Kinesiology, ISEK, in 1965.ISEK worked to create standards for EMG usage and reportingmajian. [2]

1.4 Project Main Component

1) Detecting Electrode.
2) Amplifier.
3) Microcontroller.
4) Stepper motor and driving modules.
5) Hand-shaped gripper.

1.5 Estimated Project Cost

Table (1.1): Component Cost:

No.	Description	Price/ NIS
1	Electrodes and Fillters	200
2	Amplifiers	100
3	4N25 opt-coupler	5
4	LM319D Dual-Comparator	10
5	AD620 Amplifier	140
6	Resistors + Capacitors + Rectifiers	60
7	2 Arduino + shield	400
9	Darlington Transistors	50
10	5 servo motors	1100
11	5 Flex Sensors	500
12	2 Xbee module S1+ shield	500 + 100
13	DC Motor for hand + Drive Circuit	400
14	2 Gears	150
15	design lathing (Exoskeleton)	1500
16	Hand – shaped Gripper (polyethylene)	1400
17	Other materials	300
18	Paint	400
	Total	7315

1.6 Time Diagram

Table (1.١): Time line١ of The Project:

Weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Literature review and problem statement															
Proposing methodology															
Components survey and cost estimation , selec.															
Reporting Project chapters															
Design of system part															
Report Typing															
Report submission															

Table (1.3): Time line 2 of The Project:

Weeks / Tasks	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Starting implementation of the mechanical design															
Purchasing the components															
Assembly the electrical and mechanical part															
Testing and calibration															
Typing the final report															
Report submission and preparing the project presentation															

2 Chapter Two

Structure Background

2.1 Anatomy of the Human Forearm

Initially, we talk about the Peripheral Nervous System (PNS), which is the other part of the nervous system. The main task of the PNS is to detect stimuli and send impulses to the CNS according to the stimuli. The PNS is made of receptors and nerves that carry the impulses. Receptor cells are ones whose function is to detect something about its environment.

There are many receptors in the body that are able to detect many changes like temperature, touch, light, sound and chemicals. There are some organs in the body that are there to detect just one stimulus, like the eye for example. These are called sensory organs and they can be defined as a group of receptor cells responding to specific stimuli.

Effectors are the opposite of receptors. Receptors are two detect the stimuli while effectors are two respond to it. Effectors are usually muscles and glands.

2.1.1 Neuroses (Nerve Cells)

Neuroses are one of the most important structures of the nervous systems. Neuroses act as a wire that transmits electrical impulses all over the body. Like a cable that consists of many wires, a bundle of neuroses is called a nerve. There are 3 types of neuroses; each type is to transmit electrical impulses from a specific place to another.

1) Motor Neuroses :-

This is a neurosis that transmits electrical impulses from the Central nervous system to the effectors, as shown in figure (2.1).

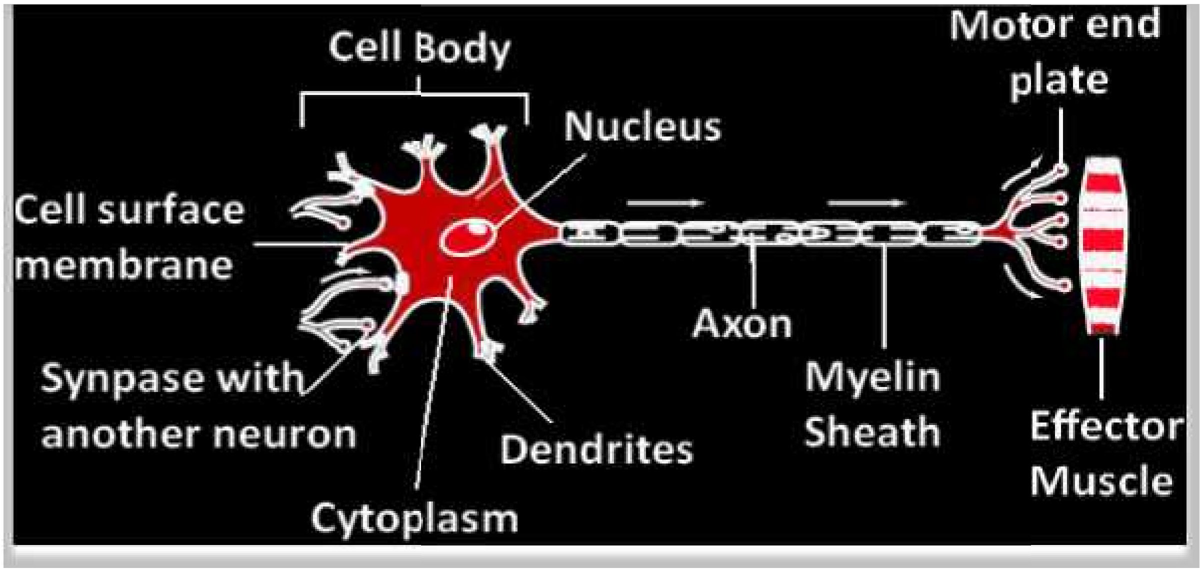


Figure (2.1):- Structure of Motor Neuroses. [4]

The Neuron is made up of three segments; the cell body which is the start of the motor Neuron and is in the CNS, axon which stretches out from the cell body all the way to end of the neuron, and the motor plate which is the end of the Neuron and is in the Effectors muscle.

Neurons have features that are common between most animal cells like a nucleus, cymiddlelasm and cell surface membrane, but they also have some exclusive features like the axon. The axon is an extended cymiddlelasm thread along which electrical impulses travel. Some motor neurons have axons of length 1 meter. Axons are coated by a layer of myelin called myelin sheath; this is an electrically insulating layer which is essential for the proper functioning of the nervous system.

Another exclusive feature of neurons is dendrites; these are several short threads of cymiddlelasm coming out of the cell body. Their function is to pick up electrical impulses from other cells.

The last exclusive feature of motor neurons only is motor end plate. This is just the end of the axon which is in the muscle. It passes the electrical impulses from the neuron to the muscle fibers.

2) Sensory Neuroses :-

Like other neurons, sensory neurons carry electrical impulses from one place to another. But sensory neurons carry electrical impulses in the direction different to that of motor neurons, from the receptors to the CNS, as shown in figure (2.2).

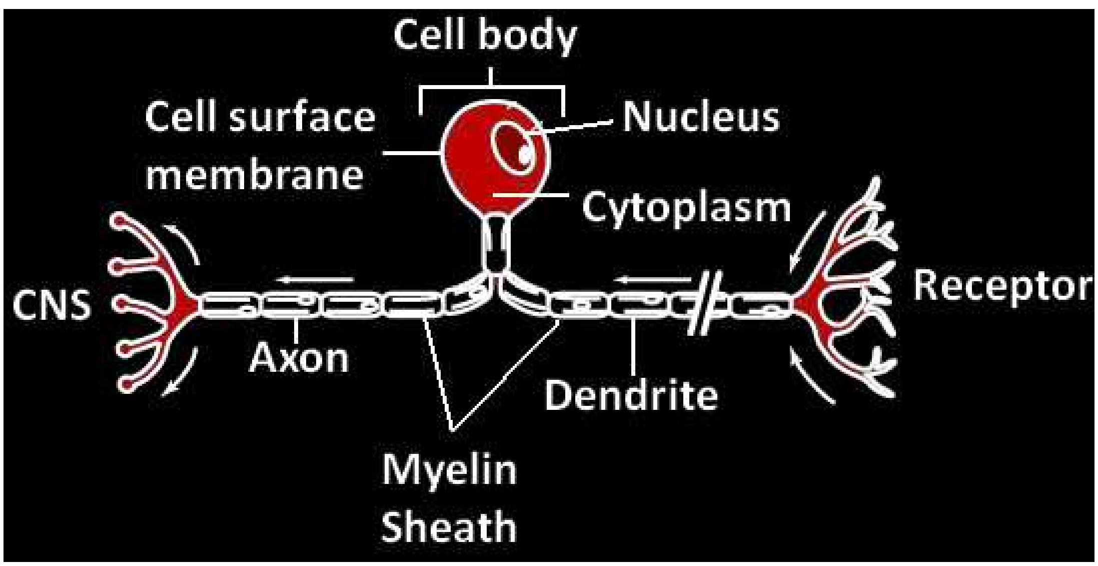


Figure (2.2):- Structure of Sensory Neuroses. [4]

3) **Relay Neurons :-**

Relay neurons are located in the CNS. Their job is to pass electrical impulses from the sensory neuron onto the motor neuron, so it acts like a diversion, as shown in figure (2.3).

Figure (2.3):- Structure of Relay Neuroses. [4]

2.1.2 Reflex Arc (Nervous System in Action)

Where neurons meet, they are not actually touching each other. Instead there is a gap called synapse or junction box. When the electrical impulses reach the end of a neuron, the neuron secretes a chemical transmitter which passes by diffusion to the other neuron causing the impulses to be carried from the first neuron to the second.

If your finger touches a hot surface, receptor cells in the skin of your finger detect a stimulus, which is a sudden rise in the temperature. The receptor uses the energy of the stimulus to generate electrical impulses. These impulses are then carried by the axons of the dendrites of the sensory neuron through cell body to axon and from the axon to the CNS. At the CNS the electrical impulses travel through the synapse to the relay neuron, which passes it onto the motor neuron. The nerve impulses are transmitted through the axon of the motor neuron to the targeted muscle which contracts when electrical impulses reach it, resulting in your finger being pulled away from the hot surface, as shown in figure (2.4).

This pathway is called the reflex arc and happens in about a fraction of a second.

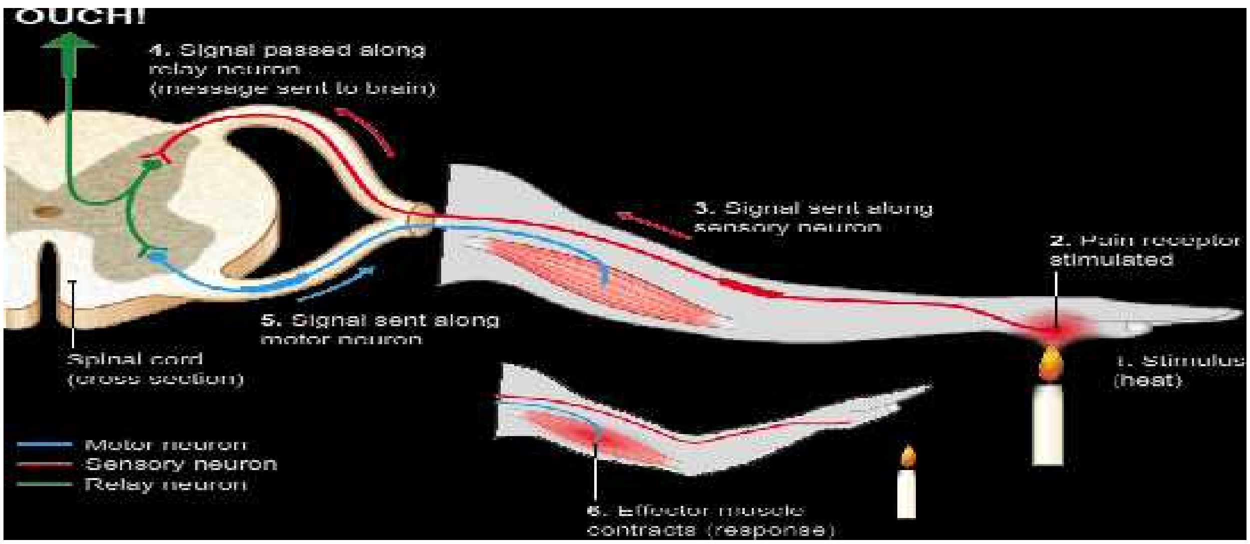


Figure (2.4):- Reflex Arc: Receptor → Sensory Neuron → CNS → Motor Neuron → Effectors. [5]

2.1.3 Antagonistic Muscles

We have just learned that in order for the pupil to get narrower or wider, two muscles work simultaneously, when one contracts the other relaxes. Pairs of muscles like that are called antagonistic muscles.

The most known antagonistic muscle pair is the biceps and triceps of the arm. The bi and the tri for short; they are what cause the movement of the arm. They work simultaneously to bend or straighten the arm. The biceps is located in front of the humerus bone of the upper arm. The biceps is joined to the radius bone of the lower arm and the triceps is joined to the ulna bone of the lower arm. Muscles are attached to bones by strong fibers called tendons.

And to learn how to deliver the pulse of the muscle, we will address the case of bend and straighten muscle:

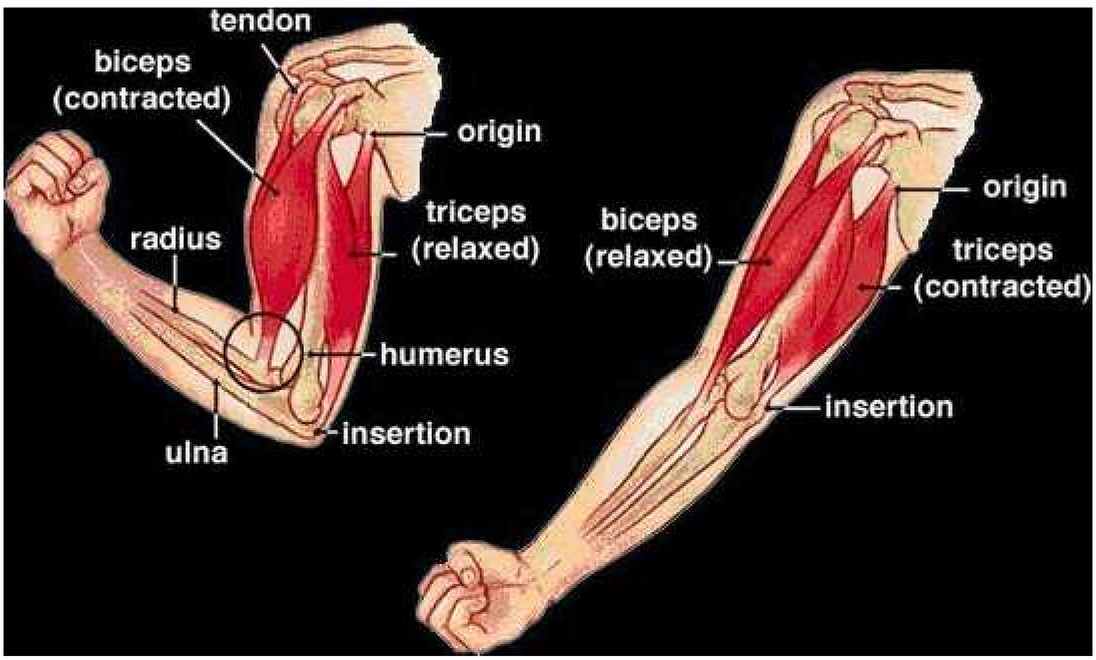


Figure (2.5):- The Effect of Bend and Straighten Arm. [6]

When you want to bend your Arm the brain send two electrical impulses, one to the bi making it contract and one to the tri telling it to relax.

To straighten your arm, the brain send electrical impulses to both muscles making the bi relax in order to leave the muscle it is attached to free. The tri contracts and becomes shorter pulling the muscle it is attached to into place and straightening the arm.

As shown in figure (2.5); the biceps can be called a flexor because it flexes (bends) the arm, the triceps can be called an extensor because it extends (straightens) the arm. It is necessary to explain the affected part of the man who will be replaced by another part mechanic to make up the shortfall effectively.

This section will be covered in detail the muscles involved with each finger movement, as shown in figure (2.6).

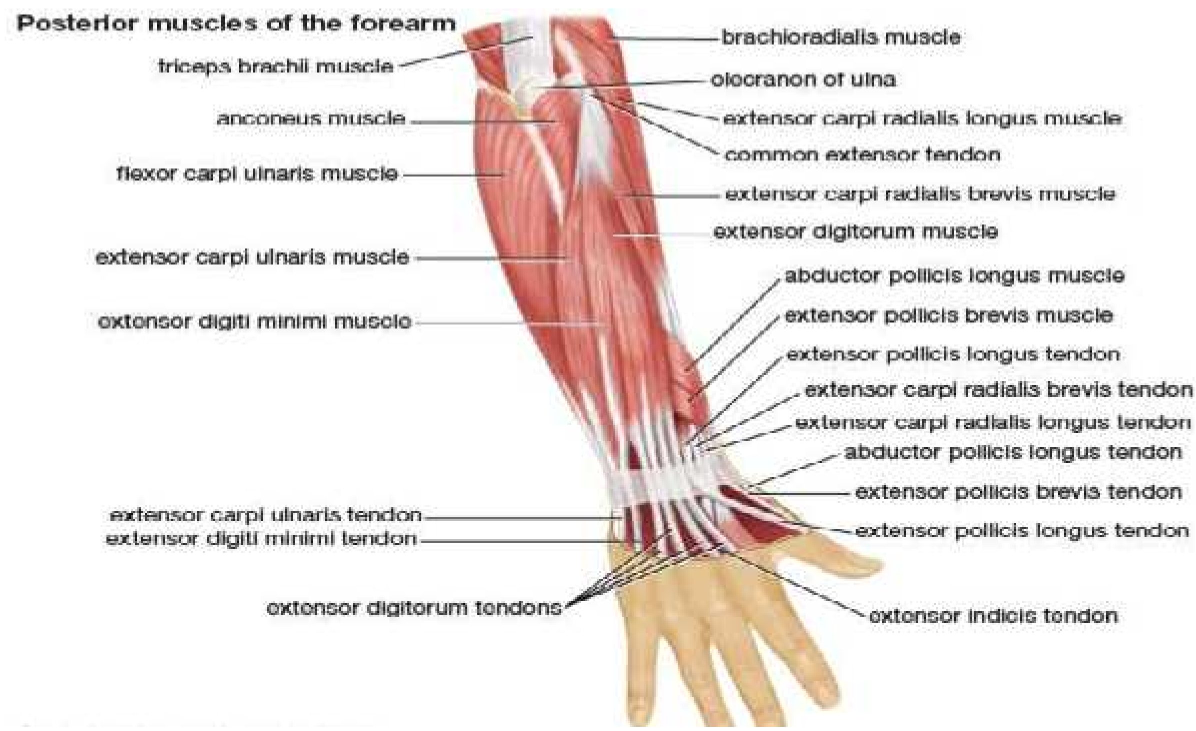


Figure (2.6):- Structural of Human Arm. [7]

The muscles of interest for determining grasp classification are the extensor muscles, generally located on the posterior side of the forearm. The extensor muscles extend the fingers outward as the grasp initially takes form. It is the proper capture and classification of the EMG signal during this initial movement that enables a real-time classifier to work. The specific extensor muscles involved are the extensor digitorum, extensor pollicis longus, extensor pollicis brevis, extensor indicis, and extensor digiti minimi. The extensor digitorum is responsible for the extension of the finger joints and wrist, and connects primarily to the middle and ring fingers, and secondarily to the index and little fingers. The extensor pollicis longus and extensor pollicis brevis are both responsible for the extension of the thumb as well as abduction at the wrist. The extensor indicis muscle controls both the extension and adduction of the joints of the index finger, while the extensor digiti minimi controls the extension of the joints of the little finger.

The approximate locations of these muscles are indicated, as shown in figure (2.7).

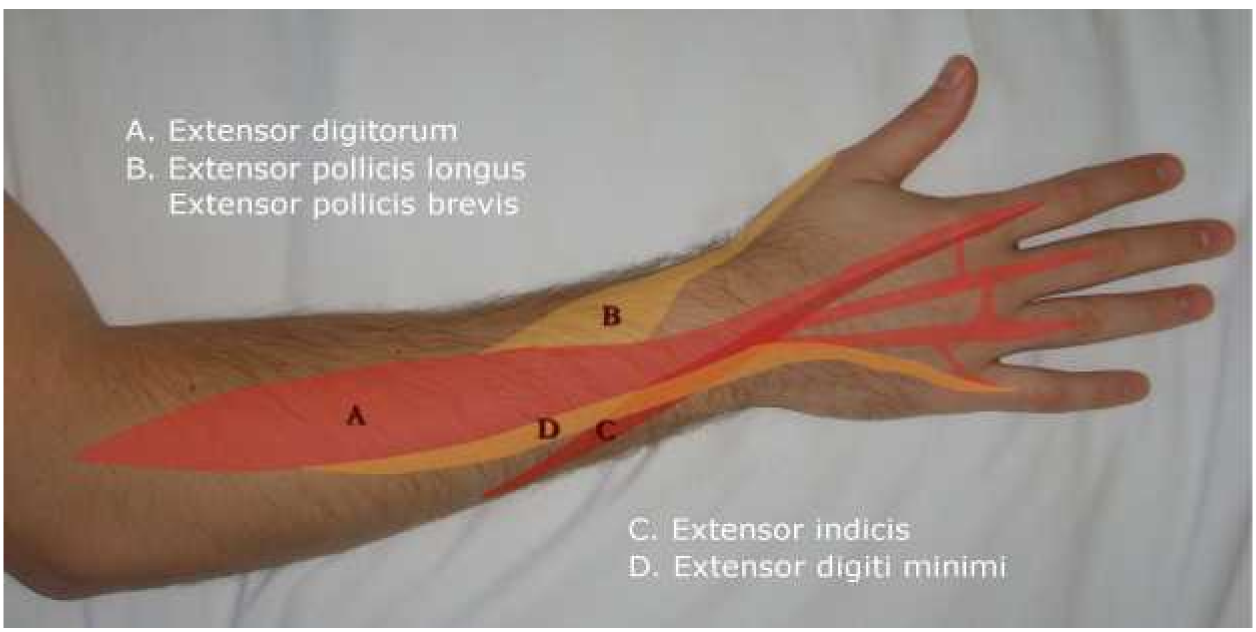


Figure (2.7):- The Approximate Locations of Muscles. [8]

The extensor indicis muscles are actually in the muscle layer below the extensor digiti minimi and extensor digitorum. Naturally, the deeper location of this muscle will have a negative impact on the energy that surface electromyography can detect.

The flexor muscles, generally located on the anterior side of the forearm, are responsible for flexion of the finger joints. For continued grasp control, following the initial classification, the flexor muscles should be monitored with additional electrodes. Ideally, the EMG collected from these muscles would indicate the closing of a grasp, the continued maintenance of a grasp, and the degree of tension used to maintain the grasp, as shown in figure (2.7).

2.2 Muscle Fibers

Muscle Fibers are formed during development from the fusion of several undifferentiated immature cells known as myoblasts into long, cylindrical, multi-nucleated cells. Differentiation into this state is primarily completed before birth with the cells continuing to grow in size thereafter. Skeletal muscle exhibits a distinctive banding pattern when viewed under the microscope due to the arrangement of cytoskeletal elements in the cytoplasm of the muscle fibers.

The principal cytoplasmic proteins are myosin and actin (also known as "thick" and "thin" filaments, respectively) which are arranged in a repeating unit called a sarcomere. The interaction of myosin and actin is responsible for muscle contraction.

- **Functional Properties of muscle fibers :-**

1) Peak Force.
2) Contraction velocity.
3) Resistance to fatigue.
4) Actino-myosin ATPase activities.

Four main types are commonly identified, although further sub- group are known. For our purposes, we will focus on the four major types described here:-

1) Fast-twitch fibers - used in Anaerobic Exercise:

(Short, high energy exercise)

a) Two types of Fast - twitch fibers (A and B).

b) Fast-twitch fibers are more glycol tic than Slow-twitch fibers.

c) More explosive.

d) Exercises such as weightlifting and sprinting.

2) Fast- twitches fibers:

a) Fast oxidative glycolytic (FOG)- these fibers have plenty of energy and oxygen.

b) Fast and fatigue resistant (maintain force production after many contractions).

3) Fast-twitch B fibers:

a) Fast glycolytic (FG)- these fibers have a low oxygen capacity making it hard to complete multiple contractions without rest.

b) Fast and fatigable (high force production but fatigued after only a few contractions).

c) Low oxidative capacity.

4) Slow-twitch fibers- used in Aerobic Exercise (long, constant energy):

a) Red=slow oxidative.

b) More oxidative.

c) Mitochondria (cells power source, gets energy out of glucose in respiration) are bigger and there are more of them.

d) More capillarieo More myoglobin (a protein with oxygen bound to it so that there is an oxygenreserve for long periods of exercise) .

e) Long twitch times, low peak forces, high fatigue resistance.

f) Exercises such as long distance running and bike riding.

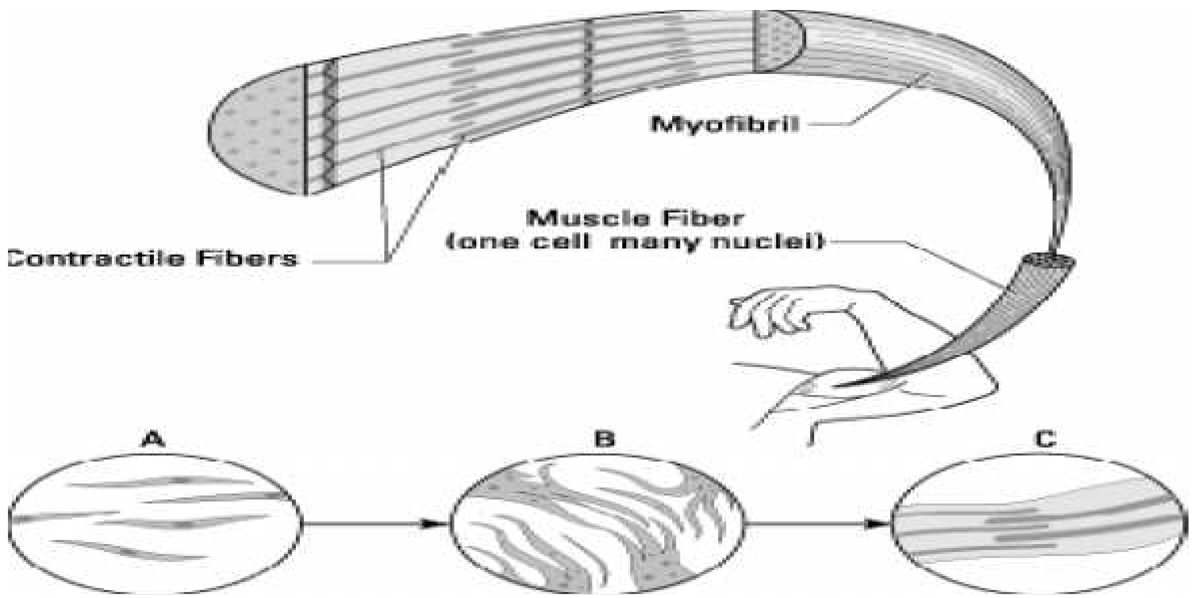


Figure (2.8):- Skeletal Muscles Move by Contracting. [9]

Each muscle is composed of tightly packed bundles of muscle Fibers, each containing proteins, which are responsible for muscle movement. Differentiation of muscle cells begins early in embryonic development. Myoblasts (A), the precursors of skeletal muscle cells, fuse together (B), to form multinucleated cells which eventually develop into myofibrils containing contractile fibers (C), as shown in figure(2.8).

After explain that previously, in our project will be the sensory neuron is inoperative, so we will compensated it by take the electrical signal from the motor neuron by using "Electrical stimulation of both sensory and motor nerves", it is used to record the reflex response of the muscle, however by:

1) At low stimulating levels some of sensitive sensory nerves are activated, but the motor nerves are not and hence **M** response is not seen. Also AP of the sensory nerves moves to spinal cord and generate reflex response.
2) For moderate stimuli both motor nerves and sensory nerves are stimulated and two responses are seen (**M** and **H**).
3) For large stimuli only **M** response is seen, as shown in figure (2.9).

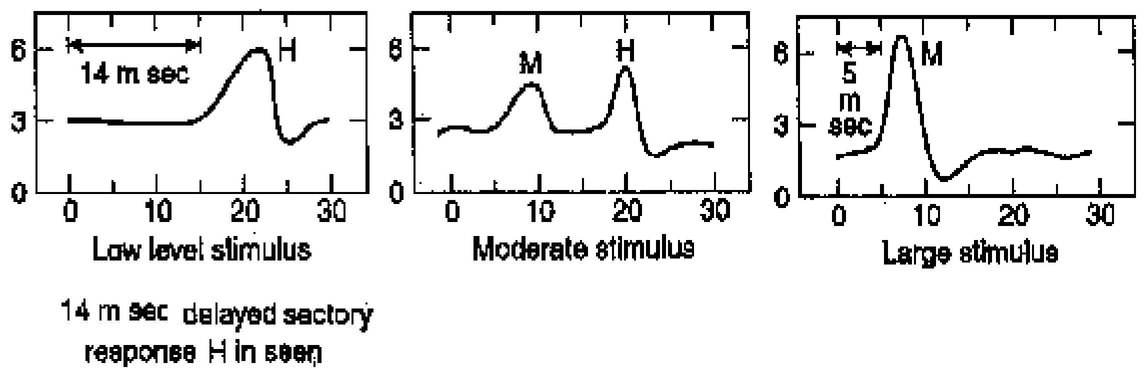


Figure (2.9):- Electrical stimulation of both sensory and motor nerves in low, moderate and high levels.

2.3 Optimal Electrode Placement

There are several factors that must be considered and addressed in order to ensure effective EMG signal detection. To receive maximum results from your stimulation, it is important to place the electrodes correctly. Electrodes from the same pair should be placed over the same muscle (surface electrodes must be placed parallel to the muscle fibers).

The optimum placement varies slightly from person to person, so we try moving the electrodes around until you get the most comfortable and effective contractions. There are many company offers different sizes of electrodes. Small electrodes are preferably used on smaller muscles and large electrodes on larger muscles. Before placing the electrodes on your body, be sure to always wash and dry the skin in order to ensure good conductivity. be sure to only place electrodes on healthy skin. And we should never place electrodes closer than 3 cm from each other.

The figure (2.10) shown muscle stimulation, the electrodes placed over or nearby the painful area.

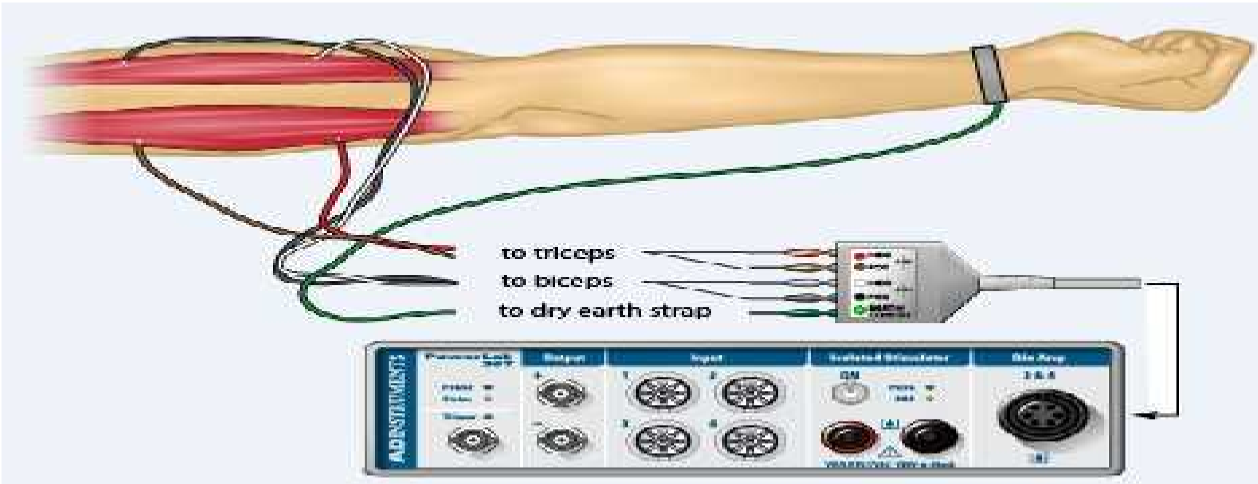


Figure (2.10):- Muscle Simulation. [10]

2.4 Skin Preparation and Electrode Placement

In order to minimize the impedance between the electrode-skin contacts, recommends that the skin surface be shaved of any hair and dead skin cells at the target location. Dry shaving works well for removing the dead skin cells. Once shaved, the skin should be cleaned with alcohol and allowed to dry before the electrodes are placed, as shown in figure (2.11).

Then, to ensure that the electrode is in the correct location, first secure the body reference electrode to the subject's wrist, on the anterior side. Then, using Siriprayoonsak's EMG Capture Program or the Establish Grasp Power procedure in the Real-Time EMG Classifier, test various positions around the target muscle area while performing a hand extension action with the corresponding muscle. The goal is to find the location that produces the greatest energy (highest amplitude) during activity and the least energy (noise) while in a rest position.

Figure (2.11):- Correct Location Test. [11]

2.5 Normalizing the Electrodes

The voltage potential of the EMG signal detected by the electrodes strongly depends on several factors, varying between individuals and also over time within an individual.

Thus, the amplitude of the EMG itself is not useful in group comparisons, or to follow events over a long period of time. The fact that the recorded EMG amplitude is never absolute is mainly due to the fact that the impedance varies between the active muscle fibers and electrodes and is unknown therefore, when comparing amplitude variables between measurements, normalization of some kind is required, and i.e. the EMG converted to a scale that is common to all measurement occasions.

Normalizing the signal amplitude with respect to force or torque is a commonly used technique. Typically, the EMG is related to a maximal contraction, or a sub maximal contraction at a known level of force.

3 Chapter Three

System Components

3.1 Hand System

3.1.1 EMG System

3.1.1.1 The Nature of EMG Signal

3.1.1.2 EMG Signal Collections

3.1.1.3 Surface Electrodes

3.1.1.4 Noise and Artifacts

3.1.1.5 EMG Implementation

3.1.1.5.1 Pre-Amplifier

3.1.1.5.2 Optical Isolation Circuit

3.1.1.5.3 Band-Reject Filter

3.1.1.5.4 Band-Pass Filter

3.1.1.5.4.1 Second-order Low Pass Active Filter circuit

3.1.1.5.4.2 Second-order Low Pass Active Filter circuit

3.1 Hand System

3.1.1 EMG System

3.1.1.1 The Nature of EMG Signal

Our muscles cause our body parts to move through contraction and relaxation. Each muscle consists of many muscle fibers, which range in length from a few millimeters (mm) to about 30 centimeters and have a diameter of between 10 and 100 micrometers. The muscle fibers will shorten to about 57% of their resting length during contraction. All of the muscle fibers making up a particular muscle do not contract simultaneously; rather, small groups of muscle fibers contract and relax together, as directed by their motor unit. The motor unit is the fundamental building block of an EMG signal. It consists of a motor neuron, its axon, and all of the muscle fibers that it controls. Countless motor units provide the pathway from the central nervous system to muscle fibers. However, individual motor units vary by size and by the number of muscle fibers that they innervate, from a few to over a thousand. Additionally, the innervated muscle fibers of multiple motor units are randomly intermingled (see Figure 3.1), meaning that a portion of a muscle may contain fibers belonging to between 20 and 50 different motor units.

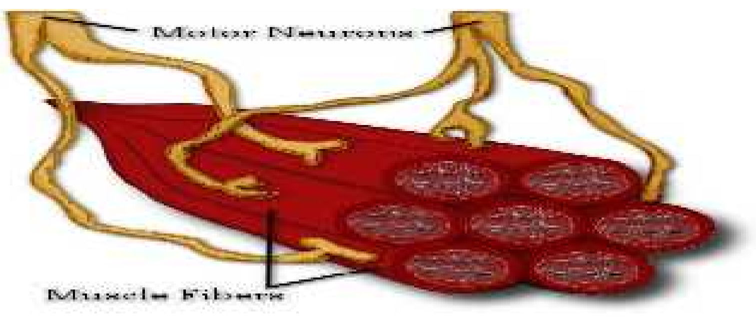


Figure (3.1): Depiction of Two Motor Units Controlling Intermingled Muscle Fibers.[12]

Just prior to muscle contraction and the application of force, an increasing number of motor units are recruited for muscle activation. The motor units are typically recruited according to their size, beginning with the smaller motor units first. The exchange of ions across the muscle fibers innervated by the recruited motor units results in small electrical currents, which combined for a particular motor unit is referred to as the motor unit action potential (MUAP) .The aggregate electric signal generated from all of the MUAPs in a detected area is referred to as the myoelectric signal, a recording of which is called an electromyogram (EMG). Note that this signal propagation precedes muscle.

Motion with about 10 to 100 mS. This 100 mS lead helps to minimize the length of the EMG signal is used to the hand grip , which is essential for the success of a real-time classifier and prosthetic hand control skeletal muscles contributes to the weight of the body , the skeleton classify muscle can rotating directly fastened by means of a joint, and the striated muscle to a bone or by means of tendon . Two or more groups of the skeletal muscles working against each other (s) extends . The skeletal muscle is composed of poly - nucleus cells. Action potential propagates from motor nerve to the muscle fibers controlled by the nerves, will cause and start after molecular mechanism. An immediate increase of calcium ions into the muscle cell reproduction After Identifying the nature of the EMG signal and their relationship with the motor unit , now we will talk about the EMG signal collection for Determined the amplitude and frequency of the discharge electrical muscle , and identify the factors All which depend on the quality of the EMG signal.

3.1.1.2 EMG Signal Collections

The basic component of skeletal muscle is the motor unit, which can be activated consciously. A number of the motor units construct a so-called muscle fiber (as explained previous in the second chapter). When a single motor unit (SMU) is activated by stimulation, a potential waveform with amplitude of 20-2000 µV, a discharge frequency of 6-30Hz, and an interval of 3-10 mS is observed. Thus, contraction of muscle fibers leads to a potential signal with larger amplitude and higher frequency.

It is electromyogram (EMG) as explained previous in chapter two. The motor unit regulates the fiber of skeletal muscle. Therefore, when a motor nerve is excited, the fibers controlled by this motor unit will all be activated. This process includes the production of action potential and contraction of muscle fibers. A single piece of muscle may be probably by hundreds of motor units. The nervous system makes an attempt to control different degrees of muscle activities by means of

Stimulating diverse numbers of motors units. More the motor units are excited; more the muscle fibers are activated.

The quality of an EMG signal is subject to several factors, including:

1) Timing and intensity of muscle contraction.
2) Distance of the electrode from the target muscle area.
3) Properties of the tissue overlying the muscle, skin thickness, and fatty tissue.
4) Properties of the electrodes and the amplifier.
5) Quality of the contact between the skin and electrode, including stability.

The first factors, timing and intensity of muscle contraction, encompass the data that we want to quantify and classify for each of the muscles involved in making a particular hand grasp. It is the changes in these factors that make distinguishing hand grasps using an EMG signal possible.

Naturally, the distance between the electrode and the target muscle area impact the quality of the EMG signal. Understanding the human anatomy and proper electrode placement, covered in sections 2.1 and 2.3, respectively, will help to minimize this distance.

There are several properties of the muscle and surrounding tissue that affect the EMG signal. The muscles are surrounded by extracellular fluid, fatty tissue, and skin, which cause inflections in the current field and varying levels of impedance.

.

Skin tissue has greater impedance than muscle tissue and therefore acts as a filter for the signal. With increasing tissue between the electrode and the target muscle, the amplitude of the EMG signals drops precipitously. Subjects with thicker skin or greater body-fat percentage will have more of the signal filtered before reaching the electrode, making proper electrode placement significantly more critical for those individuals. Muscle tissue impedance is directionally dependent, which also affects electrode placement.

Some studies have shown 7 to 10 times greater impedance levels in measurements taken perpendicular to the muscle fibers versus measurements taken in the parallel direction. The muscle tissue can also be affected by biochemical changes, which impact the conduction velocity of the muscle fibers and filtering properties of the muscle tissue. Biochemical changes occur over multiple sessions and even during the same session, to some degree. Ensuring a large training set and maintaining consistent electrode placement should mitigate some of these challenges. The properties of electrodes and amplifiers affecting the quality of the signal are addressed in detail in the next two subsections, while the quality of the electrode to skin contact is addressed in section.

After identifying that, will go to talk about electrodes, the identification of any kind of electrode kinds and the electrodes suitable location.

3.1.1.3 Surface Electrodes

Human body consists of numerous liquid cells which contain different electrolyte ions. The intracellular liquid includes ions of potassium, sodium and chloride. Action potential comes from the variations of ion concentration. When an electrode is used to detect action potential, the so-called interface potential will be generated. Imagine, when a metal electrode touch certain electrolyte solution, two kinds of chemical reactions will simultaneously occur. One is oxidation reaction in which metal atoms will release electrons and become metal ions.

The order is reduction reaction in which electrons and metal ions will be combined together and become metal atoms. In the interface between metal and electrolyte liquid, the ions with positive and negative charges will move in an opposite direction and produce two ions layers with opposite electricity. The potential difference between two ion layers is called interface potential. Immersing different between metals into electrolyte liquids will lead to different levels of interface potential.

Thus, for measuring biological signals, it is necessary to choose a metal with low interface potential as an electrode material. This can avoid the excessive interface potential during measurement. In general, the biological signal range is from 50µV-1mV and the interface potential of metal is in the range of 0.1-1V. Additionally, the interface potentials of electrodes vary with time.

There are two types of electrodes used in the recording of the EMG signals; surface electrodes and needle electrodes.

While needle electrodes are inserted through the skin into the muscle tissue, surface electrodes are placed on the surface of the skin. In this project, surface electrodes (Ag/AgCl) are used as they are easy to use and can be applied without pain. Surface electrodes come in many varieties mostly characterized by number of contacts, as figure (3.2). Nowadays silver-silver chloride (Ag/AgCl) is the most used material for the production of electrodes. This kind of electrode is principally made by silver. There is a thin layer of AgCl formed by the contact between silver and electrolyte solution. And AgCl provides silver (Ag^{+}) and chlorine (Cl^{-}) ions a bi-directional exchange.

The detected amplitude normally ranges up to 5 mV for surface electrodes and up to 10 mV when using needle electrodes .The cut-off frequency of the surface electrodes vary from 10 to 1000 Hz. As the signals obtained are too low, noise is a big problem and it must be considered in the design of the system.

The motion artifact in the electrode skin interface is one of the reasons of noise caused the electrodes, which has frequencies 0-10Hz. The use of high-pass filtering, shielded cables, carefully taping to reduce cable movement and mounting the amplifier near the electrodes can minimize this effect.

The electrode placement and location has a big importance in the EMG recording, surface electrodes must be placed parallel to the muscle fibers. The skin must be cleaned and electrode conducting jell must be used for better results. Reference electrodes must be used near the bony parts.

Figure (3.2): Surface Electrodes. [13]

3.1.1.4 Noise and Artifacts

EMG recording can be interference by noise from different sources, not only by the noise from the bioelectric generator or active cell but also from the electrical fields that occur around lead cables and electrode.
Electrical fields such as power lines, computer monitors, transformers, or even EMG amplifier itself might cause noise that wills interference the signal. Because of the electronic components acting as antennas, recording devices, ambient noises, motion artifacts the design of the amplifier should have been designed considering the noise factors.

Ambient noise can be generated from any electric device that crates electromagnetic field. The ambient noise cannot be avoided, it occurs primarily between the 50-60Hz band.

Two of the important parameters in bioelectric amplifiers are noise and drift. Drift is the change in output signal voltage due to changes in operating temperature and noise, in this case, is the thermal noise generated in resistances and semiconductor devices. Instrumentation amplifier is used in the pre-amplification stage of the project to perform the crucial differential signal combination and it is the solution to both high-gain and high-input impedance prop-lems. Instrumentation amplifier consists of three operational amplifiers; two non-inverting followers as input amplifiers followed by a differential amplifier. [14]

3.1.1.5 EMG Implementation

At the end of this section we want to get out with the implementation full of the EMG system so that it has the surface electrodes (explained previously), pre-amplifier, isolation circuit, band-reject filter, band-pass filter, gain amplifier, half-wave rectifier, integrator and buffer circuit.

3.1.1.5. 1 Pre-Amplifier

This pre-amplifier uses a two non-inverting amplifier and a typical differential amplifier circuit, which contains two inputs (positive input and negative input). The differential amplifier circuit subtracts two inputs and amplifiers the difference, as shown in Figure (3.3).

To get the right level of the input signal, we need a body reference circuit which works as a feedback from the inputs. Whenever the body temperature changes or signal changes due to noise introduced by the body, this body reference will help maintain the correct level of signal. In each input channel, there is one body reference feedback.

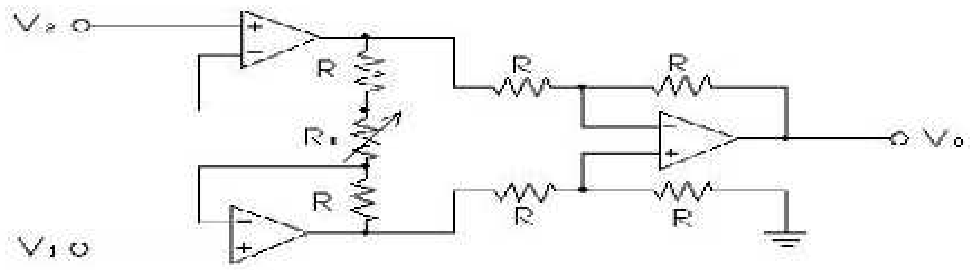


Figure (3.3):- Pre-Amplifier Circuit.

We will replace this circuit by electronic piece called AD620, because it Easy to use, low noise, high CMRR, and high Z_{in}, and high accuracy that requires only external resistor to set the gain of circuit, as shown in Figure (3.4).

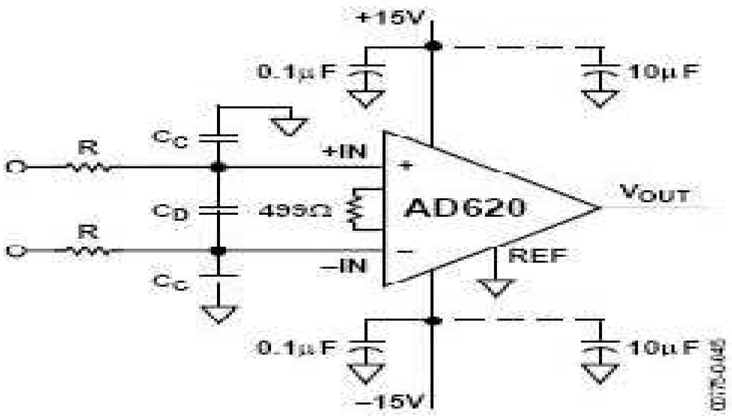


Figure (3.4):- AD620 Implementation. [15]

3.1.1.5.2 Optical Isolation Circuit

An isolation amplifier (also called a unity-gain amplifier) is an op-amp circuit which provides isolation of one part of a circuit from another, so that power is not used, drawn, or wasted in a part of the circuit the purpose of isolation amplifier isn't to amplify the signal. The same signal that is input into the op amp gets passed out exactly the same. This means that output voltage is the same exact as the input voltage.

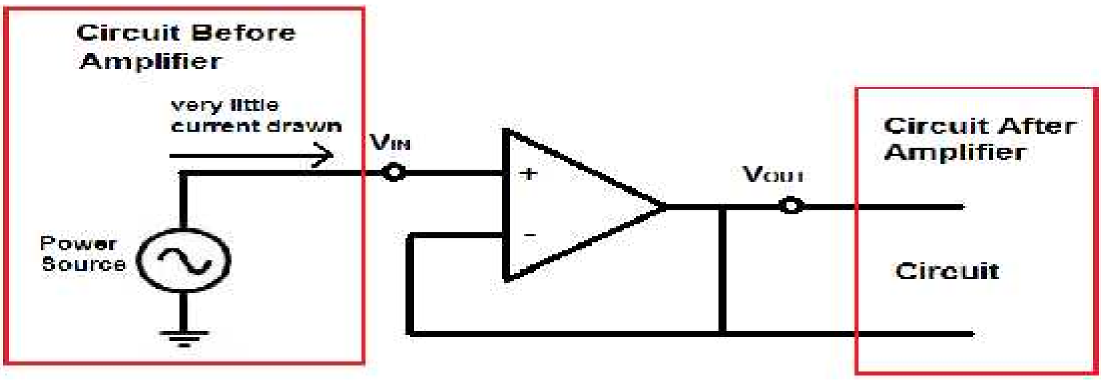


Figure (3.5):- Isolation Amplifier Circuit.

Figure (5.3) illustrates a little current from the power source above. Because the op amp has such high impedance, it draws very little current. The first part of the circuit, then, is undisturbed, and, thus, is isolated from the second part of the circuit. The op amp serves as an isolation device so that practically no current gets drawn and transferred to the second part of the circuit (circuit after the op amp), because its impedance is so high. Isolation amplifiers serve as buffers. They do not amplify signals but serve to isolate parts of circuits or different circuits from each other.

In our circuit, it is Optical connection between the pre-amplifier and the band-reject filter (A*v*=1).
The isolation is completed by an optical method:

- Optically coupled.
- Electrically isolated.

We will use in our project opt-coupler isolation (4N35), the functional block diagram as shown in figure (3.6).

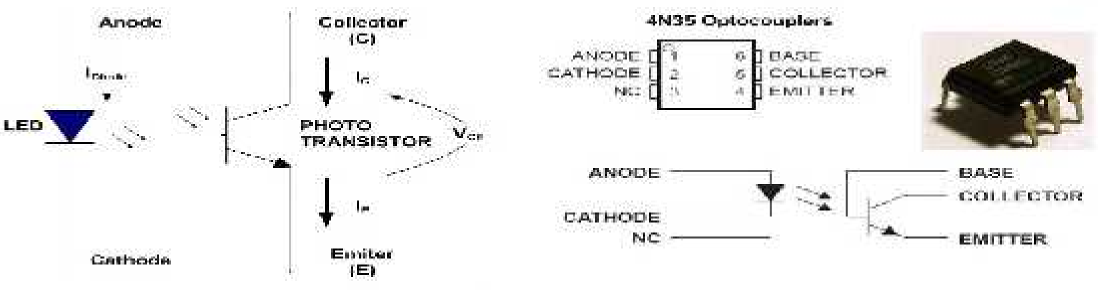


Figure (3.6):- Functional Block Diagram of The Opt-Coupler (4N35). [16]

3.1.1.5.3 Band-Reject Filter

Also called band-elimination, band-stop, or notch filters, this kind of filter passes all frequencies above and below a particular range set by the component values to neglect the wire noise. Not surprisingly, it can be made out of a low-pass and a high-pass filter, just like the band-pass design, except that this time we connect the two filter sections in parallel with each other instead of in series, as figure (3.7).

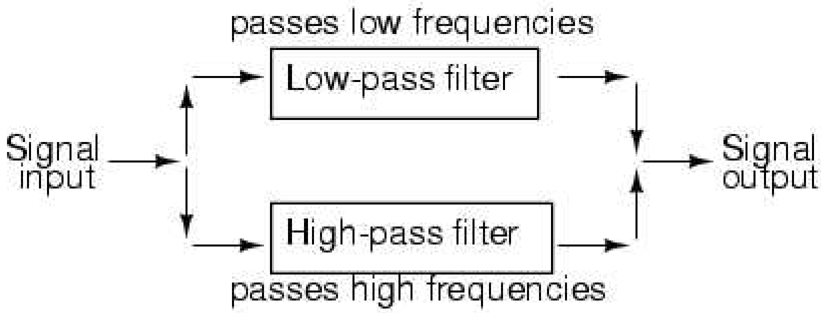


Figure (3.7):- System Level Block Diagram of a Band-Reject Filter.

Band rejection filters are used when relatively wide band of frequencies need to be rejected, is the opposite of a band-pass filter, as in figure (3.8).

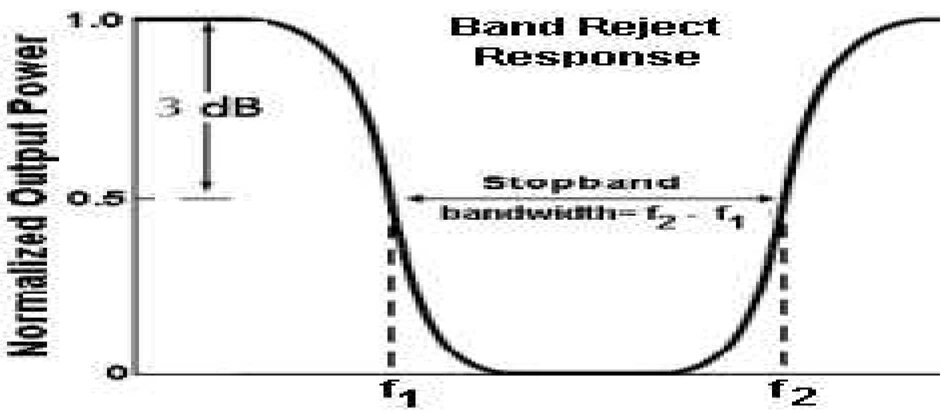


Figure (3.8):- Band-Reject Filter Frequency Response. [17]

3.1.1.5.4 Band-Pass Filter

Used in electronic systems to separate a signal at one particular frequency or a range of signals that lie within a certain "band" of frequencies from signals at all other frequencies. This band or range of frequencies is set between two cut-off or corner frequency points labeled the "lower frequency" (ƒL) and the "higher frequency" (ƒH) while attenuating any signals outside of these two points.

3.1.1.5.4.1 Second-order Low Pass Active Filter circuit

- Determines the cut-off point for high frequencies.
- The voltage gain and cut-off frequency equal:

$$A_V = 1 + \frac{R_2}{R_1} \qquad F_C = \frac{1}{2\pi * \sqrt{R_3 R_4 C_1 C_2}}$$

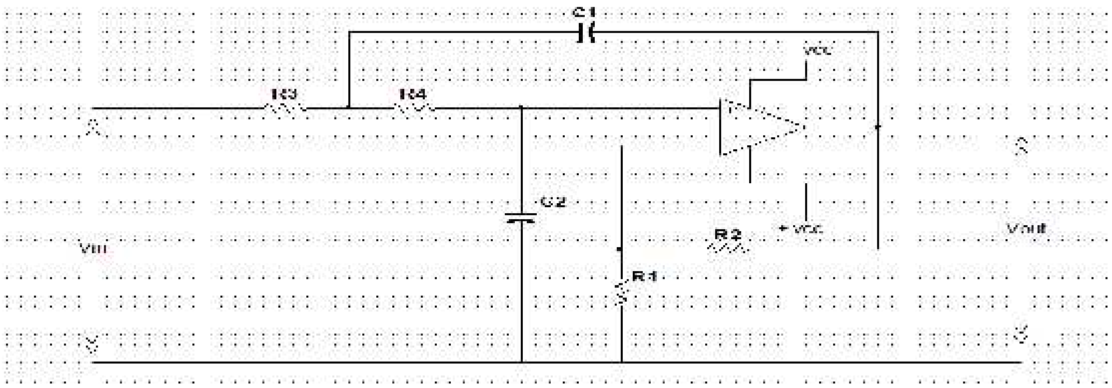


Figure (3.9):- Second-Order Low Pass Active Filter Circuit.

Second-order (two-pole) active filters are important because higher-order filters can be designed using them. By cascading together first and second-order filters, filters with an order value, either odd or even up to any value can be constructed. In the next tutorial about filters, we will see that Active High Pass Filters can be constructed by reversing the positions of the resistor and capacitor in the circuit.

3.1.1.5.4.2 Second-order High Pass Active Filter Circuit

Determines the cut-off point for high frequencies

The voltage gain equal: $A_V = 1 + \frac{R_2}{R_1}$

Cut-off frequency equal :

$$F_C = \frac{1}{2\pi * \sqrt{R_3 R_4 C_1 C_2}}$$

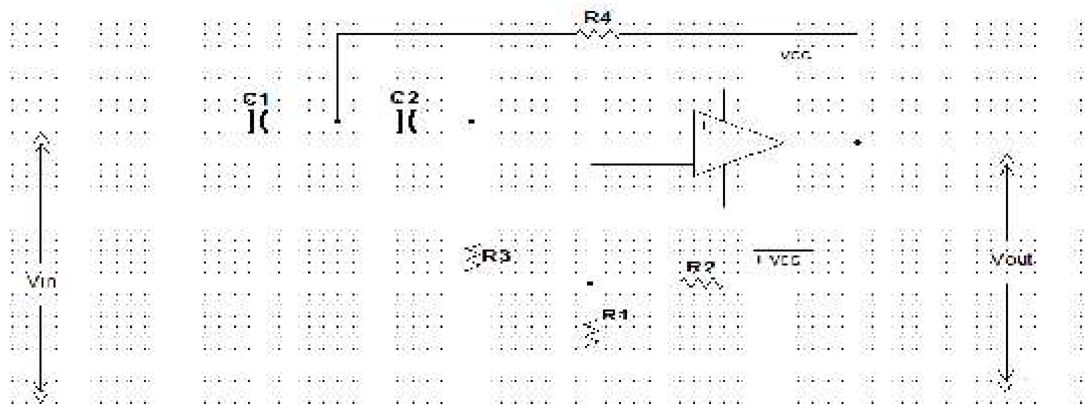


Figure (3.10):- Second-Order High Pass Active Filter Circuit.

Active Band Pass Filters can be constructed by cascading together a high pass and a low pass filter. Simple Active Band Pass Filter can be easily made by cascading together a single Low Pass Filter with a single High Pass Filter as shown in figure (3.11).

Figure (3.11):- Active Band Pass Filters Construction.

The cut-off or corner frequency of the low pass filter (LPF) is higher than the cut-off frequency of the high pass filter (HPF) and the difference between the frequencies at the -3dB point will determine the "bandwidth" of the band pass filter while attenuating any signals outside of these points. One way of making a very simple Active Band Pass Filter is to connect the basic passive high and low pass filters we look at previously to an amplifying op-amp circuit as shown in figure (3.12).

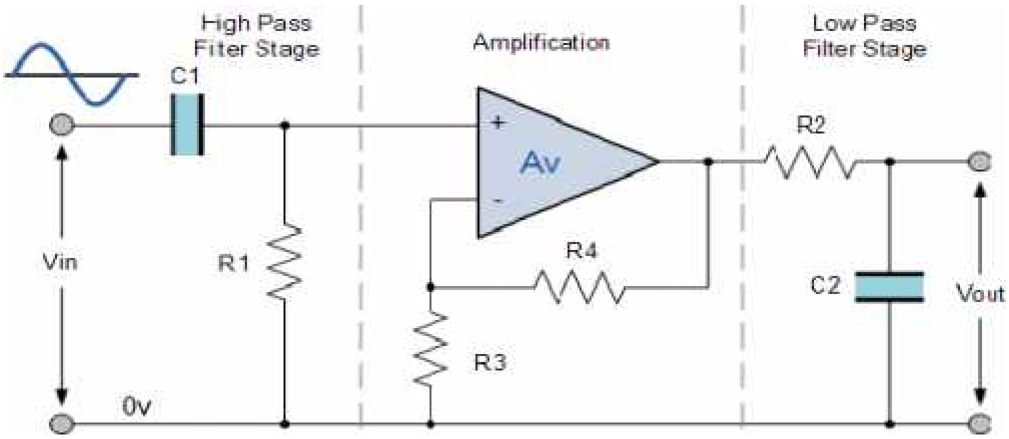


Figure (3.12):- Active Band Pass Filter Circuit.

This cascading together of the individual low and high pass passive filters produces a low "Q-factor" type filter circuit which has a wide pass band. The first stage of the filter will be the high pass stage that uses the capacitor to block any DC biasing from the source. This design has the advantage of producing a relatively flat asymmetrical pass band frequency response with one half representing the low pass response and the other half representing high pass response as shown in figure(3.13).

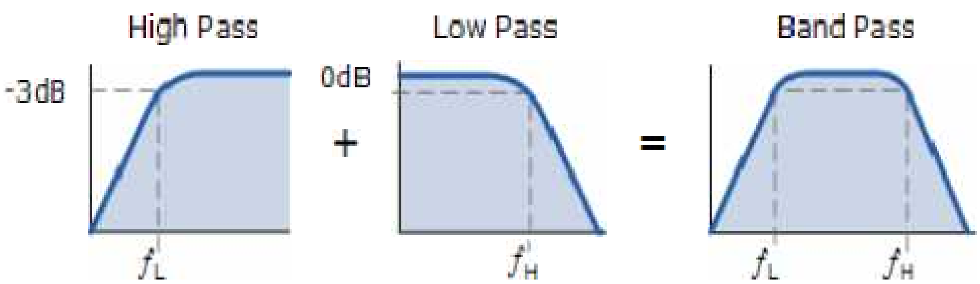


Figure (3.13):- Band-Pass Filter Response.

The amplifier also provides isolation between the two stages and defines the overall voltage gain of the circuit. The bandwidth of the filter is therefore the difference between these upper and lower -3dB Points. The normalized frequency response and phase shift for an active band pass filter will be as shown in Figure (3.14).

- **Active Band Pass Frequency Response:**

The passive tuned filter circuit will work as a band pass filter, the pass band (bandwidth) can be quite wide and this may be a problem if we want to isolate a small band of frequencies. Active band pass filter can also be made using inverting operational amplifier. So by rearranging the positions of the resistors and capacitors within the filter we can produce a much better filter circuit as shown below. For an active band pass filter, the lower cut-off -3dB point is given by ƒC2 while the upper cut-off -3dB point is given by ƒC1.

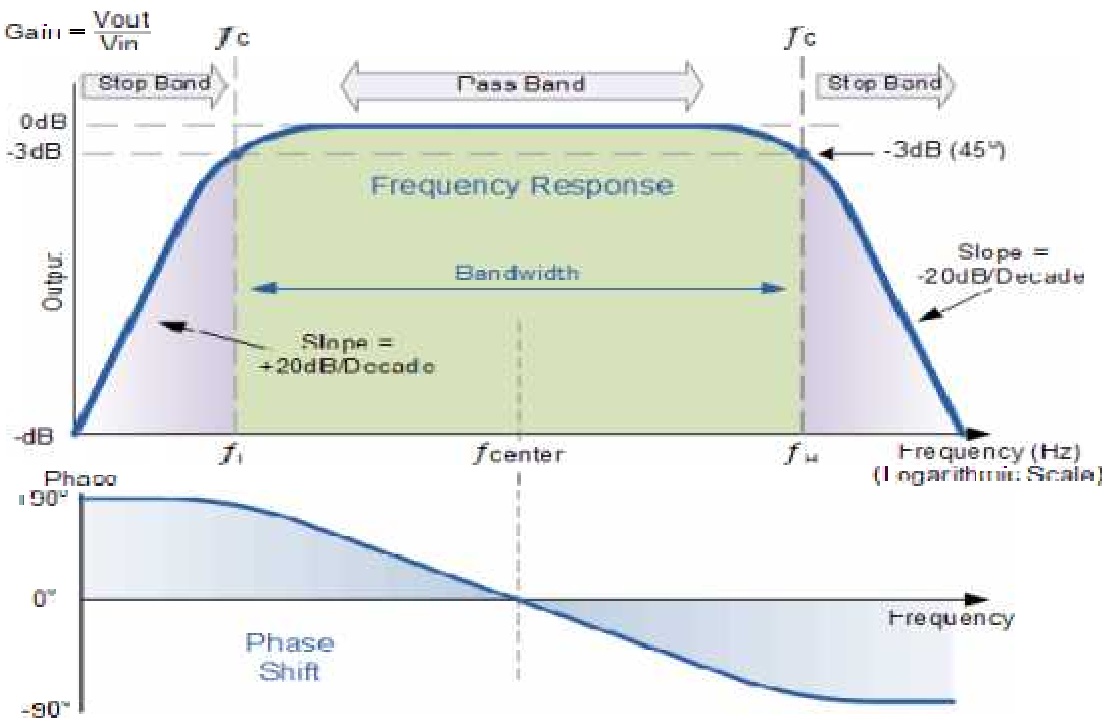


Figure (3.14):- The Normalized Frequency Response and Phase Shift for an Active Band Pass Filter. [18]

3.1.1.5.5 Gain Amplifier

Gain amplifier is as a non-inverting amplifier, such that; the output voltage changes in the same direction as the input voltage. that the non-inverting input of the operational amplifier will need a path for DC to ground; if the signal source might not give this, or if that source requires a given load impedance, the circuit will require another resistor — from input to ground. In either case, the ideal value for the feedback resistors (to give minimum offset voltage) will be such that the two resistances in parallel roughly equal the resistance to ground at the non-inverting input pin, as in figure (3.15). we will use the gain amplifier, because through change a gain of it. We get the output needed. .

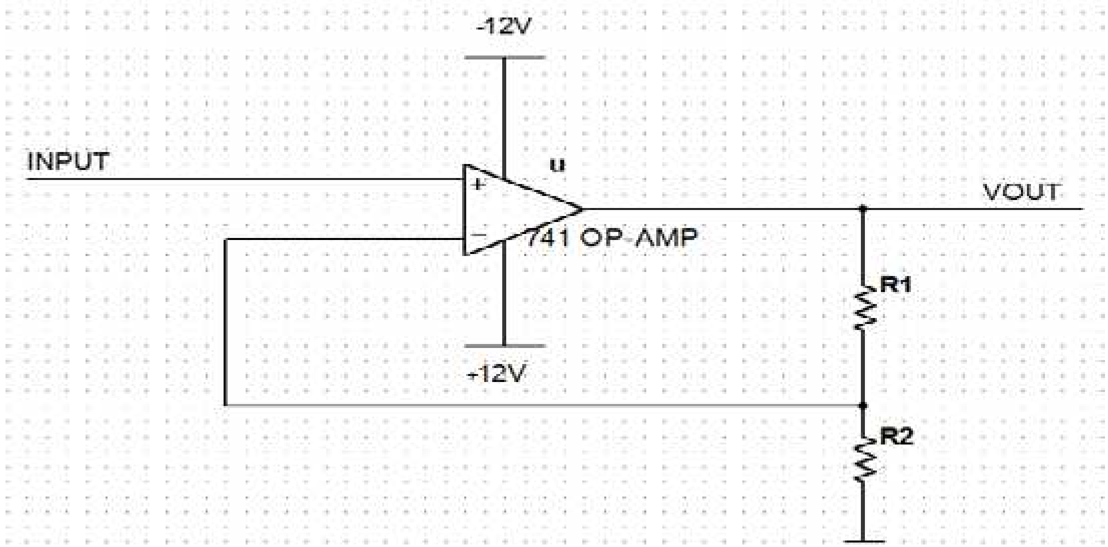


Figure (3.15):- Gain Amplifier Circuit. [19]

3.1.1.5.6 Half-Wave Rectifier

After that we need only take the positive wave of the signal, so we will use the half-wave rectifier. It is also known as a super diode, is a configuration obtained with an operational amplifier in order to have a circuit behave like an ideal diode and rectifier, it is useful for high-precision signal processing.

When the input is positive, it is amplified by the operational amplifier which switches the diode on. Current flows through the load and, because of the feedback, the output voltage is equal to the input voltage.

When the input is greater than zero, D1 is OFF and D2 is ON, so the output is zero because one side of R_2 is connected to the virtual ground, and there is no current through it. When the input is less than zero, D1 is ON and D2 is OFF, and the output is like the input with an amplification of $-R_2/R_1$. This circuit has the benefit that the op-amp never goes into saturation, as shown in figure (3.16).

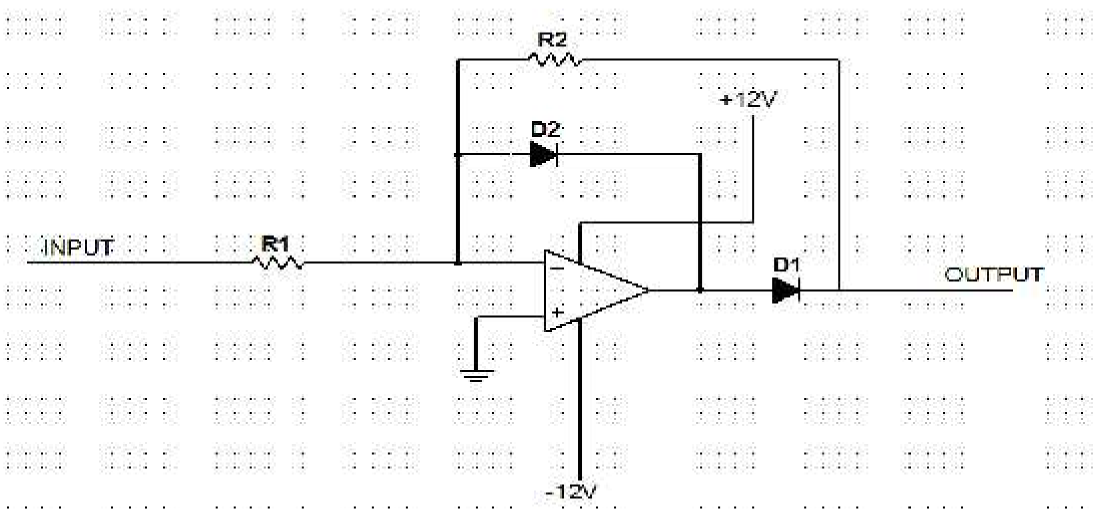


Figure (3.16):- Half-Wave Rectifier Circuit. [20]

3.1.1.5.7 Dual-Comparator

After that we will have two signals, one coming from a biceps muscle and other from a triceps muscle, enter each one to the different comparator by using dual-comparator, such that, When reach the signal from the biceps muscle, go out signal from the first comparator to move the motor, but when reach a signal from the triceps muscle, go out signal from the second comparator to reverse the motor rotation. In other word (how move the hand, moves the motor). We will use in our project (LM319D) dual comparator, The LM319 is a dual high speed voltage comparator designed to operate from a single +5V supply up to ±15V dual supplies, as shown in figure (3.17).

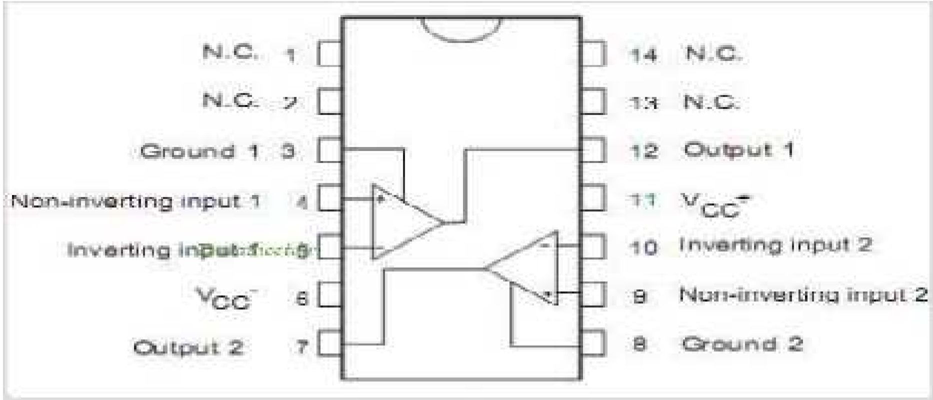


Figure (3.17):- LM319D (Dual-Comparator) Implementation. [21]

3.1.1.6 Block Diagram of completed EMG System

After identified all previously, now we will be show the block diagram of completed EMG system, as in Figure (3.18).

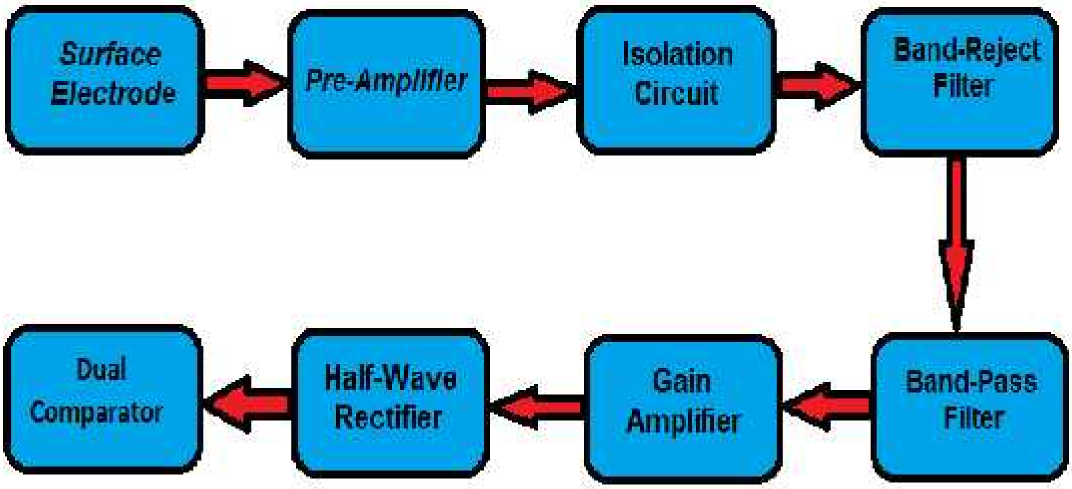


Figure (3.18):- Block Diagram of The Completed EMG System.

3.1.2 Motor Drive

After getting the electrical signal from the hand muscle for either contraction or diastole by an EMG device, as explained previously, introduced this signal to the microcontroller (Arduino) for control movement motor is installed on the side arm hand. So, that if the signal is outside of the bi muscle; motor rotates counter clock wise to contraction of hand, else if the signal is outside of the tri muscle, motor rotates clock wise to diastole of hand.

We used DC motor type of power window LH as shown in figure (3.1٩), Where we will design it in order to get moves 90 degrees and this movement is very suitable for the movement of the hand, it also has high torque approximately 30 kg.cm, speed of about 85 RPM, size of acceptable and needs to be fed by a 12 V.

Figure (3.19):- Power Window Motor LH.[22]

3.2 Fingers System

In previous chapters, we have able to move the infected hand using the EMG signal that taken from the bi and tri muscles by a surface electrodes, But in order to take fingers signals from the muscles is so difficult and need to use a needle electrodes, and that need to surgery under the supervision of a doctor, and this is not available, to avoid this problem, we find a solution, which is take the fingers signals from the other right hand.

And we did it by installed a five flex sensors on the all fingers of the other right hand, when move this fingers will result from this sensors five signals, enter to the microcontroller to processing this signals as character and through serial pin in arduino. And to avoid contact wires in the hands of the patient and provide freedom of movement for him, we will use a wireless transfer data xbee module using a zigbee's technique . then uploading a code from first arduino to sending Xbee module, Which will be sending this code to receiving Xbee module installed on the infected hand through wireless characteristic, connect this Xbee module with other arduino to enter this code to it . And therefore, this code will move the servo motor as required. Now will recall all the pieces used full characteristics and principles operation each and explain why we used in detail.

3.2.1 Flex Sensor

Flex sensor are sensors that change in resistance depending on the amount of bend on the sensor , they convert the change in bend to electrical resistance – the more the bend , the more the resistance value .

The working principle as follows : the flex sensor are analog resistors they work as variable analog voltage dividers , inside the flex sensor are carbon resistive elements within a thin flexible substrate. More carbon means less resistance when the substrate is bent the sensor produces a resistance output relative to the bend radius . as shown in figure (3.20)

Figure (3.20):- Flex Sensors.[23]

The impedance buffer in the Basic Flex Sensor Circuit is a single sided Operational Amplifier, used with these sensors because the low bias current of the Op-Amp reduces error due to source impedance of the flex sensor as voltage divider, as shown in figure (3.21).

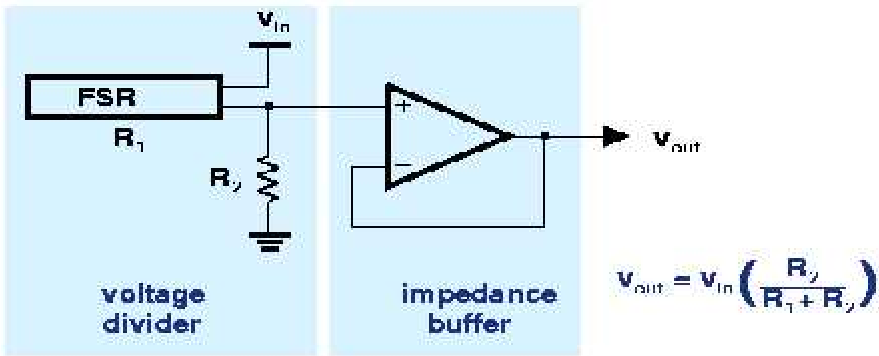


Figure (3.21) :- Basic Flex Sensor Circuit.

After fixed this flex sensors on the other right hand finger, we have become a five analog signals from the five fingers, and we connect after each flex sensor resistance of 1 KΩ for protection, then we will use are as an analog inputs to the first microcontroller, as shown in figure (3.22).

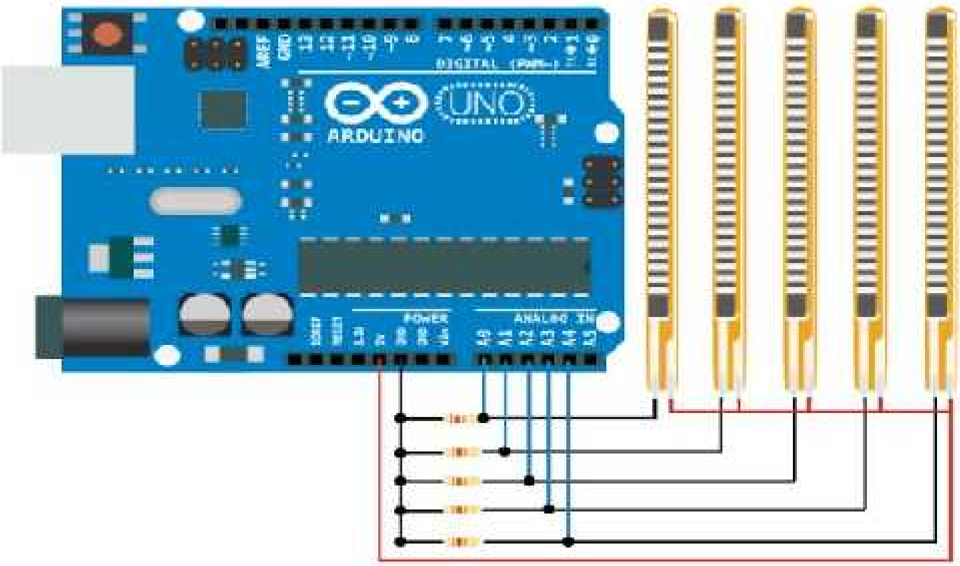


Figure (3.22):- How to Connect The Flex Sensor With a Microcontroller.

3.2.2 Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started, as shown in figure (3.23)

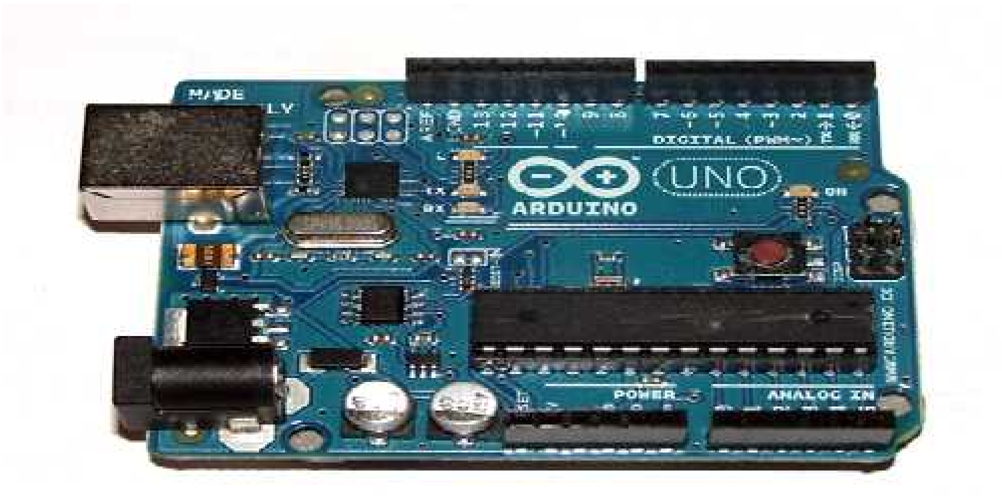


Figure (3.23):- Arduino Uno. [24]

Each of the 14 digital pins on the Uno can be used as an input or output, using pin Mode(), digital Write(), and digital Read() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 KΩ. In addition, some pins have specialized functions:

- **Serial**: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.
- **External Interrupts**: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attach Interrupt() function for details.
- **PWM**: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analog Write() function.
- **SPI**: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication using the SPI library.

The arduino is used as the core of the system, it captures analog signals from flex sensors, converts them to digital through the integrated ADC module and do the recognition process by using a lookup table; when the letter is recognized, a corresponding digital value will be sent via the TX pin (integrated serial module) to the XBee transmitter serial module board, by write asuitable code, we will explain it in the next chapters.

3.2.3 XBee Module

XBee is a wireless RF module using the wireless communication standard 802.15.4; it has longer range than Bluetooth but lower power consumption than WiFi (802.11). It has a 250 kbps RF data rate. It operates at 2.4 GHz. The XBee modules have sleep modes for extended battery life.

We will use two pieces of the XBee module, one as a transmitter and the last one as a receiver, and now we will explain how to connect are with each other based on the figure (3.24).

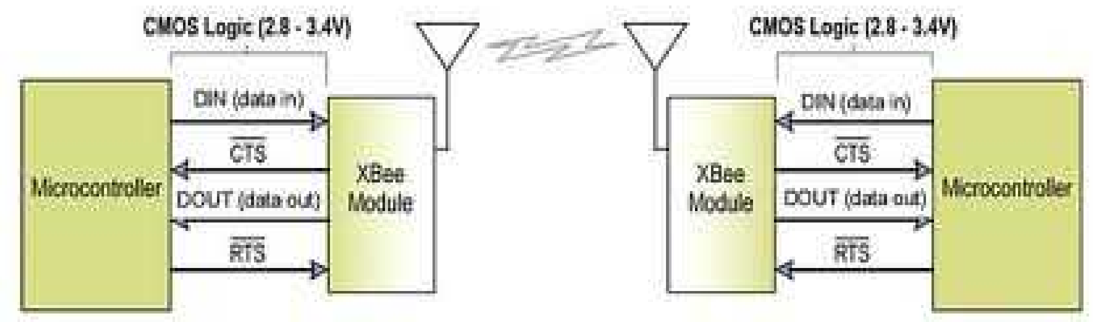


Figure (3.24):- System Data Flow Diagram in a UART-Interfaced Environment.

3.2.3.1 XBee transmitter

We will connect the first microcontroller with the XBee transmitter, such that; Devices that have a UART interface can connect directly to the pins of the RF module, data enters the module UART through the DI pin (pin 3) as an asynchronous serial signal. The signal should idle high when no data is being transmitted.

Each data byte consists of a start bit (low), 8 data bits (least significant bit first) and a stop bit (high), the serial bit pattern of data passing through the module, as shown in figure(3.25).

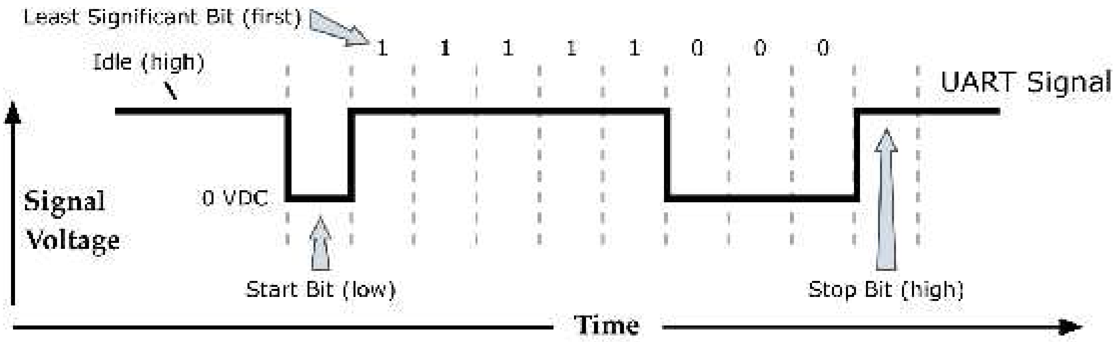


Figure (3.25) :- UART Data Packet 0x1F (Decimal Number " 31") as Transmitted Through The RF Module. [25]

Serial communications depend on the two UARTs (the microcontroller's and the RF) to be configured with compatible settings (baud rate, parity, start bits, stop bits, data bits). The UART baud rate and parity settings on the XBee module can be configured with the BD and SB commands, respectively.

When serial data enters the RF module through the DI pin (pin 3), the data is stored in the DI Buffer until it can be processed, When the DI buffer is 17 bytes away from being full; by default, the module de-asserts CTS (high) to signal to the host device to stop sending data [refer to D7 (DIO7 Configuration) parameter, CTS is re-asserted after the DI Buffer has 34 bytes of memory available.

Case in which the DI buffer may become full and possibly over flow; if the module is receiving a continuous stream of RF data, any serial data that arrives on the DI pin is placed in the DI Buffer, the data in the DI buffer will be transmitted over-the-air when the module is no longer receiving RF data in the network.

3.2.3.2 Xbee Reciever

When RF data is received, the data enters the DO buffer and is sent out the serial port to a second microcontroller, once the DO Buffer reaches capacity, any additional incoming RF data is lost, as shown in the figure (3.26).

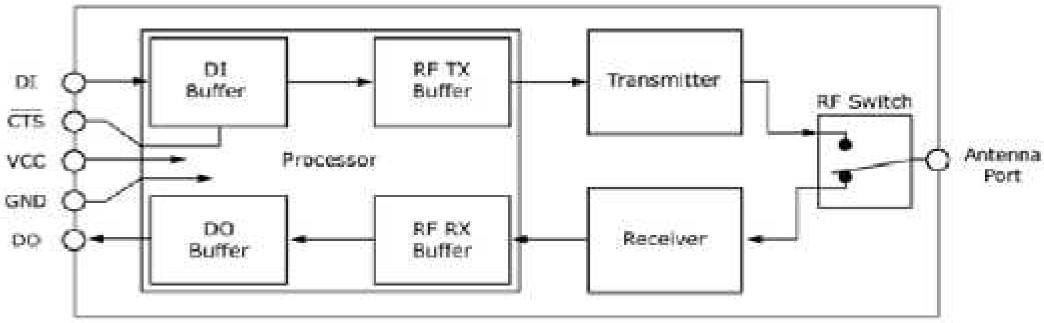


Figure (3.26):- Internal Data Flow Diagram. [25]

The second microcontroller will enter it two different inputs, the first one come from EMG device to control the motor movement to move the hand, and the last one come from the XBee receiver module to control a five servo motors to move the fingers.

3.2.4 Servo Motors

We have to control the servo motors using the microcontroller, so that when we move the fingers of the other hand right, servo motors moves are allowed to move the fingers of the infected hand also moved a similar right Other Hand**.**

Where they put the servo motors on the soles of the hand inside the plastic box, and connects with shaft every one of them copper wire is strong and taut dramatically transmission as Hey, connecting joints ferrous mounted on the fingers of the hand infected and in this way we were able to move the fingers of the hand are easy to smooth close to reality**,** as shown in figure (3.27).

Figure (3.27):- Servo Motor Place in The Design.

We will use servo motor type of high torque – standard size (**FS5105B**), is a powerful, low-cost, reliable servo for all your mechatronic needs. This servo is able to take in 6 volts and deliver 83.47 oz-in of maximum torque at 0.16 sec/60° and Rotation 180°, this is a tough little servo with a standard 3 pin powers and control cable, as shown in figure (3.28).

Figure (3.28):- Servo Motor High Torque - Standard Size (FS5105B). [26]

We used servo motors because it contains many advantages such as; a clear torque advantage for servo motors at the high speeds gained by electric actuators, When high speed and high torque is required, a significant edge goes to these type of motors, and A servo motor continuously reads in current position data vs. the commanded position data and provides current to the motor proportional to the degree of error. In summary, the inherent use of an encoder aids the servo motor in its ability to have a position fault error limit, ther clear advantage of using a servo motor is the capability of achieving high speed at relatively high torque values over a much larger amount of time.

The motor can better handle dynamic loading applications. Due to this extended time, a servo motor is capable of providing short bursts of additional torque over the entire speed spectrum of cylinder length. In situations where the load is dynamic, the reserve of torque allows more changing and flexible motion control, a major weakness of servo motors is its cost due to having the complex encoder feedback device in the hardware. All of the performance capability comes at a premium cost.

3.2.5 Power Circuit

3.2.5.1 Battaries (Power Supplies)

Any project in the electric field of industrial or other, where electronic or electrical pieces need a feed source for the work, these pieces differ in the amount of effort they need.

In our project there are several electric or electronic pieces need to source feed and vary the amount of effort they need, for example to the servo motors need to 5 V and 12 V need amplifiers, microcontrollers also require 5 V and XBee needs 3.3 V, so we choose the battery gives a larger effort our piece and we distribute the voltage on the other pieces by using the voltage dividers to reach the effort required for each piece.

Our project is a exoskeleton of hand for the paralyzed, the paralyzed person can't always stay close to the source of nutrition, so we will use 12 V portable battery, we fix it on the side of the person to facilitate the unimpeded movement, comes with this battery charger for shipment when it will be discharges, as shown in figure (3.29).

Figure (3.29):- Portable Battery 12v DC. [27]

3.2.5.2 Voltage Regulators

Regulators provide a power source which remains very close to a fixed value, independent of the load placed on it, provided that the current drawn doesn't exceed the rating of the device, the minimum and maximum output voltage specification for fixed voltage regulators indicated the values which can be expected with variations in load on the device, the same specification for adjustable regulators indicated the range of voltage output which can be achieved through external component.

We used two types of voltage regulators, the first LD1117-3.3 V for the XBee module, and the other is LM1084 5 V for the microcontrollers and the servo motors, as shown in figure (3.30).

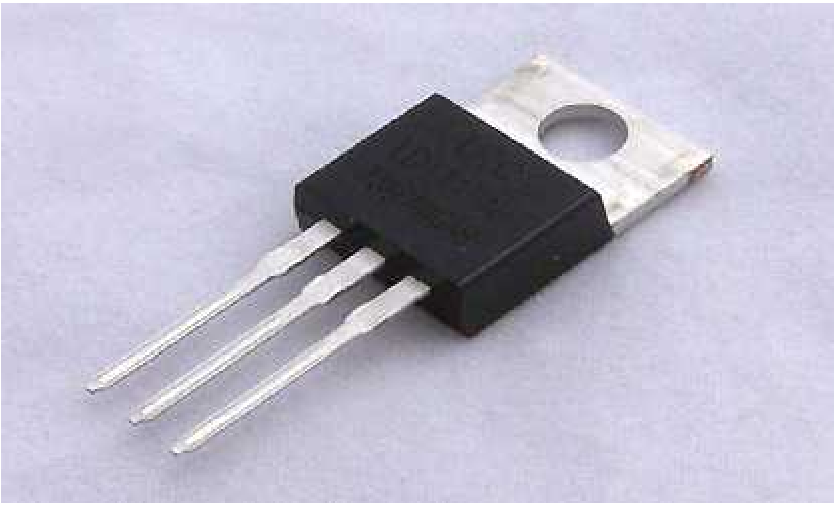


Figure (3.30):- Voltage Regulators. [28]

4

Chapter Four

Calculations and Measurements

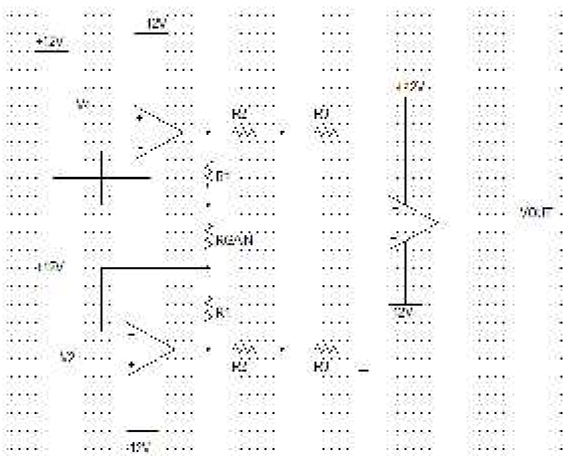
In this chapter we will calculate every input and output value of the devices to go out with the wanted results, for EMG device and DC motor practically.

4.1 EMG Device

4.1.1 Pre-Amplifier

The pre-amplifier circuit (Instrumentation amplifier usually with A*v*=10) is used for picking up the unipolar EMG signals.

And we used IC represent this circuit called AD 620, as shown in figure (4.1a+b)



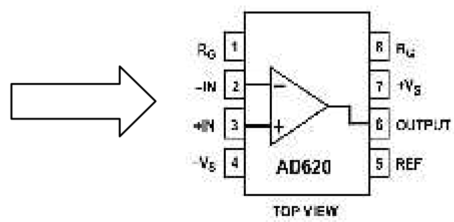


Figure (4.1a):- Pre-Amplifier Circuit Implementation.

Figure (4.1b):- AD620

Where R_g the gain resistance is is used to determine the gain of the amplifier.

$$A_v = \frac{49.4\ k\Omega}{R_g} + 1$$

We used gain (A_v) equal 10, then

$$10 = \frac{49.4\ k\Omega}{R_g} + 1 \quad \Longrightarrow \quad R_g = 5.48\ k\Omega$$

$R_g = 5.48\ k\Omega$,is used to control in the gain .

So, as tacked previous a potential waveform with an amplitude of 20-2000 µV

Then V_{in}=20-2000 µV, and Av=10.

Then V_{OUT} of the pre-amplifier = 20-2000 µV * 10 = 0.2-20 mV. [31]

4.1.2 Optical Isolation Circuit

Optical connection between the preamplifier and the band-reject filter (A*v*=1), as shown in figure (4.2).

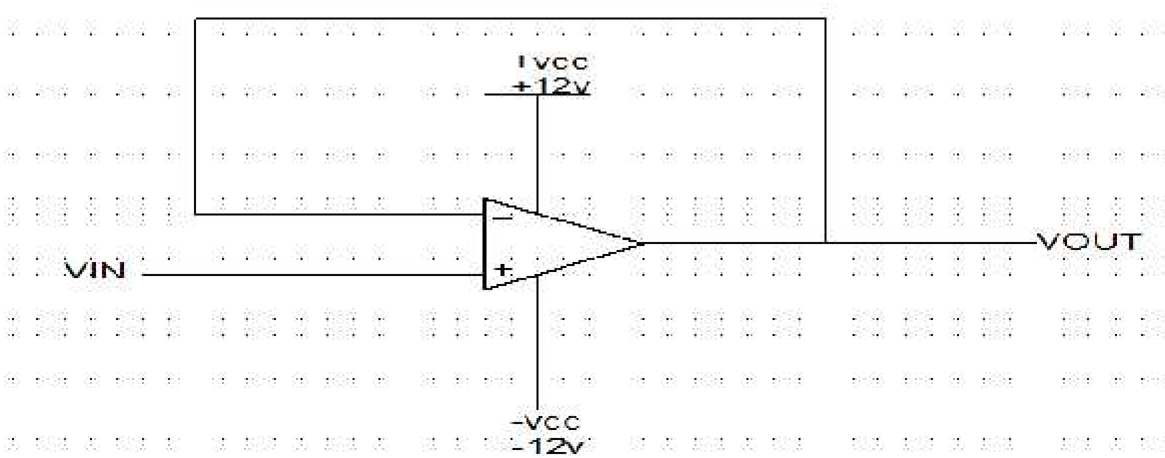


Figure (4.2):- Isolation Circuit.

Av = 1, then V_{in}= V_{OUT}

So, V_{OUT} = 0.2-20 mV.

4.1.3 Band-Reject Filter

The band-reject filter is used to remove the noise from power line (50 or 60 Hz).

- If (C_1=C_2, R_1=R_2, R_1=2R_3 and C_3=2C_1), as shown in figure(4.3) then :

The center frequency can be calculated by:

$$f_c = \frac{1}{2\text{®}\,C1\,R1} = 50\ Hz$$

Let C_1 = 1µF = C_2 ⟹ C_3 = 2 µF , then

50 = 1/[(6.28* 1µF)* R_1] ⟹ R_1 = 3.2KΩ = R_2

⟹ R_3 = 1.6 KΩ , 0 < R4 < (R1 + R2).

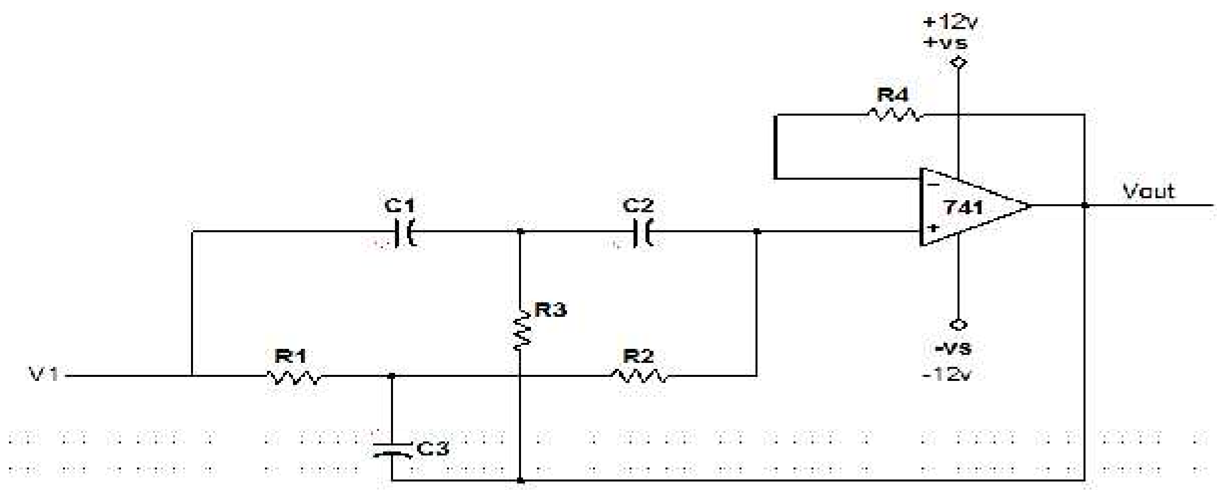


Figure (4.3):- Band-Reject Filter Circuit. [31]

4.1.4 Band-Pass Filter

The op-amp is used to construct an active 2nd order low-pass and high-pass filters. As shown in figure (4.4).

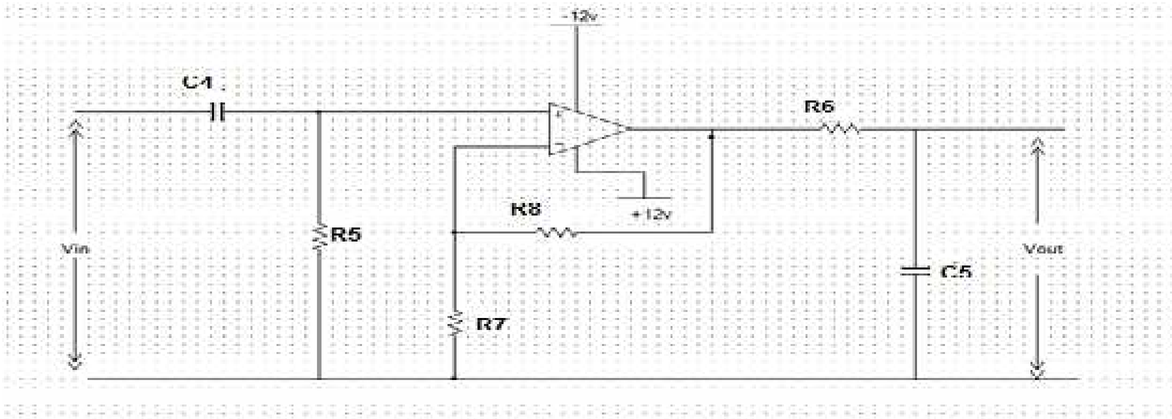


Figure (4.4):- Active Band-Pass Filter Circuit.

In Band-Pass Filter must a Av=1.56, to keep not increasing the noise of the signal.

$$A_v = \left(\frac{R_8}{R_7}\right) + 1$$

$$1.56 = \left(\frac{R_8}{R_7}\right) + 1 \Longrightarrow \left(\frac{R_8}{R_7}\right) = 1.56$$

Let $R_8 = 100\text{k}\Omega$ and $R_7 = 180\text{k}\Omega$

- The range of the frequency for band pass filter between (6 - 30 Hz) so ,

Such that, $F_{CH} = 6\,Hz$ and $F_{Cl} = 30\,Hz$.

- Suppose, C_4=1 μF and C_5 =1μF.

Such that, $F_{CH} = \frac{1}{2\pi R_5 C_4}$, then :

$$6 = \frac{1}{2*3.14*1\,\mu F*R_5} \Longrightarrow R_5 = 26.5\text{ k}\Omega.$$

$$\text{And}, F_{Cl} = \frac{1}{2 * \pi * R_6 * C_5}$$

Then, $30 = \frac{1}{2*3.14*1\mu F*R_6}$ $\Longrightarrow$ $R_1 = 5.3\ k\Omega$.

So, V_{OUT} = 1.56*(0.2-20) mV = (0.312 - 31.2) mV. [29]

4.1.5 Gain Amplifier

In this stage we can amplify the signal to any wanted value without any noise, that by use the gain amplifier, as shown in figure (4.5).

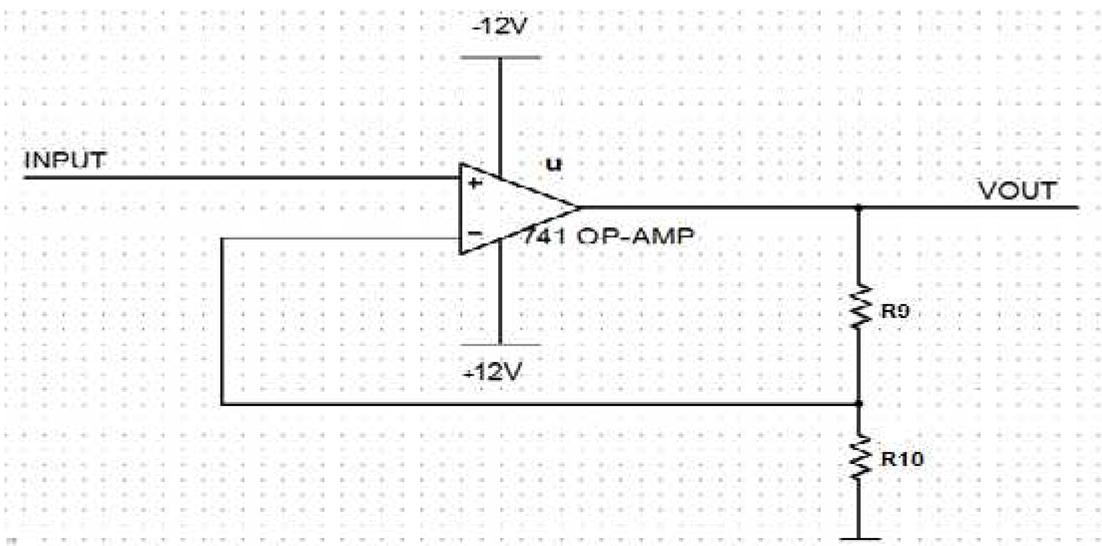


Figure (4.5):- Gain Amplifier Circuit.

As shown in figure (5.5), Suppose $R_1 = 100\,K\Omega$, $R_2 = 700\Omega$, then :

$$A_v = \frac{R_9}{R_{10}} + 1 = \frac{100K\Omega}{700\Omega} + 1 = 145.$$

Then, V_{OUT}= 145 * (0.312-31.2) = (0.045 – 4.5) V. [**31**]

4.1.6 Precise Half-Wave Rectifier Circuit

In this stage, we aim to take the positive part of the signal, so we will use the precise half-wave rectifier, as shown in figure (4.6)

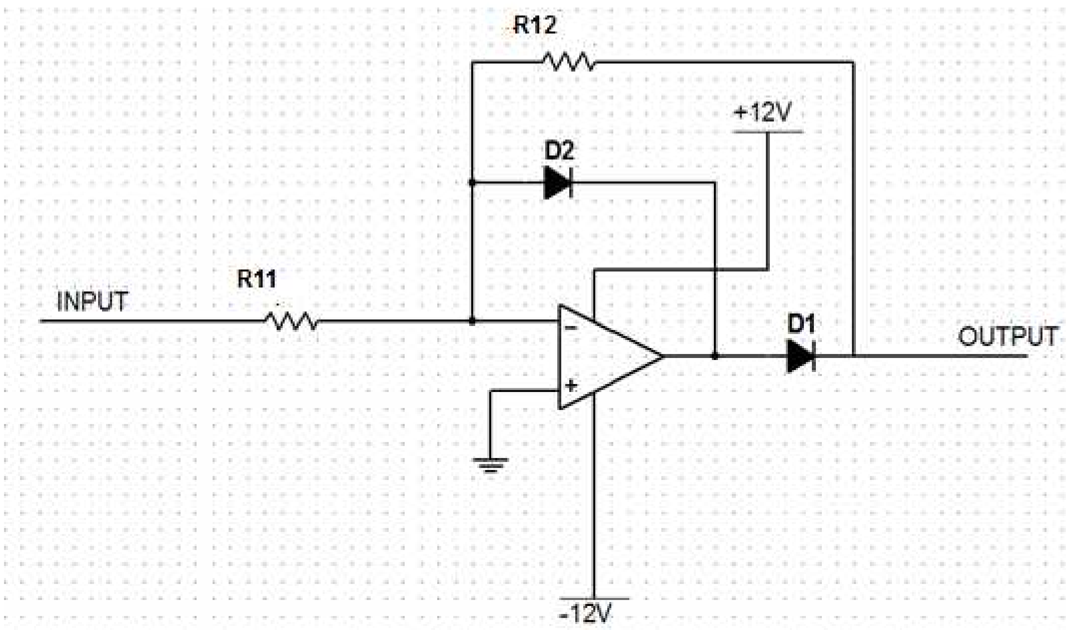


Figure (4.6):- Precise Half-Wave Rectifier Circuit.

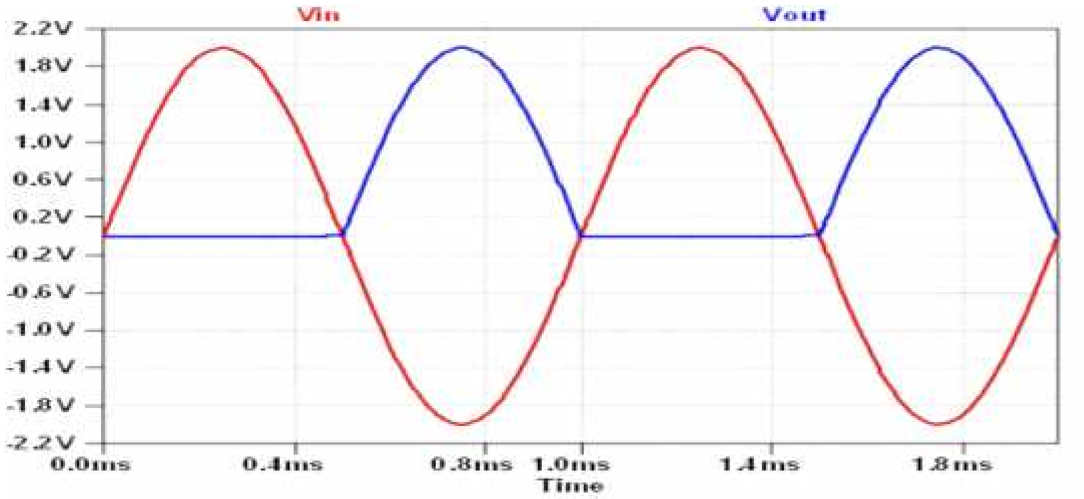


Figure (4.7):- Input-output Relationship of Half-Wave Rectifier Circuit.

Assume $R_{11} = R_{12} = 1\ K\Omega$

We used $R_{11} = R_{12}$ until the output voltage is have the same of amplitude for input voltage, then V_{OUT} = (0.045 – 4.5) V. [**31**]

4.1.7 Dual-Comparator

In this stage we want to get 5v exactly, so we will use a comparator, such that, the value at pin number 4 equal 5V, and the value at pin number 5 it is the output of the Precise half-wave rectifier circuit, the same thing for the second comparator, as shown in figure (4.8).

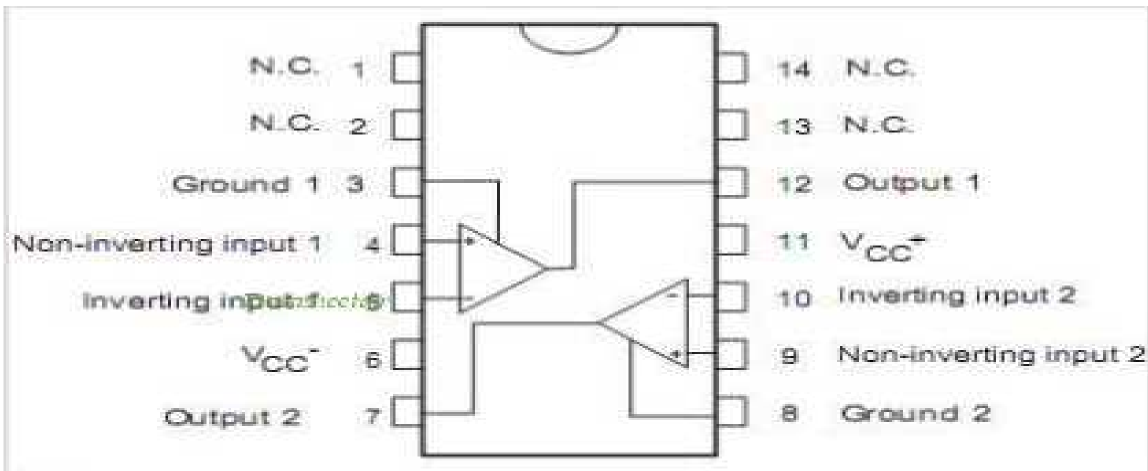


Figure (4.8):- LM319D Dual-Comparator Implementation.

Finally, because the output of the precise half-wave rectifier circuit is less than 5V always, then the output of the EMG System equal 5V.

4.2 Selection the Appropriate Motor and Actuators

For precise calculations of the appropriate motor that being used for moving exoskeleton hand, an analyzes of the forces acting on the arm being conducted in order to choose the motor can able to move this structure . Therefore there is a need to understand the concept of static and dynamics equilibrium and solving related tasks.

While statics is the study of structures at a fixed point in time, dynamics is the study of structures over a period of time. Basically statics describes things that don't move, while dynamics describes things that do some movements. Statics is concerned with moments, forces, stresses, torque, pressure, etc. Dynamics is concerned with displacement, velocity, acceleration, momentum, etc. If we want to calculate and optimize forces generated or required for a moving Exo-skeleton for arm, this chapter has the basics that we will need to understand. It is highly recommended you read the statics tutorial first as this tutorial will build off of it.

When one undertakes an analysis of any human movement, one must take into account a number of forces acting on the system, to simplify the problem for better understanding, a free body diagram is often used. A free body diagram is a stick figure drawing of the system showing the vector representations of the external forces acting on the system. In biomechanics, the system refers to the total human body or parts of the human body and any other objects that may be important in the analysis [**32**].

4.2.1 Static Analysis

The free body diagram as in figure (4.9), showing the vector representations of the external forces acting on the system.

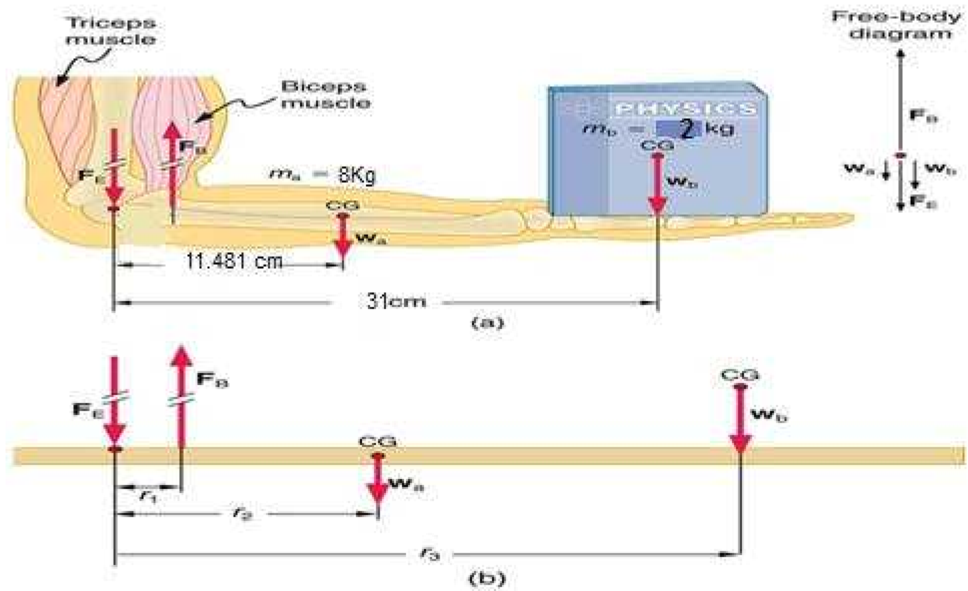


Figure (4.9):- Analysis Forces for The Free Body Figure Diagram of The Arm.

The static case is devoted to systems at rest or moving at a constant velocity. In both of these situations, the acceleration of the system is zero. When the acceleration of a system is zero, the system is said to be in equilibrium. A system is in equilibrium when, as stated in Newton's first law, it remains at rest or it is in motion at a constant velocity. [33]

In translational motion, when a system is in equilibrium, all forces that are acting on the system cancel each other out, and the effect is zero. That is, the sum of all forces acting on the system must total zero. This is expressed algebraically as:

$\sum F_{system} = 0$ .... (1).

$F_B - F_E - W_A - W_B = 0$ .... (2).

Where:

F_B : force resulting of biceps muscles.

F_E: force resulting of triceps muscles.

W_A: The outcome of the weight of the arm and hand and Exo-skeleton.

W_B: *An external body weight.*

We will design a motor to compensate for the force resulting from the muscles. The force/torque resulting from the motor must be equal the force/torque from the muscles.

- To calculate the force :

    The force equals the weight of objects.

- Weight of the parts:

Table (4.1) Mean Segment Weights Expressed as Percentages % of Total Body Weight.

Segment	Males (sample = 35)	Females (sample = 73)
Head	8.26	8.20
Whole trunk	55.10	53.20
Thorax	20.10	17.02
Abdomen	13.06	12.24
Pelvis	13.66	15.96
Total arm	5.77	4.97
Upper arm	3.25	2.90
Forearm	1.87	1.57
Hand	0.65	0.50
Forearm and hand	2.52	2.07
Total leg	16.68	18.43
Thigh	10.50	11.75
Leg	4.75	5.35
Foot	1.43	1.33
Leg and Foot	6.18	6.68

1) Arm:

Arm mass varies from person to person and depends on the total mass of the human body. We will calculate the weight of the arm based on previous studies by Plagenhoef in 1983 accomplishing that applied on a sample of 37 men and 100 women [**34**], as table (4.9).

Weight = mass * acceleration of gravity.
We will be assumed the patient is male

And can be calculate as:

a) forearm :

Let body mass = 76.5 N, then the body weight equal:

Body weight = 76.5 *9.81 = 750 kg. N/s^2 = 750 N

The Forearm and Hand weights can be calculate as:

Forearm weight = 1.87% * total body weight

= 0.0187* 750 N = 14.025 N (⇩)

b) Hand :

Hand weight = 0.65% * total body weight.

= 0.0065*750 = 4.875 N (⇩)

2) Exo-skeleton and other objects:

Assume; weight = 80 N (⇩)

Total force = total weight = forearm weight + hand weight + Exo-skeleton and other objects weight.

Total force = 14.025 + 4.875 + 80 = 98.9 N. ⇨ Total mass = 10 Kg.

Therefore, you must be the force resulting from the motor greater or equal to the sum of the forces acting on the arm to achieve equilibrium.

F_M> = 98.9 N.

- To calculate the torque :

Torque equals applied force multiplied by the perpendicular distance (R) from the line of action of the force to the pivot point.

To measure the perpendicular distance between the line of action of the force and the pivot point we must identify the length of arm, then we identify the center of mass for arm.

Depending on previous studies by Plagenhoef in 1983 accomplishing that applied on a sample of 37 men and 100 women [**25**], as tables (4.2+4.3).

- Length of arm:

1) Forearm:

Length of forearm = 0.157 * total human length.
Let, total human length = 170 cm.
Then, length of forearm = 0.157 * 170 = 26.7 cm.

2) Hand:

Length of hand = 0.0575 * total human length.
Then, length of hand = 0.0575 * 170 = 9.775 cm.

Table (4.2) Mean Segment Lengths Expressed as Percentages (%) of Total Body Height.

Segment	Males (sample = 35)	Females (sample = 73)
Head	10.75	10.75
Trunk (hip to shoulder)	30.00	29.00
Thorax	12.70	12.70
Abdomen	8.10	8.10
Pelvis	9.30	9.30
Upper arm	17.20	17.30
Forearm	15.70	16.00
Hand	5.75	5.75
Thigh	23.20	24.90
Leg	24.70	25.70
Foot	4.25	4.25
Biacromial	24.50	20.00
Bi-iliac	11.30	12.00

After identify the length of the forearm and the hand, now we can identify the center mass of each.

- Center of mass :

Forearm center of mass = 43% * long of forearm

= 0.43 * 26.7 = 11.481 cm.

Hand center of mass = 46.8 % * long of hand

= 0.468 * 9.775 = 4.5747 cm.

Let: - Exoskeleton Length = 36.5 cm.

- Exoskeleton Center of Mass = 18.25 cm.

Table (4.3) Segmental Center of Gravity Locations Expressed as Percentages (%) of Segment Lengths Measured From The Proximal Ends.

Segment	Males (sample = 7)	Females (sample = 9)
Head and neck	55.0	55.0
Trunk	63.0	56.9
Upper arm	43.6	45.8
Forearm	43.0	43.4
Hand	46.8	46.8
Pelvis	5.0	5.0
Abdomen	46.0	46.0
Thorax	56.7	56.3
Thigh	43.3	42.8
Leg	43.4	41.9
Foot	50.0	50.0
Abdomen and pelvis	44.5	39.0

Then, total torque = $\sum(F * R)$ = [(forearm weight * Center of mass for forearm weight) + (Hand weight * Center of mass for hand) + (Exo-skeleton and other objects * Center of mass for Exo-skeleton and other objects)].

Total torque = [(14.025 N * 0.11481) + (4.875 N* 0.045747) + (80 N * 0.1825)]

= 1.61021 + 0.2230167 + 14.6

= 16.43 N.m

4.2.2 Dynamic Analysis

The above equations only deal with the case where the Exo-skeleton is being held horizontally (not in motion). For the arm to move from a rest position, acceleration is required. To solve for this added torque, it is known that the sum of torques acting at a pivot point is equal to the moment of inertia (I) multiplied by the angular acceleration (alpha). [35]

- To calculate the force acting on the axis:

$F_T = m_t * \alpha * r_G$................equ.(1)

To calculate α:

$\alpha = \frac{a}{r_G}$ .... equ.(1.1) ; but :

a = $\frac{v}{t}$ .... equ. (1.2)

We must assume that the values of the time be suitable for moving the hand properly. Then;

Assume:

t = 5 second.

To find v:

v = $\frac{l}{t}$ .... equ (1.3); but:

We will calculate the maximum circular distance traveled round hand.

Then be angle = 90 , so it becomes the length of the circular Arc, as shown in figure (4.10).

$$l = \frac{\pi}{4} r_G = \frac{\pi}{4} * 0.182.$$

$$= 0.14326\, m \qquad \dots\dots\dots \quad sub.in\, equ(1.3)$$

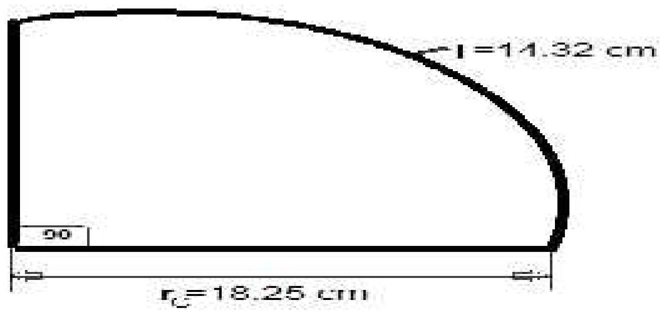


Figure (4.10):- Path Movement of The Arm.

$$v = \frac{l}{t} = \frac{0.14326}{5} = 0.02865 \text{ m/S} \qquad \dots\dots\dots\ sub.in\, equ\ (1.2)$$

$$a = \frac{v}{t} = \frac{0.02865}{5} = 0.00573 \text{ m}/s^2 \qquad \dots\dots\dots\ sub.in\, equ(1.1)$$

$$\alpha = \frac{a}{r_G} = \frac{0.00573}{0.1825} = 0.0134\ 1/s^2 \quad \dots\dots\dots\dots\dots\ sub.in\, e\, qu\ (1)$$

$$F_T = m_t * \alpha * r_G = 10 * 0.0314 * 0.1825 = 0.0573\, \frac{kg * m}{s^2}$$

Icon Symbols used in equations:

m_t**:** Total mass (hand and forearm and Exo-skeleton).

α angular acceleration .

r_G Distance between shaft of motor to force acting on center of mass.

a : Acceleration.

v : velocity .

t : time .

l : The length of a quarter circular arc.

- To calculate the moment caused by the force:

Moment is equal to the output torque of static and dynamic

$\sum M_G = I_G * \alpha + T_S$ .... equ(2).

$$I_G = \frac{m_t * l^2}{12} = \frac{10 * (0.365)^2}{12} = 0.111\, kg.m^2 \ldots\ldots\ldots.sub.in\ equ(2)$$

$$\sum M_G = I_G * \alpha + T_S = 0.111 * 0.0314 + 16.43 = 16.4335\, N.m$$

Where;

T_S **:** $output\ torque\ of\ static\ analysis.$

I_G:$moment\ of\ inertia$.

Safety factor: we must add additional torque to the total output torque for safety as equals:

Safety factor = 1.5 * total output torque.

= 1.5 * 16.4335 = 24.65 N.m

And to supplement the process of selecting the appropriate DC motor, speed must be determined:

- To find speed:

$$n = \frac{w*60}{2\pi} \quad \ldots\ldots\ldots \text{ equ(3).}$$

$$w = \frac{v}{r_G} = \frac{0.02865}{0.1825} = 0.157\ rad/seconde \quad \ldots\ldots\ldots\ldots \text{ sub. in equ(3).}$$

$$n = \frac{0.157*60}{2\pi} = 90\ rps$$

Where:

n: speed of motor in rpm.

w: angular speed .

⇒ The appropriate DC motor speed and torque equal:

Speed = 90 rps.

Torque = 24.65 N.m

4.3 Gear Calculation

Motor driven systems usually have optimal motor speeds at which the motor operates with the greatest power and efficiency. These motor speeds are expressed in rotations per minute (RPM) of the motor shaft. In many applications, this optimal motor speed is not the optimal speed (RPM) at which the load should be driven. Gearing is used in the form of differently sized gears. These gears are attached to the motor shaft and load shaft, and are coupled together by inter-meshed teeth. This produces a gear ratio, which is a direct measure of the ratio of motor shaft rotational speed to load shaft rotational speed. The gear divided into two parts, a drive gear and driven gear.

A drive gear attached to the motor shaft and a driven gear attached to the load shaft.

1) Gear ratio:

- Number of teeth on each gear used in the system:

Gear ratio is determined starting with the drive gear, so it should be noted which gear in the gear load, counting from the drive gear to the driven gear, has what number of teeth, figure(4.11).

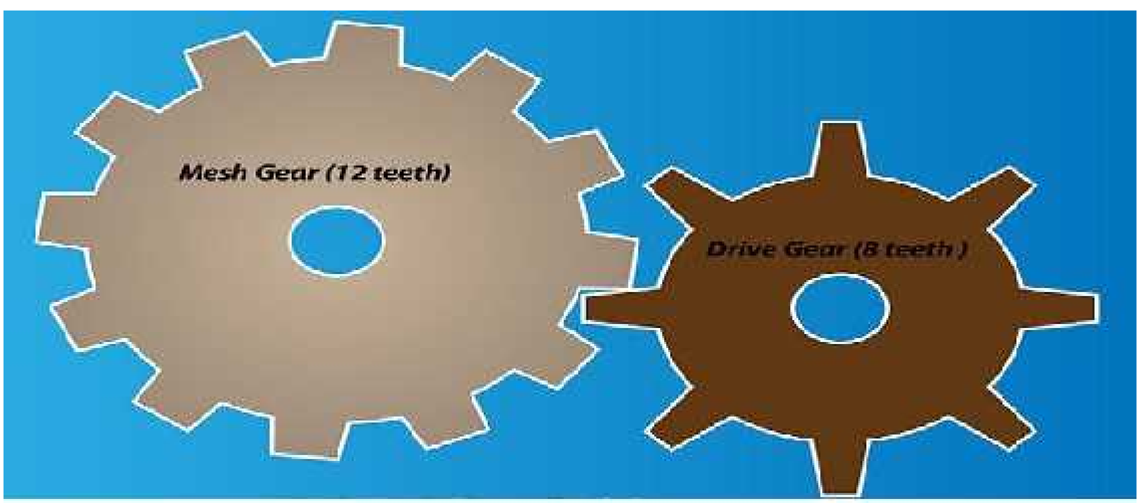


Figure (4.11):- Structure of Gear. [36]

And can be calculate as:

Gear Ratio = $\frac{number\ of\ teeth\ for\ driven}{number\ of\ teeth\ for\ drive} = \frac{12}{8} = 1.5$

That means when motor turns 1 time the gear load turns 1.5 time.

2) Gear efficiency (η):

$$\eta = \frac{\text{input power}}{output\ power} = \frac{input\ speed*input\ torque}{output\ speed*output\ torque} = \frac{w_1*p_1}{w_2*p_2}$$

Output power = η * input power
Assume η=0.8
Output power=0.8*$T_1 * w_1$
Output from the previous equations T_1 =24.65 and $w_1 = 0.157$

Output power=0.8*$T_1 * w_1 = 0.8 * 24.65 * 0.157 = 3.1\ watt$

After selecting the appropriate DC motor and gear we will link this gear with Exo-skeleton.

4.4 Servo Motor Calculation

To calculate the torque load of the finger to select the suitable motor is capable of pulling the finger, was chosen motor is capable of pulling times a pregnancy resulting from the withdrawal of the largest and longest finger, a middle finger in the hand, and thus the rest of the motor is able to pull the finger because the other fingers smaller and shorter than the middle finger, therefore calculations were only for the middle finger of the hand.

For adults, the weight of the middle finger of the hand almost = 150 gm, and the distance from the center of mass of the finger to the end of the finger almost = 8cm.

So, M = 150 g and D = 8 cm, where:-

M:-the weight of the middle finger of the hand. (Kg)

D:-the distance b=from the center of mass of the finger to the end of it. (m)

T:-torque load of the finger. (N.m)

Then, T = M.D

= 150 gm * 8cm = 1200gm.cm = 0.012 N.m.

To a motor can carry a hand when it carry a light load, was double the torque load, then the total load torque = 5*0.012 = 0.06 N.m.

So were selected servo motors torque is equal 0.34 N.m according to datasheet for it.

5 Chapter Five

Designand Results

5.1 Mechanical Design

5.1.1 Hand Exoskeleton Design

5.1.2 Fingers Exoskeleton Design

5.2 Electrical Design

5.2.1 EMG Circuit

5.2.2 Transmitter Circuit

5.2.3 Receiver Circuit

5.3 Codes

5.4 Block Diagram of the Project

Will detailed explanation the work process that has been done as the form of steps.

5.1 Mechanical Design

5.1.1 Hand Exoskeleton Design

Step 1:- Polyethylene is used for forming artificial arm that resembles natural hand,as shown in figure (5.1).

Figure (5.1):- Forming Artificial Arm Using Polyethylene.

Polyethylene (PE) resins are a general class of thermoplastics produced from ethylene gas. Ethylene gas is derived from the cracking of natural gas feed stocks or petroleum byproducts. Under broad ranges of pressures, temperatures and catalysts (depending PE type), ethylene generally polymerizes to form very long polymer chains, this article is too harsh, when placed in hot water becomes very soft take it out, and shape in any way and after a while takes the desired shape, as shown in figure (5.2).

Figure (5.2):- Polyethylene Plate.

It was also a box of polyethylene, which is a five of servo motors with a specific shape as shown in the figure (5.3), where not inconsistent shafts of this motors with each other.

Figure (5.3):- FixedThe Five Servo Motor in Box That Made of Polyethylene.

After that, dish of sponge on the parties to the pieces to ensure the protection of the patient from scratch, coverage pieces of leather plate to give a form is nice and comfortable to the patient, as shown in figure (5.4).

Figure (5.4):-Pieces of PolyethyleneLeather Covered.

Then we installed a DC motor on the first piece of figure (5.4), and connect the shaft of motor with gear, and connect a gear with another gear installed on the elbow by belt, then connect the second gear with the second piece, as shown in figure (5.5).

Figure (5.5):- Mechanical Design of Hand.

5.1.2 Fingers Exoskeleton Design

Was installed the Flex sensors on glove over the fingers of the right hand, as shown in figure (5.6).

Figure (5.6):- Installed The Flex Sensors on The Fingers

Was formed 3 pieces of polyethylene for each finger of the hand,as shown in figure (5.7).

Figure (5.7):- Formed Fingers of Hand Using Polyethylene.

And was installed each piece using the stud to get stretched and removed when needed, and the connection between these pieces by a small spring replace the hinge, as shown in figure (5.8).

Figure (5.8):- InstalledEach Pieces Using Stud.

And each finger has been linked with a servo motorcustom for him using a very strong plastic cord, as shown in figure (5.9).

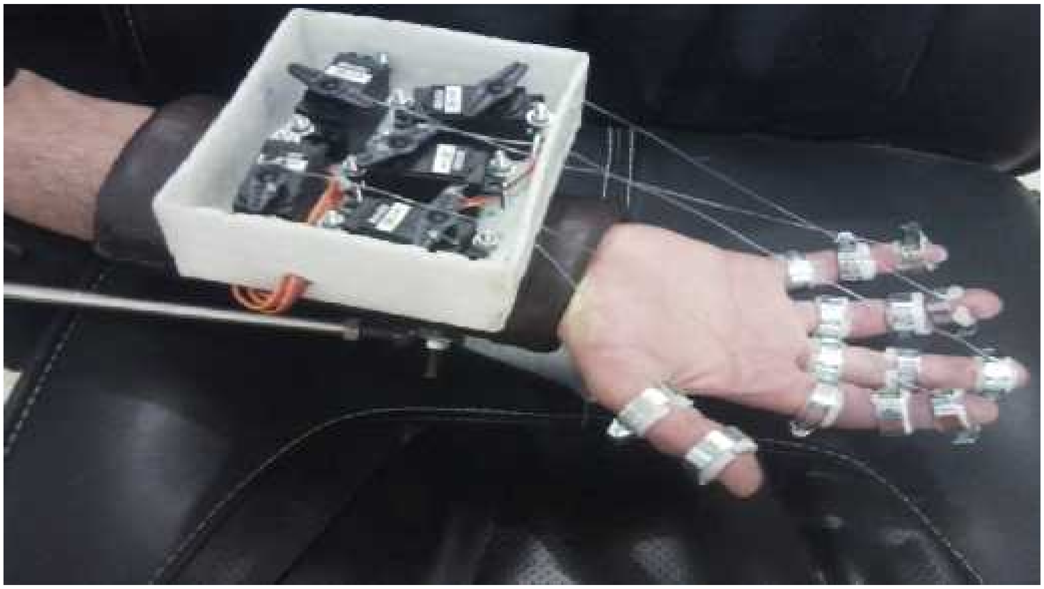


Figure (5.9) :- Connected The Servo Motors With The Fingers.

Finally, to come up with a complete mechanical design of the project, as shown in figure (5.10).

Figure (5.10):- Complete Mechanical Design of Exoskeleton.

5.2 Electrical Design

The electrical design of the project was built in 3 circuits, and these circuits have been designed using proteus 8 professional program, these circuits are:-

5.2.1 EMG Circuit

This circuit is designed to extract electrical muscle signal, then amplified and filtered this signal to introduced to microcontrollers to control the movement of the DC motor, where havepre-amplifier, optical isolation circuit, band-reject filter, band-pass filter,gain amplifier,half-wave rectifier and dual-comparator, where is drawn using proteus 8 professional program as schematic, as shown in figure (5.11).

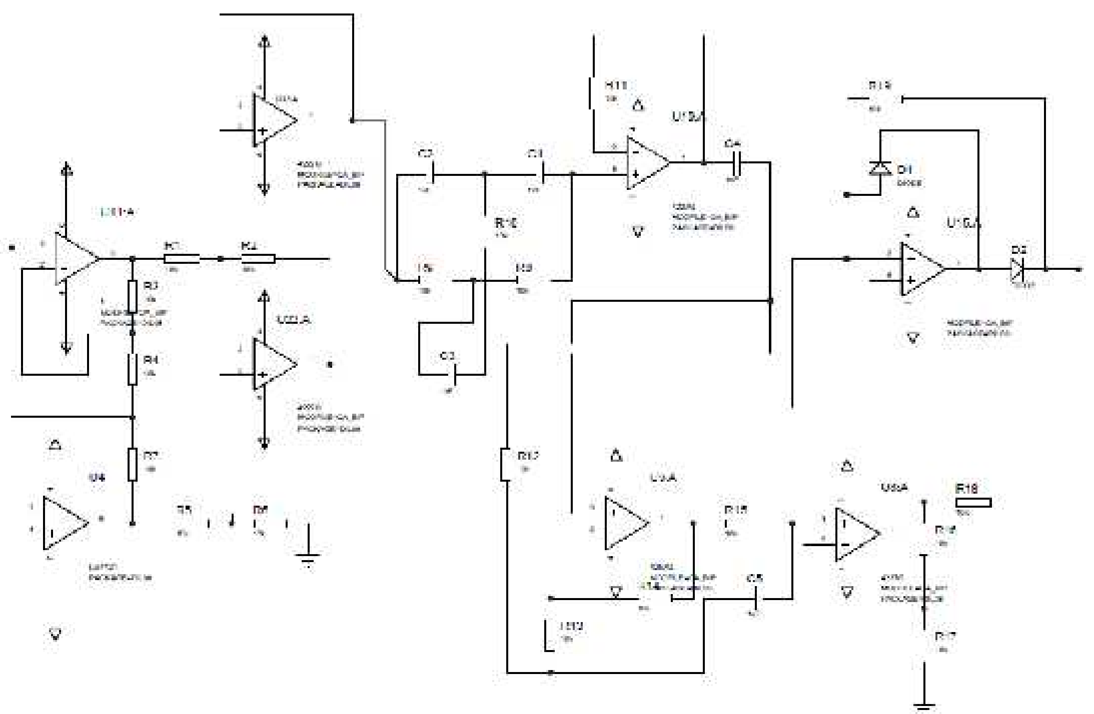


Figure (5.11):- Schematic of EMG Circuit.

And converted to PCB layout to enter it to the electronic board printed machine,as shown in figure (5.12).

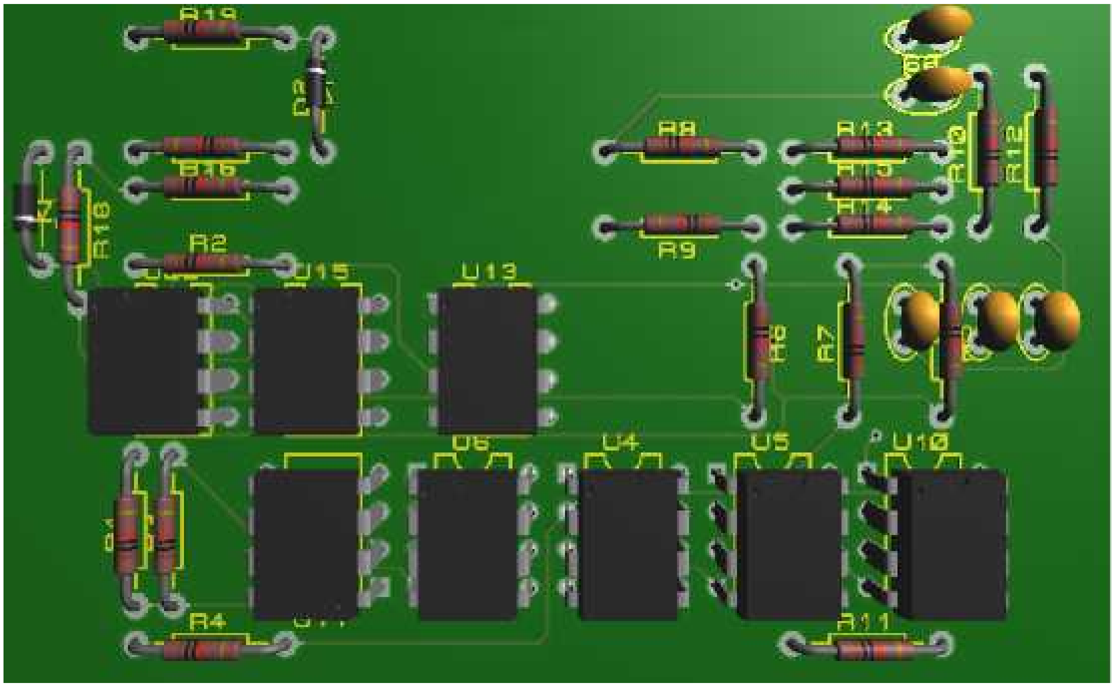


Figure (5.12):- EMG Circuit on PCB Board.

5.2.2 Transmitter Circuit

This circuit is designed to take a signal of right fingers and enter it to the microcontroller (ATMEGA 328P) and transfer it to transmitter Xbee through serial bins to send it to the receiver Xbee wirelessly, where is drawn usingproteus 8 professional program as schematic, as shown in figure (5.13).

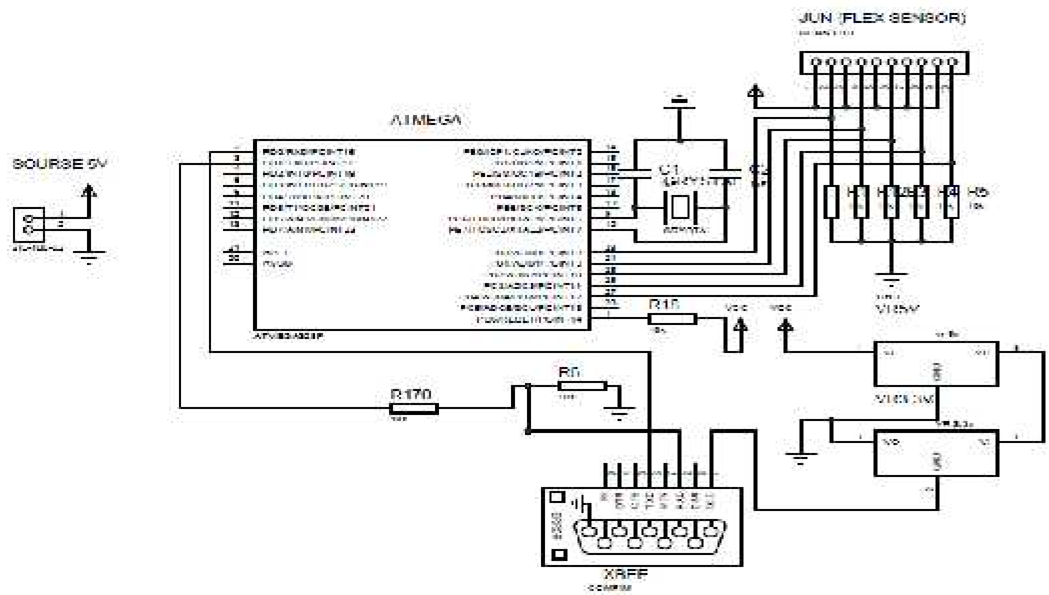


Figure (5.13):- Schematic of Transmitter Circuit.

And converted to PCB layout to enter it to the electronic board printed machine, as shown in figure (5.14).

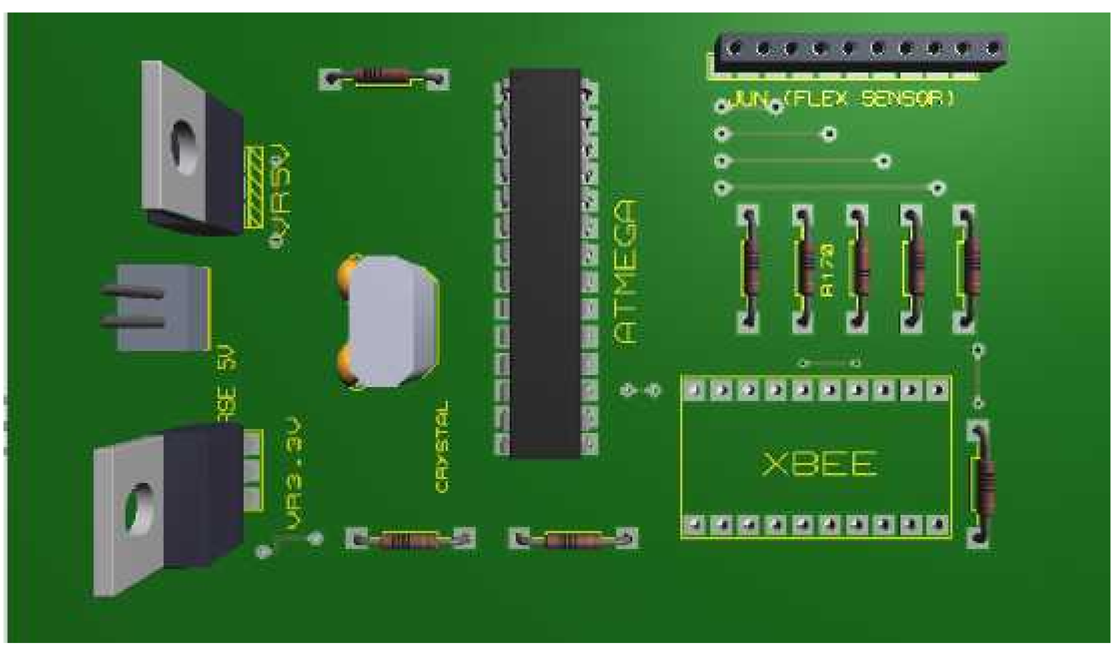


Figure (5.14):- Transmitter Circuit on PCB Board.

5.2.3 Receiver Circuit

This circuit designed to receive the text from the transmitter Xbee through the receiver Xbee and enter it to the microcontroller (ATMEGA 328P), to control the 5 servo motors movements, where is drawn using proteus 8 professional program as schematic, as shown in figure (5.15).

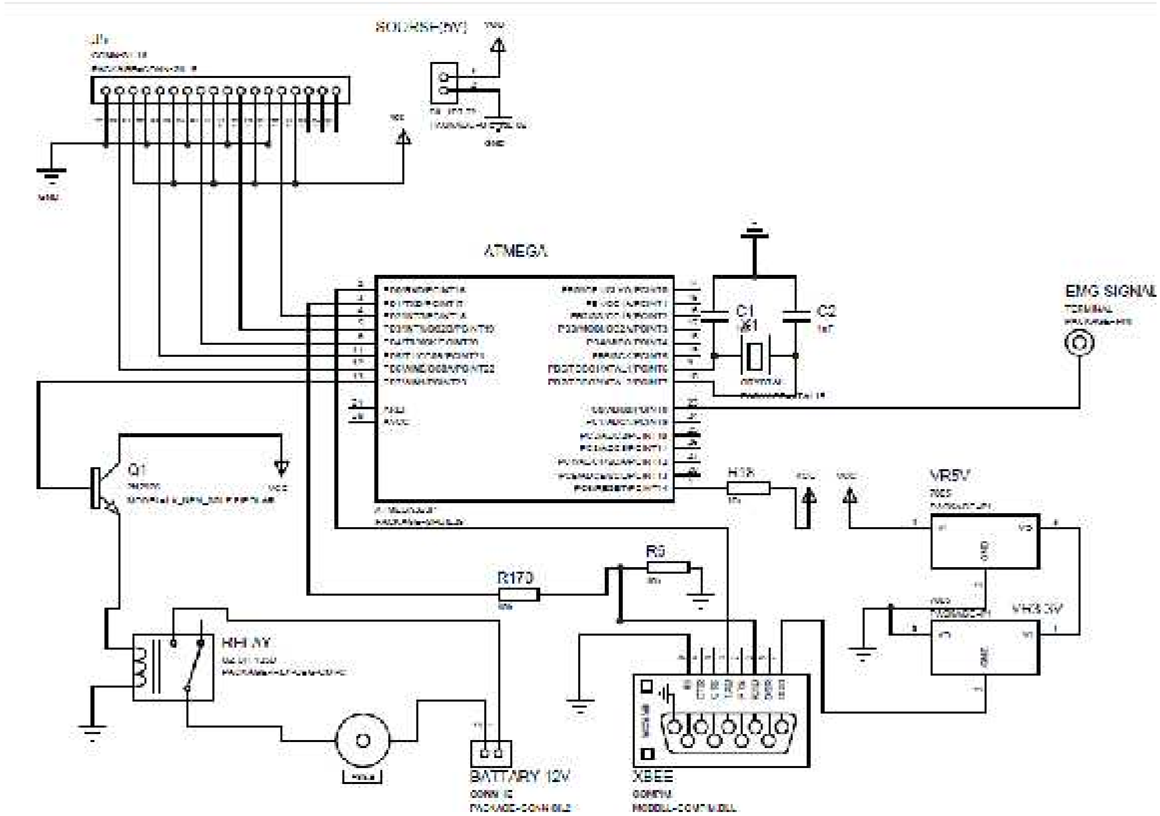


Figure (5.15):- Schematic of ReceiverCircuit.

And converted to PCB layout to enter it to the electronic board printed machine, as shown in figure (5.16).

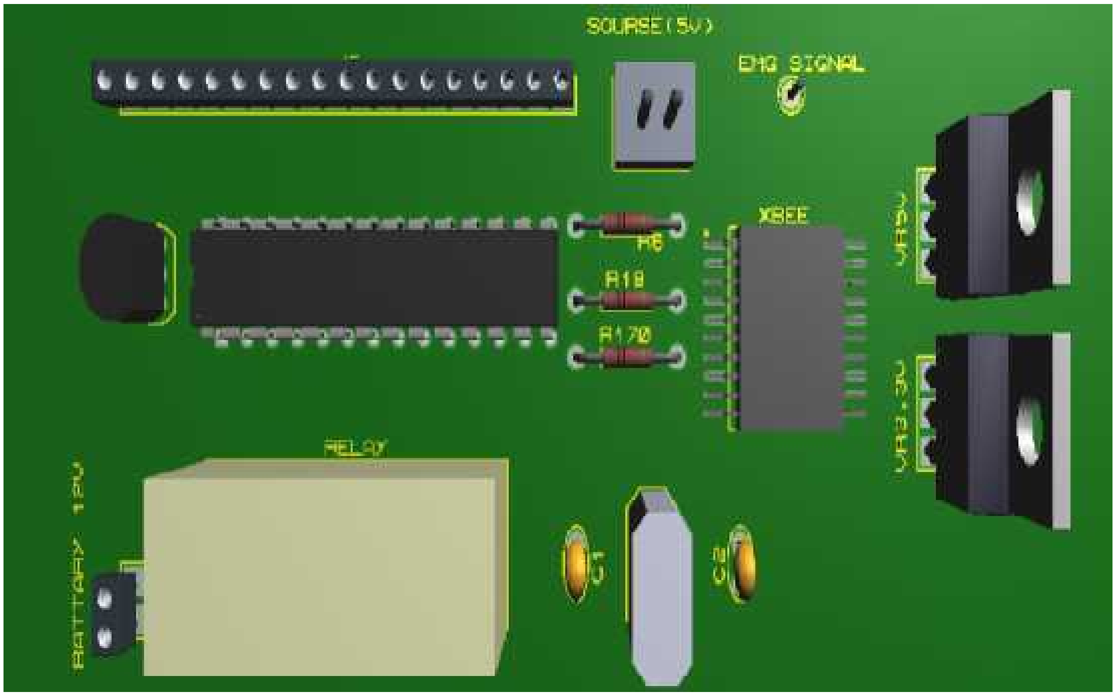


Figure (5.16):- ReceiverCircuit on PCB Board.

5.3 Codes

In this section will give the codes, that downloaded on the microcontroller (ATMEGA 328P) using Arduino shield, such that; there are two microcontroller (ATMEGA 328P), the first to read the signals from the flex sensors and send that by the transmitter Xbee, and the second to read the serial text from the receiver Xbee and send orders to the servo motors.

- The code for the first ATMEGA328P :

```
const int analogInPin1 = A0;          // Analog input pin that the flex sensors are attached to
const int analogInPin2 = A1;
const int analogInPin3 = A2;
const int analogInPin4 = A3;
const int analogInPin5 = A4;
int sensorValue1 = 0;                 // value read from the flex sensors
int sensorValue2 = 0;
int sensorValue3 = 0;
int sensorValue4 = 0;
int sensorValue5 = 0;
void setup() {
Serial.begin(9600); // initialize serial communications at 9600 bps:
}
void loop() {
  // read the analog in value:
  sensorValue1 = analogRead(analogInPin1);
  sensorValue2 = analogRead(analogInPin2);
  sensorValue3 = analogRead(analogInPin3);
  sensorValue4 = analogRead(analogInPin4);
```

```
sensorValue5 = analogRead(analogInPin5);
// map it to the range of the analog out:
 sensorValue1 = map(sensorValue1, 150,340, 180, 30); //for small sensor
sensorValue2 = map(sensorValue2, 150,340, 180, 30);
sensorValue3 = map(sensorValue3, 512,614, 0, 180);  // for the large sensors
sensorValue4 = map(sensorValue4, 512,614, 0, 180);
sensorValue5 = map(sensorValue5, 512,614, 0, 180);
  // change the analog out value:
  // print the results to the serial monitor:
Serial.print(sensorValue1);
Serial.print("a");
Serial.print(sensorValue2);
Serial.print("b");
Serial.print(sensorValue3);
  Serial.print("c");
Serial.print(sensorValue4);
  Serial.print("d");
Serial.print(sensorValue5);
  Serial.print("e");
delay(10);                         // wait 10 ms
}
```

- The code for the second ATMEGA328P:-

```
#include <Servo.h>
Servo servo1;
Servo servo2;
Servo servo3;
Servo servo4;
Servo servo5;
int motorPin=8;
int analogPin=A0;
int sensorvalue=0;
void setup() {
pinMode(8,OUTPUT);
 servo1.attach(2);
 servo2.attach(3);
 servo3.attach(4);
 servo4.attach(5);
 servo5.attach(6);
Serial.begin(9600);
Serial.println("Ready");
}
```

```
void loop() {
sensorvalue=analogRead(analogPin);
 if(sensorvalue>=70 & sensorvalue<=140)
 {  digitalWrite(motorPin, HIGH);
}
else
{
digitalWrite(motorPin, LOW);
}
static int v = 0;
 if ( Serial.available()) {
 char ch = Serial.read();
switch(ch) {
case '0'...'9':
        v = v * 10 + ch - '0';
 break;
case 'a':
        servo1.write(v);
        v = 0;
 break;
```

```
case 'b':
        servo2.write(v);
        v = 0;
 break;
case 'c':
        servo3.write(v);
        v = 0;
 break;
 case 'd':
        servo4.write(v);
        v = 0;
break;
case 'e':
        servo5.write(v);
        v = 0;
break;
    }
  }
}
```

5.4 Block Diagram of the Project

The figure (5.17) illustrates the general block diagram for our project.

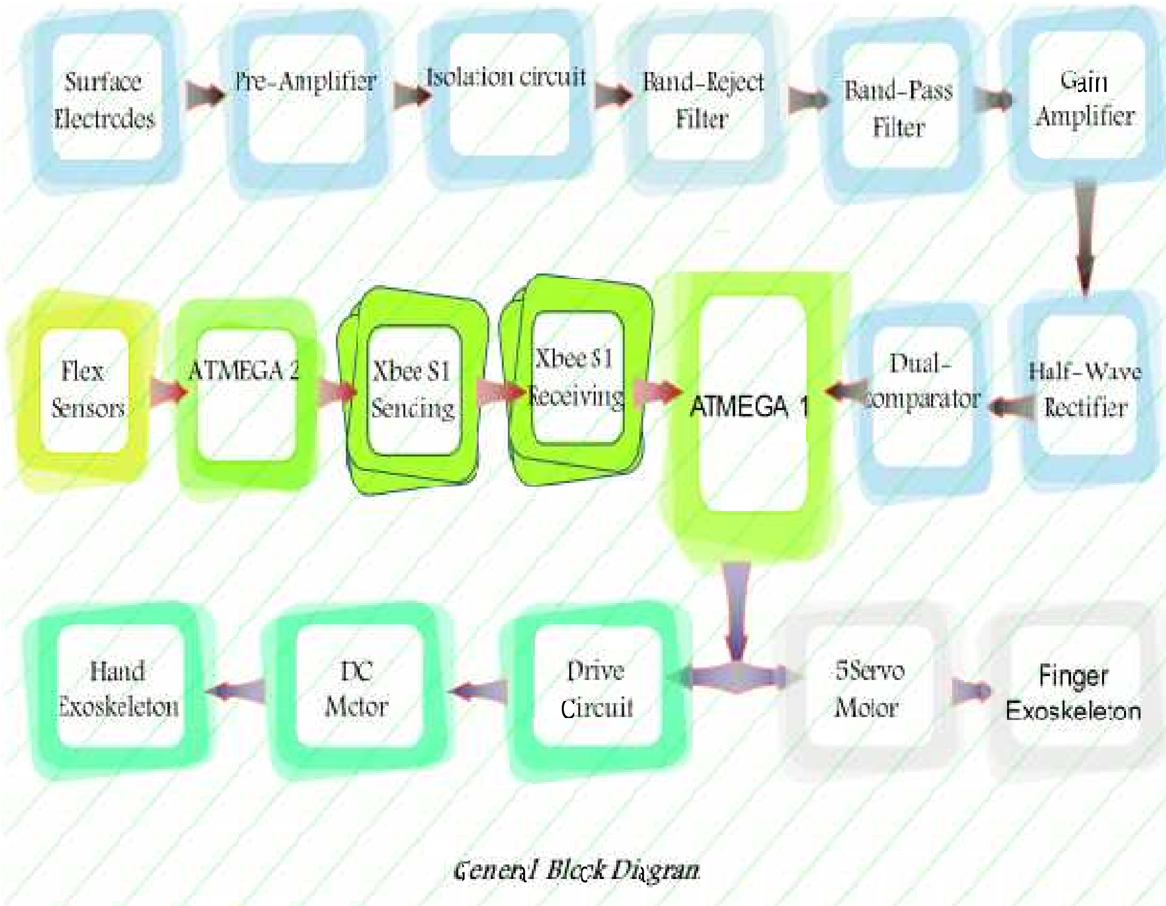


Figure (5.17):- The General Block Diagram of Project.

6

Chapter Six

Conclusions, Challenges and Recommendation

6.1 Conclusions

1- The team extracted the muscle electrical signal through building a device that sensing the difference voltage resulting from muscle and then amplified and filtered it to aim of the ability to deal with the resultant signal.

2- The team has implemented mechanism congruence between the movement of non-infected fingers and movement of infected fingers through use a flex sensors to responds with fingers movement.

3- The microcontroller was the human mind in this project,where the team has done a program to control the movement of motors based on the extracted signals.

4- The team used the ZIG-BEE technology through piece called XBEE and that to send signals wirelessly to avoid block the movement of paralyzed.

5-The team used two types of motors, the first is DC motor of adequate capacity to do the hand-carry, and the second is servo motors to do the fingers movement.

6- The team designed the exoskeleton using Chemical material called polyethylene for easy formed and solidity after restructuring.

6.2 Challenges

The challenge was to extract a signals of fingers, Where that this moderation require a surgery to transplant the electrodes , that because the responsible nerve that transfer the signals to fingers non surface and could be reached only through the conduct of such operations. The solution was,the team has done to take these responsible signals to moving the fingers of the infected hand in the non-infected hand using flex sensors and send the signals antenna to provide freedom of movement of the paralyzed.

6.3 Recommendation

1- An alternative to taking finger's signals from the hand self using needle electrodes recompense taking it from the fingers of the other hand.

2- An alternative to using plastic cord that tension the fingers.

3- Improving electrical muscle for people who suffer from weakness in the nervous system of gonorrhea in a certain way instead of going into the enlarged and purified and control of the weak signals.

4- Work on moving the hand in three directions instead of just moving it in two directions.

Appendix Paper

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Data sheets

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Low Cost, Low Power Instrumentation Amplifier

AD620

FEATURES
EASY TO USE
Gain Set with One External Resistor
(Gain Range 1 to 1000)
Wide Power Supply Range (±2.3 V to ±18 V)
Higher Performance than Three Op Amp IA Designs
Available in 8-Lead DIP and SOIC Packaging
Low Power, 1.3 mA max Supply Current

EXCELLENT DC PERFORMANCE ("B GRADE")
50 μV max, Input Offset Voltage
0.6 μV/°C max, Input Offset Drift
1.0 nA max, Input Bias Current
100 dB min Common-Mode Rejection Ratio (G = 10)

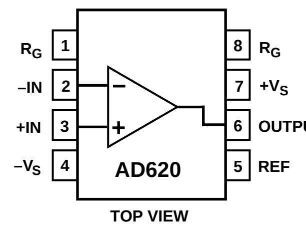
LOW NOISE
9 nV/$\sqrt{Hz}$, @ 1 kHz, Input Voltage Noise
0.28 μV p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS
120 kHz Bandwidth (G = 100)
15 μs Settling Time to 0.01%

APPLICATIONS
Weigh Scales
ECG and Medical Instrumentation
Transducer Interface
Data Acquisition Systems
Industrial Process Controls
Battery Powered and Portable Equipment

CONNECTION DIAGRAM

8-Lead Plastic Mini-DIP (N), Cerdip (Q) and SOIC (R) Packages



PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 1000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs, and offers lower power (only 1.3 mA max supply current), making it a good fit for battery powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 μV max and offset drift of 0.6 μV/°C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superβeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/$\sqrt{Hz}$ at 1 kHz, 0.28 μV p-p in the 0.1 Hz to 10 Hz band, 0.1 pA/$\sqrt{Hz}$ input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 μs to 0.01% and its cost is low enough to enable designs with one in-amp per channel.

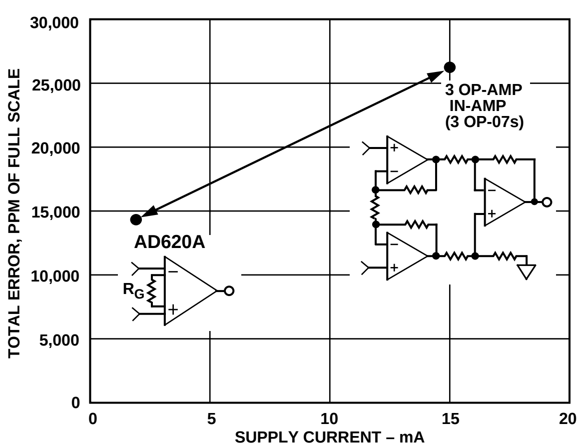


Figure 1. Three Op Amp IA Designs vs. AD620

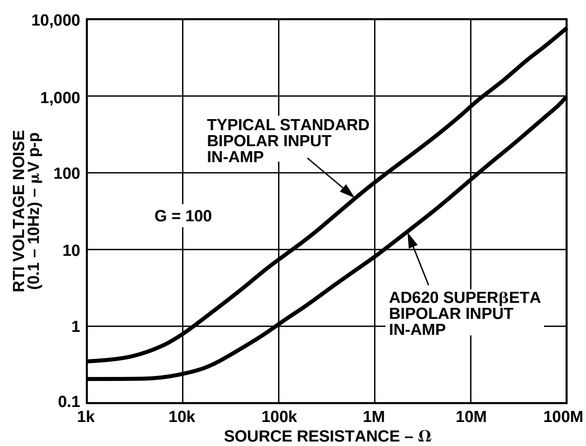


Figure 2. Total Voltage Noise vs. Source Resistance

REV. E

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781/329-4700 World Wide Web Site: http://www.analog.com
Fax: 781/326-8703

AD620–SPECIFICATIONS (Typical @ +25°C, V_S = ±15 V, and R_L = 2 kΩ, unless otherwise noted)

Model	Conditions	AD620A			AD620B			AD620S[1]			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
GAIN	G = 1 + (49.4 k/R_G)										
Gain Range		1		10,000	1		10,000	1		10,000	
Gain Error[2]	V_{OUT} = ±10 V										
G = 1			0.03	0.10		0.01	0.02		0.03	0.10	%
G = 10			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 100			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 1000			0.40	0.70		0.35	0.50		0.40	0.70	%
Nonlinearity,	V_{OUT} = –10 V to +10 V,										
G = 1–1000	R_L = 10 kΩ		10	40		10	40		10	40	ppm
G = 1–100	R_L = 2 kΩ		10	95		10	95		10	95	ppm
Gain vs. Temperature											
	G =1			10			10			10	ppm/°C
	Gain >1[2]			–50			–50			–50	ppm/°C
VOLTAGE OFFSET	(Total RTI Error = V_{OSI} + V_{OSO}/G)										
Input Offset, V_{OSI}	V_S = ±5 V to ±15 V		30	125		15	50		30	125	µV
Over Temperature	V_S = ±5 V to ±15 V			185			85			225	µV
Average TC	V_S = ±5 V to ±15 V		0.3	1.0		0.1	0.6		0.3	1.0	µV/°C
Output Offset, V_{OSO}	V_S = ±15 V		400	1000		200	500		400	1000	µV
	V_S = ±5 V			1500			750			1500	µV
Over Temperature	V_S = ±5 V to ±15 V			2000			1000			2000	µV
Average TC	V_S = ±5 V to ±15 V		5.0	15		2.5	7.0		5.0	15	µV/°C
Offset Referred to the Input vs.											
Supply (PSR)	V_S = ±2.3 V to ±18 V										
G = 1		80	100		80	100		80	100		dB
G = 10		95	120		100	120		95	120		dB
G = 100		110	140		120	140		110	140		dB
G = 1000		110	140		120	140		110	140		dB
INPUT CURRENT											
Input Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
Over Temperature				2.5			1.5			4	nA
Average TC			3.0			3.0			8.0		pA/°C
Input Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
Over Temperature				1.5			0.75			2.0	nA
Average TC			1.5			1.5			8.0		pA/°C
INPUT											
Input Impedance											
Differential			10‖2			10‖2			10‖2		GΩ‖pF
Common-Mode			10‖2			10‖2			10‖2		GΩ‖pF
Input Voltage Range[3]	V_S = ±2.3 V to ±5 V	$-V_S$ + 1.9		$+V_S$ – 1.2	$-V_S$ + 1.9		$+V_S$ – 1.2	$-V_S$ + 1.9		$+V_S$ – 1.2	V
Over Temperature		$-V_S$ + 2.1		$+V_S$ – 1.3	$-V_S$ + 2.1		$+V_S$ – 1.3	$-V_S$ + 2.1		$+V_S$ – 1.3	V
	V_S = ±5 V to ±18 V	$-V_S$ + 1.9		$+V_S$ – 1.4	$-V_S$ + 1.9		$+V_S$ – 1.4	$-V_S$ + 1.9		$+V_S$ – 1.4	V
Over Temperature		$-V_S$ + 2.1		$+V_S$ – 1.4	$-V_S$ + 2.1		$+V_S$ – 1.4	$-V_S$ + 2.3		$+V_S$ – 1.4	V
Common-Mode Rejection Ratio DC to 60 Hz with											
I kΩ Source Imbalance	V_{CM} = 0 V to ±10 V										
G = 1		73	90		80	90		73	90		dB
G = 10		93	110		100	110		93	110		dB
G = 100		110	130		120	130		110	130		dB
G = 1000		110	130		120	130		110	130		dB
OUTPUT											
Output Swing	R_L = 10 kΩ,										
	V_S = ±2.3 V to ±5 V	$-V_S$ + 1.1		$+V_S$ – 1.2	$-V_S$ + 1.1		$+V_S$ – 1.2	$-V_S$ + 1.1		$+V_S$ – 1.2	V
Over Temperature		$-V_S$ + 1.4		$+V_S$ – 1.3	$-V_S$ + 1.4		$+V_S$ – 1.3	$-V_S$ + 1.6		$+V_S$ – 1.3	V
	V_S = ±5 V to ±18 V	$-V_S$ + 1.2		$+V_S$ – 1.4	$-V_S$ + 1.2		$+V_S$ – 1.4	$-V_S$ + 1.2		$+V_S$ – 1.4	V
Over Temperature		$-V_S$ + 1.6		$+V_S$ – 1.5	$-V_S$ + 1.6		$+V_S$ – 1.5	$-V_S$ + 2.3		$+V_S$ – 1.5	V
Short Current Circuit			±18			±18			±18		mA

Model	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Units
DYNAMIC RESPONSE											
Small Signal –3 dB Bandwidth											
G = 1			1000			1000			1000		kHz
G = 10			800			800			800		kHz
G = 100			120			120			120		kHz
G = 1000			12			12			12		kHz
Slew Rate		0.75	1.2		0.75	1.2		0.75	1.2		V/µs
Settling Time to 0.01%	10 V Step										
G = 1–100			15			15			15		µs
G = 1000			150			150			150		µs
NOISE											
Voltage Noise, 1 kHz	$Total\ RTI\ Noise = \sqrt{(e^2_{ni}) + (e_{no}/G)^2}$										
Input, Voltage Noise, e_{ni}			9	13		9	13		9	13	$nV/\sqrt{Hz}$
Output, Voltage Noise, e_{no}			72	100		72	100		72	100	$nV/\sqrt{Hz}$
RTI, 0.1 Hz to 10 Hz											
G = 1			3.0			3.0	6.0		3.0	6.0	µV p-p
G = 10			0.55			0.55	0.8		0.55	0.8	µV p-p
G = 100–1000			0.28			0.28	0.4		0.28	0.4	µV p-p
Current Noise	f = 1 kHz		100			100			100		$fA/\sqrt{Hz}$
0.1 Hz to 10 Hz			10			10			10		pA p-p
REFERENCE INPUT											
R_{IN}			20			20			20		kΩ
I_{IN}	V_{IN+}, $V_{REF} = 0$		+50	+60		+50	+60		+50	+60	µA
Voltage Range		$-V_S + 1.6$		$+V_S - 1.6$	$-V_S + 1.6$		$+V_S - 1.6$	$-V_S + 1.6$		$+V_S - 1.6$	V
Gain to Output			1 ± 0.0001			1 ± 0.0001			1 ± 0.0001		
POWER SUPPLY											
Operating Range[4]		±2.3		±18	±2.3		±18	±2.3		±18	V
Quiescent Current	V_S = ±2.3 V to ±18 V		0.9	1.3		0.9	1.3		0.9	1.3	mA
Over Temperature			1.1	1.6		1.1	1.6		1.1	1.6	mA
TEMPERATURE RANGE											
For Specified Performance			–40 to +85			–40 to +85			–55 to +125		°C

NOTES

[1]See Analog Devices military data sheet for 883B tested specifications.

[2]Does not include effects of external resistor R_G.

[3]One input grounded. G = 1.

[4]This is defined as the same supply range which is used to specify PSR.

Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS[1]

Supply Voltage . . . . ±18 V
Internal Power Dissipation[2] . . . . 650 mW
Input Voltage (Common Mode) . . . . $\pm V_S$
Differential Input Voltage . . . . ±25 V
Output Short Circuit Duration . . . . Indefinite
Storage Temperature Range (Q) . . . . –65°C to +150°C
Storage Temperature Range (N, R) . . . . –65°C to +125°C
Operating Temperature Range
  AD620 (A, B) . . . . –40°C to +85°C
  AD620 (S) . . . . –55°C to +125°C
Lead Temperature Range
  (Soldering 10 seconds) . . . . +300°C

NOTES
[1]Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.
[2]Specification is for device in free air:
8-Lead Plastic Package: θ_{JA} = 95°C/W
8-Lead Cerdip Package: θ_{JA} = 110°C/W
8-Lead SOIC Package: θ_{JA} = 155°C/W

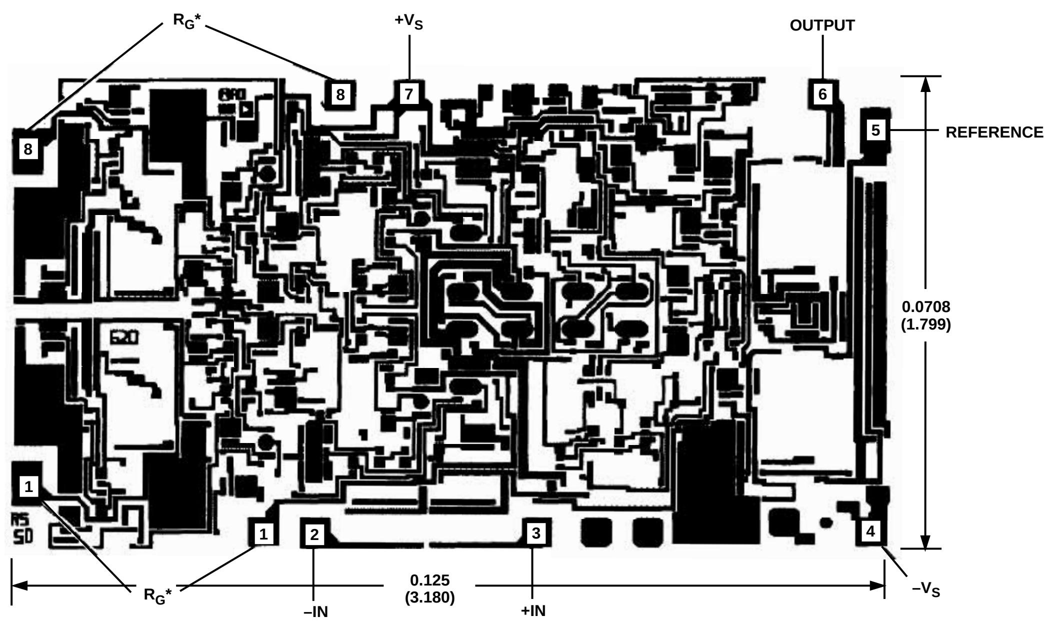
ORDERING GUIDE

Model	Temperature Ranges	Package Options*
AD620AN	–40°C to +85°C	N-8
AD620BN	–40°C to +85°C	N-8
AD620AR	–40°C to +85°C	SO-8
AD620AR-REEL	–40°C to +85°C	13" REEL
AD620AR-REEL7	–40°C to +85°C	7" REEL
AD620BR	–40°C to +85°C	SO-8
AD620BR-REEL	–40°C to +85°C	13" REEL
AD620BR-REEL7	–40°C to +85°C	7" REEL
AD620ACHIPS	–40°C to +85°C	Die Form
AD620SQ/883B	–55°C to +125°C	Q-8

*N = Plastic DIP; Q = Cerdip; SO = Small Outline.

METALIZATION PHOTOGRAPH

Dimensions shown in inches and (mm).
Contact factory for latest dimensions.



*FOR CHIP APPLICATIONS: THE PADS 1R_G AND 8R_G MUST BE CONNECTED IN PARALLEL TO THE EXTERNAL GAIN REGISTER R_G. DO NOT CONNECT THEM IN SERIES TO R_G. FOR UNITY GAIN APPLICATIONS WHERE R_G IS NOT REQUIRED, THE PADS 1R_G MAY SIMPLY BE BONDED TOGETHER, AS WELL AS THE PADS 8R_G.

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the AD620 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

Typical Characteristics (@ +25°C, V_S = ±15 V, R_L = 2 kΩ, unless otherwise noted)

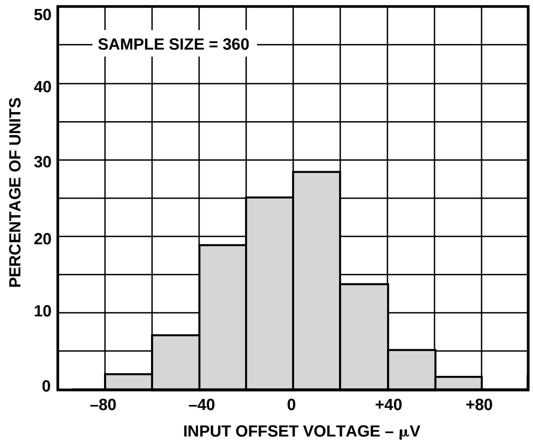


Figure 3. Typical Distribution of Input Offset Voltage

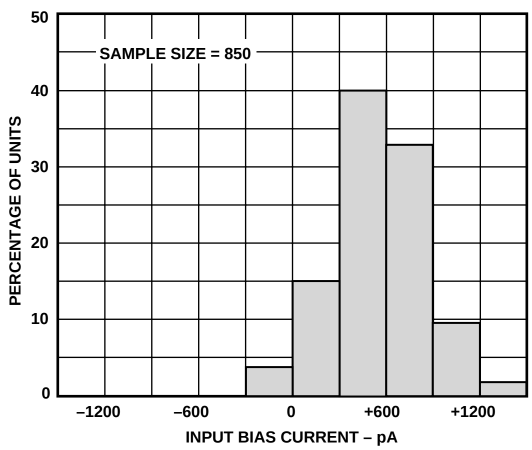


Figure 4. Typical Distribution of Input Bias Current

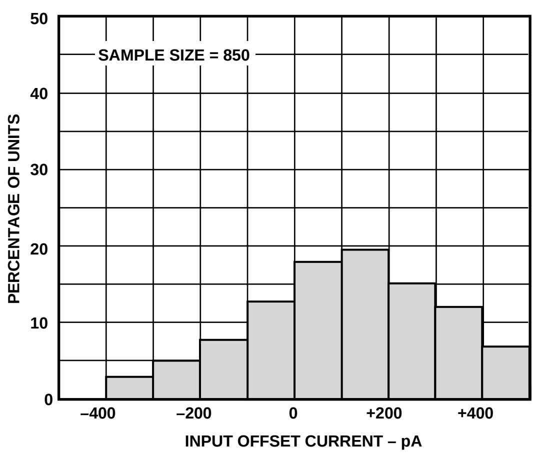


Figure 5. Typical Distribution of Input Offset Current

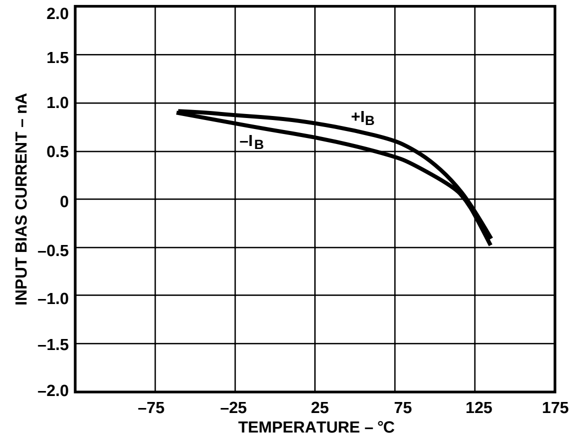


Figure 6. Input Bias Current vs. Temperature

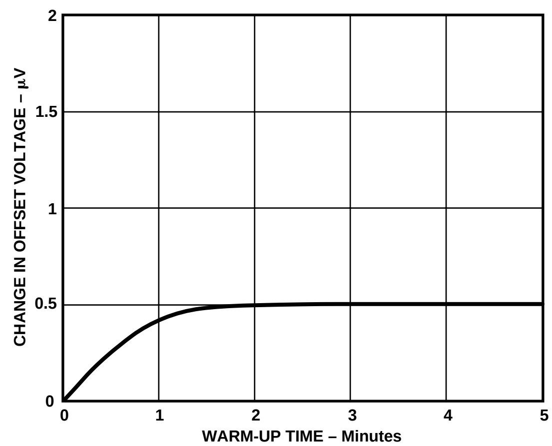


Figure 7. Change in Input Offset Voltage vs. Warm-Up Time

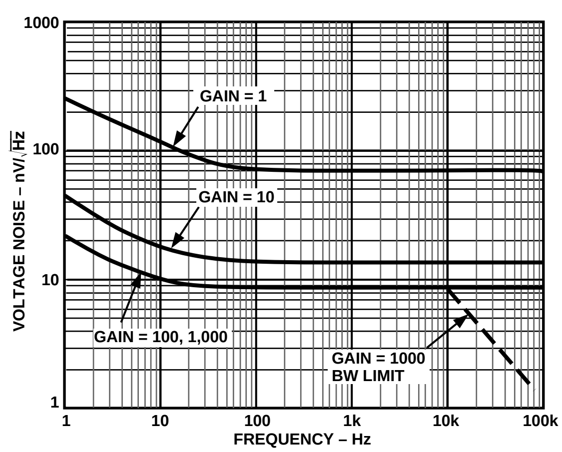


Figure 8. Voltage Noise Spectral Density vs. Frequency, (G = 1–1000)

AD620–Typical Characteristics

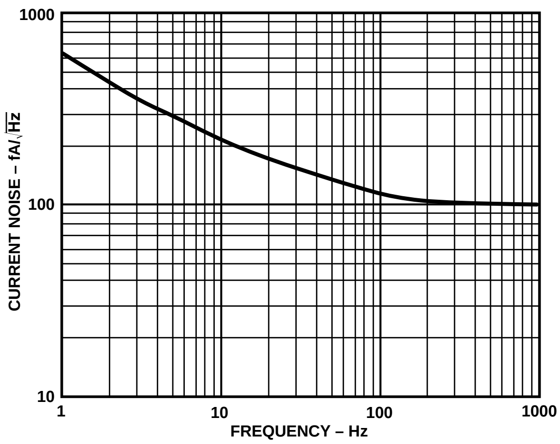


Figure 9. Current Noise Spectral Density vs. Frequency

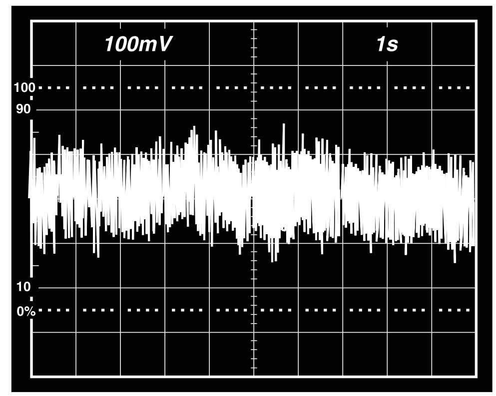


Figure 11. 0.1 Hz to 10 Hz Current Noise, 5 pA/Div

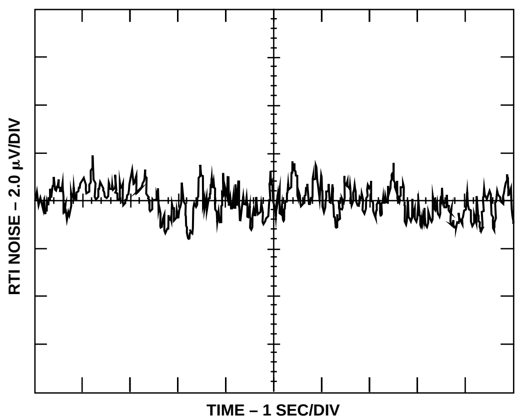


Figure 10a. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1)

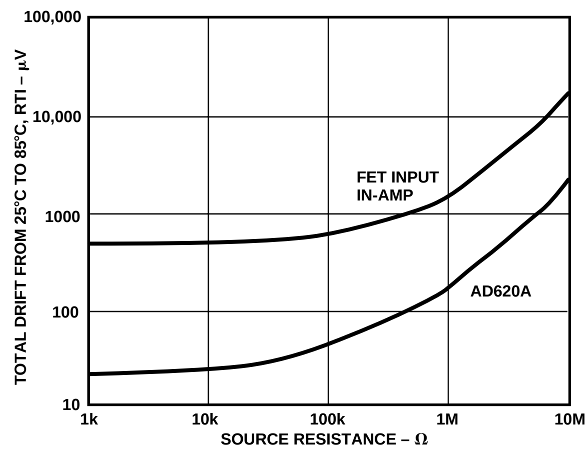


Figure 12. Total Drift vs. Source Resistance

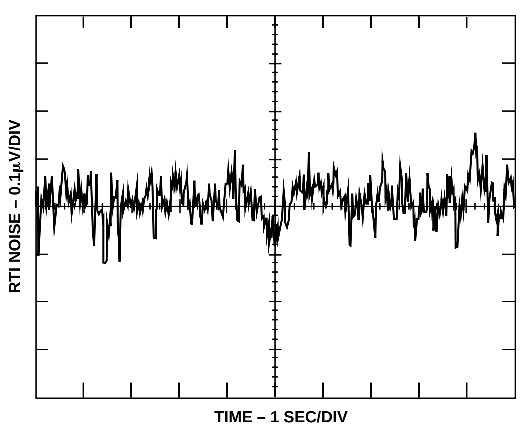


Figure 10b. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1000)

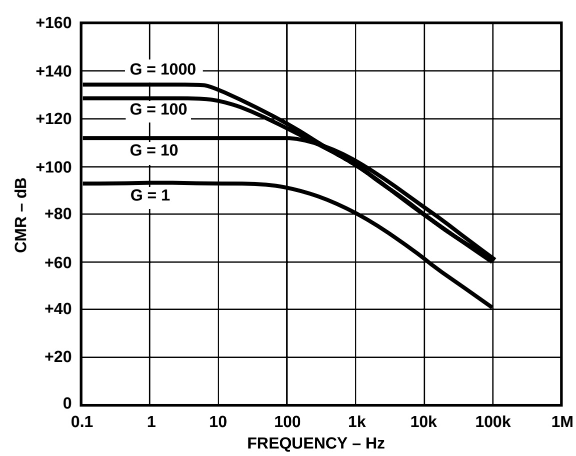


Figure 13. CMR vs. Frequency, RTI, Zero to 1 kΩ Source Imbalance

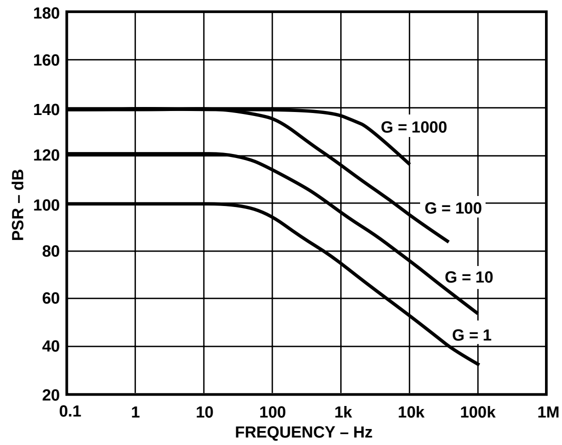


Figure 14. Positive PSR vs. Frequency, RTI (G = 1–1000)

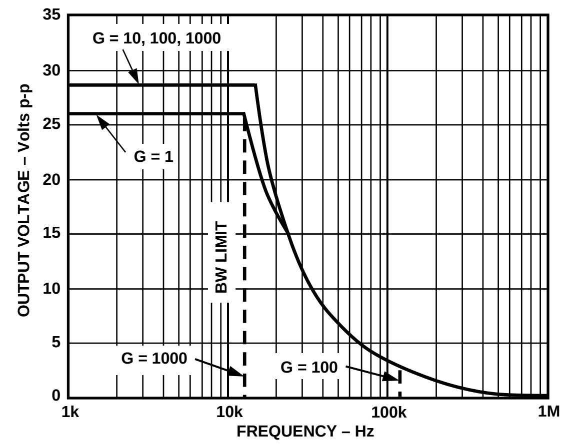


Figure 17. Large Signal Frequency Response

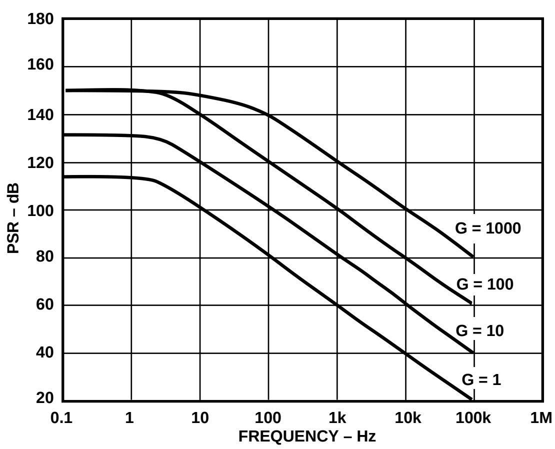


Figure 15. Negative PSR vs. Frequency, RTI (G = 1–1000)

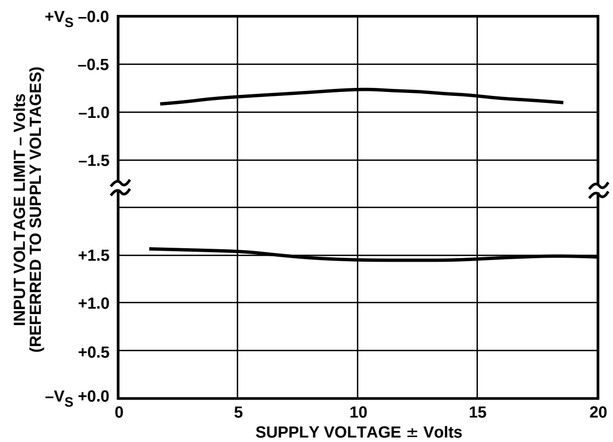


Figure 18. Input Voltage Range vs. Supply Voltage, G = 1

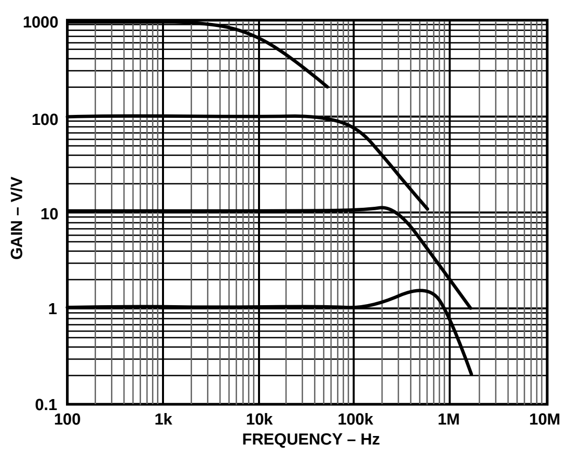


Figure 16. Gain vs. Frequency

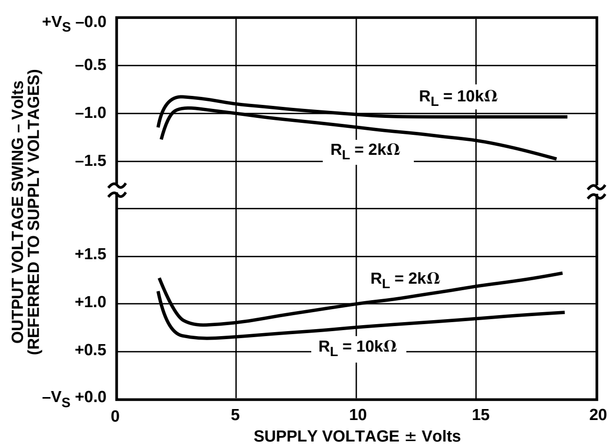


Figure 19. Output Voltage Swing vs. Supply Voltage, G = 10

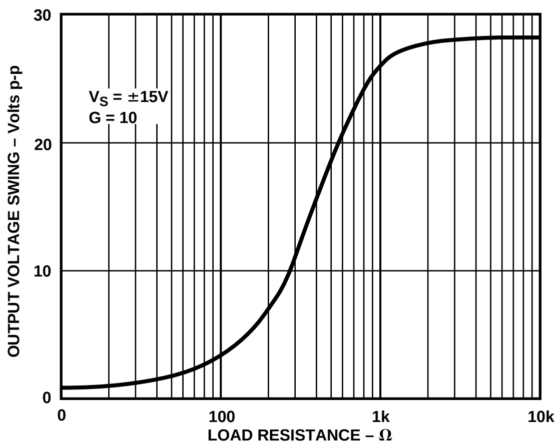


Figure 20. Output Voltage Swing vs. Load Resistance

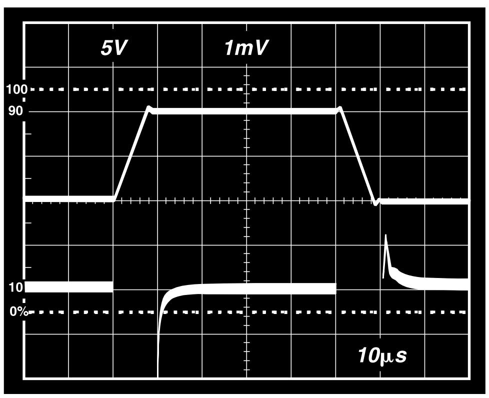


Figure 21. Large Signal Pulse Response and Settling Time G = 1 (0.5 mV = 0.01%)

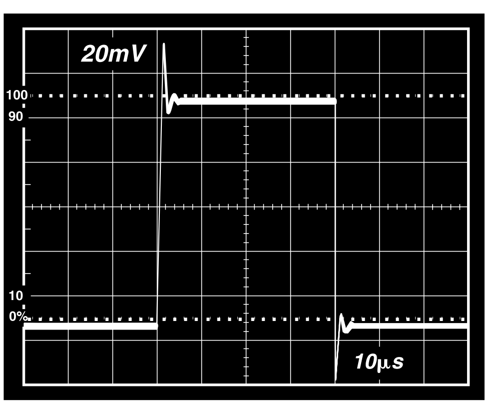


Figure 22. Small Signal Response, G = 1, R_L = 2 kΩ, C_L = 100 pF

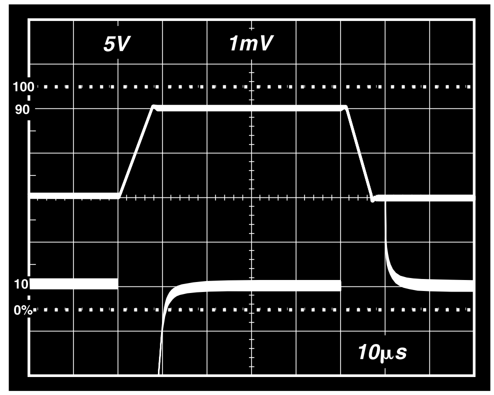


Figure 23. Large Signal Response and Settling Time, G = 10 (0.5 mV = 001%)

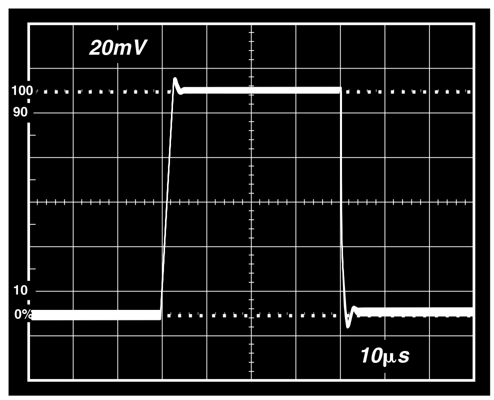


Figure 24. Small Signal Response, G = 10, R_L = 2 kΩ, C_L = 100 pF

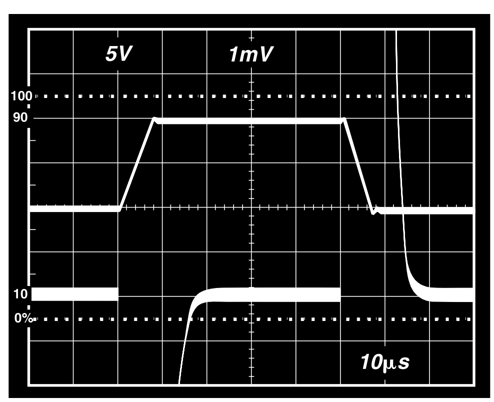


Figure 25. Large Signal Response and Settling Time, G = 100 (0.5 mV = 0.01%)

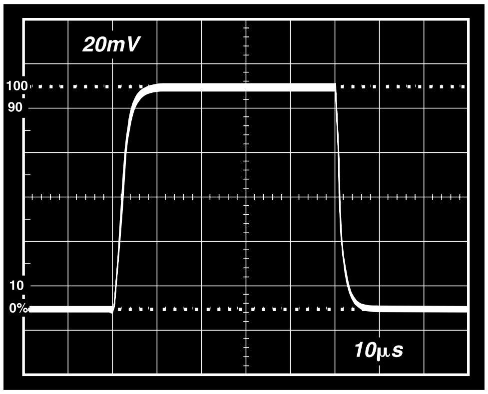


Figure 26. Small Signal Pulse Response, G = 100, R_L = 2 kΩ, C_L = 100 pF

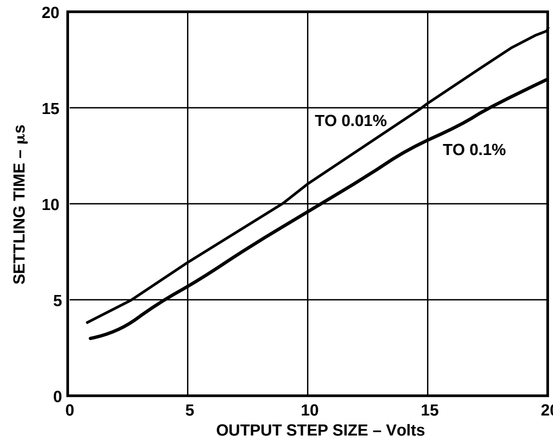


Figure 29. Settling Time vs. Step Size (G = 1)

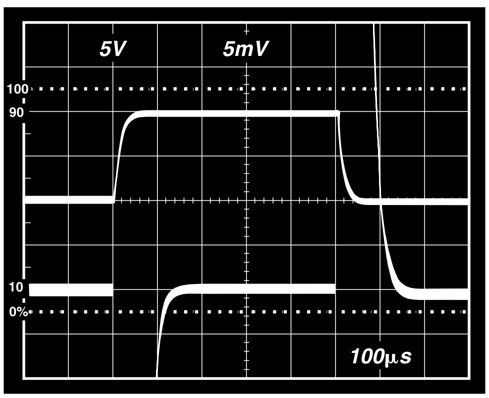


Figure 27. Large Signal Response and Settling Time, G = 1000 (0.5 mV = 0.01%)

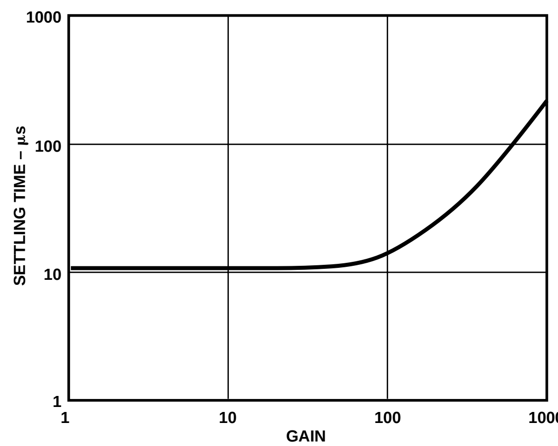


Figure 30. Settling Time to 0.01% vs. Gain, for a 10 V Step

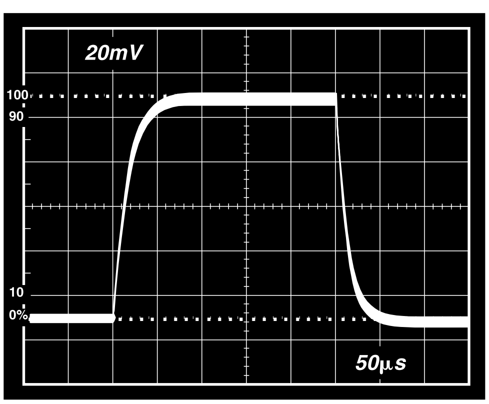


Figure 28. Small Signal Pulse Response, G = 1000, R_L = 2 kΩ, C_L = 100 pF

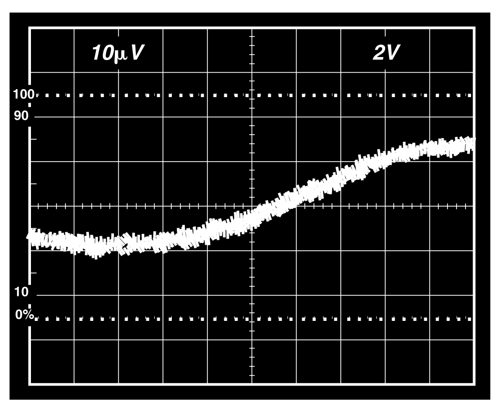


Figure 31a. Gain Nonlinearity, G = 1, R_L = 10 kΩ (10 μV = 1 ppm)

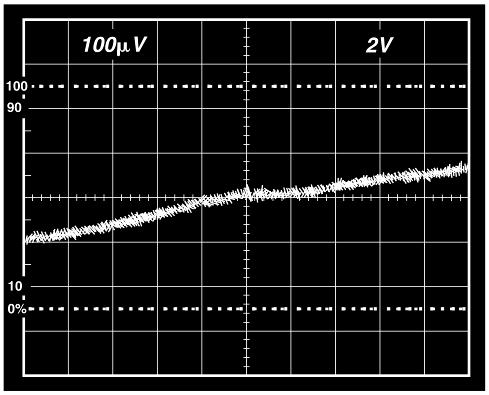


Figure 31b. Gain Nonlinearity, G = 100, R_L = 10 kΩ (100 µV = 10 ppm)

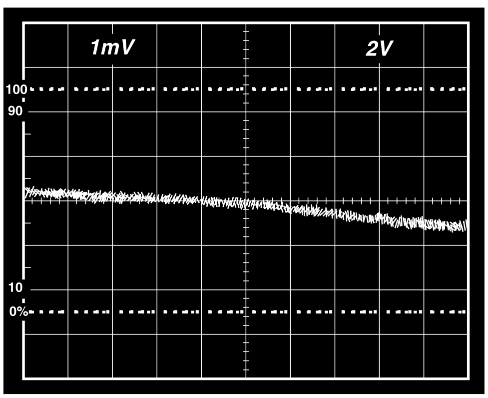


Figure 31c. Gain Nonlinearity, G = 1000, R_L = 10 kΩ (1 mV = 100 ppm)

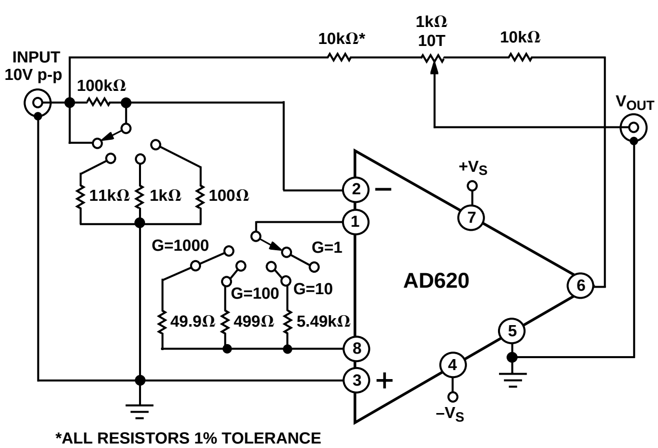


Figure 32. Settling Time Test Circuit

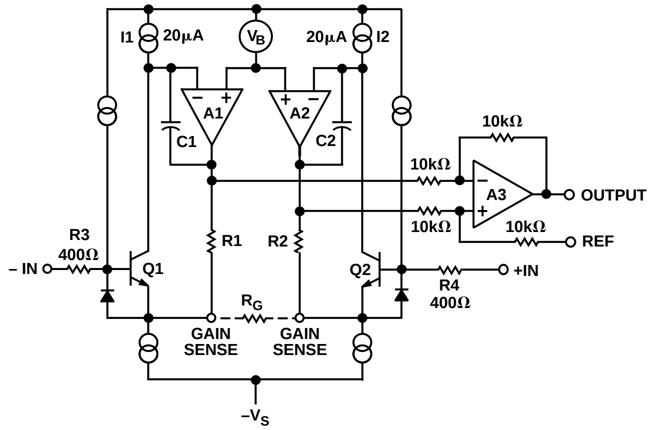


Figure 33. Simplified Schematic of AD620

THEORY OF OPERATION

The AD620 is a monolithic instrumentation amplifier based on a modification of the classic three op amp approach. Absolute value trimming allows the user to program gain *accurately* (to 0.15% at G = 100) with only one resistor. Monolithic construction and laser wafer trimming allow the tight matching and tracking of circuit components, thus ensuring the high level of performance inherent in this circuit.

The input transistors Q1 and Q2 provide a single differential-pair bipolar input for high precision (Figure 33), yet offer 10× lower Input Bias Current thanks to Superβeta processing. Feedback through the Q1-A1-R1 loop and the Q2-A2-R2 loop maintains constant collector current of the input devices Q1, Q2 thereby impressing the input voltage across the external gain setting resistor R_G. This creates a differential gain from the inputs to the A1/A2 outputs given by G = (R1 + R2)/R_G + 1. The unity-gain subtracter A3 removes any common-mode signal, yielding a single-ended output referred to the REF pin potential.

The value of R_G also determines the transconductance of the preamp stage. As R_G is reduced for larger gains, the transconductance increases asymptotically to that of the input transistors. This has three important advantages: (a) Open-loop gain is boosted for increasing programmed gain, thus reducing gain-related errors. (b) The gain-bandwidth product (determined by C1, C2 and the preamp transconductance) increases with programmed gain, thus optimizing frequency response. (c) The input voltage noise is reduced to a value of 9 nV/$\sqrt{\text{Hz}}$, determined mainly by the collector current and base resistance of the input devices.

The internal gain resistors, R1 and R2, are trimmed to an absolute value of 24.7 kΩ, allowing the gain to be programmed accurately with a single external resistor.

The gain equation is then

$$G = \frac{49.4\ k\Omega}{R_G} + 1$$

so that

$$R_G = \frac{49.4\ k\Omega}{G - 1}$$

Make vs. Buy: A Typical Bridge Application Error Budget

The AD620 offers improved performance over "homebrew" three op amp IA designs, along with smaller size, fewer components and 10× lower supply current. In the typical application, shown in Figure 34, a gain of 100 is required to amplify a bridge output of 20 mV full scale over the industrial temperature range of –40°C to +85°C. The error budget table below shows how to calculate the effect various error sources have on circuit accuracy.

Regardless of the system in which it is being used, the AD620 provides greater accuracy, and at low power and price. In simple systems, absolute accuracy and drift errors are by far the most significant contributors to error. In more complex systems with an intelligent processor, an autogain/autozero cycle will remove all absolute accuracy and drift errors leaving only the resolution errors of gain nonlinearity and noise, thus allowing full 14-bit accuracy.

Note that for the homebrew circuit, the OP07 specifications for input voltage offset and noise have been multiplied by $\sqrt{2}$. This is because a three op amp type in-amp has two op amps at its inputs, both contributing to the overall input error.

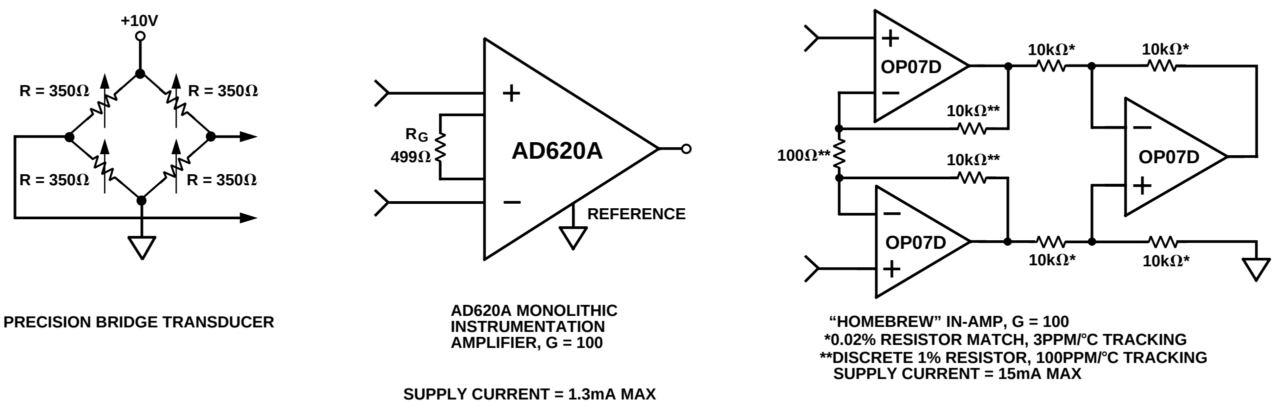


Figure 34. Make vs. Buy

Table I. Make vs. Buy Error Budget

Error Source	AD620 Circuit Calculation	"Homebrew" Circuit Calculation	Error, ppm of Full Scale AD620	Homebrew
ABSOLUTE ACCURACY at T_A = +25°C				
Input Offset Voltage, μV	125 μV/20 mV	(150 μV × $\sqrt{2}$)/20 mV	6,250	10,607
Output Offset Voltage, μV	1000 μV/100/20 mV	((150 μV × 2)/100)/20 mV	500	150
Input Offset Current, nA	2 nA × 350 Ω/20 mV	(6 nA × 350 Ω)/20 mV	18	53
CMR, dB	110 dB→3.16 ppm, × 5 V/20 mV	(0.02% Match × 5 V)/20 mV/100	791	500
		Total Absolute Error	7,558	11,310
DRIFT TO +85°C				
Gain Drift, ppm/°C	(50 ppm + 10 ppm) × 60°C	100 ppm/°C Track × 60°C	3,600	6,000
Input Offset Voltage Drift, μV/°C	1 μV/°C × 60°C/20 mV	(2.5 μV/°C × $\sqrt{2}$ × 60°C)/20 mV	3,000	10,607
Output Offset Voltage Drift, μV/°C	15 μV/°C × 60°C/100/20 mV	(2.5 μV/°C × 2 × 60°C)/100/20 mV	450	150
		Total Drift Error	7,050	16,757
RESOLUTION				
Gain Nonlinearity, ppm of Full Scale	40 ppm	40 ppm	40	40
Typ 0.1 Hz–10 Hz Voltage Noise, μV p-p	0.28 μV p-p/20 mV	(0.38 μV p-p × $\sqrt{2}$)/20 mV	14	27
		Total Resolution Error	54	67
		Grand Total Error	14,662	28,134

G = 100, V_S = ±15 V.

(All errors are min/max and referred to input.)

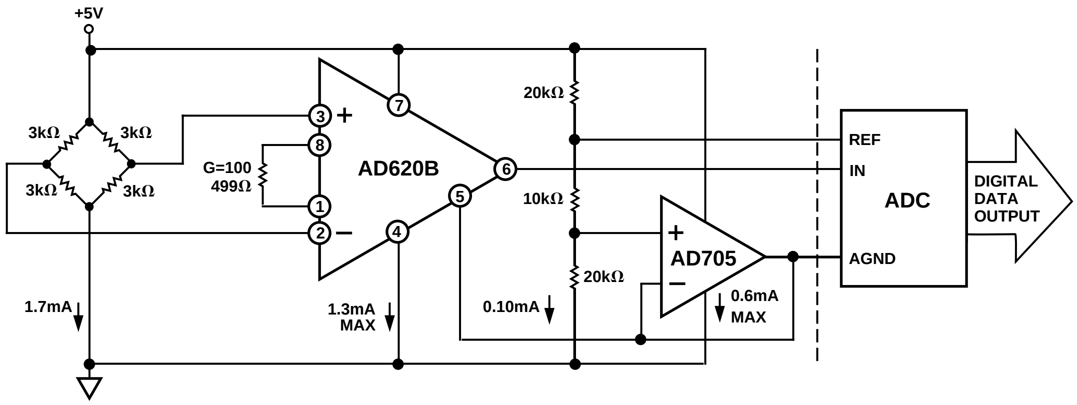


Figure 35. A Pressure Monitor Circuit which Operates on a +5 V Single Supply

Pressure Measurement

Although useful in many bridge applications such as weigh scales, the AD620 is especially suitable for higher resistance pressure sensors powered at lower voltages where small size and low power become more significant.

Figure 35 shows a 3 kΩ pressure transducer bridge powered from +5 V. In such a circuit, the bridge consumes only 1.7 mA. Adding the AD620 and a buffered voltage divider allows the signal to be conditioned for only 3.8 mA of total supply current.

Small size and low cost make the AD620 especially attractive for voltage output pressure transducers. Since it delivers low noise and drift, it will also serve applications such as diagnostic non-invasive blood pressure measurement.

Medical ECG

The low current noise of the AD620 allows its use in ECG monitors (Figure 36) where high source resistances of 1 MΩ or higher are not uncommon. The AD620's low power, low supply voltage requirements, and space-saving 8-lead mini-DIP and SOIC package offerings make it an excellent choice for battery powered data recorders.

Furthermore, the low bias currents and low current noise coupled with the low voltage noise of the AD620 improve the dynamic range for better performance.

The value of capacitor C1 is chosen to maintain stability of the right leg drive loop. Proper safeguards, such as isolation, must be added to this circuit to protect the patient from possible harm.

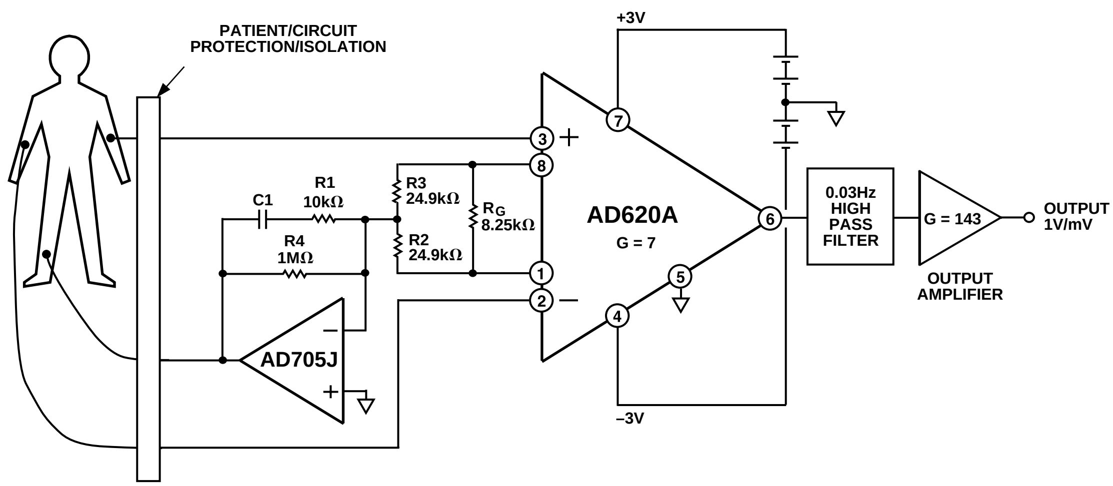


Figure 36. A Medical ECG Monitor Circuit

Precision V-I Converter

The AD620, along with another op amp and two resistors, makes a precision current source (Figure 37). The op amp buffers the reference terminal to maintain good CMR. The output voltage V_X of the AD620 appears across R1, which converts it to a current. This current less only, the input bias current of the op amp, then flows out to the load.

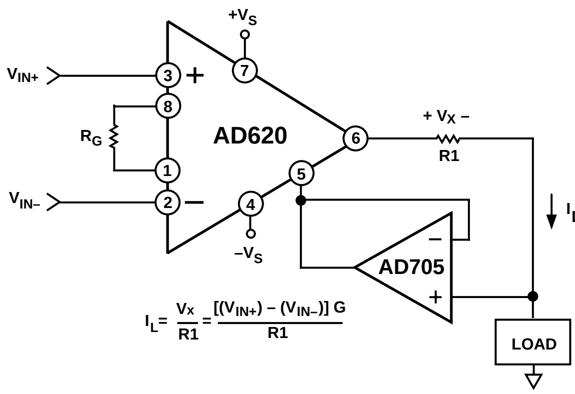


Figure 37. Precision Voltage-to-Current Converter (Operates on 1.8 mA, ±3 V)

GAIN SELECTION

The AD620's gain is resistor programmed by R_G, or more precisely, by whatever impedance appears between Pins 1 and 8. The AD620 is designed to offer accurate gains using 0.1%–1% resistors. Table II shows required values of R_G for various gains. Note that for G = 1, the R_G pins are unconnected ($R_G = \infty$). For any arbitrary gain R_G can be calculated by using the formula:

$$R_G = \frac{49.4\ k\Omega}{G - 1}$$

To minimize gain error, avoid high parasitic resistance in series with R_G; to minimize gain drift, R_G should have a low TC—less than 10 ppm/°C—for the best performance.

Table II. Required Values of Gain Resistors

1% Std Table Value of R_G, Ω	Calculated Gain	0.1% Std Table Value of R_G, Ω	Calculated Gain
49.9 k	1.990	49.3 k	2.002
12.4 k	4.984	12.4 k	4.984
5.49 k	9.998	5.49 k	9.998
2.61 k	19.93	2.61 k	19.93
1.00 k	50.40	1.01 k	49.91
499	100.0	499	100.0
249	199.4	249	199.4
100	495.0	98.8	501.0
49.9	991.0	49.3	1,003

INPUT AND OUTPUT OFFSET VOLTAGE

The low errors of the AD620 are attributed to two sources, input and output errors. The output error is divided by G when referred to the input. In practice, the input errors dominate at high gains and the output errors dominate at low gains. The total V_{OS} for a given gain is calculated as:

Total Error RTI = input error + (output error/G)

Total Error RTO = (input error × G) + output error

REFERENCE TERMINAL

The reference terminal potential defines the zero output voltage, and is especially useful when the load does not share a precise ground with the rest of the system. It provides a direct means of injecting a precise offset to the output, with an allowable range of 2 V within the supply voltages. Parasitic resistance should be kept to a minimum for optimum CMR.

INPUT PROTECTION

The AD620 features 400 Ω of series thin film resistance at its inputs, and will safely withstand input overloads of up to ±15 V or ±60 mA for several hours. This is true for all gains, and power on and off, which is particularly important since the signal source and amplifier may be powered separately. For longer time periods, the current should not exceed 6 mA ($I_{IN} \leq V_{IN}/400\ \Omega$). For input overloads beyond the supplies, clamping the inputs to the supplies (using a low leakage diode such as an FD333) will reduce the required resistance, yielding lower noise.

RF INTERFERENCE

All instrumentation amplifiers can rectify out of band signals, and when amplifying small signals, these rectified voltages act as small dc offset errors. The AD620 allows direct access to the input transistor bases and emitters enabling the user to apply some first order filtering to unwanted RF signals (Figure 38), where $RC \approx 1/(2\pi f)$ and where $f \geq$ the bandwidth of the AD620; $C \leq 150$ pF. Matching the extraneous capacitance at Pins 1 and 8 and Pins 2 and 3 helps to maintain high CMR.

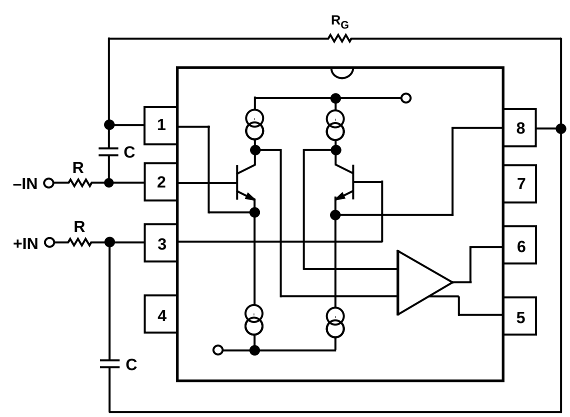


Figure 38. Circuit to Attenuate RF Interference

COMMON-MODE REJECTION

Instrumentation amplifiers like the AD620 offer high CMR, which is a measure of the change in output voltage when both inputs are changed by equal amounts. These specifications are usually given for a full-range input voltage change and a specified source imbalance.

For optimal CMR the reference terminal should be tied to a low impedance point, and differences in capacitance and resistance should be kept to a minimum between the two inputs. In many applications shielded cables are used to minimize noise, and for best CMR over frequency the shield should be properly driven. Figures 39 and 40 show active data guards that are configured to improve ac common-mode rejections by "bootstrapping" the capacitances of input cable shields, thus minimizing the capacitance mismatch between the inputs.

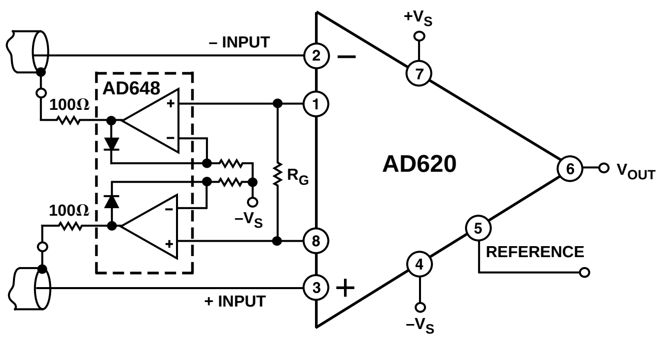


Figure 39. Differential Shield Driver

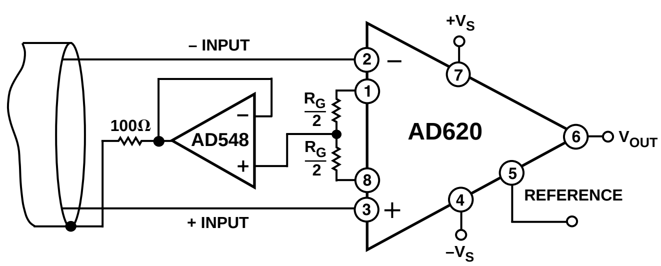


Figure 40. Common-Mode Shield Driver

GROUNDING

Since the AD620 output voltage is developed with respect to the potential on the reference terminal, it can solve many grounding problems by simply tying the REF pin to the appropriate "local ground."

In order to isolate low level analog signals from a noisy digital environment, many data-acquisition components have separate analog and digital ground pins (Figure 41). It would be convenient to use a single ground line; however, current through ground wires and PC runs of the circuit card can cause hundreds of millivolts of error. Therefore, separate ground returns should be provided to minimize the current flow from the sensitive points to the system ground. These ground returns must be tied together at some point, usually best at the ADC package as shown.

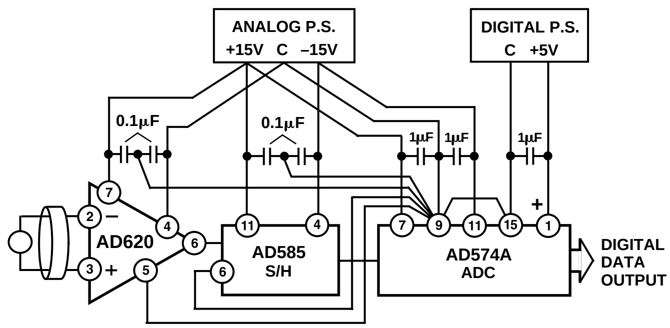


Figure 41. Basic Grounding Practice

GROUND RETURNS FOR INPUT BIAS CURRENTS

Input bias currents are those currents necessary to bias the input transistors of an amplifier. There must be a direct return path for these currents; therefore, when amplifying "floating" input sources such as transformers, or ac-coupled sources, there must be a dc path from each input to ground as shown in Figure 42. Refer to the *Instrumentation Amplifier Application Guide* (free from Analog Devices) for more information regarding in amp applications.

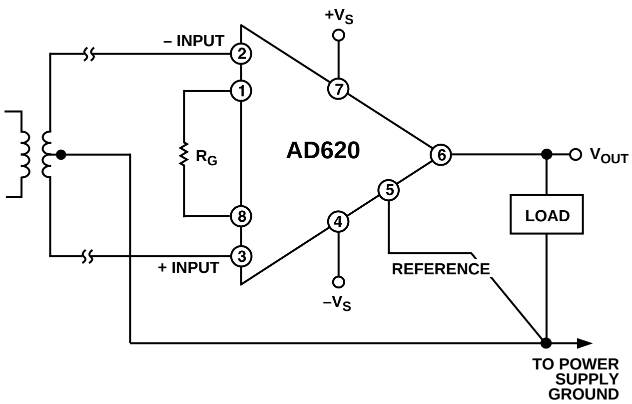


Figure 42a. Ground Returns for Bias Currents with Transformer Coupled Inputs

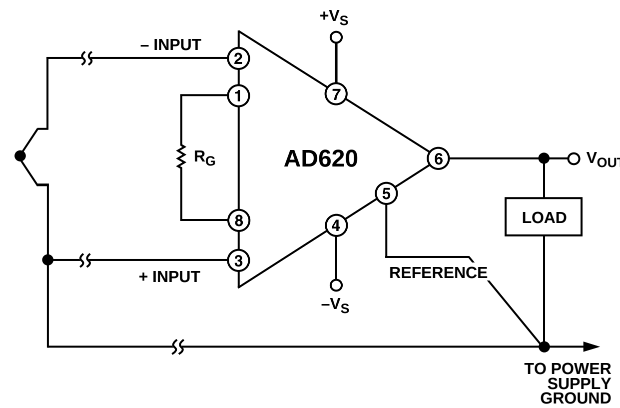


Figure 42b. Ground Returns for Bias Currents with Thermocouple Inputs

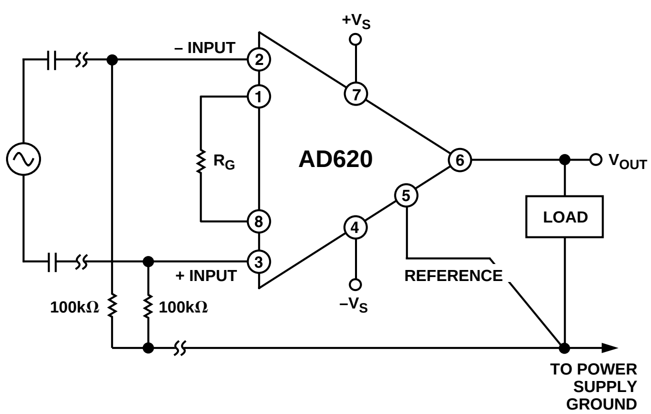
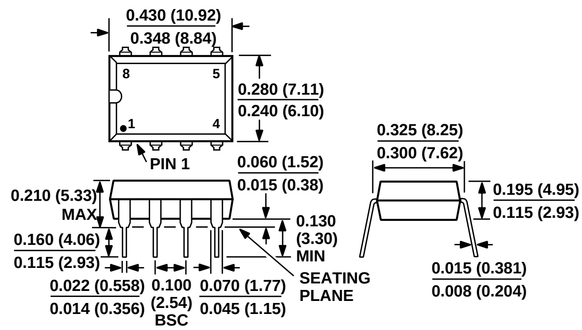


Figure 42c. Ground Returns for Bias Currents with AC Coupled Inputs

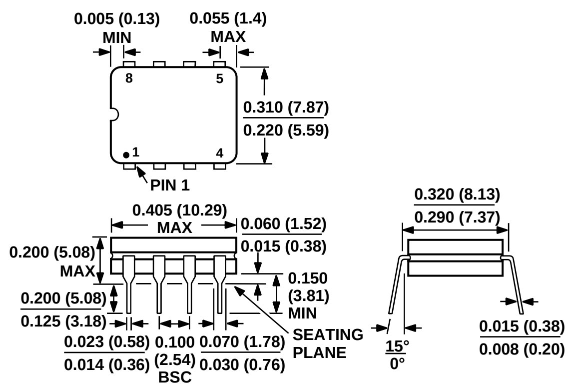
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

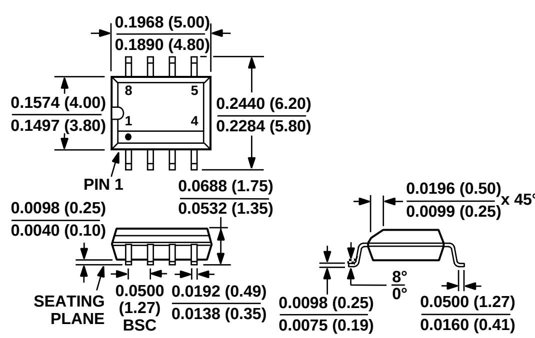
Plastic DIP (N-8) Package



Cerdip (Q-8) Package



SOIC (SO-8) Package

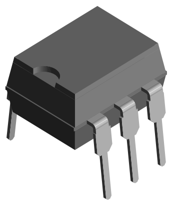


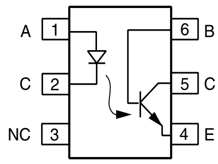
C1599c–0–7/99

PRINTED IN U.S.A.

Optocoupler, Phototransistor Output, With Base Connection

Features
- Isolation Test Voltage 5300 V_{RMS}
- Interfaces with Common Logic Families
- Input-output Coupling Capacitance < 0.5 pF
- Industry Standard Dual-in-line 6-pin Package
- Lead-free component
- Component in accordance to RoHS 2002/95/EC and WEEE 2002/96/EC





i179004

Agency Approvals
- UL1577, File No. E52744 System Code H or J, Double Protection
- DIN EN 60747-5-2 (VDE0884)
  DIN EN 60747-5-5 pending
  Available with Option 1

Applications
AC Mains Detection
Reed relay driving
Switch Mode Power Supply Feedback
Telephone Ring Detection
Logic Ground Isolation
Logic Coupling with High Frequency Noise Rejection

Description
The 4N25 family is an Industry Standard Single Channel Phototransistor Coupler.This family includes the 4N25/ 4N26/ 4N27/ 4N28. Each optocoupler consists of gallium arsenide infrared LED and a silicon NPN phototransistor.

These couplers are Underwriters Laboratories (UL) listed to comply with a 5300 V_{RMS} isolation test voltage. This isolation performance is accomplished through special Vishay manufacturing process.

Compliance to DIN EN 60747-5-2(VDE0884)/ DIN EN 60747-5-5 pending partial discharge isolation specification is available by ordering option1.

These isolation processes and the Vishay ISO9001 quality program results in the highest isolation performance available for a commercial plastic phototransistor optocoupler.

The devices are also available in lead formed configuration suitable for surface mounting and are available either on tape and reel, or in standard tube shipping containers.

Note:
For additional design information see Application Note 45 Normalized Curves

Order Information

Part	Remarks
4N25	CTR > 20 %, DIP-6
4N26	CTR > 20 %, DIP-6
4N27	CTR > 10 %, DIP-6
4N28	CTR > 10 %, DIP-6
4N25-X006	CTR > 20 %, DIP-6 400 mil (option 6)
4N25-X007	CTR > 20 %, SMD-6 (option 7)
4N25-X009	CTR > 20 %, SMD-6 (option 9)
4N26-X006	CTR > 20 %, DIP-6 400 mil (option 6)
4N26-X007	CTR > 20 %, SMD-6 (option 7)
4N26-X009	CTR > 20 %, SMD-6 (option 9)
4N27-X007	CTR > 10 %, SMD-6 (option 7)
4N27-X009	CTR > 10 %, SMD-6 (option 9)
4N28-X009	CTR > 10 %, SMD-6 (option 9)

For additional information on the available options refer to Option Information.

Absolute Maximum Ratings

T_{amb} = 25 °C, unless otherwise specified
Stresses in excess of the absolute Maximum Ratings can cause permanent damage to the device. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of this document. Exposure to absolute Maximum Rating for extended periods of the time can adversely affect reliability.

Input

Parameter	Test condition	Symbol	Value	Unit
Reverse voltage		V_R	6.0	V
Forward current		I_F	60	mA
Surge current	t < 10 µs	I_{FSM}	2.5	A
Power dissipation		P_{diss}	100	mW

Output

Parameter	Test condition	Symbol	Value	Unit
Collector-emitter breakdown voltage		V_{CEO}	70	V
Emitter-base breakdown voltage		V_{EBO}	7.0	V
Collector current		I_C	50	mA
Collector currrent	t < 1.0 ms	I_C	100	mA
Power dissipation		P_{diss}	150	mW

Coupler

Parameter	Test condition	Symbol	Value	Unit
Isolation test voltage		V_{ISO}	5300	V_{RMS}
Creepage			≥ 7.0	mm
Clearance			≥ 7.0	mm
Isolation thickness between emitter and detector			≥ 0.4	mm
Comparative tracking index	DIN IEC 112/VDE0303, part 1		175	
Isolation resistance	V_{IO} = 500 V, T_{amb} = 25 °C	R_{IO}	10^{12}	Ω
	V_{IO} = 500 V, T_{amb} = 100 °C	R_{IO}	10^{11}	Ω
Storage temperature		T_{stg}	- 55 to + 150	°C
Operating temperature		T_{amb}	- 55 to + 100	°C
Junction temperature		T_j	100	°C
Soldering temperature	max.10 s, dip soldering: distance to seating plane ≥ 1.5 mm	T_{sld}	260	°C

Electrical Characteristics

T_{amb} = 25 °C, unless otherwise specified
Minimum and maximum values are testing requirements. Typical values are characteristics of the device and are the result of engineering evaluation. Typical values are for information only and are not part of the testing requirements.

Input

Parameter	Test condition	Symbol	Min	Typ.	Max	Unit
Forward voltage[1)]	I_F = 50 mA	V_F		1.3	1.5	V
Reverse current[1)]	V_R = 3.0 V	I_R		0.1	100	µA
Capacitance	V_R = 0 V	C_O		25		pF

[1)] Indicates JEDEC registered values

Output

Parameter	Test condition	Part	Symbol	Min	Typ.	Max	Unit
Collector-base breakdown voltage[1)]	I_C = 100 µA		BV_{CBO}	70			V
Collector-emitter breakdown voltage[1)]	I_C = 1.0 mA		BV_{CEO}	30			V
Emitter-collector breakdown voltage[1)]	I_E = 100 µA		BV_{ECO}	7.0			V
I_{CEO}(dark)[1)]	V_{CE} = 10 V, (base open)	4N25			5.0	50	nA
		4N26			5.0	50	nA
		4N27			5.0	50	nA
		4N28			10	100	nA
I_{CBO}(dark)[1)]	V_{CB} = 10 V, (emitter open)				2.0	20	nA
Collector-emitter capacitance	V_{CE} = 0		C_{CE}		6.0		pF

[1)] Indicates JEDEC registered values

Coupler

Parameter	Test condition	Part	Symbol	Min	Typ.	Max	Unit
Isolation voltage[1)]	Peak, 60 Hz	4N25	V_{IO}	2500			V
		4N26	V_{IO}	1500			V
		4N27	V_{IO}	1500			V
		4N28	V_{IO}	500			V
Saturation voltage, collector-emitter	I_{CE} = 2.0 mA, I_F = 50 mA		$V_{CE(sat)}$			0.5	V
Resistance, input output[1)]	V_{IO} = 500 V		R_{IO}	100			GΩ
Capacitance (input-output)	f = 1.0 MHz		C_{IO}		0.5		pF

[1)] Indicates JEDEC registered values

Current Transfer Ratio

Parameter	Test condition	Part	Symbol	Min	Typ.	Max	Unit
DC Current Transfer Ratio[1)]	V_{CE} = 10 V, I_F = 10 mA	4N25	CTR_{DC}	20	50		%
		4N26	CTR_{DC}	20	50		%
		4N27	CTR_{DC}	10	30		%
		4N28	CTR_{DC}	10	30		%

[1)] Indicates JEDEC registered value

Switching Characteristics

Parameter	Test condition	Symbol	Min	Typ.	Max	Unit
Rise and fall times	V_{CE} = 10 V, I_F = 10 mA, R_L = 100 Ω	t_r, t_f		2.0		µs

Typical Characteristics (Tamb = 25 °C unless otherwise specified)

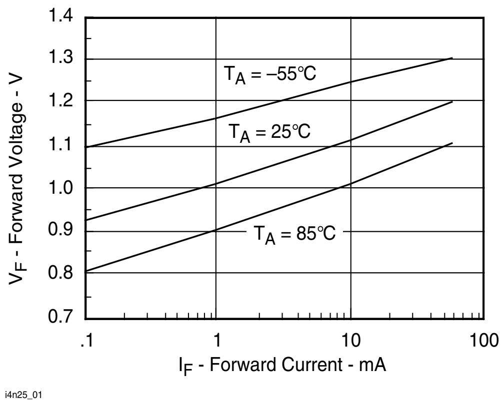


Figure 1. Forward Voltage vs. Forward Current

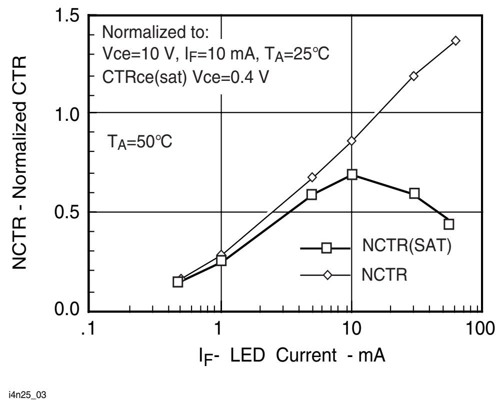


Figure 3. Normalized Non-saturated and Saturated CTR vs. LED Current

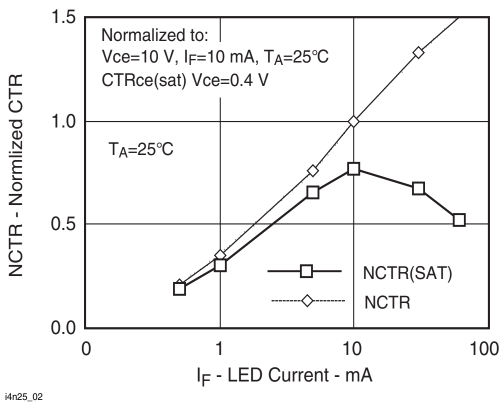


Figure 2. Normalized Non-Saturated and Saturated CTR vs. LED Current

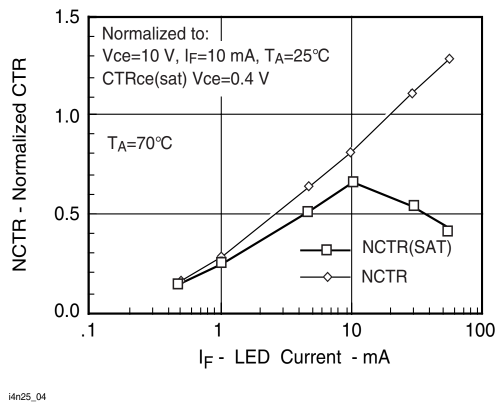


Figure 4. Normalized Non-saturated and saturated CTR vs. LED Current

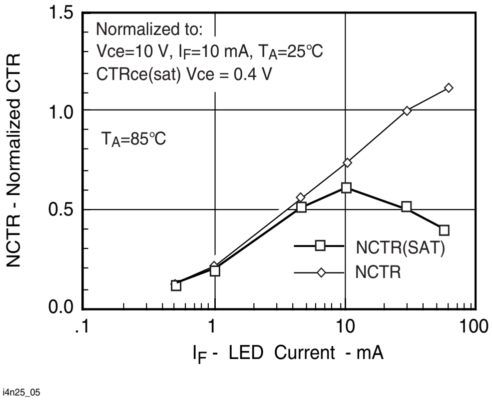


Figure 5. Normalized Non-saturated and saturated CTR vs. LED Current

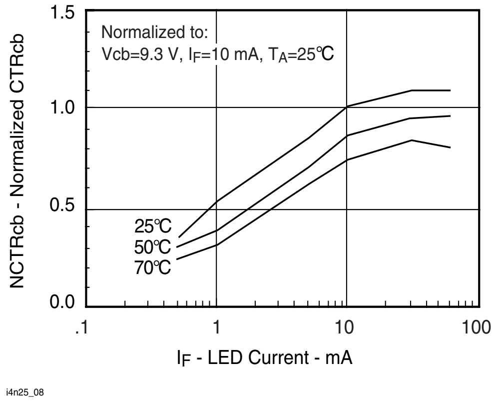


Figure 8. Normalized CTRcb vs. LED Current and Temp.

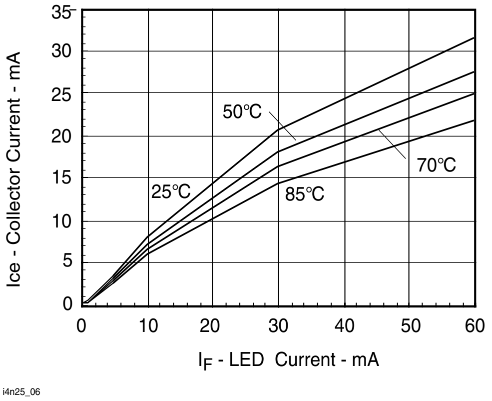


Figure 6. Collector-Emitter Current vs. Temperature and LED Current

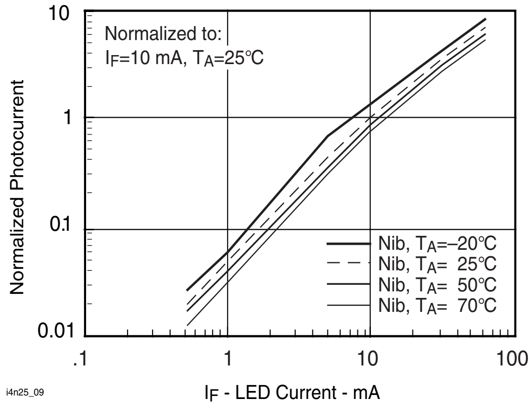


Figure 9. Normalized Photocurrent vs. I_F and Temp.

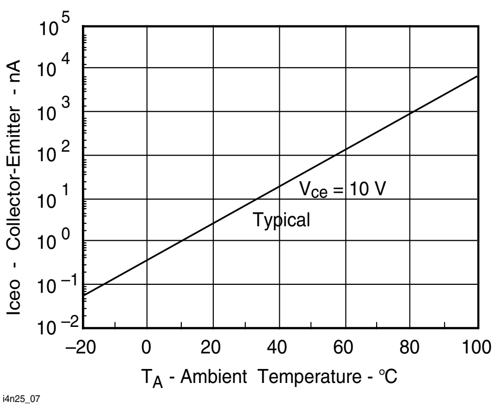


Figure 7. Collector-Emitter Leakage Current vs.Temp.

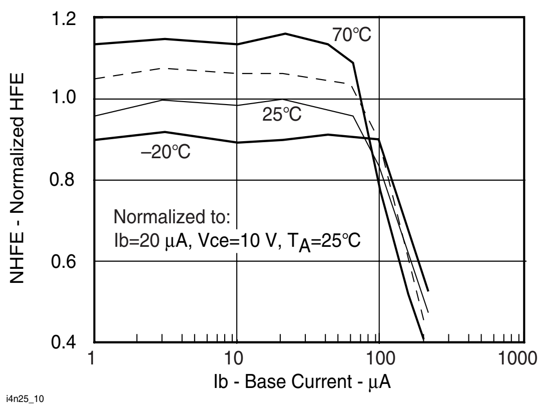


Figure 10. Normalized Non-saturated HFE vs. Base Current and Temperature

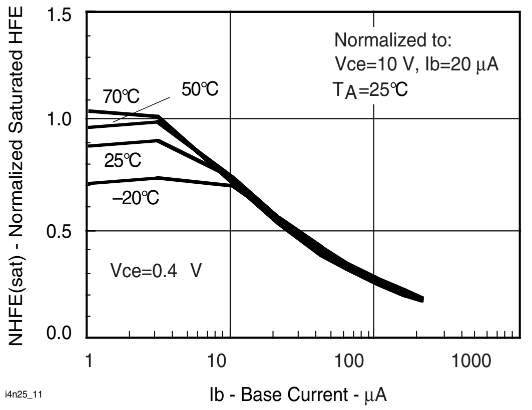


Figure 11. Normalized HFE vs. Base Current and Temp.

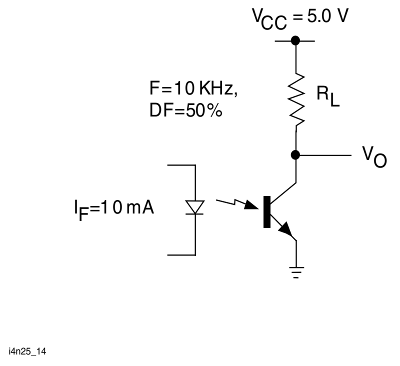


Figure 14. Switching Schematic

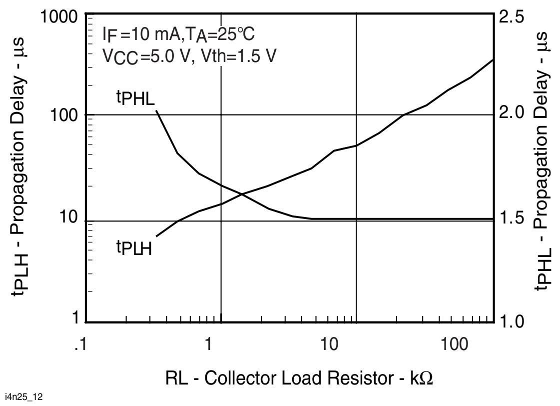


Figure 12. Propagation Delay vs. Collector Load Resistor

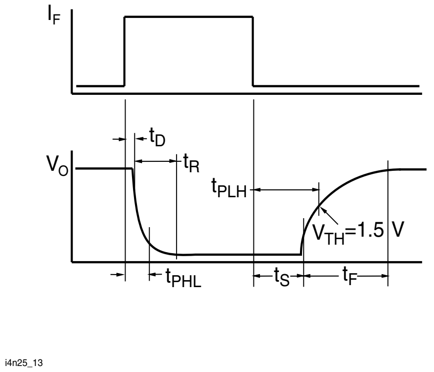
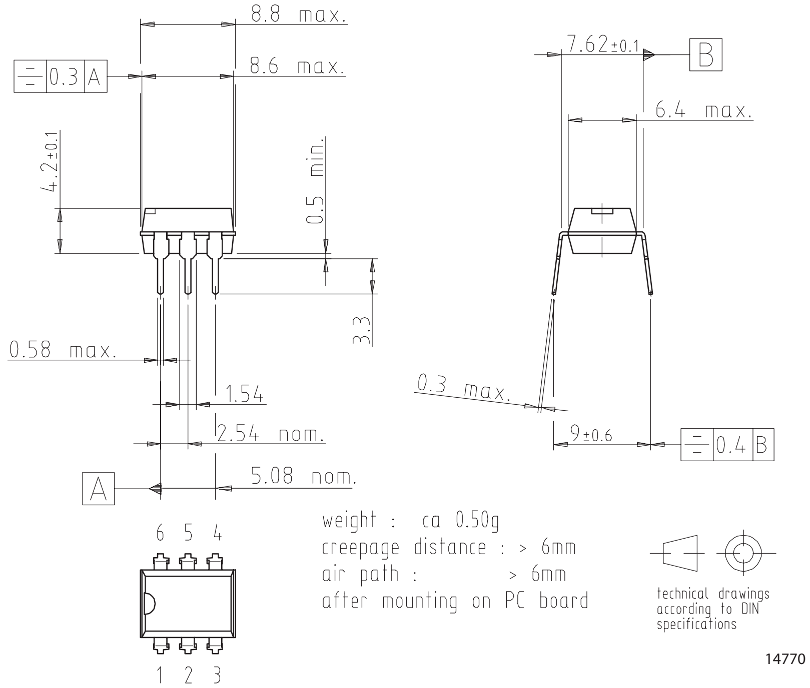


Figure 13. Switching Timing

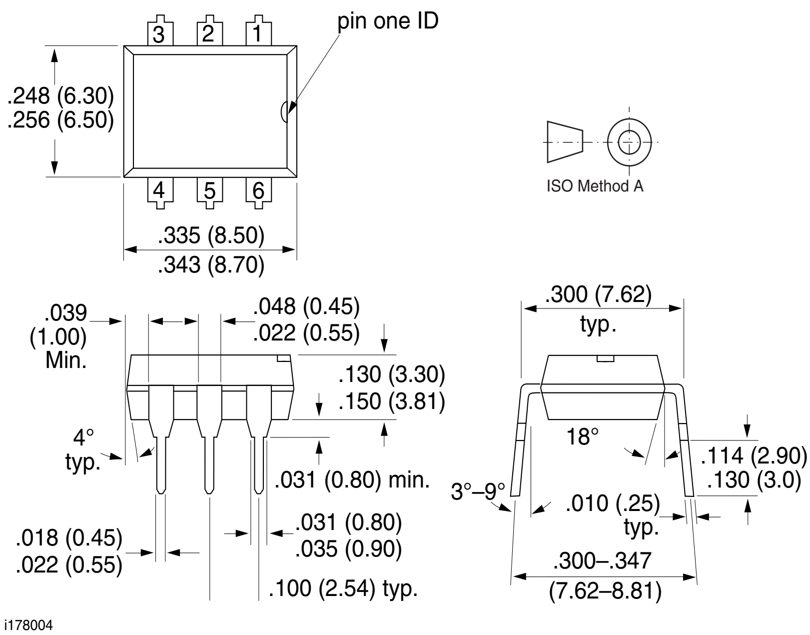
Package Dimensions in Inches (mm)

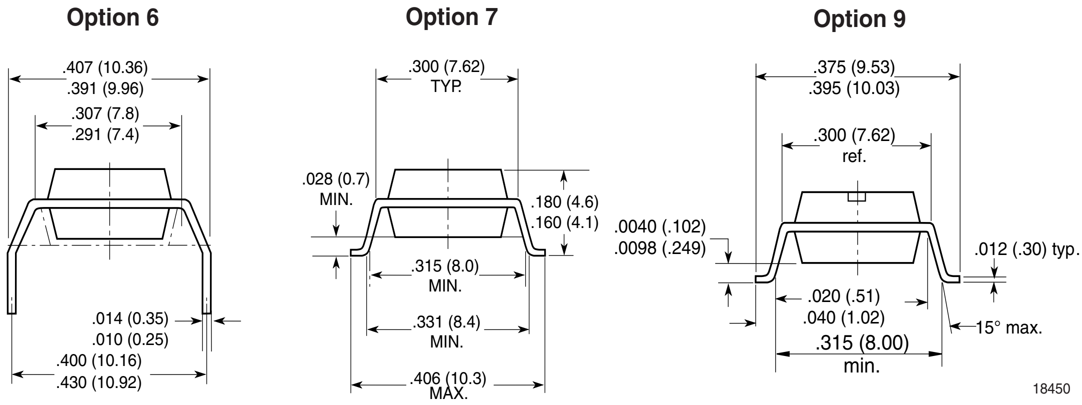
For 4N25/26/27..... see DIL300-6 Package dimension in the Package Section.
For 4N28 and for products with an option designator (e.g. 4N25-X001 or 4N26-X007)..... see DIP-6 Package dimensions in the Package Section.

DIL300-6 Package Dimensions



DIP-6 Package Dimensions




Option 6
.407 (10.36)
.391 (9.96)
.307 (7.8)
.291 (7.4)
.014 (0.35)
.010 (0.25)
.400 (10.16)
.430 (10.92)
Option 7
.300 (7.62)
TYP.
.028 (0.7)
MIN.
.180 (4.6)
.160 (4.1)
.315 (8.0)
MIN.
.331 (8.4)
MIN.
.406 (10.3)
MAX.
Option 9
.375 (9.53)
.395 (10.03)
.300 (7.62)
ref.
.0040 (.102)
.0098 (.249)
.012 (.30) typ.
.020 (.51)
.040 (1.02)
.315 (8.00)
min.
15° max.
18450

Ozone Depleting Substances Policy Statement

It is the policy of Vishay Semiconductor GmbH to

1. Meet all present and future national and international statutory requirements.
2. Regularly and continuously improve the performance of our products, processes, distribution and operatingsystems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

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

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

1. Annex A, B and list of transitional substances of the Montreal Protocol and the London Amendments respectively
2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA
3. Council Decision 88/540/EEC and 91/690/EEC Annex A, B and C (transitional substances) respectively.

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

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

www.fairchildsemi.com

LM741

Single Operational Amplifier

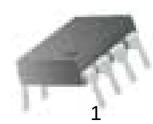
Features

- Short circuit protection
- Excellent temperature stability
- Internal frequency compensation
- High Input voltage range
- Null of offset

Description

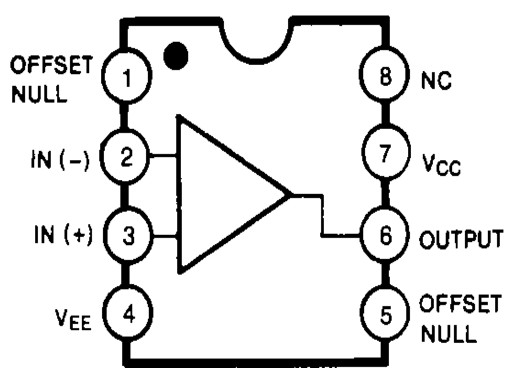
The LM741 series are general purpose operational amplifiers. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in intergrator, summing amplifier, and general feedback applications.

8-DIP



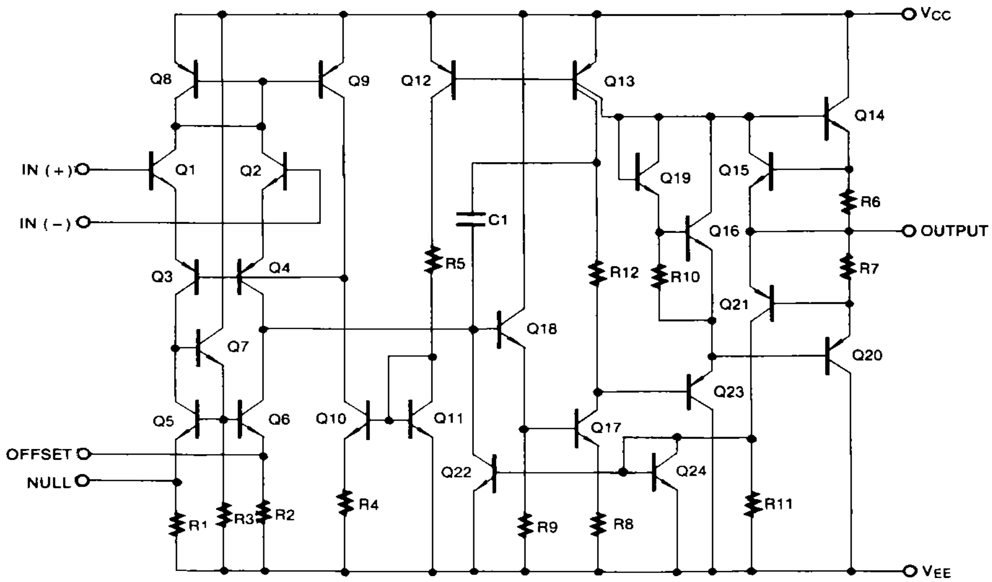
8-SOP

Internal Block Diagram



Rev. 1.0.1

Schematic Diagram



Absolute Maximum Ratings (T_A = 25°C)

Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	±18	V
Differential Input Voltage	$V_{I(DIFF)}$	30	V
Input Voltage	V_I	±15	V
Output Short Circuit Duration	-	Indefinite	-
Power Dissipation	P_D	500	mW
Operating Temperature Range LM741C LM741I	T_{OPR}	0 ~ + 70 -40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ + 150	°C

Electrical Characteristics

(V_{CC} = 15V, V_{EE} = - 15V. T_A = 25 °C, unless otherwise specified)

Parameter	Symbol	Conditions	LM741C/LM741I Min.	LM741C/LM741I Typ.	LM741C/LM741I Max.	Unit
Input Offset Voltage	V_{IO}	$R_S \le 10K\Omega$	-	2.0	6.0	mV
		$R_S \le 50\Omega$	-	-	-	
Input Offset Voltage Adjustment Range	$V_{IO(R)}$	$V_{CC} = \pm 20V$	-	±15	-	mV
Input Offset Current	I_{IO}	-	-	20	200	nA
Input Bias Current	I_{BIAS}	-	-	80	500	nA
Input Resistance (Note1)	R_I	$V_{CC} = \pm 20V$	0.3	2.0	-	MΩ
Input Voltage Range	$V_{I(R)}$	-	±12	±13	-	V
Large Signal Voltage Gain	G_V	$R_L \ge 2K\Omega$, $V_{CC} = \pm 20V$, $V_{O(P-P)} = \pm 15V$	-	-	-	V/mV
		$R_L \ge 2K\Omega$, $V_{CC} = \pm 15V$, $V_{O(P-P)} = \pm 10V$	20	200	-	
Output Short Circuit Current	I_{SC}	-	-	25	-	mA
Output Voltage Swing	$V_{O(P-P)}$	$V_{CC} = \pm 20V$, $R_L \ge 10K\Omega$	-	-	-	V
		$V_{CC} = \pm 20V$, $R_L \ge 2K\Omega$	-	-	-	
		$V_{CC} = \pm 15V$, $R_L \ge 10K\Omega$	±12	±14	-	
		$V_{CC} = \pm 15V$, $R_L \ge 2K\Omega$	±10	±13	-	
Common Mode Rejection Ratio	CMRR	$R_S \le 10K\Omega$, $V_{CM} = \pm 12V$	70	90	-	dB
		$R_S \le 50\Omega$, $V_{CM} = \pm 12V$	-	-	-	
Power Supply Rejection Ratio	PSRR	$V_{CC} = \pm 15V$ to $V_{CC} = \pm 15V$ $R_S \le 50\Omega$	-	-	-	dB
		$V_{CC} = \pm 15V$ to $V_{CC} = \pm 15V$ $R_S \le 10K\Omega$	77	96	-	
Transient Response: Rise Time	T_R	Unity Gain	-	0.3	-	μs
Transient Response: Overshoot	OS	Unity Gain	-	10	-	%
Bandwidth	BW	-	-	-	-	MHz
Slew Rate	SR	Unity Gain	-	0.5	-	V/μs
Supply Current	I_{CC}	$R_L = \infty\Omega$	-	1.5	2.8	mA
Power Consumption	P_C	$V_{CC} = \pm 20V$	-	-	-	mW
		$V_{CC} = \pm 15V$	-	50	85	

Note:
1. Guaranteed by design.

Electrical Characteristics

(0°C ≤T_A≤70 °C V_{CC} = ±15V, unless otherwise specified)
The following specification apply over the range of 0°C ≤ T_A ≤ +70 °C for the LM741C; and the -40°C ≤ T_A ≤ +85 °C for the LM741I

Parameter	Symbol	Conditions		LM741C/LM741I			Unit
				Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	R_S≤50Ω		-	-	-	mV
		R_S≤10KΩ		-	-	7.5	
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	-		-	-		µV/ °C
Input Offset Current	I_{IO}	-		-	-	300	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-		-	-		nA/ °C
Input Bias Current	I_{BIAS}	-		-	-	0.8	µA
Input Resistance (Note1)	R_I	V_{CC} = ±20V		-	-	-	MΩ
Input Voltage Range	$V_{I(R)}$	-		±12	±13	-	V
Output Voltage Swing	$V_{O(P-P)}$	V_{CC} =±20V	R_S≥10KΩ	-	-	-	V
			R_S≥2KΩ	-	-	-	
		V_{CC} =±15V	R_S≥10KΩ	±12	±14	-	
			R_S≥2KΩ	±10	±13	-	
Output Short Circuit Current	I_{SC}	-		10	-	40	mA
Common Mode Rejection Ratio	CMRR	R_S≤10KΩ, V_{CM} = ±12V		70	90	-	dB
		R_S≤50Ω, V_{CM} = ±12V		-	-	-	
Power Supply Rejection Ratio	PSRR	V_{CC} = ±20V to ±5V	R_S≤50Ω	-	-	-	dB
			R_S≤10KΩ	77	96	-	
Large Signal Voltage Gain	G_V	R_S≥2KΩ	V_{CC} = ±20V, $V_{O(P-P)}$ = ±15V	-	-	-	V/mV
			V_{CC} = ±15V, $V_{O(P.P)}$ = ±10V	15	-	-	
			V_{CC} = ±15V, $V_{O(P-P)}$ = ±2V	-	-	-	

Note :
1. Guaranteed by design.

Typical Performance Characteristics

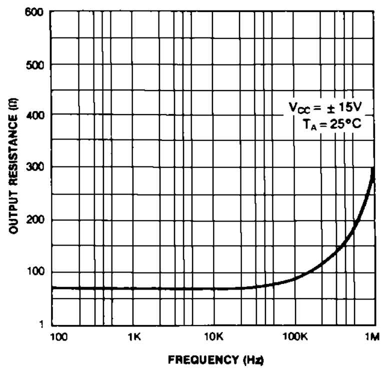


Figure 1. Output Resistance vs Frequency

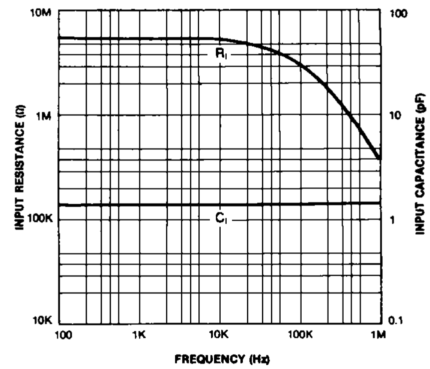


Figure 2. Input Resistance and Input Capacitance vs Frequency

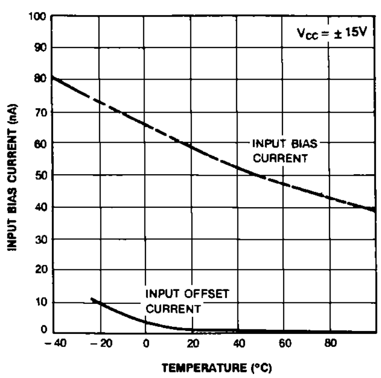


Figure 3. Input Bias Current vs Ambient Temperature

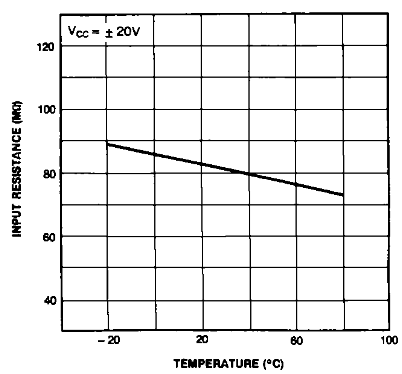


Figure 4. Power Consumption vs Ambient Temperature

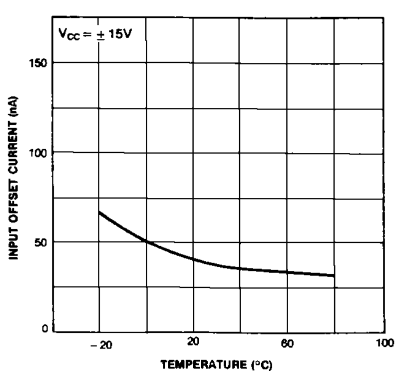


Figure 5. Input Offset Current vs Ambient Temperature

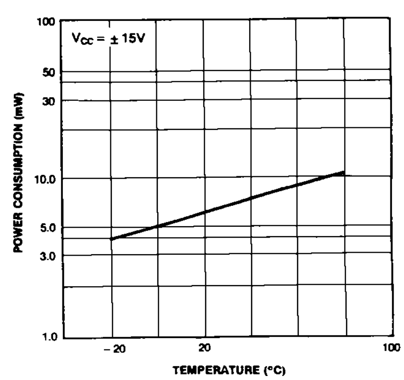


Figure 6. Input Resistance vs Ambient Temperature

Typical Performance Characteristics (continued)

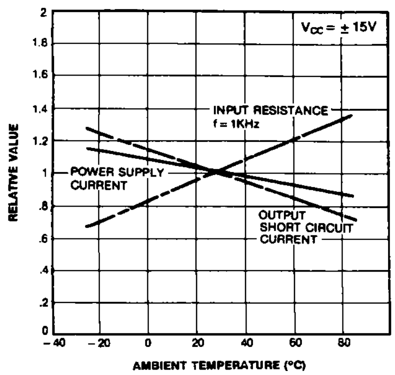


Figure 7. Normalized DC Parameters vs Ambient Temperature

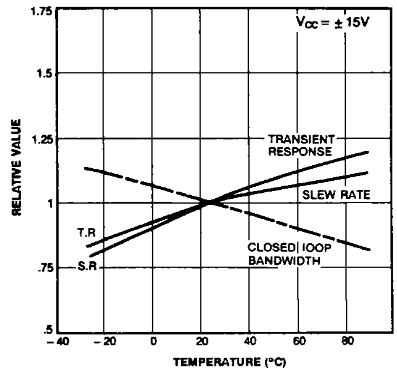


Figure 8. Frequency Characteristics vs Ambient Temperature

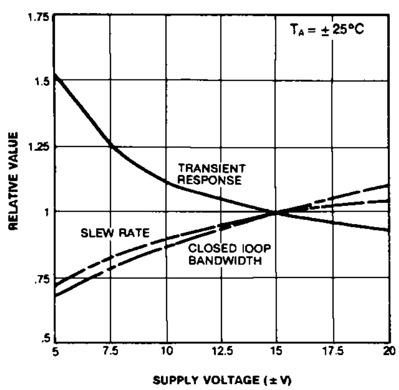


Figure 9. Frequency Characteristics vs Supply Voltage

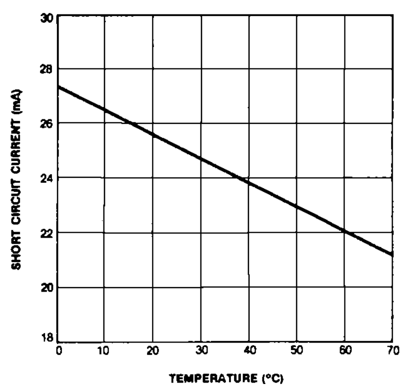


Figure 10. Output Short Circuit Current vs Ambient Temperature

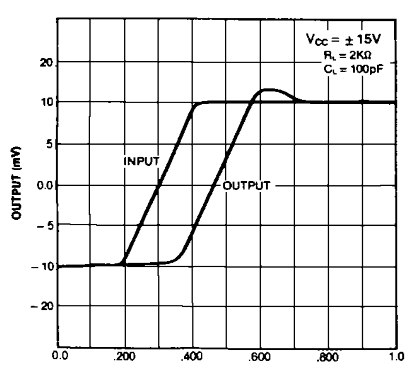


Figure 11. Transient Response

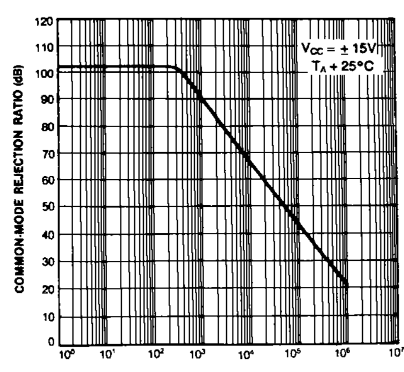


Figure 12. Common-Mode Rejection Ratio vs Frequency

Typical Performance Characteristics (continued)

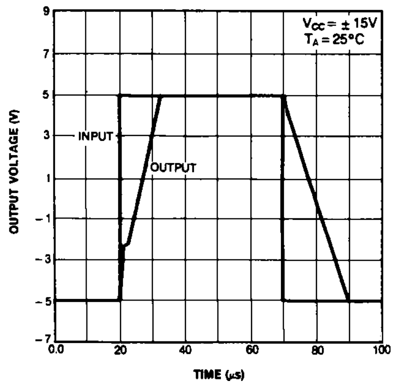


Figure 13. Voltage Follower Large Signal Pulse Response

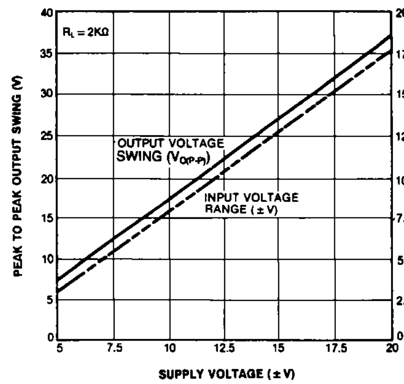
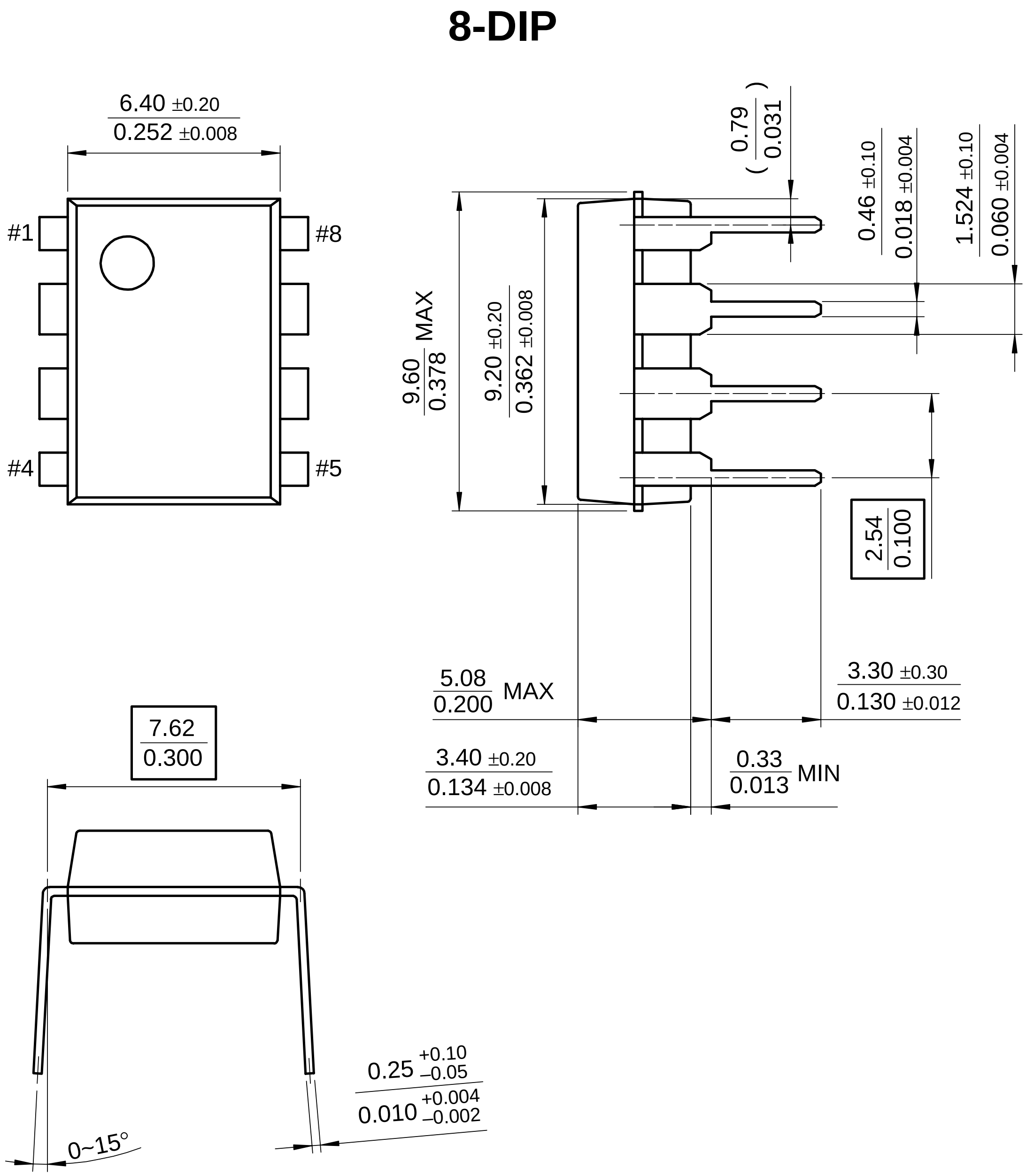


Figure 14. Output Swing and Input Range vs Supply Voltage

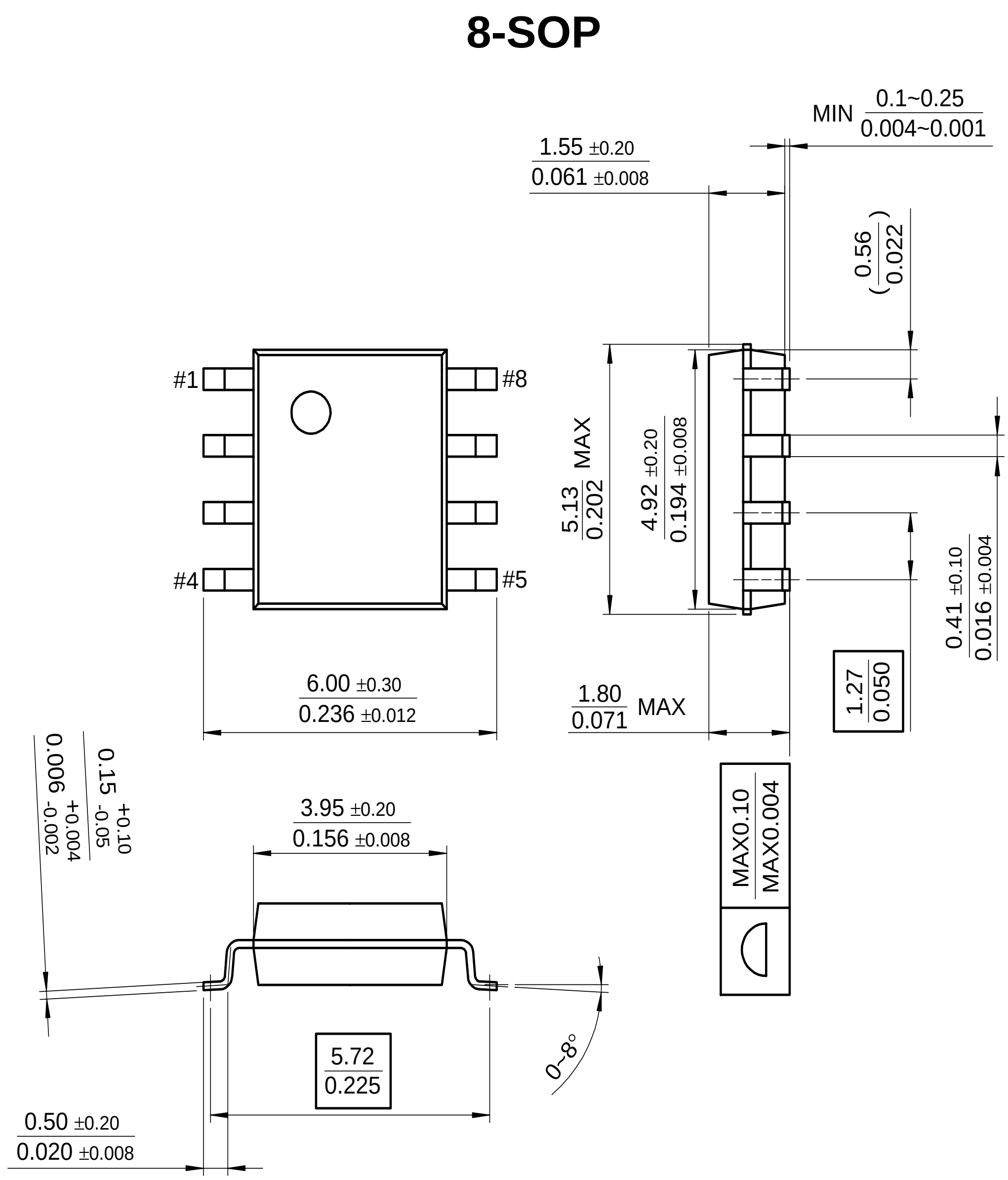
Mechanical Dimensions

Package



Mechanical Dimensions (Continued)

Package



Ordering Information

Product Number	Package	Operating Temperature
LM741CN	8-DIP	0 ~ + 70°C
LM741CM	8-SOP	
LM741IN	8-DIP	-40 ~ + 85°C

6/1/01 0.0m 001
Stock#DSxxxxxxxx

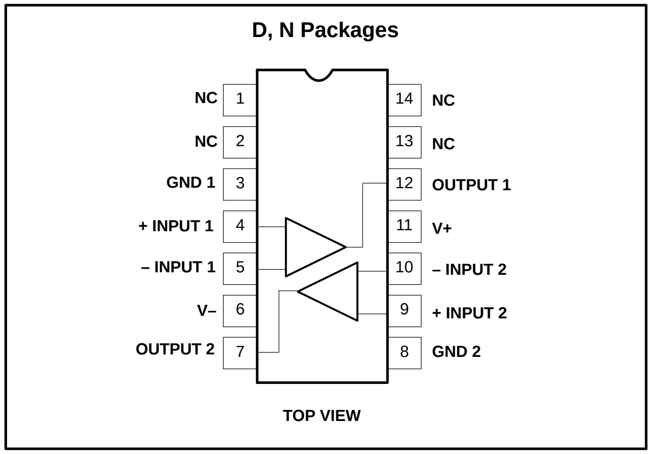
Dual voltage comparator | LM219/319

DESCRIPTION

The LM319 series are precision high-speed dual comparators fabricated on a single monolithic chip. They are designed to operate over a wide range of supply voltages down to a single 5V logic supply and ground. Further, they have higher gain and lower input currents than devices like the µA710. The uncommitted collector of the output stage makes the LM319 compatible with RTL, DTL, and TTL as well as capable of driving lamps and relays at currents up to 25mA.

Although designed primarily for applications requiring operation from digital logic supplies, the LM319 series are fully specified for power supplies up to ±15V. It features faster response than the LM111 at the expense of higher power dissipation. However, the high-speed, wide operating voltage range and low package count make the LM319 much more versatile than older devices like the µA711.

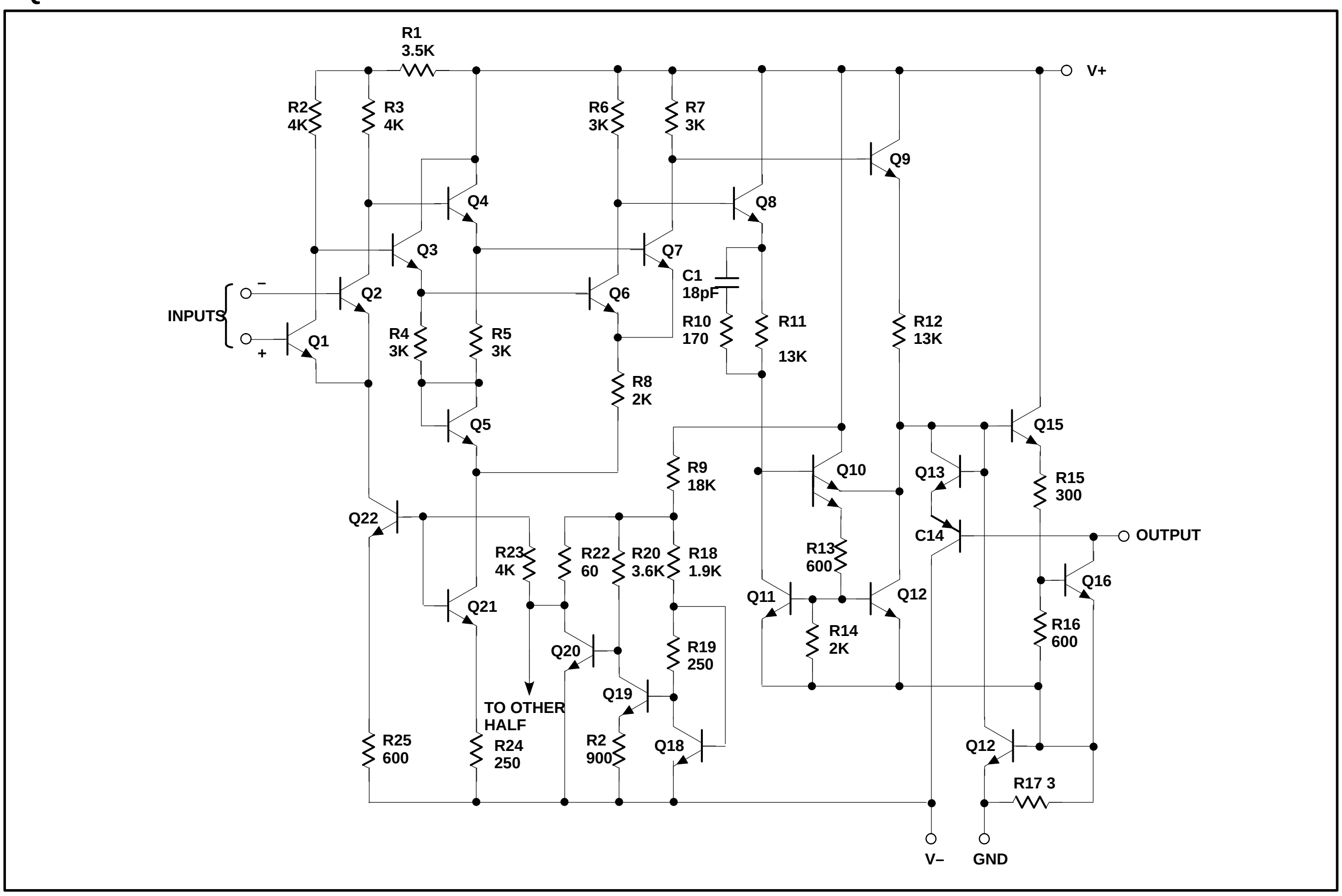
PIN CONFIGURATION



FEATURES

- Two independent comparators
- Operates from a single 5V supply
- Typically 80ns response time at ±15V
- Minimum fanout of 3 (each side)
- Maximum input current of 1µA over temperature
- Inputs and outputs can be isolated from system ground
- High common-mode slew rate

EQUIVALENT SCHEMATIC



ORDERING INFORMATION

DESCRIPTION	TEMPERATURE RANGE	ORDER CODE	DWG #
14-Pin Plastic Small Outline (SO) Package	-25 to +85°C	LM219D	0175D
14-Pin Plastic Small Outline (SO) Package	0 to +70°C	LM319D	0175D
14-Pin Plastic Dual In-Line Package (DIP)	0 to +70°C	LM319N	0405B

ABSOLUTE MAXIMUM RATINGS

SYMBOL	PARAMETER	RATING	UNIT
V_S	Total supply voltage	36	V
	Output to negative supply voltage	36	V
	Ground to negative supply voltage	25	V
	Ground to positive supply voltage	18	V
	Differential input voltage	±5	V
V_{IN}	Input voltage[1]	±15	V
	Maximum power dissipation, T_A=25°C (still-air)[2]		
	N package	1420	mW
	D package	1040	mW
	Output short-circuit duration	10	s
T_A	Operating temperature range LM219 LM319	-25 to +85 0 to +70	°C
T_{STG}	Storage temperature range	-65 to +150	°C
T_{SOLD}	Lead soldering temperature (10sec max)	300	°C

NOTES:
1. For supply voltages less than ±15V, the absolute maximum rating is equal to the supply voltage.
2. Derate above 25°C, at the following rates:
   N package at 11.4mW/°C
   D package at 8.3mW/°C

DC ELECTRICAL CHARACTERISTICS

V_S=±15V, -25°C ≤ T_A ≤ 85°C for LM219, 0°C ≤ T_A ≤ 70°C for LM319, unless otherwise specified.

SYMBOL	PARAMETER	TEST CONDITIONS	LM219			LM319			UNIT
			Min	Typ	Max	Min	Typ	Max	
V_{OS}	Input offset voltage[1, 2]	R_S≤5kΩ, T_A=25°C Over temp.		0.7	4.0 7		2.0	8.0 10	mV
I_{OS}	Input offset current[1, 2]	T_A=25°C Over temp.		30	75 100		80	200 300	nA
I_B	Input bias current[1]	T_A=25°C Over temp.		150	500 1000		250	1000 1200	nA nA
A_V	Voltage gain	T_A=25°C	8	40		8	40		V/mV
V_{OL}	Saturation voltage	V_{IN}≤-10mV, I_{OUT}=25mA, T_A=25°C, V+≥4.5V, V-=0 V_{IN}≤-10mV, I_{OUT}=3.2mA		0.75 0.3	1.5 0.6		0.75 0.3	1.5 0.4	V
I_{OH}	Output leakage current	V-=0V, V_{IN}≥10mV V_{OUT}=35V, T_A=25°C		0.2	10		0.2	10	μA
V_{IN}	Input voltage range	V_S=±15V V+=5V, V-=0V	 1	±13	 3	 1	±13	 3	V
V_{ID}	Differential input voltage				±5			±5	V
I+	Positive supply current	V+=5V, V-=0V, T_A=25°C		4.3			4.3		mA
I+	Positive supply current	V_S=±15V, T_A=25°C		8.0	12.5		8.0	12.5	mA
I-	Negative supply current	V_S=±15V, T_A=25°C		3.0	5.0		3.0	5.0	mA

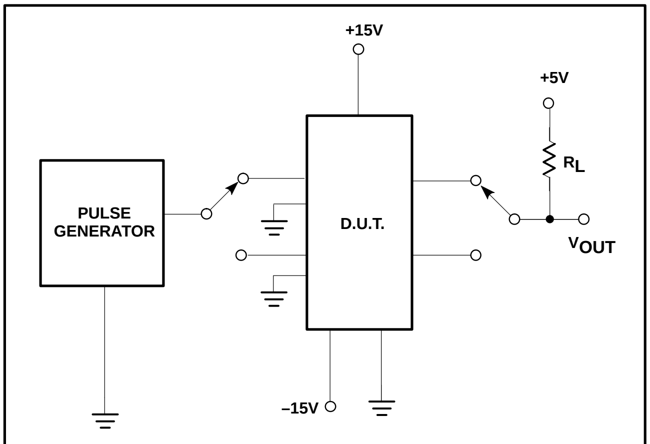
NOTES:
1. V_{OS}, I_{OS} and I_B specifications apply for a supply voltage range of V_S=±15V down to a single 5V supply.
2. The offset voltages and offset currents given are the maximum values required to drive the output to within 1V of either supply with a 1mA load. Thus these parameters define an error band and take into account the worst case effects of voltage gain and input impedance.

AC ELECTRICAL CHARACTERISTICS

SYMBOL	PARAMETER	TEST CONDITIONS	LIMITS			UNIT
			Min	Typ	Max	
t_R	Response time[1]	V_S=±15V, T_A=25°C R_L=500Ω (see test figure)		80		ns

NOTES:
1. The response time specified is for a 100mV step with 5mV overdrive.

TEST CIRCUIT

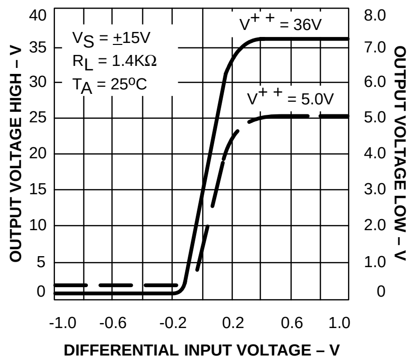


Response Time Measurement

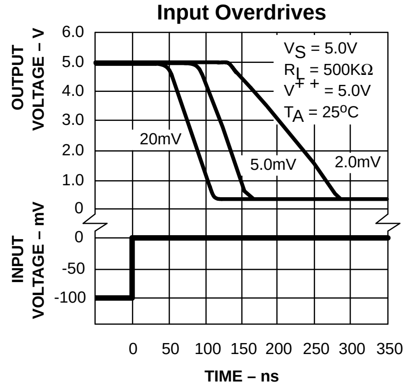
Dual voltage comparator LM219/319

TYPICAL PERFORMANCE CHARACTERISTICS

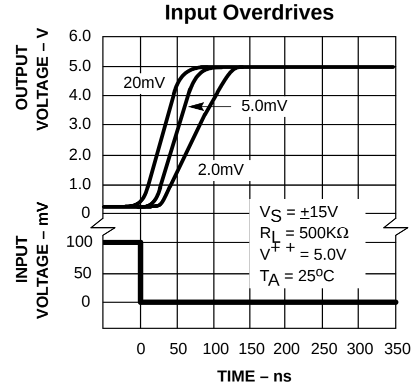
Transfer Function



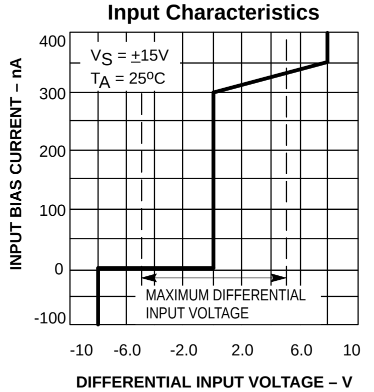
Response Time for Various Input Overdrives



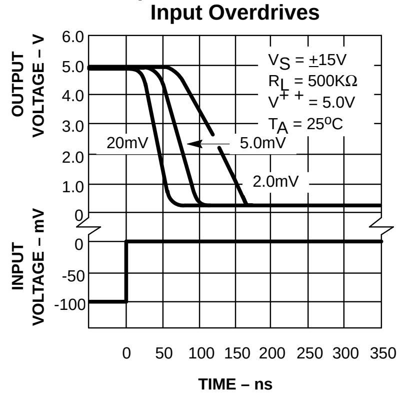
Response Time for Various Input Overdrives



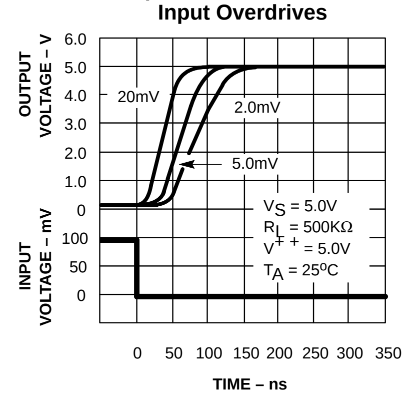
Input Characteristics



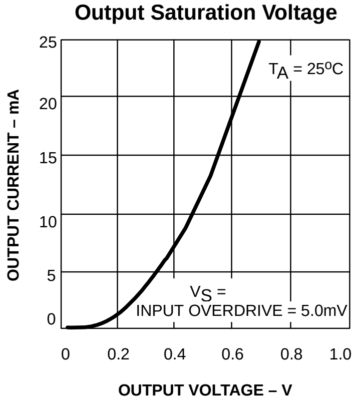
Response Time for Various Input Overdrives



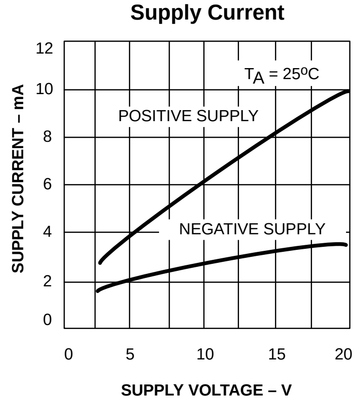
Response Time for Various Input Overdrives



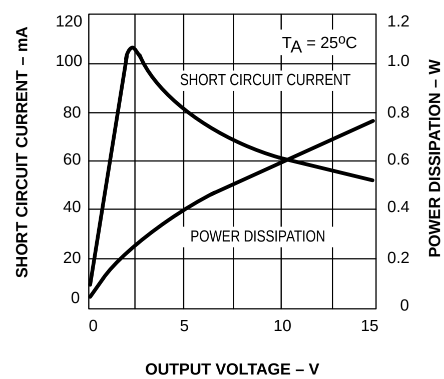
Output Saturation Voltage



Supply Current

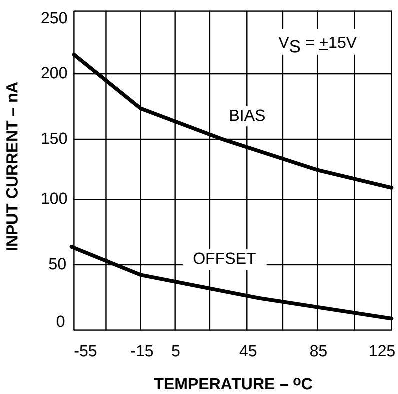


Output Limitiung Characteristics

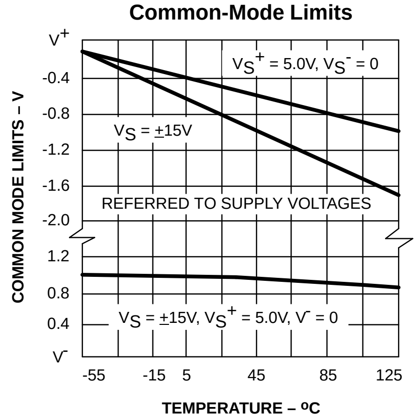


TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

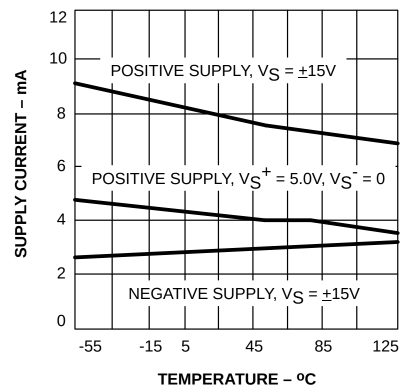
Input Currents



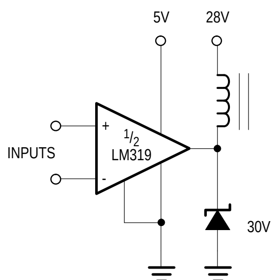
Common-Mode Limits



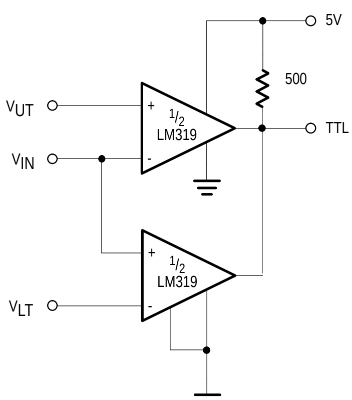
Supply Current



TYPICAL APPLICATIONS

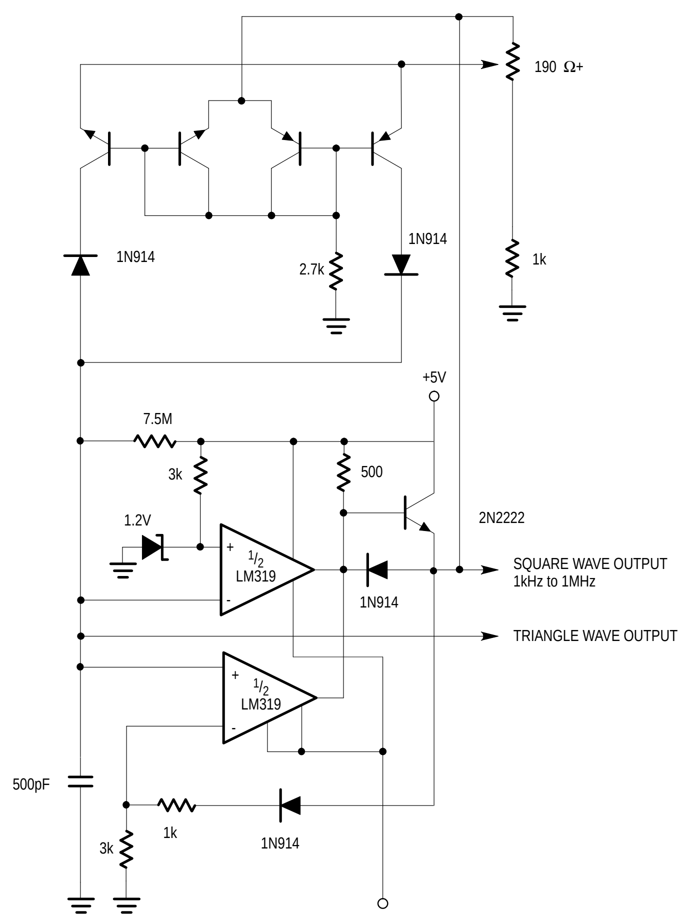


Relay Driver



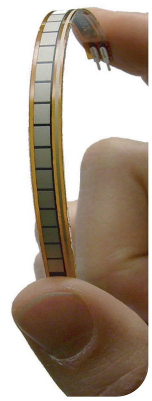
Window Detector

NOTES:
V_{OUT} = 5V for $V_{LT} < V_{IN} < V_{UT}$
V_{OUT} = 0V for $V_{IN} < V_{LT}$ or $V_{IN} > V_{UT}$



NOTE:
Frequency adjust must be buffered for $R_L \leq 10\Omega$

Wide Range Variable Oscillator



Flex Sensor FS

Features

- Angle Displacement Measurement
- Bends and Flexes physically with motion device
- Possible Uses
  - Robotics
  - Gaming (Virtual Motion)
  - Medical Devices
  - Computer Peripherals
  - Musical Instruments
  - Physical Therapy
- Simple Construction
- Low Profile

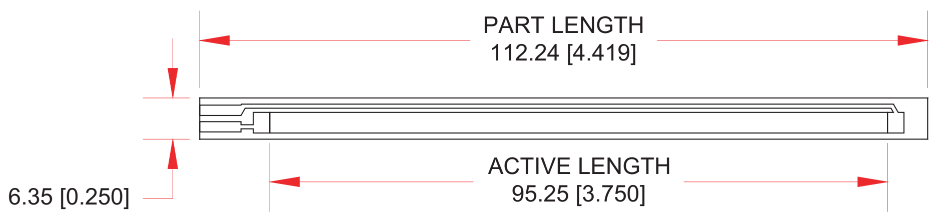
Mechanical Specifications

-Life Cycle: >1 million
-Height: ≤0.43mm (0.017")
-Temperature Range: -35°C to +80°C

Electrical Specifications

-Flat Resistance: 10K Ohms
-Resistance Tolerance: ±30%
-Bend Resistance Range: 60K to 110K Ohms
-Power Rating : 0.50 Watts continuous. 1 Watt Peak

Dimensional Diagram - Stock Flex Sensor

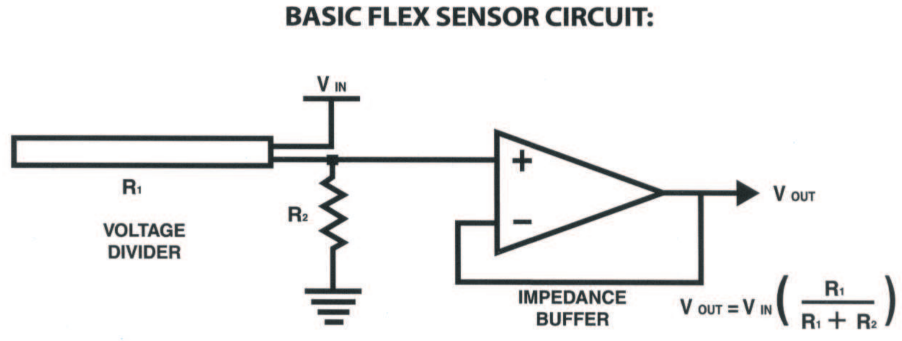


How to Order - Stock Flex Sensor

FS — L — 0095 — 103 — ST

Series	Model	Active Length	Resistance	Connectors
FS = Flex Sensor	L = Linear	0095 = 95.25mm	103 = 10 KOhms	ST = Solder Tab

How It Works

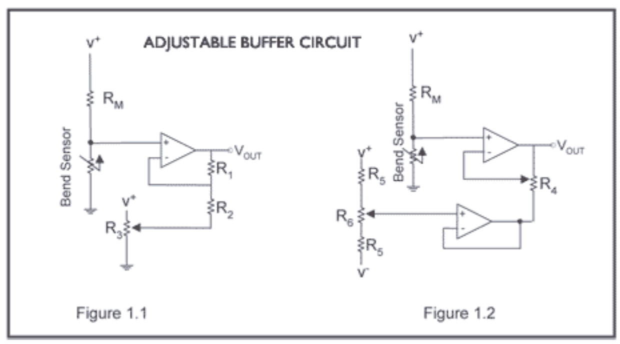


Following are notes from the ITP Flex Sensor Workshop

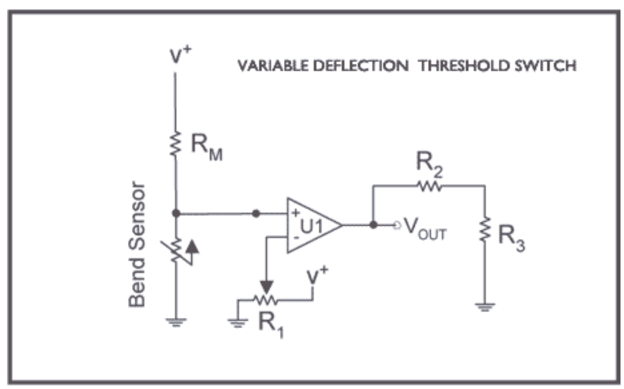
"The impedance buffer in the [Basic Flex Sensor Circuit] (above) is a single sided operational amplifier, used with these sensors because the low bias current of the op amp reduces errer due to source impedance of the flex sensor as voltage divider. Suggested op amps are the LM358 or LM324."

"You can also test your flex sensor using the simplest circut, and skip the op amp."

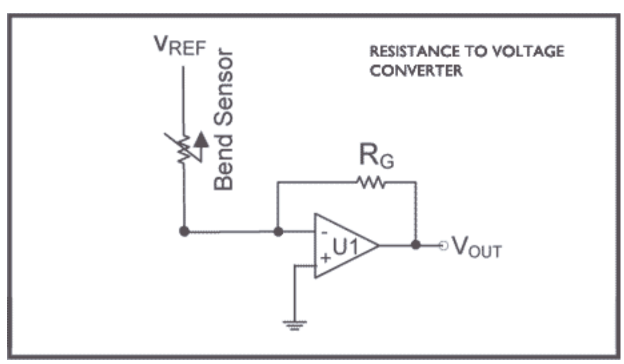
"Adjustable Buffer - a potentiometer can be added to the circuit to adjust the sensitivity range."



"Variable Deflection Threshold Switch - an op amp is used and outputs either high or low depending on the voltage of the inverting input. In this way you can use the flex sensor as a switch without going through a microcontroller."

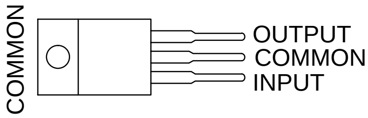


"Resistance to Voltage Converter - use the sensor as the input of a resistance to voltage converter using a dual sided supply op-amp. A negative reference voltage will give a positive output. Should be used in situations when you want output at a low degree of bending."

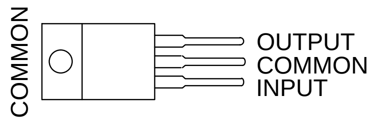


- 3-Terminal Regulators
- Output Current up to 1.5 A
- Internal Thermal-Overload Protection
- High Power-Dissipation Capability
- Internal Short-Circuit Current Limiting
- Output Transistor Safe-Area Compensation

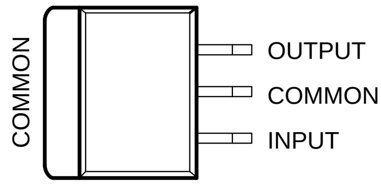
KC (TO-220) PACKAGE
(TOP VIEW)



KCS (TO-220) PACKAGE
(TOP VIEW)



KTE PACKAGE
(TOP VIEW)



description/ordering information

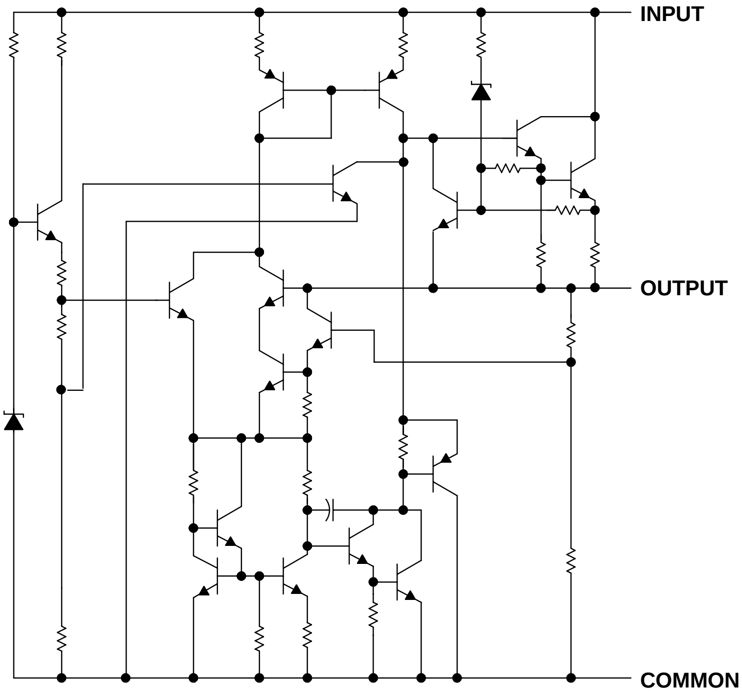
This series of fixed-voltage integrated-circuit voltage regulators is designed for a wide range of applications. These applications include on-card regulation for elimination of noise and distribution problems associated with single-point regulation. Each of these regulators can deliver up to 1.5 A of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

ORDERING INFORMATION

T_J	$V_{O(NOM)}$ (V)	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 125°C	5	POWER-FLEX (KTE)	Reel of 2000	μA7805CKTER	μA7805C
		TO-220 (KC)	Tube of 50	μA7805CKC	μA7805C
		TO-220, short shoulder (KCS)	Tube of 20	μA7805CKCS	
	8	POWER-FLEX (KTE)	Reel of 2000	μA7808CKTER	μA7808C
		TO-220 (KC)	Tube of 50	μA7808CKC	μA7808C
		TO-220, short shoulder (KCS)	Tube of 20	μA7808CKCS	
	10	POWER-FLEX (KTE)	Reel of 2000	μA7810CKTER	μA7810C
		TO-220 (KC)	Tube of 50	μA7810CKC	μA7810C
	12	POWER-FLEX (KTE)	Reel of 2000	μA7812CKTER	μA7812C
		TO-220 (KC)	Tube of 50	μA7812CKC	μA7812C
		TO-220, short shoulder (KCS)	Tube of 20	μA7812CKCS	
	15	POWER-FLEX (KTE)	Reel of 2000	μA7815CKTER	μA7815C
		TO-220 (KC)	Tube of 50	μA7815CKC	μA7815C
		TO-220, short shoulder (KCS)	Tube of 20	μA7815CKCS	
	24	POWER-FLEX (KTE)	Reel of 2000	μA7824CKTER	μA7824C
		TO-220 (KC)	Tube of 50	μA7824CKC	μA7824C

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

schematic



absolute maximum ratings over virtual junction temperature range (unless otherwise noted)†

Input voltage, V_I: μA7824C . . . . 40 V
All others . . . . 35 V
Operating virtual junction temperature, T_J . . . . 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds . . . . 260°C
Storage temperature range, T_{stg} . . . . –65°C to 150°C

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

package thermal data (see Note 1)

PACKAGE	BOARD	θ_{JC}	θ_{JA}
POWER-FLEX (KTE)	High K, JESD 51-5	3°C/W	23°C/W
TO-220 (KC/KCS)	High K, JESD 51-5	3°C/W	19°C/W

NOTE 1: Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.

recommended operating conditions

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

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

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

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

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

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

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

electrical characteristics at specified virtual junction temperature, V_I = 17 V, I_O = 500 mA (unless otherwise noted)

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

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

electrical characteristics at specified virtual junction temperature, V_I = 19 V, I_O = 500 mA (unless otherwise noted)

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

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

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

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

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

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

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

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

APPLICATION INFORMATION

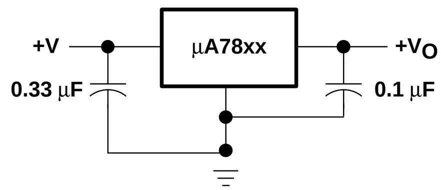


Figure 1. Fixed-Output Regulator

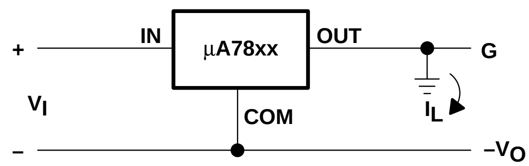
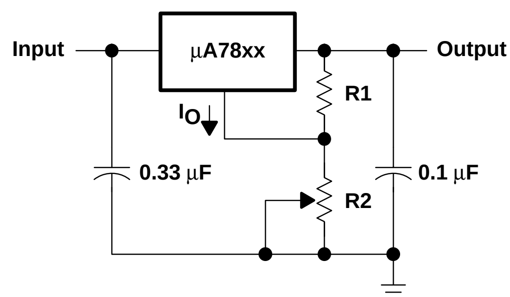


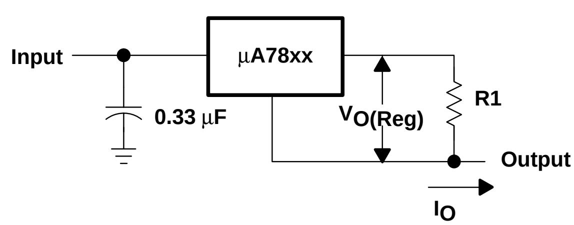
Figure 2. Positive Regulator in Negative Configuration (V_I Must Float)



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

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

Figure 3. Adjustable-Output Regulator



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

Figure 4. Current Regulator

APPLICATION INFORMATION

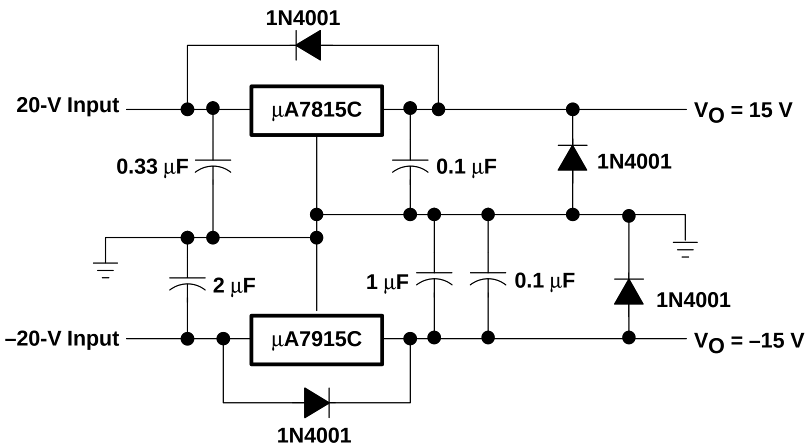


Figure 5. Regulated Dual Supply

operation with a load common to a voltage of opposite polarity

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

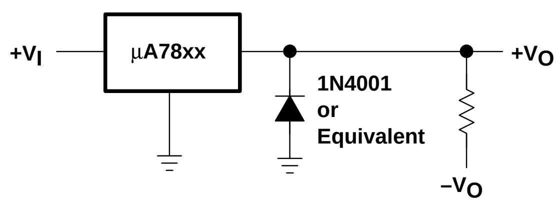


Figure 6. Output Polarity-Reversal-Protection Circuit

reverse-bias protection

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

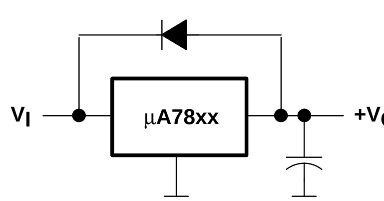
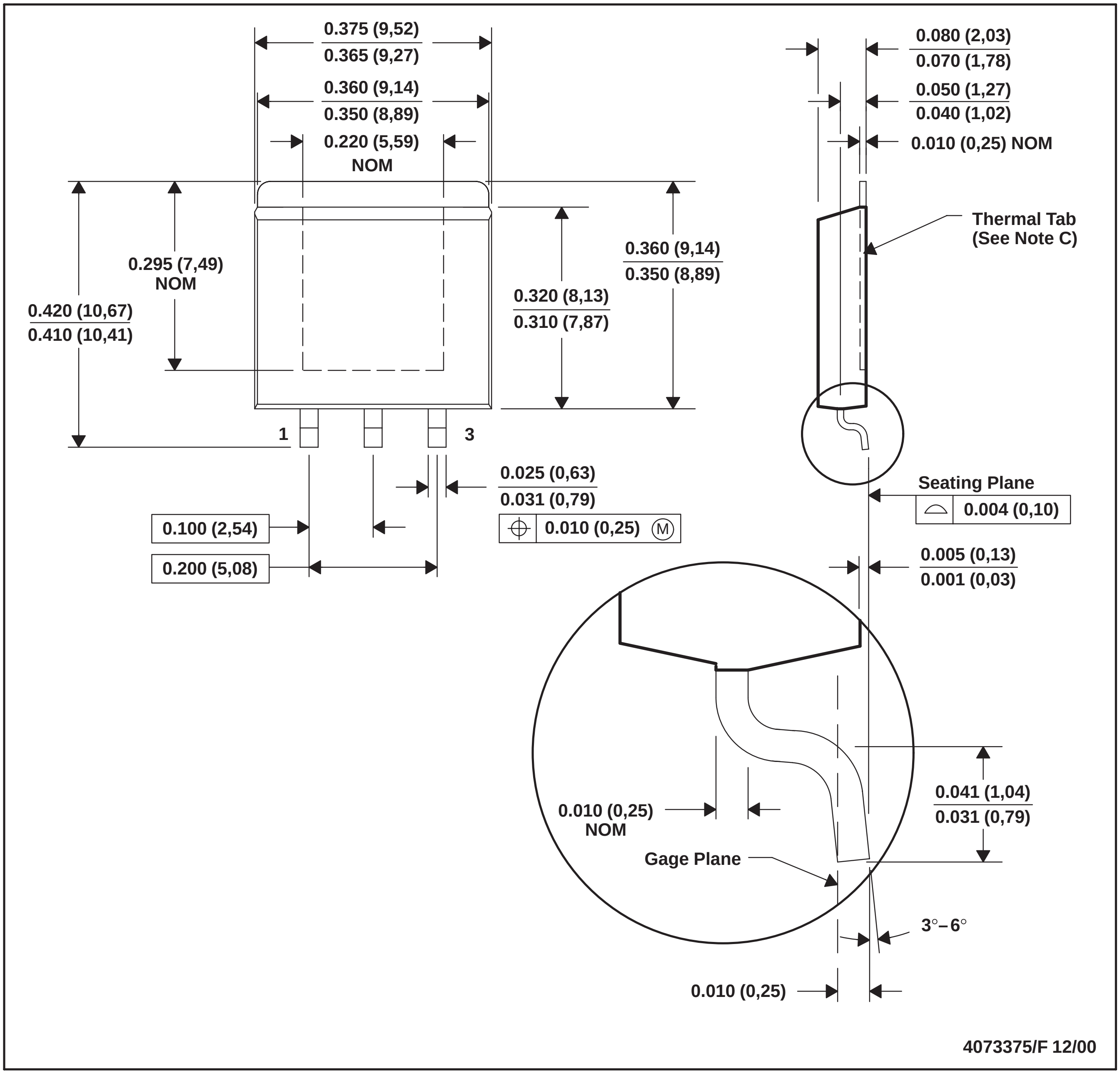


Figure 7. Reverse-Bias-Protection Circuit

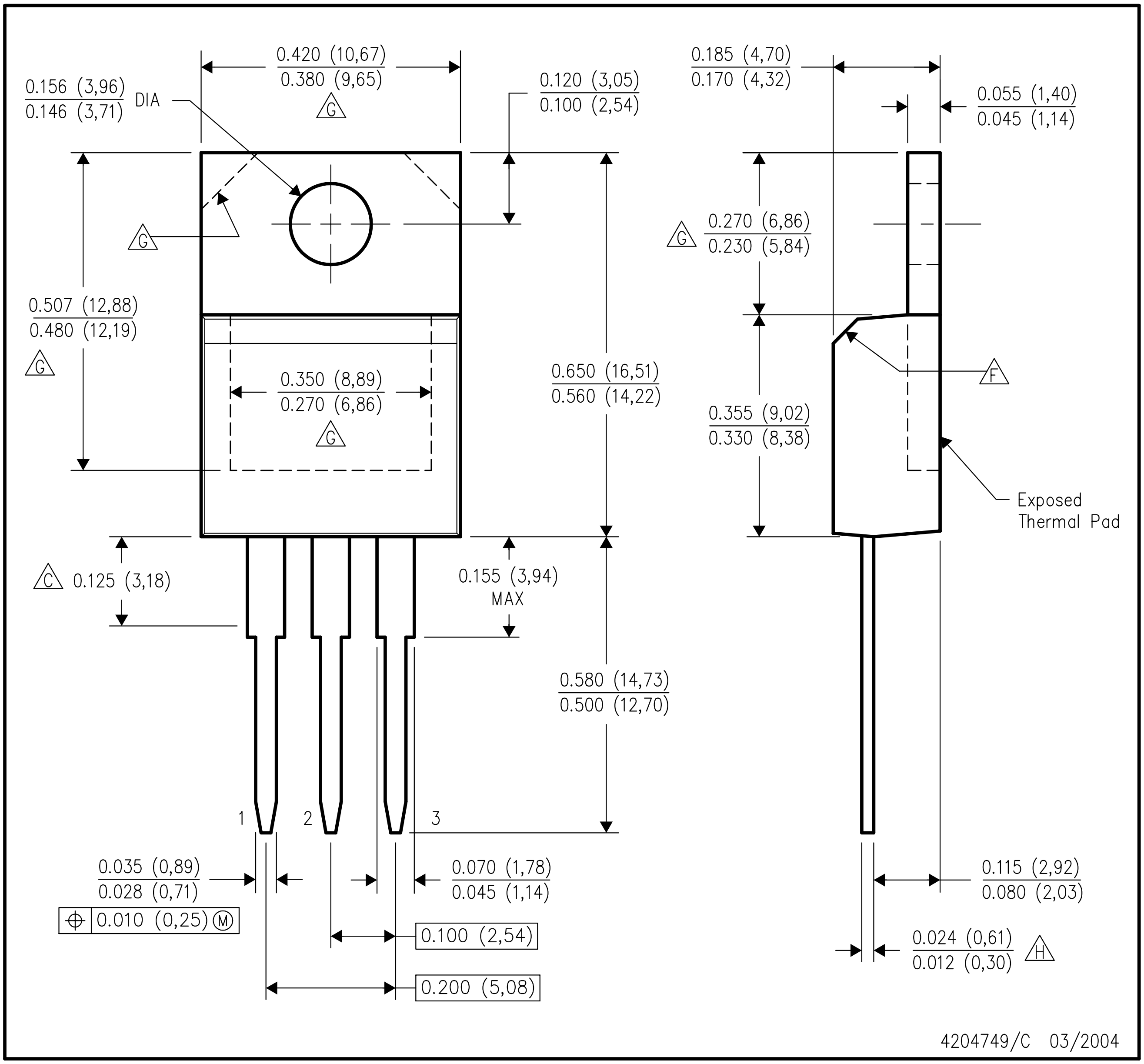
KTE (R-PSFM-G3) **PowerFLEX™ PLASTIC FLANGE-MOUNT**



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

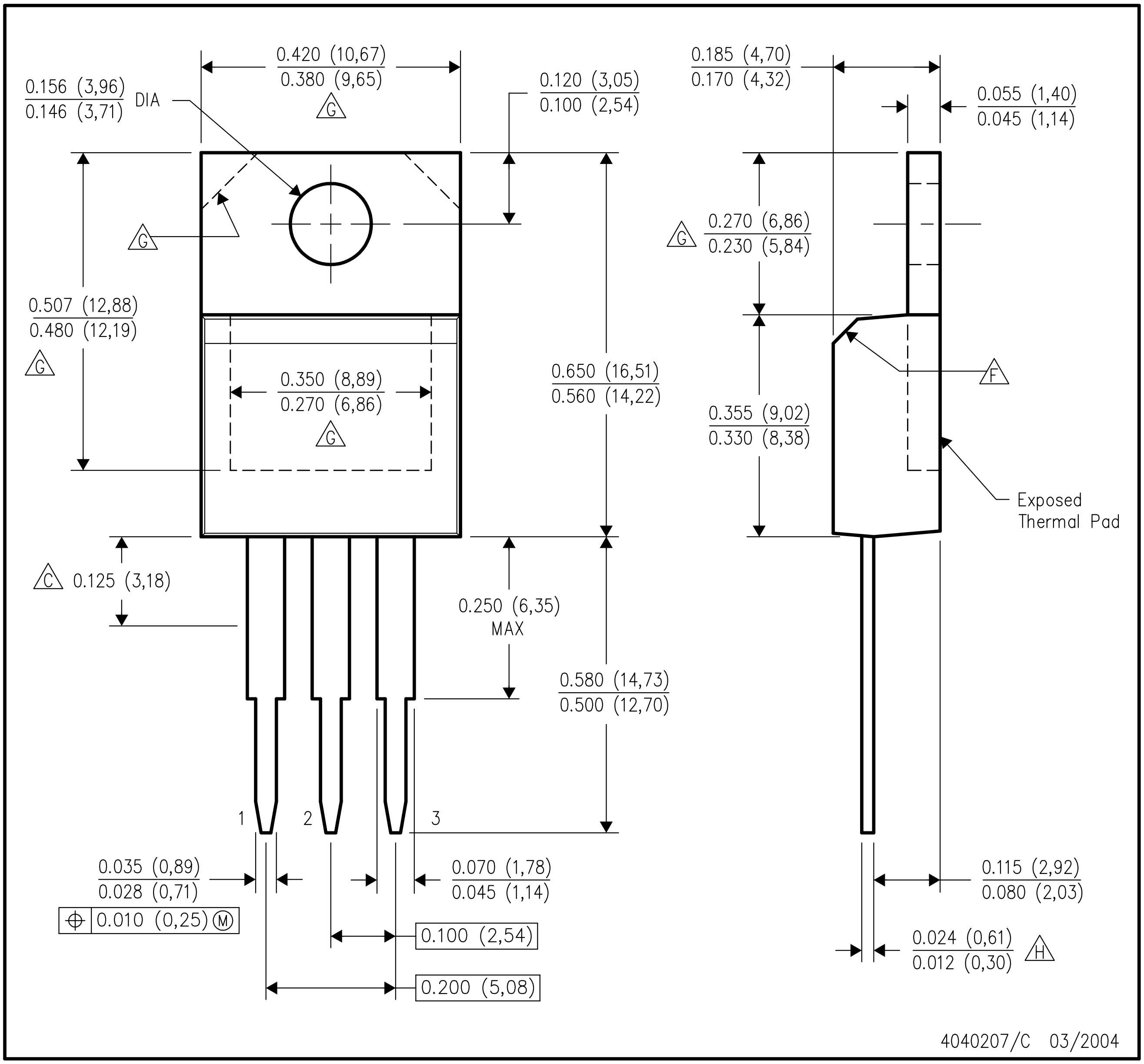
PowerFLEX is a trademark of Texas Instruments.

KCS (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.

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.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
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Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265

XBee®/XBee-PRO® RF Modules

XBee®/XBee-PRO® RF Modules

RF Module Operation

RF Module Configuration

Appendices

Product Manual v1.xEx - 802.15.4 Protocol

For RF Module Part Numbers: XB24-A...-001, XBP24-A...-001

IEEE® 802.15.4 RF Modules by Digi International

Digi International Inc.
11001 Bren Road East
Minnetonka, MN 55343
877 912-3444 or 952 912-3444
http://www.digi.com

90000982_B
2009.09.23

Technical Support:	Phone:	(866) 765-9885 toll-free U.S.A. & Canada (801) 765-9885 Worldwide 8:00 am - 5:00 pm [U.S. Mountain Time]
	Live Chat:	www.digi.com
	Online Support:	http://www.digi.com/support/eservice/login.jsp
	Email:	rf-experts@digi.com

Contents

1. XBee®/XBee-PRO® RF Modules

The XBee and XBee-PRO RF Modules were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices.

The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other.

Key Features

Long Range Data Integrity

XBee

- Indoor/Urban: up to 100’ (30 m)
- Outdoor line-of-sight: up to 300’ (90 m)
- Transmit Power: 1 mW (0 dBm)
- Receiver Sensitivity: -92 dBm

XBee-PRO

- Indoor/Urban: up to 300’ (90 m), 200' (60 m) for International variant
- Outdoor line-of-sight: up to 1 mile (1600 m), 2500' (750 m) for International variant
- Transmit Power: 63mW (18dBm), 10mW (10dBm) for International variant
- Receiver Sensitivity: -100 dBm

RF Data Rate: 250,000 bps

Advanced Networking & Security

Retries and Acknowledgements

DSSS (Direct Sequence Spread Spectrum)

Each direct sequence channels has over 65,000 unique network addresses available

Source/Destination Addressing

Unicast & Broadcast Communications

Point-to-point, point-to-multipoint and peer-to-peer topologies supported

Low Power

XBee

- TX Peak Current: 45 mA (@3.3 V)
- RX Current: 50 mA (@3.3 V)
- Power-down Current: < 10 µA

XBee-PRO

- TX Peak Current: 250mA (150mA for international variant)
- TX Peak Current (RPSMA module only): 340mA (180mA for international variant
- RX Current: 55 mA (@3.3 V)
- Power-down Current: < 10 µA

ADC and I/O line support

Analog-to-digital conversion, Digital I/O

I/O Line Passing

Easy-to-Use

No configuration necessary for out-of box RF communications

Free X-CTU Software
(Testing and configuration software)

AT and API Command Modes for configuring module parameters

Extensive command set

Small form factor

Worldwide Acceptance

FCC Approval (USA) Refer to Appendix A [p64] for FCC Requirements.
Systems that contain XBee®/XBee-PRO® RF Modules inherit Digi Certifications.

ISM (Industrial, Scientific & Medical) **2.4 GHz frequency band**

Manufactured under **ISO 9001:2000** registered standards

XBee®/XBee-PRO® RF Modules are optimized for use in the United States, Canada, Australia, Japan, and Europe. Contact Digi for complete list of government agency approvals.

Specifications

Table 1-01. Specifications of the XBee®/XBee-PRO® RF Modules

Specification	XBee	XBee-PRO
Performance		
Indoor/Urban Range	Up to 100 ft (30 m)	Up to 300 ft. (90 m), up to 200 ft (60 m) International variant
Outdoor RF line-of-sight Range	Up to 300 ft (90 m)	Up to 1 mile (1600 m), up to 2500 ft (750 m) international variant
Transmit Power Output (software selectable)	1mW (0 dBm)	63mW (18dBm)* 10mW (10 dBm) for International variant
RF Data Rate	250,000 bps	250,000 bps
Serial Interface Data Rate (software selectable)	1200 bps - 250 kbps (non-standard baud rates also supported)	1200 bps - 250 kbps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)	-100 dBm (1% packet error rate)
Power Requirements		
Supply Voltage	2.8 – 3.4 V	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)	250mA (@3.3 V) (150mA for international variant) RPSMA module only: 340mA (@3.3 V) (180mA for international variant)
Idle / Receive Current (typical)	50mA (@ 3.3 V)	55mA (@ 3.3 V)
Power-down Current	< 10 µA	< 10 µA
General		
Operating Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960” x 1.087” (2.438cm x 2.761cm)	0.960” x 1.297” (2.438cm x 3.294cm)
Operating Temperature	-40 to 85º C (industrial)	-40 to 85º C (industrial)
Antenna Options	Integrated Whip, Chip or U.FL Connector, RPSMA Connector	Integrated Whip, Chip or U.FL Connector, RPSMA Connector
Networking & Security		
Supported Network Topologies	Point-to-point, Point-to-multipoint & Peer-to-peer	
Number of Channels (software selectable)	16 Direct Sequence Channels	12 Direct Sequence Channels
Addressing Options	PAN ID, Channel and Addresses	PAN ID, Channel and Addresses
Agency Approvals		
United States (FCC Part 15.247)	OUR-XBEE	OUR-XBEEPRO
Industry Canada (IC)	4214A XBEE	4214A XBEEPRO
Europe (CE)	ETSI	ETSI (Max. 10 dBm transmit power output)*
Japan	R201WW07215214	R201WW08215111 (Max. 10 dBm transmit power output)*
Austraila	C-Tick	C-Tick

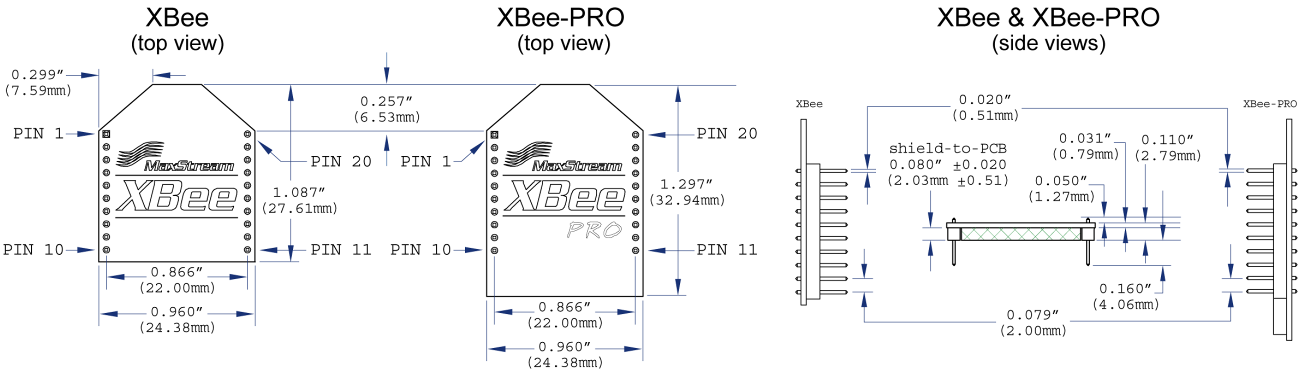
* See Appendix A for region-specific certification requirements.

Antenna Options: The ranges specified are typical when using the integrated Whip (1.5 dBi) and Dipole (2.1 dBi) antennas. The Chip antenna option provides advantages in its form factor; however, it typically yields shorter range than the Whip and Dipole antenna options when transmitting outdoors.For more information, refer to the "XBee Antennas" Knowledgebase Article located on Digi's Support Web site

Mechanical Drawings

Figure 1-01. Mechanical drawings of the XBee®/XBee-PRO® RF Modules (antenna options not shown)

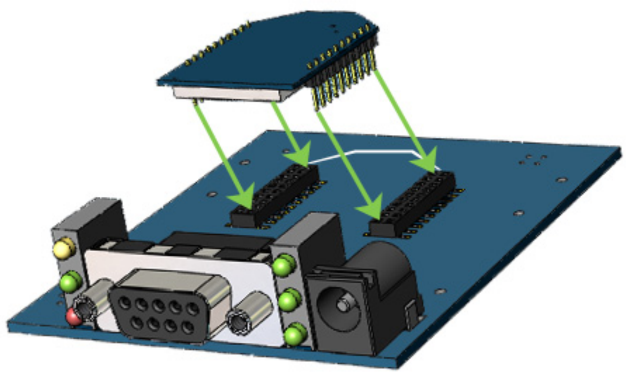
The XBee and XBee-PRO RF Modules are pin-for-pin compatible.



Mounting Considerations

The XBee®/XBee-PRO® RF Module was designed to mount into a receptacle (socket) and therefore does not require any soldering when mounting it to a board. The XBee Development Kits contain RS-232 and USB interface boards which use two 20-pin receptacles to receive modules.

Figure 1-02. XBee Module Mounting to an RS-232 Interface Board.



The receptacles used on Digi development boards are manufactured by Century Interconnect. Several other manufacturers provide comparable mounting solutions; however, Digi currently uses the following receptacles:

- Through-hole single-row receptacles -
  Samtec P/N: MMS-110-01-L-SV (or equivalent)
- Surface-mount double-row receptacles -
  Century Interconnect P/N: CPRMSL20-D-0-1 (or equivalent)
- Surface-mount single-row receptacles -
  Samtec P/N: SMM-110-02-SM-S

Digi also recommends printing an outline of the module on the board to indicate the orientation the module should be mounted.

Pin Signals

Figure 1-03. XBee®/XBee-PRO® RF Module Pin Numbers

(top sides shown - shields on bottom)

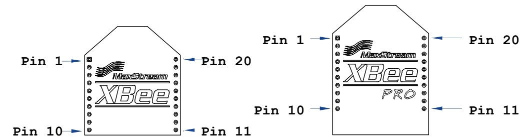


Table 1-02. Pin Assignments for the XBee and XBee-PRO Modules
(Low-asserted signals are distinguished with a horizontal line above signal name.)

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / CONFIG	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	RESET	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	CTS / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / SLEEP	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	RTS / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

* Function is not supported at the time of this release

Design Notes:

- Minimum connections: VCC, GND, DOUT & DIN
- Minimum connections for updating firmware: VCC, GND, DIN, DOUT, RTS & DTR
- Signal Direction is specified with respect to the module
- Module includes a 50k Ω pull-up resistor attached to RESET
- Several of the input pull-ups can be configured using the PR command
- Unused pins should be left disconnected

Electrical Characteristics

Table 1-03. DC Characteristics (VCC = 2.8 - 3.4 VDC)

Symbol	Characteristic	Condition	Min	Typical		Max	Unit
V_{IL}	Input Low Voltage	All Digital Inputs	-	-		0.35 * VCC	V
V_{IH}	Input High Voltage	All Digital Inputs	0.7 * VCC	-		-	V
V_{OL}	Output Low Voltage	I_{OL} = 2 mA, VCC >= 2.7 V	-	-		0.5	V
V_{OH}	Output High Voltage	I_{OH} = -2 mA, VCC >= 2.7 V	VCC - 0.5	-		-	V
II_{IN}	Input Leakage Current	V_{IN} = VCC or GND, all inputs, per pin	-	0.025		1	µA
II_{OZ}	High Impedance Leakage Current	V_{IN} = VCC or GND, all I/O High-Z, per pin	-	0.025		1	µA
TX	Transmit Current	VCC = 3.3 V	-	45 (XBee)	215, 140 (PRO, Int)	-	mA
RX	Receive Current	VCC = 3.3 V	-	50 (XBee)	55 (PRO)	-	mA
PWR-DWN	Power-down Current	SM parameter = 1	-	< 10		-	µA

Table 1-04. ADC Characteristics (Operating)

Symbol	Characteristic	Condition	Min	Typical	Max	Unit
V_{REFH}	VREF - Analog-to-Digital converter reference range		2.08	-	V_{DDAD}*	V
I_{REF}	VREF - Reference Supply Current	Enabled	-	200	-	µA
		Disabled or Sleep Mode	-	< 0.01	0.02	µA
V_{INDC}	Analog Input Voltage[1]		V_{SSAD} - 0.3	-	V_{DDAD} + 0.3	V

1. Maximum electrical operating range, not valid conversion range.

* V_{DDAD} is connected to VCC.

Table 1-05. ADC Timing/Performance Characteristics[1]

Symbol	Characteristic	Condition	Min	Typical	Max	Unit
R_{AS}	Source Impedance at Input[2]		-	-	10	kΩ
V_{AIN}	Analog Input Voltage[3]		V_{REFL}		V_{REFH}	V
RES	Ideal Resolution (1 LSB)[4]	2.08V ≤ V_{DDAD} ≤ 3.6V	2.031	-	3.516	mV
DNL	Differential Non-linearity[5]		-	±0.5	±1.0	LSB
INL	Integral Non-linearity[6]		-	±0.5	±1.0	LSB
E_{ZS}	Zero-scale Error[7]		-	±0.4	±1.0	LSB
F_{FS}	Full-scale Error[8]		-	±0.4	±1.0	LSB
E_{IL}	Input Leakage Error[9]		-	±0.05	±5.0	LSB
E_{TU}	Total Unadjusted Error[10]		-	±1.1	±2.5	LSB

1. All ACCURACY numbers are based on processor and system being in WAIT state (very little activity and no IO switching) and that adequate low-pass filtering is present on analog input pins (filter with 0.01 µF to 0.1 µF capacitor between analog input and VREFL). Failure to observe these guidelines may result in system or microcontroller noise causing accuracy errors which will vary based on board layout and the type and magnitude of the activity.

Data transmission and reception during data conversion may cause some degradation of these specifications, depending on the number and timing of packets. It is advisable to test the ADCs in your installation if best accuracy is required.

2. R_{AS} is the real portion of the impedance of the network driving the analog input pin. Values greater than this amount may not fully charge the input circuitry of the ATD resulting in accuracy error.
3. Analog input must be between V_{REFL} and V_{REFH} for valid conversion. Values greater than V_{REFH} will convert to $3FF.
4. The resolution is the ideal step size or 1LSB = $(V_{REFH}–V_{REFL})/1024$
5. Differential non-linearity is the difference between the current code width and the ideal code width (1LSB). The current code width is the difference in the transition voltages to and from the current code.
6. Integral non-linearity is the difference between the transition voltage to the current code and the adjusted ideal transition voltage for the current code. The adjusted ideal transition voltage is $(Current\ Code–1/2)*(1/((V_{REFH}+E_{FS})–(V_{REFL}+E_{ZS})))$.
7. Zero-scale error is the difference between the transition to the first valid code and the ideal transition to that code. The Ideal transition voltage to a given code is $(Code–1/2)*(1/(V_{REFH}–V_{REFL}))$.
8. Full-scale error is the difference between the transition to the last valid code and the ideal transition to that code. The ideal transition voltage to a given code is $(Code–1/2)*(1/(V_{REFH}–V_{REFL}))$.
9. Input leakage error is error due to input leakage across the real portion of the impedance of the network driving the analog pin. Reducing the impedance of the network reduces this error.

10. Total unadjusted error is the difference between the transition voltage to the current code and the ideal straight-line transfer function. This measure of error includes inherent quantization error (1/2LSB) and circuit error (differential, integral, zero-scale, and full-scale) error. The specified value of E_{TU} assumes zero E_{IL} (no leakage or zero real source impedance).

2. RF Module Operation

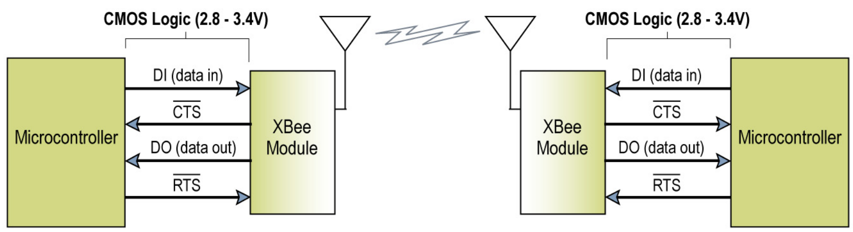
Serial Communications

The XBee®/XBee-PRO® RF Modules interface to a host device through a logic-level asynchronous serial port. Through its serial port, the module can communicate with any logic and voltage compatible UART; or through a level translator to any serial device (For example: Through a Digi proprietary RS-232 or USB interface board).

UART Data Flow

Devices that have a UART interface can connect directly to the pins of the RF module as shown in the figure below.

Figure 2-01. System Data Flow Diagram in a UART-interfaced environment
(Low-asserted signals distinguished with horizontal line over signal name.)

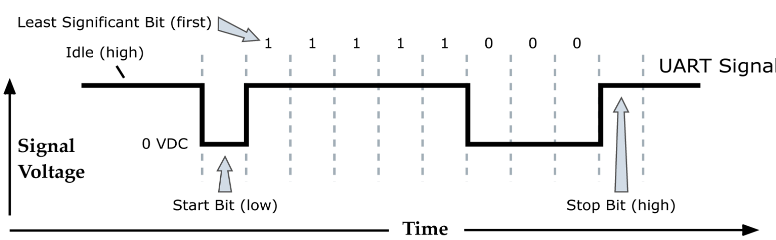


Serial Data

Data enters the module UART through the DI pin (pin 3) as an asynchronous serial signal. The signal should idle high when no data is being transmitted.

Each data byte consists of a start bit (low), 8 data bits (least significant bit first) and a stop bit (high). The following figure illustrates the serial bit pattern of data passing through the module.

Figure 2-02. UART data packet 0x1F (decimal number "31") as transmitted through the RF module
Example Data Format is 8-N-1 (bits - parity - # of stop bits)



Serial communications depend on the two UARTs (the microcontroller's and the RF module's) to be configured with compatible settings (baud rate, parity, start bits, stop bits, data bits).

The UART baud rate and parity settings on the XBee module can be configured with the BD and SB commands, respectively. See the command table in Chapter 3 for details.

Transparent Operation

By default, XBee®/XBee-PRO® RF Modules operate in Transparent Mode. When operating in this mode, the modules act as a serial line replacement - all UART data received through the DI pin is queued up for RF transmission. When RF data is received, the data is sent out the DO pin.

Serial-to-RF Packetization

Data is buffered in the DI buffer until one of the following causes the data to be packetized and transmitted:

1. No serial characters are received for the amount of time determined by the RO (Packetization Timeout) parameter. If RO = 0, packetization begins when a character is received.
2. The maximum number of characters that will fit in an RF packet (100) is received.
3. The Command Mode Sequence (GT + CC + GT) is received. Any character buffered in the DI buffer before the sequence is transmitted.

If the module cannot immediately transmit (for instance, if it is already receiving RF data), the serial data is stored in the DI Buffer. The data is packetized and sent at any RO timeout or when 100 bytes (maximum packet size) are received.

If the DI buffer becomes full, hardware or software flow control must be implemented in order to prevent overflow (loss of data between the host and module).

API Operation

API (Application Programming Interface) Operation is an alternative to the default Transparent Operation. The frame-based API extends the level to which a host application can interact with the networking capabilities of the module.

When in API mode, all data entering and leaving the module is contained in frames that define operations or events within the module.

Transmit Data Frames (received through the DI pin (pin 3)) include:

- RF Transmit Data Frame
- Command Frame (equivalent to AT commands)

Receive Data Frames (sent out the DO pin (pin 2)) include:

- RF-received data frame
- Command response
- Event notifications such as reset, associate, disassociate, etc.

The API provides alternative means of configuring modules and routing data at the host application layer. A host application can send data frames to the module that contain address and payload information instead of using command mode to modify addresses. The module will send data frames to the application containing status packets; as well as source, RSSI and payload information from received data packets.

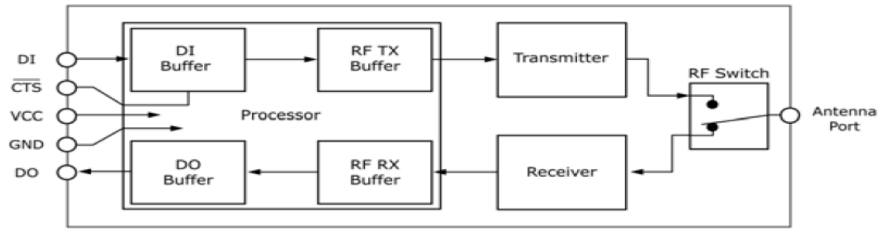
The API operation option facilitates many operations such as the examples cited below:

-> Transmitting data to multiple destinations without entering Command Mode
-> Receive success/failure status of each transmitted RF packet
-> Identify the source address of each received packet

To implement API operations, refer to API sections [p57].

Flow Control

Figure 2-03. Internal Data Flow Diagram



DI (Data In) Buffer

When serial data enters the RF module through the DI pin (pin 3), the data is stored in the DI Buffer until it can be processed.

Hardware Flow Control (CTS). When the DI buffer is 17 bytes away from being full; by default, the module de-asserts CTS (high) to signal to the host device to stop sending data [refer to D7 (DIO7 Configuration) parameter]. CTS is re-asserted after the DI Buffer has 34 bytes of memory available.

How to eliminate the need for flow control:

1. Send messages that are smaller than the DI buffer size (202 bytes).
2. Interface at a lower baud rate [BD (Interface Data Rate) parameter] than the throughput data rate.

Case in which the DI Buffer may become full and possibly overflow:

If the module is receiving a continuous stream of RF data, any serial data that arrives on the DI pin is placed in the DI Buffer. The data in the DI buffer will be transmitted over-the-air when the module is no longer receiving RF data in the network.

Refer to the RO (Packetization Timeout), BD (Interface Data Rate) and D7 (DIO7 Configuration) command descriptions for more information.

DO (Data Out) Buffer

When RF data is received, the data enters the DO buffer and is sent out the serial port to a host device. Once the DO Buffer reaches capacity, any additional incoming RF data is lost.

Hardware Flow Control (RTS). If RTS is enabled for flow control (D6 (DIO6 Configuration) Parameter = 1), data will not be sent out the DO Buffer as long as RTS (pin 16) is de-asserted.

Two cases in which the DO Buffer may become full and possibly overflow:

1. If the RF data rate is set higher than the interface data rate of the module, the module will receive data from the transmitting module faster than it can send the data to the host.
2. If the host does not allow the module to transmit data out from the DO buffer because of being held off by hardware or software flow control.

Refer to the D6 (DIO6 Configuration) command description for more information.

ADC and Digital I/O Line Support

The XBee®/XBee-PRO® RF Modules support ADC (Analog-to-digital conversion) and digital I/O line passing. The following pins support multiple functions:

Table 2-01. Pin functions and their associated pin numbers and commands
AD = Analog-to-Digital Converter, DIO = Digital Input/Output
Pin functions not applicable to this section are denoted within (parenthesis).

Pin Function	Pin#	AT Command
AD0 / DIO0	20	D0
AD1 / DIO1	19	D1
AD2 / DIO2	18	D2
AD3 / DIO3 / (COORD_SEL)	17	D3
AD4 / DIO4	11	D4
AD5 / DIO5 / (ASSOCIATE)	15	D5
DIO6 / (RTS)	16	D6
DIO7 / (CTS)	12	D7
DI8 / (DTR) / (Sleep_RQ)	9	D8

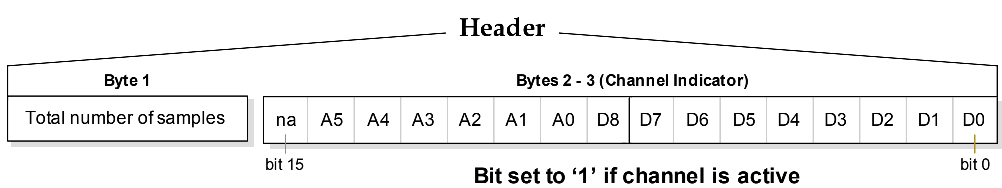
To enable ADC and DIO pin functions:

For ADC Support:	Set ATDn = 2
For Digital Input support:	Set ATDn = 3
For Digital Output Low support:	Set ATDn = 4
For Digital Output High support:	Set ATDn = 5

I/O Data Format

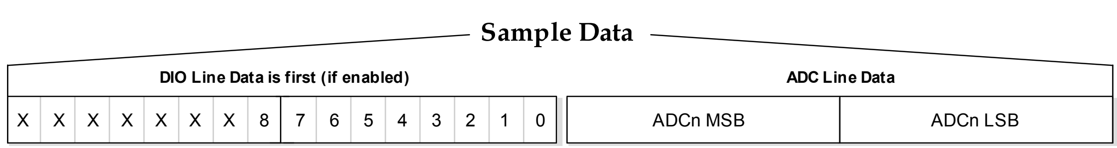
I/O data begins with a header. The first byte of the header defines the number of samples forth-coming. The last 2 bytes of the header (Channel Indicator) define which inputs are active. Each bit represents either a DIO line or ADC channel.

Figure 2-04. Header



Sample data follows the header and the channel indicator frame is used to determine how to read the sample data. If any of the DIO lines are enabled, the first 2 bytes are the DIO sample. The ADC data follows. ADC channel data is represented as an unsigned 10-bit value right-justified on a 16- bit boundary.

Figure 2-05. Sample Data



API Support

I/O data is sent out the UART using an API frame. All other data can be sent and received using Transparent Operation [refer to p11] or API framing if API mode is enabled (AP > 0).

API Operations support two RX (Receive) frame identifiers for I/O data (set 16-bit address to 0xFFFE and the module will do 64-bit addressing):

- 0x82 for RX (Receive) Packet: 64-bit address I/O
- 0x83 for RX (Receive) Packet: 16-bit address I/O

The API command header is the same as shown in the "RX (Receive) Packet: 64-bit Address" and "RX (Receive) Packet: 64-bit Address" API types [refer to p63]. RX data follows the format described in the I/O Data Format section [p13].

Applicable Commands: AP (API Enable)

Sleep Support

Automatic wakeup sampling can be suppressed by setting SO bit 1.When an RF module wakes, it will always do a sample based on any active ADC or DIO lines. This allows sampling based on the sleep cycle whether it be Cyclic Sleep (SM parameter = 4 or 5) or Pin Sleep (SM = 1 or 2). To gather more samples when awake, set the IR (Sample Rate) parameter.

For Cyclic Sleep modes: If the IR parameter is set, the module will stay awake until the IT (Samples before TX) parameter is met. The module will stay awake for ST (Time before Sleep) time.

Applicable Commands: IR (Sample Rate), IT (Samples before TX), SM (Sleep Mode), IC (DIO Change Detect), SO (Sleep Options)

DIO Pin Change Detect

When "DIO Change Detect" is enabled (using the IC command), DIO lines 0-7 are monitored. When a change is detected on a DIO line, the following will occur:

1. An RF packet is sent with the updated DIO pin levels. This packet will not contain any ADC samples.
2. Any queued samples are transmitted before the change detect data. This may result in receiving a packet with less than IT (Samples before TX) samples.

Note: Change detect will not affect Pin Sleep wake-up. The D8 pin (DTR/Sleep_RQ/DI8) is the only line that will wake a module from Pin Sleep. If not all samples are collected, the module will still enter Sleep Mode after a change detect packet is sent.

Applicable Commands: IC (DIO Change Detect), IT (Samples before TX)

NOTE: Change detect is only supported when the Dx (DIOx Configuration) parameter equals 3,4 or 5.

Sample Rate (Interval)

The Sample Rate (Interval) feature allows enabled ADC and DIO pins to be read periodically on modules that are not configured to operate in Sleep Mode. When one of the Sleep Modes is enabled and the IR (Sample Rate) parameter is set, the module will stay awake until IT (Samples before TX) samples have been collected.

Once a particular pin is enabled, the appropriate sample rate must be chosen. The maximum sample rate that can be achieved while using one A/D line is 1 sample/ms or 1 KHz (Note that the modem will not be able to keep up with transmission when IR & IT are equal to "1" and that configuring the modem to sample at rates greater than once every 20ms is not recommended).

Applicable Commands: IR (Sample Rate), IT (Samples before TX), SM (Sleep Mode)

I/O Line Passing

Virtual wires can be set up between XBee®/XBee-PRO® Modules. When an RF data packet is received that contains I/O data, the receiving module can be setup to update any enabled outputs (PWM and DIO) based on the data it receives.

Note that I/O lines are mapped in pairs. For example: AD0 can only update PWM0 and DI5 can only update DO5. The default setup is for outputs not to be updated, which results in the I/O data being sent out the UART (refer to the IU (Enable I/O Output) command). To enable the outputs to be updated, the IA (I/O Input Address) parameter must be setup with the address of the module that has the appropriate inputs enabled. This effectively binds the outputs to a particular module's input. This does not affect the ability of the module to receive I/O line data from other modules - only its ability to update enabled outputs. The IA parameter can also be setup to accept I/O data for output changes from any module by setting the IA parameter to 0xFFFF.

When outputs are changed from their non-active state, the module can be setup to return the output level to it non-active state. The timers are set using the Tn (Dn Output Timer) and PT (PWM Output Timeout) commands. The timers are reset every time a valid I/O packet (passed IA check) is received. The IC (Change Detect) and IR (Sample Rate) parameters can be setup to keep the output set to their active output if the system needs more time than the timers can handle.

Note: DI8 cannot be used for I/O line passing.

Applicable Commands: IA (I/O Input Address), Tn (Dn Output Timeout), P0 (PWM0 Configuration), P1 (PWM1 Configuration), M0 (PWM0 Output Level), M1 (PWM1 Output Level), PT (PWM Output Timeout), RP (RSSSI PWM Timer)

Configuration Example

As an example for a simple A/D link, a pair of RF modules could be set as follows:

Remote Configuration	Base Configuration
DL = 0x1234	DL = 0x5678
MY = 0x5678	MY = 0x1234
D0 = 2	P0 = 2
D1 = 2	P1 = 2
IR = 0x14	IU = 1
IT = 5	IA = 0x5678 (or 0xFFFF)

These settings configure the remote module to sample AD0 and AD1 once each every 20 ms. It then buffers 5 samples each before sending them back to the base module. The base should then receive a 32-Byte transmission (20 Bytes data and 12 Bytes framing) every 100 ms.

XBee®/XBee-PRO® Networks

The following terms will be used to explicate the network operations:

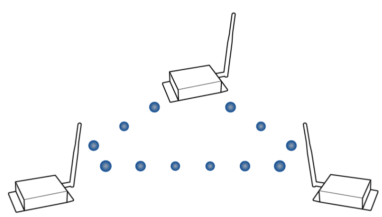
Table 2-02. Terms and definitions

Term	Definition
PAN	Personal Area Network - A data communication network that includes one or more End Devices and optionally a Coordinator.
Coordinator	A Full-function device (FFD) that provides network synchronization by polling nodes [NonBeacon (w/ Coordinator) networks only]
End Device	*When in the same network as a Coordinator* - RF modules that rely on a Coordinator for synchronization and can be put into states of sleep for low-power applications.
Association	The establishment of membership between End Devices and a Coordinator. Association is only applicable in NonBeacon (w/Coordinator) networks.

Peer-to-Peer

By default, XBee®/XBee-PRO RF Modules are configured to operate within a Peer-to-Peer network topology and therefore are not dependent upon Master/Slave relationships. NonBeacon systems operate within a Peer-to-Peer network topology and therefore are not dependent upon Master/Slave relationships. This means that modules remain synchronized without use of master/server configurations and each module in the network shares both roles of master and slave. Digi's peer-to-peer architecture features fast synchronization times and fast cold start times. This default configuration accommodates a wide range of RF data applications.

Figure 2-06. Peer-to-Peer Architecture



A peer-to-peer network can be established by configuring each module to operate as an End Device (CE = 0), disabling End Device Association on all modules (A1 = 0) and setting ID and CH parameters to be identical across the network.

NonBeacon (w/ Coordinator)

A device is configured as a Coordinator by setting the CE (Coordinator Enable) parameter to “1”. Coordinator power-up is governed by the A2 (Coordinator Association) parameter.

In a Coordinator system, the Coordinator can be configured to use direct or indirect transmissions. If the SP (Cyclic Sleep Period) parameter is set to “0”, the Coordinator will send data immediately. Otherwise, the SP parameter determines the length of time the Coordinator will retain the data before discarding it. Generally, SP (Cyclic Sleep Period) and ST (Time before Sleep) parameters should be set to match the SP and ST settings of the End Devices.

Association

Association is the establishment of membership between End Devices and a Coordinator. The establishment of membership is useful in scenarios that require a central unit (Coordinator) to relay messages to or gather data from several remote units (End Devices), assign channels or assign PAN IDs.

An RF data network that consists of one Coordinator and one or more End Devices forms a PAN (Personal Area Network). Each device in a PAN has a PAN Identifier [ID (PAN ID) parameter]. PAN IDs must be unique to prevent miscommunication between PANs. The Coordinator PAN ID is set using the ID (PAN ID) and A2 (Coordinator Association) commands.

An End Device can associate to a Coordinator without knowing the address, PAN ID or channel of the Coordinator. The A1 (End Device Association) parameter bit fields determine the flexibility of an End Device during association. The A1 parameter can be used for an End Device to dynamically set its destination address, PAN ID and/or channel.

For example: If the PAN ID of a Coordinator is known, but the operating channel is not; the A1 command on the End Device should be set to enable the 'Auto_Associate' and 'Reassign_Channel' bits. Additionally, the ID parameter should be set to match the PAN ID of the associated Coordinator.

Coordinator / End Device Setup and Operation

To configure a module to operate as a Coordinator, set the CE (Coordinator Enable) parameter to '1'. Set the CE parameter of End Devices to '0' (default). Coordinator and End Devices should contain matching firmware versions.

NonBeacon (w/ Coordinator) Systems

The Coordinator can be configured to use direct or indirect transmissions. If the SP (Cyclic Sleep Period) parameter is set to '0', the Coordinator will send data immediately. Otherwise, the SP parameter determines the length of time the Coordinator will retain the data before discarding it. Generally, SP (Cyclic Sleep Period) and ST (Time before Sleep) parameters should be set to match the SP and ST settings of the End Devices.

Coordinator Start-up

Coordinator power-up is governed by the A2 (Coordinator Association) command. On power-up, the Coordinator undergoes the following sequence of events:

1. Check A2 parameter- Reassign_PANID Flag

Set (bit 0 = 1) - The Coordinator issues an Active Scan. The Active Scan selects one channel and transmits a request to the broadcast address (0xFFFF) and broadcast PAN ID (0xFFFF). It then listens on that channel for beacons from any Coordinator operating on that channel. The listen time on each channel is determined by the SD (Scan Duration) parameter value.

Once the time expires on that channel, the Active Scan selects another channel and again transmits the BeaconRequest as before. This process continues until all channels have been scanned, or until 5 PANs have been discovered. When the Active Scan is complete, the results include a list of PAN IDs and Channels that are being used by other PANs. This list is used to assign an unique PAN ID to the new Coordinator. The ID parameter will be retained if it is not found in the Active Scan results. Otherwise, the ID (PAN ID) parameter setting will be updated to a PAN ID that was not detected.

Not Set (bit 0 = 0) - The Coordinator retains its ID setting. No Active Scan is performed.

2. Check A2 parameter - Reassign_Channel Flag (bit 1)

Set (bit 1 = 1) - The Coordinator issues an Energy Scan. The Energy Scan selects one channel and scans for energy on that channel. The duration of the scan is specified by the SD (Scan Duration) parameter. Once the scan is completed on a channel, the Energy Scan selects the next channel and begins a new scan on that channel. This process continues until all channels have been scanned.

When the Energy Scan is complete, the results include the maximal energy values detected on each channel. This list is used to determine a channel where the least energy was detected. If an Active Scan was performed (Reassign_PANID Flag set), the channels used by the detected PANs are eliminated as possible channels. Thus, the results of the Energy Scan and the Active Scan (if performed) are used to find the best channel (channel with the least energy that is not used by any detected PAN). Once the best channel has been selected, the CH (Channel) parameter value is updated to that channel.

Not Set (bit 1 = 0) - The Coordinator retains its CH setting. An Energy Scan is not performed.

3. Start Coordinator

The Coordinator starts on the specified channel (CH parameter) and PAN ID (ID parameter). Note, these may be selected in steps 1 and/or 2 above. The Coordinator will only allow End Devices to associate to it if the A2 parameter "AllowAssociation" flag is set. Once the Coordinator has successfully started, the Associate LED will blink 1 time per second. (The LED is solid if the Coordinator has not started.)

4. Coordinator Modifications

Once a Coordinator has started:
Modifying the A2 (Reassign_Channel or Reassign_PANID bits), ID, CH or MY parameters will cause the Coordinator's MAC to reset (The Coordinator RF module (including volatile RAM) is not reset). Changing the A2 AllowAssociation bit will not reset the Coordinator's MAC. In a non-beaconing system, End Devices that associated to the Coordinator prior to a MAC reset will have knowledge of the new settings on the Coordinator. Thus, if the Coordinator were to change its ID, CH or MY settings, the End Devices would no longer be able to communicate with the non-beacon Coordinator. Once a Coordinator has started, the ID, CH, MY or A2 (Reassign_Channel or Reassign_PANID bits) should not be changed.

End Device Start-up

End Device power-up is governed by the A1 (End Device Association) command. On power-up, the End Device undergoes the following sequence of events:

1. Check A1 parameter - AutoAssociate Bit

Set (bit 2 = 1) - End Device will attempt to associate to a Coordinator. (refer to steps 2-3).

Not Set (bit 2 = 0) - End Device will not attempt to associate to a Coordinator. The End Device will operate as specified by its ID, CH and MY parameters. Association is considered complete and the Associate LED will blink quickly (5 times per second). When the AutoAssociate bit is not set, the remaining steps (2-3) do not apply.

2. Discover Coordinator (if Auto-Associate Bit Set)

The End Device issues an Active Scan. The Active Scan selects one channel and transmits a BeaconRequest command to the broadcast address (0xFFFF) and broadcast PAN ID (0xFFFF). It then listens on that channel for beacons from any Coordinator operating on that channel. The listen time on each channel is determined by the SD parameter.

Once the time expires on that channel, the Active Scan selects another channel and again transmits the BeaconRequest command as before. This process continues until all channels have been scanned, or until 5 PANs have been discovered. When the Active Scan is complete, the results include a list of PAN IDs and Channels that are being used by detected PANs.

The End Device selects a Coordinator to associate with according to the A1 parameter "Reassign_PANID" and "Reassign_Channel" flags:

Reassign_PANID Bit Set (bit 0 = 1)- End Device can associate with a PAN with any ID value.

Reassign_PANID Bit Not Set (bit 0 = 0) - End Device will only associate with a PAN whose ID setting matches the ID setting of the End Device.

Reassign_Channel Bit Set (bit 1 = 1) - End Device can associate with a PAN with any CH value.

Reassign_Channel Bit Not Set (bit 1 = 0)- End Device will only associate with a PAN whose CH setting matches the CH setting of the End Device.

After applying these filters to the discovered Coordinators, if multiple candidate PANs exist, the End Device will select the PAN whose transmission link quality is the strongest. If no valid Coordinator is found, the End Device will either go to sleep (as dictated by its SM (Sleep Mode) parameter) or retry Association.

Note - An End Device will also disqualify Coordinators if they are not allowing association (A2 - AllowAssociation bit); or, if the Coordinator is not using the same NonBeacon scheme as the End Device. (They must both be programmed with NonBeacon code.)

3. Associate to Valid Coordinator

Once a valid Coordinator is found (step 2), the End Device sends an AssociationRequest message to the Coordinator. It then waits for an AssociationConfirmation to be sent from the Coordinator. Once the Confirmation is received, the End Device is Associated and the Associate LED will blink rapidly (2 times per second). The LED is solid if the End Device has not associated.

4. End Device Changes once an End Device has associated

Changing A1, ID or CH parameters will cause the End Device to disassociate and restart the Association procedure.

If the End Device fails to associate, the AI command can give some indication of the failure.

XBee®/XBee-PRO® Addressing

Every RF data packet sent over-the-air contains a Source Address and Destination Address field in its header. The RF module conforms to the 802.15.4 specification and supports both short 16-bit addresses and long 64-bit addresses. A unique 64-bit IEEE source address is assigned at the factory and can be read with the SL (Serial Number Low) and SH (Serial Number High) commands. Short addressing must be configured manually. A module will use its unique 64-bit address as its Source Address if its MY (16-bit Source Address) value is "0xFFFF" or "0xFFFE".

To send a packet to a specific module using 64-bit addressing: Set the Destination Address (DL + DH) of the sender to match the Source Address (SL + SH) of the intended destination module.

To send a packet to a specific module using 16-bit addressing: Set DL (Destination Address Low) parameter to equal the MY parameter of the intended destination module and set the DH (Destination Address High) parameter to '0'.

Unicast Mode

By default, the RF module operates in Unicast Mode. Unicast Mode is the only mode that supports retries. While in this mode, receiving modules send an ACK (acknowledgement) of RF packet reception to the transmitter. If the transmitting module does not receive the ACK, it will re-send the packet up to three times or until the ACK is received.

Short 16-bit addresses. The module can be configured to use short 16-bit addresses as the Source Address by setting (MY < 0xFFFE). Setting the DH parameter (DH = 0) will configure the Destination Address to be a short 16-bit address (if DL < 0xFFFE). For two modules to communicate using short addressing, the Destination Address of the transmitter module must match the MY parameter of the receiver.

The following table shows a sample network configuration that would enable Unicast Mode communications using short 16-bit addresses.

Table 2-03. Sample Unicast Network Configuration (using 16-bit addressing)

Parameter	RF Module 1	RF Module 2
MY (Source Address)	0x01	0x02
DH (Destination Address High)	0	0
DL (Destination Address Low)	0x02	0x01

Long 64-bit addresses. The RF module's serial number (SL parameter concatenated to the SH parameter) can be used as a 64-bit source address when the MY (16-bit Source Address) parameter is disabled. When the MY parameter is disabled (MY = 0xFFFF or 0xFFFE), the module's source address is set to the 64-bit IEEE address stored in the SH and SL parameters.

When an End Device associates to a Coordinator, its MY parameter is set to 0xFFFE to enable 64-bit addressing. The 64-bit address of the module is stored as SH and SL parameters. To send a packet to a specific module, the Destination Address (DL + DH) on the sender must match the Source Address (SL + SH) of the desired receiver.

Broadcast Mode

Any RF module within range will accept a packet that contains a broadcast address. When configured to operate in Broadcast Mode, receiving modules do not send ACKs (Acknowledgements) and transmitting modules do not automatically re-send packets as is the case in Unicast Mode.

To send a broadcast packet to all modules regardless of 16-bit or 64-bit addressing, set the destination addresses of all the modules as shown below.

Sample Network Configuration (All modules in the network):

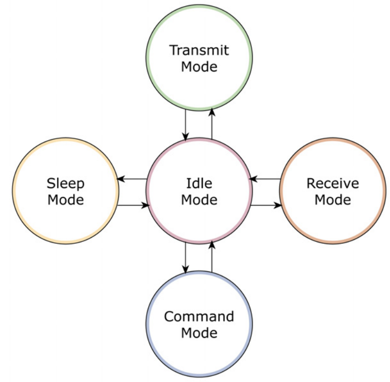
- DL (Destination Low Address) = 0x0000FFFF
- DH (Destination High Address) = 0x00000000 (default value)

NOTE: When programming the module, parameters are entered in hexadecimal notation (without the "0x" prefix). Leading zeros may be omitted.

Modes of Operation

XBee®/XBee-PRO® RF Modules operate in five modes.

Figure 2-07. Modes of Operation



Idle Mode

When not receiving or transmitting data, the RF module is in Idle Mode. The module shifts into the other modes of operation under the following conditions:

- Transmit Mode (Serial data is received in the DI Buffer)
- Receive Mode (Valid RF data is received through the antenna)
- Sleep Mode (Sleep Mode condition is met)
- Command Mode (Command Mode Sequence is issued)

Transmit/Receive Modes

RF Data Packets

Each transmitted data packet contains a Source Address and Destination Address field. The Source Address matches the address of the transmitting module as specified by the MY (Source Address) parameter (if MY >= 0xFFFE), the SH (Serial Number High) parameter or the SL (Serial Number Low) parameter. The <Destination Address> field is created from the DH (Destination Address High) and DL (Destination Address Low) parameter values. The Source Address and/or Destination Address fields will either contain a 16-bit short or long 64-bit long address.

The RF data packet structure follows the 802.15.4 specification.

[Refer to the XBee/XBee-PRO Addressing section for more information]

Direct and Indirect Transmission

There are two methods to transmit data:

- Direct Transmission - data is transmitted immediately to the Destination Address
- Indirect Transmission - A packet is retained for a period of time and is only transmitted after the destination module (Source Address = Destination Address) requests the data.

Indirect Transmissions can only occur on a Coordinator. Thus, if all nodes in a network are End Devices, only Direct Transmissions will occur. Indirect Transmissions are useful to ensure packet delivery to a sleeping node. The Coordinator currently is able to retain up to 2 indirect messages.

Direct Transmission

A Coordinator can be configured to use only Direct Transmission by setting the SP (Cyclic Sleep Period) parameter to "0". Also, a Coordinator using indirect transmissions will revert to direct transmission if it knows the destination module is awake.

To enable this behavior, the ST (Time before Sleep) value of the Coordinator must be set to match the ST value of the End Device. Once the End Device either transmits data to the Coordinator or polls the Coordinator for data, the Coordinator will use direct transmission for all subsequent data transmissions to that module address until ST time occurs with no activity (at which point it will revert to using indirect transmissions for that module address). "No activity" means no transmission or reception of messages with a specific address. Global messages will not reset the ST timer.

Indirect Transmission

To configure Indirect Transmissions in a PAN (Personal Area Network), the SP (Cyclic Sleep Period) parameter value on the Coordinator must be set to match the longest sleep value of any End Device. The sleep period value on the Coordinator determines how long (time or number of beacons) the Coordinator will retain an indirect message before discarding it.

An End Device must poll the Coordinator once it wakes from Sleep to determine if the Coordinator has an indirect message for it. For Cyclic Sleep Modes, this is done automatically every time the module wakes (after SP time). For Pin Sleep Modes, the A1 (End Device Association) parameter value must be set to enable Coordinator polling on pin wake-up. Alternatively, an End Device can use the FP (Force Poll) command to poll the Coordinator as needed.

CCA (Clear Channel Assessment)

Prior to transmitting a packet, a CCA (Clear Channel Assessment) is performed on the channel to determine if the channel is available for transmission. The detected energy on the channel is compared with the CA (Clear Channel Assessment) parameter value. If the detected energy exceeds the CA parameter value, the packet is not transmitted.

Also, a delay is inserted before a transmission takes place. This delay is settable using the RN (Backoff Exponent) parameter. If RN is set to “0”, then there is no delay before the first CCA is performed. The RN parameter value is the equivalent of the “minBE” parameter in the 802.15.4 specification. The transmit sequence follows the 802.15.4 specification.

By default, the MM (MAC Mode) parameter = 0. On a CCA failure, the module will attempt to resend the packet up to two additional times.

When in Unicast packets with RR (Retries) = 0, the module will execute two CCA retries. Broadcast packets always get two CCA retries.

Acknowledgement

If the transmission is not a broadcast message, the module will expect to receive an acknowledgement from the destination node. If an acknowledgement is not received, the packet will be resent up to 3 more times. If the acknowledgement is not received after all transmissions, an ACK failure is recorded.

Sleep Mode

Sleep Modes enable the RF module to enter states of low-power consumption when not in use. In order to enter Sleep Mode, one of the following conditions must be met (in addition to the module having a non-zero SM parameter value):

- Sleep_RQ (pin 9) is asserted and the module is in a pin sleep mode (SM = 1, 2, or 5)
- The module is idle (no data transmission or reception) for the amount of time defined by the ST (Time before Sleep) parameter. [NOTE: ST is only active when SM = 4-5.]

Table 2-04. Sleep Mode Configurations

Sleep Mode Setting	Transition into Sleep Mode	Transition out of Sleep Mode (wake)	Characteristics	Related Commands	Power Consumption
Pin Hibernate (SM = 1)	Assert (high) Sleep_RQ (pin 9)	De-assert (low) Sleep_RQ	Pin/Host-controlled / NonBeacon systems only / Lowest Power	(SM)	< 10 µA (@3.0 VCC)
Pin Doze (SM = 2)	Assert (high) Sleep_RQ (pin 9)	De-assert (low) Sleep_RQ	Pin/Host-controlled / NonBeacon systems only / Fastest wake-up	(SM)	< 50 µA
Cyclic Sleep (SM = 4)	Automatic transition to Sleep Mode as defined by the SM (Sleep Mode) and ST (Time before Sleep) parameters.	Transition occurs after the cyclic sleep time interval elapses. The time interval is defined by the SP (Cyclic Sleep Period) parameter.	RF module wakes in pre-determined time intervals to detect if RF data is present / When SM = 5	(SM), SP, ST	< 50 µA when sleeping
Cyclic Sleep (SM = 5)	Automatic transition to Sleep Mode as defined by the SM (Sleep Mode) and ST (Time before Sleep) parameters or or on a falling edge transition of the SLEEP_RQ pin.	Transition occurs after the cyclic sleep time interval elapses. The time interval is defined by the SP (Cyclic Sleep Period) parameter.	RF module wakes in pre-determined time intervals to detect if RF data is present. Module also wakes on a falling edge of SLEEP_RQ	(SM), SP, ST	< 50 µA when sleeping

The SM command is central to setting Sleep Mode configurations. By default, Sleep Modes are disabled (SM = 0) and the module remains in Idle/Receive Mode. When in this state, the module is constantly ready to respond to serial or RF activity.

Pin/Host-controlled Sleep Modes

The transient current when waking from pin sleep (SM = 1 or 2) does not exceed the idle current of the module. The current ramps up exponentially to its idle current.

Pin Hibernate (SM = 1)

- Pin/Host-controlled
- Typical power-down current: < 10 µA (@3.0 VCC)
- Wake-up time: 13.2 msec

Pin Hibernate Mode minimizes quiescent power (power consumed when in a state of rest or inactivity). This mode is voltage level-activated; when Sleep_RQ (pin 9) is asserted, the module will finish any transmit, receive or association activities, enter Idle Mode, and then enter a state of sleep. The module will not respond to either serial or RF activity while in pin sleep.

To wake a sleeping module operating in Pin Hibernate Mode, de-assert Sleep_RQ (pin 9). The module will wake when Sleep_RQ is de-asserted and is ready to transmit or receive when the CTS line is low. When waking the module, the pin must be de-asserted at least two 'byte times' after CTS goes low. This assures that there is time for the data to enter the DI buffer.

Pin Doze (SM = 2)

- Pin/Host-controlled
- Typical power-down current: < 50 µA
- Wake-up time: 2 msec

Pin Doze Mode functions as does Pin Hibernate Mode; however, Pin Doze features faster wake-up time and higher power consumption.

To wake a sleeping module operating in Pin Doze Mode, de-assert Sleep_RQ (pin 9). The module will wake when Sleep_RQ is de-asserted and is ready to transmit or receive when the CTS line is low. When waking the module, the pin must be de-asserted at least two 'byte times' after CTS goes low. This assures that there is time for the data to enter the DI buffer.

Cyclic Sleep Modes

Cyclic Sleep Remote (SM = 4)

- Typical Power-down Current: < 50 µA (when asleep)
- Wake-up time: 2 msec

The Cyclic Sleep Modes allow modules to periodically check for RF data. When the SM parameter is set to '4', the module is configured to sleep, then wakes once a cycle to check for data from a module configured as a Cyclic Sleep Coordinator (SM = 0, CE = 1). The Cyclic Sleep Remote sends a poll request to the coordinator at a specific interval set by the SP (Cyclic Sleep Period) parameter. The coordinator will transmit any queued data addressed to that specific remote upon receiving the poll request.

If no data is queued for the remote, the coordinator will not transmit and the remote will return to sleep for another cycle. If queued data is transmitted back to the remote, it will stay awake to allow for back and forth communication until the ST (Time before Sleep) timer expires.

Also note that $\overline{\text{CTS}}$ will go low each time the remote wakes, allowing for communication initiated by the remote host if desired.

Cyclic Sleep Remote with Pin Wake-up (SM = 5)

Use this mode to wake a sleeping remote module through either the RF interface or by the de-assertion of Sleep_RQ for event-driven communications. The cyclic sleep mode works as described above (Cyclic Sleep Remote) with the addition of a pin-controlled wake-up at the remote module. The Sleep_RQ pin is edge-triggered, not level-triggered. The module will wake when a low is detected then set $\overline{\text{CTS}}$ low as soon as it is ready to transmit or receive.

Any activity will reset the ST (Time before Sleep) timer so the module will go back to sleep only after there is no activity for the duration of the timer. Once the module wakes (pin-controlled), further pin activity is ignored. The module transitions back into sleep according to the ST time regardless of the state of the pin.

[Cyclic Sleep Coordinator (SM = 6)]

- Typical current = Receive current
- Always awake

NOTE: The SM=6 parameter value exists solely for backwards compatibility with firmware version 1.x60. If backwards compatibility with the older firmware version is not required, always use the CE (Coordinator Enable) command to configure a module as a Coordinator.

This mode configures a module to wake cyclic sleeping remotes through RF interfacing. The Coordinator will accept a message addressed to a specific remote 16 or 64-bit address and hold it in a buffer until the remote wakes and sends a poll request. Messages not sent directly (buffered and requested) are called "Indirect messages". The Coordinator only queues one indirect message at a time. The Coordinator will hold the indirect message for a period 2.5 times the sleeping period indicated by the SP (Cyclic Sleep Period) parameter. The Coordinator's SP parameter should be set to match the value used by the remotes.

Command Mode

To modify or read RF Module parameters, the module must first enter into Command Mode - a state in which incoming characters are interpreted as commands. Two Command Mode options are supported: AT Command Mode [refer to section below] and API Command Mode [p57].

AT Command Mode

To Enter AT Command Mode:

Send the 3-character command sequence "+++" and observe guard times before and after the command characters. [Refer to the "Default AT Command Mode Sequence" below.]

Default AT Command Mode Sequence (for transition to Command Mode):

- No characters sent for one second [GT (Guard Times) parameter = 0x3E8]
- Input three plus characters ("+++") within one second [CC (Command Sequence Character) parameter = 0x2B.]
- No characters sent for one second [GT (Guard Times) parameter = 0x3E8]

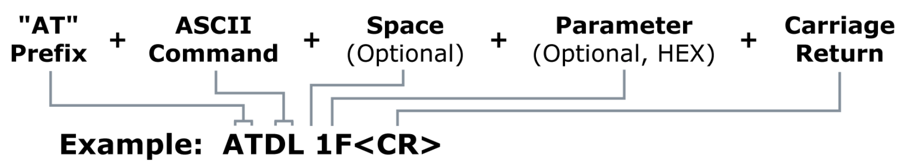
All of the parameter values in the sequence can be modified to reflect user preferences.

NOTE: Failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the 'Baud' setting on the "PC Settings" tab matches the interface data rate of the RF module. By default, the BD parameter = 3 (9600 bps).

To Send AT Commands:

Send AT commands and parameters using the syntax shown below.

Figure 2-08. Syntax for sending AT Commands



To read a parameter value stored in the RF module's register, omit the parameter field.

The preceding example would change the RF module Destination Address (Low) to "0x1F". To store the new value to non-volatile (long term) memory, subsequently send the WR (Write) command.

For modified parameter values to persist in the module's registry after a reset, changes must be saved to non-volatile memory using the WR (Write) Command. Otherwise, parameters are restored to previously saved values after the module is reset.

System Response. When a command is sent to the module, the module will parse and execute the command. Upon successful execution of a command, the module returns an "OK" message. If execution of a command results in an error, the module returns an "ERROR" message.

To Exit AT Command Mode:

1. Send the ATCN (Exit Command Mode) command (followed by a carriage return).

   [OR]

2. If no valid AT Commands are received within the time specified by CT (Command Mode Timeout) Command, the RF module automatically returns to Idle Mode.

For an example of programming the RF module using AT Commands and descriptions of each configurable parameter, refer to the RF Module Configuration chapter [p26].

3. RF Module Configuration

Programming the RF Module

Refer to the Command Mode section [p25] for more information about entering Command Mode, sending AT commands and exiting Command Mode. For information regarding module programming using API Mode, refer to the API Operation sections [p57].

Programming Examples

Setup

The programming examples in this section require the installation of Digi's X-CTU Software and a serial connection to a PC. (Digi stocks RS-232 and USB boards to facilitate interfacing with a PC.)

1. Install Digi's X-CTU Software to a PC by double-clicking the "setup_X-CTU.exe" file. (The file is located on the Digi CD and www.digi.com/xctu.)
2. Mount the RF module to an interface board, then connect the module assembly to a PC.
3. Launch the X-CTU Software and select the 'PC Settings' tab. Verify the baud and parity settings of the Com Port match those of the RF module.

NOTE: Failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the 'Baud' setting on the 'PC Settings' tab matches the interface data rate of the RF module. By default, the BD parameter = 3 (which corresponds to 9600 bps).

Sample Configuration: Modify RF Module Destination Address

Example: Utilize the X-CTU "Terminal" tab to change the RF module's DL (Destination Address Low) parameter and save the new address to non-volatile memory.

After establishing a serial connection between the RF module and a PC [refer to the 'Setup' section above], select the "Terminal" tab of the X-CTU Software and enter the following command lines ('CR' stands for carriage return):

Method 1 (One line per command)

Send AT Command	System Response
+++	OK <CR> (Enter into Command Mode)
ATDL <Enter>	{current value} <CR> (Read Destination Address Low)
ATDL1A0D <Enter>	OK <CR> (Modify Destination Address Low)
ATWR <Enter>	OK <CR> (Write to non-volatile memory)
ATCN <Enter>	OK <CR> (Exit Command Mode)

Method 2 (Multiple commands on one line)

Send AT Command	System Response
+++	OK <CR> (Enter into Command Mode)
ATDL <Enter>	{current value} <CR> (Read Destination Address Low)
ATDL1A0D,WR,CN <Enter>	OK<CR> OK<CR> OK<CR>

Sample Configuration: Restore RF Module Defaults

Example: Utilize the X-CTU "Modem Configuration" tab to restore default parameter values.

After establishing a connection between the module and a PC [refer to the 'Setup' section above], select the "Modem Configuration" tab of the X-CTU Software.

1. Select the 'Read' button.
2. Select the 'Restore' button.

Remote Configuration Commands

The API firmware has provisions to send configuration commands to remote devices using the Remote Command Request API frame (see API Operation). This API frame can be used to send commands to a remote module to read or set command parameters.

The API firmware has provisions to send configuration commands (set or read) to a remote module using the Remote Command Request API frame (see API Operations). Remote commands can be issued to read or set command parameters on a remote device.

Sending a Remote Command

To send a remote command, the Remote Command Request frame should be populated with values for the 64 bit and 16 bit addresses. If 64 bit addressing is desired then the 16 bit address field should be filled with 0xFFFE. If any value other than 0xFFFE is used in the 16 bit address field then the 64 bit address field will be ignored and 16 bit addressing will be used. If a command response is desired, the Frame ID should be set to a non-zero value.

Applying Changes on Remote

When remote commands are used to change command parameter settings on a remote device, parameter changes do not take effect until the changes are applied. For example, changing the BD parameter will not change the actual serial interface rate on the remote until the changes are applied. Changes can be applied using remote commands in one of three ways:

Set the apply changes option bit in the API frame

Issue an AC command to the remote device

Issue a WR + FR command to the remote device to save changes and reset the device.

Remote Command Responses

If the remote device receives a remote command request transmission, and the API frame ID is non-zero, the remote will send a remote command response transmission back to the device that sent the remote command. When a remote command response transmission is received, a device sends a remote command response API frame out its UART. The remote command response indicates the status of the command (success, or reason for failure), and in the case of a command query, it will include the register value.

The device that sends a remote command will not receive a remote command response frame if:

The destination device could not be reached

The frame ID in the remote command request is set to 0.

Command Reference Tables

XBee®/XBee-PRO® RF Modules expect numerical values in hexadecimal. Hexadecimal values are designated by a “0x” prefix. Decimal equivalents are designated by a “d” suffix. Commands are contained within the following command categories (listed in the order that their tables appear):

- Special
- Networking & Security
- RF Interfacing
- Sleep (Low Power)
- Serial Interfacing
- I/O Settings
- Diagnostics
- AT Command Options

All modules within a PAN should operate using the same firmware version.

Special

Table 3-01. XBee-PRO Commands - Special

AT Command	Command Category	Name and Description	Parameter Range	Default
WR	Special	**Write**. Write parameter values to non-volatile memory so that parameter modifications persist through subsequent power-up or reset. Note: Once WR is issued, no additional characters should be sent to the module until after the response "OK\r" is received.	-	-
RE	Special	**Restore Defaults**. Restore module parameters to factory defaults.	-	-
FR (v1.x80*)	Special	**Software Reset**. Responds immediately with an OK then performs a hard reset ~100ms later.	-	-

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Networking & Security

Table 3-02. XBee®/XBee-PRO® Commands - Networking & Security (Sub-categories designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
CH	Networking {Addressing}	**Channel**. Set/Read the channel number used for transmitting and receiving data between RF modules (uses 802.15.4 protocol channel numbers).	0x0B - 0x1A (XBee) 0x0C - 0x17 (XBee-PRO)	0x0C (12d)
ID	Networking {Addressing}	**PAN ID**. Set/Read the PAN (Personal Area Network) ID. Use 0xFFFF to broadcast messages to all PANs.	0 - 0xFFFF	0x3332 (13106d)
DH	Networking {Addressing}	**Destination Address High**. Set/Read the upper 32 bits of the 64-bit destination address. When combined with DL, it defines the destination address used for transmission. To transmit using a 16-bit address, set DH parameter to zero and DL less than 0xFFFF. 0x000000000000FFFF is the broadcast address for the PAN.	0 - 0xFFFFFFFF	0
DL	Networking {Addressing}	**Destination Address Low**. Set/Read the lower 32 bits of the 64-bit destination address. When combined with DH, DL defines the destination address used for transmission. To transmit using a 16-bit address, set DH parameter to zero and DL less than 0xFFFF. 0x000000000000FFFF is the broadcast address for the PAN.	0 - 0xFFFFFFFF	0
MY	Networking {Addressing}	**16-bit Source Address.** Set/Read the RF module 16-bit source address. Set MY = 0xFFFF to disable reception of packets with 16-bit addresses. 64-bit source address (serial number) and broadcast address (0x000000000000FFFF) is always enabled.	0 - 0xFFFF	0
SH	Networking {Addressing}	**Serial Number High**. Read high 32 bits of the RF module's unique IEEE 64-bit address. 64-bit source address is always enabled.	0 - 0xFFFFFFFF [read-only]	Factory-set
SL	Networking {Addressing}	**Serial Number Low**. Read low 32 bits of the RF module's unique IEEE 64-bit address. 64-bit source address is always enabled.	0 - 0xFFFFFFFF [read-only]	Factory-set
RR (v1.xA0*)	Networking {Addressing}	**XBee Retries**. Set/Read the maximum number of retries the module will execute in addition to the 3 retries provided by the 802.15.4 MAC. For each XBee retry, the 802.15.4 MAC can execute up to 3 retries.	0 - 6	0
RN	Networking {Addressing}	**Random Delay Slots.** Set/Read the minimum value of the back-off exponent in the CSMA-CA algorithm that is used for collision avoidance. If RN = 0, collision avoidance is disabled during the first iteration of the algorithm (802.15.4 - macMinBE).	0 - 3 [exponent]	0
MM (v1.x80*)	Networking {Addressing}	**MAC Mode.** MAC Mode. Set/Read MAC Mode value. MAC Mode enables/disables the use of a Digi header in the 802.15.4 RF packet. When Modes 0 or 3 are enabled (MM=0,3), duplicate packet detection is enabled as well as certain AT commands. Please see the detailed MM description on page 47 for additional information.	0 - 3 0 = Digi Mode 1 = 802.15.4 (no ACKs) 2 = 802.15.4 (with ACKs) 3 = Digi Mode (no ACKs)	0
NI (v1.x80*)	Networking {Identification}	**Node Identifier.** Stores a string identifier. The register only accepts printable ASCII data. A string can not start with a space. Carriage return ends command. Command will automatically end when maximum bytes for the string have been entered. This string is returned as part of the ND (Node Discover) command. This identifier is also used with the DN (Destination Node) command.	20-character ASCII string	-
ND (v1.x80*)	Networking {Identification}	**Node Discover.** Discovers and reports all RF modules found. The following information is reported for each module discovered (the example cites use of Transparent operation (AT command format) - refer to the long ND command description regarding differences between Transparent and API operation). MY<CR> SH<CR> SL<CR> DB<CR> NI<CR><CR> The amount of time the module allows for responses is determined by the NT parameter. In Transparent operation, command completion is designated by a <CR> (carriage return). ND also accepts a Node Identifier as a parameter. In this case, only a module matching the supplied identifier will respond. If ND self-response is enabled (NO=1) the module initiating the node discover will also output a response for itself.	optional 20-character NI value	
NT (v1.xA0*)	Networking {Identification}	**Node Discover Time.** Set/Read the amount of time a node will wait for responses from other nodes when using the ND (Node Discover) command.	0x01 - 0xFC [x 100 ms]	0x19

Table 3-02. XBee®/XBee-PRO® Commands - Networking & Security (Sub-categories designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
NO (v1xC5)	Networking {Identification}	**Node Discover Options**. Enables node discover self-response on the module.	0-1	0
DN (v1.x80*)	Networking {Identification}	**Destination Node.** Resolves an NI (Node Identifier) string to a physical address. The following events occur upon successful command execution: 1. DL and DH are set to the address of the module with the matching Node Identifier. 2. "OK" is returned. 3. RF module automatically exits AT Command Mode If there is no response from a module within 200 msec or a parameter is not specified (left blank), the command is terminated and an "ERROR" message is returned.	20-character ASCII string	-
CE (v1.x80*)	Networking {Association}	**Coordinator Enable**. Set/Read the coordinator setting.	0 - 1 0 = End Device 1 = Coordinator	0
SC (v1.x80*)	Networking {Association}	**Scan Channels**. Set/Read list of channels to scan for all Active and Energy Scans as a bitfield. This affects scans initiated in command mode (AS, ED) and during End Device Association and Coordinator startup: bit 0 - 0x0B bit 4 - 0x0F bit 8 - 0x13 bit12 - 0x17 bit 1 - 0x0C bit 5 - 0x10 bit 9 - 0x14 bit13 - 0x18 bit 2 - 0x0D bit 6 - 0x11 bit 10 - 0x15 bit14 - 0x19 bit 3 - 0x0E bit 7 - 0x12 bit 11 - 0x16 bit 15 - 0x1A	0 - 0xFFFF [bitfield] (bits 0, 14, 15 not allowed on the XBee-PRO)	0x1FFE (all XBee-PRO Channels)
SD (v1.x80*)	Networking {Association}	**Scan Duration**. Set/Read the scan duration exponent. ***End Device*** - Duration of Active Scan during Association. ***Coordinator*** - If 'ReassignPANID' option is set on Coordinator [refer to A2 parameter], SD determines the length of time the Coordinator will scan channels to locate existing PANs. If 'ReassignChannel' option is set, SD determines how long the Coordinator will perform an Energy Scan to determine which channel it will operate on. 'Scan Time' is measured as (# of channels to scan] * (2 ^ SD) * 15.36ms). The number of channels to scan is set by the SC command. The XBee can scan up to 16 channels (SC = 0xFFFF). The XBee PRO can scan up to 13 channels (SC = 0x3FFE). Example: The values below show results for a 13 channel scan: If SD = 0, time = 0.18 sec SD = 8, time = 47.19 sec SD = 2, time = 0.74 sec SD = 10, time = 3.15 min SD = 4, time = 2.95 sec SD = 12, time = 12.58 min SD = 6, time = 11.80 sec SD = 14, time = 50.33 min	0-0x0F [exponent]	4
A1 (v1.x80*)	Networking {Association}	**End Device Association**. Set/Read End Device association options. bit 0 - ReassignPanID 0 - Will only associate with Coordinator operating on PAN ID that matches module ID 1 - May associate with Coordinator operating on any PAN ID bit 1 - ReassignChannel 0 - Will only associate with Coordinator operating on matching CH Channel setting 1 - May associate with Coordinator operating on any Channel bit 2 - AutoAssociate 0 - Device will not attempt Association 1 - Device attempts Association until success Note: This bit is used only for Non-Beacon systems. End Devices in Beacon-enabled system must always associate to a Coordinator bit 3 - PollCoordOnPinWake 0 - Pin Wake will not poll the Coordinator for indirect (pending) data 1 - Pin Wake will send Poll Request to Coordinator to extract any pending data bits 4 - 7 are reserved	0 - 0x0F [bitfield]	0
A2 (v1.x80*)	Networking {Association}	**Coordinator Association**. Set/Read Coordinator association options. bit 0 - ReassignPanID 0 - Coordinator will not perform Active Scan to locate available PAN ID. It will operate on ID (PAN ID). 1 - Coordinator will perform Active Scan to determine an available ID (PAN ID). If a PAN ID conflict is found, the ID parameter will change. bit 1 - ReassignChannel - 0 - Coordinator will not perform Energy Scan to determine free channel. It will operate on the channel determined by the CH parameter. 1 - Coordinator will perform Energy Scan to find a free channel, then operate on that channel. bit 2 - AllowAssociation - 0 - Coordinator will not allow any devices to associate to it. 1 - Coordinator will allow devices to associate to it. bits 3 - 7 are reserved	0 - 7 [bitfield]	0

Table 3-02. XBee®/XBee-PRO® Commands - Networking & Security (Sub-categories designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
AI (v1.x80*)	Networking {Association}	**Association Indication**. Read errors with the last association request: 0x00 - Successful Completion - Coordinator successfully started or End Device association complete 0x01 - Active Scan Timeout 0x02 - Active Scan found no PANs 0x03 - Active Scan found PAN, but the CoordinatorAllowAssociation bit is not set 0x04 - Active Scan found PAN, but Coordinator and End Device are not configured to support beacons 0x05 - Active Scan found PAN, but the Coordinator ID parameter does not match the ID parameter of the End Device 0x06 - Active Scan found PAN, but the Coordinator CH parameter does not match the CH parameter of the End Device 0x07 - Energy Scan Timeout 0x08 - Coordinator start request failed 0x09 - Coordinator could not start due to invalid parameter 0x0A - Coordinator Realignment is in progress 0x0B - Association Request not sent 0x0C - Association Request timed out - no reply was received 0x0D - Association Request had an Invalid Parameter 0x0E - Association Request Channel Access Failure. Request was not transmitted - CCA failure 0x0F - Remote Coordinator did not send an ACK after Association Request was sent 0x10 - Remote Coordinator did not reply to the Association Request, but an ACK was received after sending the request 0x11 - [reserved] 0x12 - Sync-Loss - Lost synchronization with a Beaconing Coordinator 0x13 - Disassociated - No longer associated to Coordinator 0xFF - RF Module is attempting to associate	0 - 0x13 [read-only]	-
DA (v1.x80*)	Networking {Association}	**Force Disassociation**. End Device will immediately disassociate from a Coordinator (if associated) and reattempt to associate.	-	-
FP (v1.x80*)	Networking {Association}	**Force Poll**. Request indirect messages being held by a coordinator.	-	-
AS (v1.x80*)	Networking {Association}	**Active Scan**. Send Beacon Request to Broadcast Address (0xFFFF) and Broadcast PAN (0xFFFF) on every channel. The parameter determines the time the radio will listen for Beacons on each channel. A PanDescriptor is created and returned for every Beacon received from the scan. Each PanDescriptor contains the following information: CoordAddress (SH, SL)<CR> CoordPanID (ID)<CR> CoordAddrMode <CR> 0x02 = 16-bit Short Address 0x03 = 64-bit Long Address Channel (CH parameter) <CR> SecurityUse<CR> ACLEntry<CR> SecurityFailure<CR> SuperFrameSpec<CR> (2 bytes): bit 15 - Association Permitted (MSB) bit 14 - PAN Coordinator bit 13 - Reserved bit 12 - Battery Life Extension bits 8-11 - Final CAP Slot bits 4-7 - Superframe Order bits 0-3 - Beacon Order GtsPermit<CR> RSSI<CR> (RSSI is returned as -dBm) TimeStamp<CR> (3 bytes) <CR> A carriage return <CR> is sent at the end of the AS command. The Active Scan is capable of returning up to 5 PanDescriptors in a scan. The actual scan time on each channel is measured as Time = [(2 ^SD PARAM) * 15.36] ms. Note the total scan time is this time multiplied by the number of channels to be scanned (16 for the XBee and 13 for the XBee-PRO). Also refer to SD command description.	0 - 6	-
ED (v1.x80*)	Networking {Association}	**Energy Scan**. Send an Energy Detect Scan. This parameter determines the length of scan on each channel. The maximal energy on each channel is returned & each value is followed by a carriage return. An additional carriage return is sent at the end of the command. The values returned represent the detected energy level in units of -dBm. The actual scan time on each channel is measured as Time = [(2 ^ED) * 15.36] ms. Note the total scan time is this time multiplied by the number of channels to be scanned (refer to SD parameter).	0 - 6	-
EE (v1.xA0*)	Networking {Security}	**AES Encryption Enable**. Disable/Enable 128-bit AES encryption support. Use in conjunction with the KY command.	0 - 1	0 (disabled)
KY (v1.xA0*)	Networking {Security}	**AES Encryption Key**. Set the 128-bit AES (Advanced Encryption Standard) key for encrypting/decrypting data. The KY register cannot be read.	0 - (any 16-Byte value)	-

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

RF Interfacing

Table 3-03. XBee/XBee-PRO Commands - RF Interfacing

AT Command	Command Category	Name and Description	Parameter Range	Default
PL	RF Interfacing	**Power Level**. Select/Read the power level at which the RF module transmits conducted power.	0 - 4 (XBee / XBee-PRO) 0 = -10 / 10 dBm 1 = -6 / 12 dBm 2 = -4 / 14 dBm 3 = -2 / 16 dBm 4 = 0 / 18 dBm XBee-PRO International variant: PL=4: 10 dBm PL=3: 8 dBm PL=2: 2 dBm PL=1: -3 dBm PL=0: -3 dBm	4
CA (v1.x80*)	RF Interfacing	**CCA Threshold**. Set/read the CCA (Clear Channel Assessment) threshold. Prior to transmitting a packet, a CCA is performed to detect energy on the channel. If the detected energy is above the CCA Threshold, the module will not transmit the packet.	0x24 - 0x50 [-dBm]	0x2C (-44d dBm)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Sleep (Low Power)

Table 3-04. XBee®/XBee-PRO® Commands - Sleep (Low Power)

AT Command	Command Category	Name and Description	Parameter Range	Default
SM	Sleep (Low Power)	**Sleep Mode**. Set/Read Sleep Mode configurations.	0 - 5 0 = No Sleep 1 = Pin Hibernate 2 = Pin Doze 3 = Reserved 4 = Cyclic sleep remote 5 = Cyclic sleep remote w/ pin wake-up 6 = [Sleep Coordinator] for backwards compatibility w/ v1.x6 only; otherwise, use CE command.	0
SO	Sleep (Low Power)	Sleep Options Set/Read the sleep mode options. Bit 0 - Poll wakeup disable 0 - Normal operations. A module configured for cyclic sleep will poll for data on waking. 1 - Disable wakeup poll. A module configured for cyclic sleep will not poll for data on waking. Bit 1 - ADC/DIO wakeup sampling disable. 0 - Normal operations. A module configured in a sleep mode with ADC/DIO sampling enabled will automatically perform a sampling on wakeup. 1 - Suppress sample on wakeup. A module configured in a sleep mode with ADC/DIO sampling enabled will not automatically sample on wakeup.	0-4	0
ST	Sleep (Low Power)	**Time before Sleep.** <NonBeacon firmware> Set/Read time period of inactivity (no serial or RF data is sent or received) before activating Sleep Mode. ST parameter is only valid with Cyclic Sleep settings (SM = 4 - 5). Coordinator and End Device ST values must be equal. Also note, the GT parameter value must always be less than the ST value. (If GT > ST, the configuration will render the module unable to enter into command mode.) If the ST parameter is modified, also modify the GT parameter accordingly.	1 - 0xFFFF [x 1 ms]	0x1388 (5000d)
SP	Sleep (Low Power)	**Cyclic Sleep Period.** <NonBeacon firmware> Set/Read sleep period for cyclic sleeping remotes. Coordinator and End Device SP values should always be equal. To send Direct Messages, set SP = 0. *End Device* - SP determines the sleep period for cyclic sleeping remotes. Maximum sleep period is 268 seconds (0x68B0). *Coordinator* - If non-zero, SP determines the time to hold an indirect message before discarding it. A Coordinator will discard indirect messages after a period of (2.5 * SP).	0 - 0x68B0 [x 10 ms]	0
DP (1.x80*)	Sleep (Low Power)	**Disassociated Cyclic Sleep Period.** <NonBeacon firmware> *End Device* - Set/Read time period of sleep for cyclic sleeping remotes that are configured for Association but are not associated to a Coordinator. (i.e. If a device is configured to associate, configured as a Cyclic Sleep remote, but does not find a Coordinator, it will sleep for DP time before reattempting association.) Maximum sleep period is 268 seconds (0x68B0). DP should be > 0 for NonBeacon systems.	1 - 0x68B0 [x 10 ms]	0x3E8 (1000d)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Serial Interfacing

Table 3‐05. XBee‐PRO Commands ‐ Serial Interfacing

AT Command	Command Category	Name and Description	Parameter Range	Default
BD	Serial Interfacing	**Interface Data Rate**. Set/Read the serial interface data rate for communications between the RF module serial port and host. Request non-standard baud rates with values above 0x80 using a terminal window. Read the BD register to find actual baud rate achieved.	0 - 7 (standard baud rates) 0 = 1200 bps 1 = 2400 2 = 4800 3 = 9600 4 = 19200 5 = 38400 6 = 57600 7 = 115200 0x80 - 0x3D090 (non-standard baud rates up to 250 Kbps)	3
RO	Serial Interfacing	**Packetization Timeout**. Set/Read number of character times of inter-character delay required before transmission. Set to zero to transmit characters as they arrive instead of buffering them into one RF packet.	0 - 0xFF [x character times]	3
AP (v1.x80*)	Serial Interfacing	**API Enable**. Disable/Enable API Mode.	0 - 2 0 =Disabled 1 = API enabled 2 = API enabled (w/escaped control characters)	0
NB	Serial Interfacing	**Parity.** Set/Read parity settings.	0 - 4 0 = 8-bit no parity 1 = 8-bit even 2 = 8-bit odd 3 = 8-bit mark 4 = 8-bit space	0
PR (v1.x80*)	Serial Interfacing	**Pull-up Resistor Enable**. Set/Read bitfield to configure internal pull-up resistor status for I/O lines Bitfield Map: bit 0 - AD4/DIO4 (pin11) bit 1 - AD3 / DIO3 (pin17) bit 2 - AD2/DIO2 (pin18) bit 3 - AD1/DIO1 (pin19) bit 4 - AD0 / DIO0 (pin20) bit 5 - RTS / AD6 / DIO6 (pin16) bit 6 - DTR / SLEEP_RQ / DI8 (pin9) bit 7 - DIN/CONFIG (pin3) Bit set to "1" specifies pull-up enabled; "0" specifies no pull-up	0 - 0xFF	0xFF

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

I/O Settings

Table 3‐06. XBee‐PRO Commands ‐ I/O Settings (sub‐category designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
D8	I/O Settings	**DI8 Configuration**. Select/Read options for the DI8 line (pin 9) of the RF module.	0 - 1 0 = Disabled 3 = DI (1,2,4 & 5 n/a)	0
D7 (v1.x80*)	I/O Settings	**DIO7 Configuration**. Select/Read settings for the DIO7 line (pin 12) of the RF module. Options include CTS flow control and I/O line settings.	0 - 1 0 = Disabled 1 = CTS Flow Control 2 = (n/a) 3 = DI 4 = DO low 5 = DO high 6 = RS485 Tx Enable Low 7 = RS485 Tx Enable High	1
D6 (v1.x80*)	I/O Settings	**DIO6 Configuration**. Select/Read settings for the DIO6 line (pin 16) of the RF module. Options include RTS flow control and I/O line settings.	0 - 1 0 = Disabled 1 = RTS flow control 2 = (n/a) 3 = DI 4 = DO low 5 = DO high	0

Table 3-06. **XBee-PRO Commands - I/O Settings** (sub-category designated within {brackets})

AT Command	Command Category	Name and Description	Parameter Range	Default
D5 (v1.x80*)	I/O Settings	**DIO5 Configuration**. Configure settings for the DIO5 line (pin 15) of the RF module. Options include Associated LED indicator (blinks when associated) and I/O line settings.	0 - 1 0 = Disabled 1 = Associated indicator 2 = ADC 3 = DI 4 = DO low 5 = DO high	1
D0 - D4 (v1.xA0*)	I/O Settings	**(DIO4 -DIO4) Configuration**. Select/Read settings for the following lines: AD0/DIO0 (pin 20), AD1/DIO1 (pin 19), AD2/DIO2 (pin 18), AD3/DIO3 (pin 17), AD4/DIO4 (pin 11). Options include: Analog-to-digital converter, Digital Input and Digital Output.	0 - 1 0 = Disabled 1 = (n/a) 2 = ADC 3 = DI 4 = DO low 5 = DO high	0
IU (v1.xA0*)	I/O Settings	**I/O Output Enable.** Disables/Enables I/O data received to be sent out UART. The data is sent using an API frame regardless of the current AP parameter value.	0 - 1 0 = Disabled 1 = Enabled	1
IT (v1.xA0*)	I/O Settings	**Samples before TX.** Set/Read the number of samples to collect before transmitting data. Maximum number of samples is dependent upon the number of enabled inputs.	1 - 0xFF	1
IS (v1.xA0*)	I/O Settings	**Force Sample.** Force a read of all enabled inputs (DI or ADC). Data is returned through the UART. If no inputs are defined (DI or ADC), this command will return error.	8-bit bitmap (each bit represents the level of an I/O line setup as an output)	-
IO (v1.xA0*)	I/O Settings	**Digital Output Level.** Set digital output level to allow DIO lines that are setup as outputs to be changed through Command Mode.	-	-
IC (v1.xA0*)	I/O Settings	**DIO Change Detect.** Set/Read bitfield values for change detect monitoring. Each bit enables monitoring of DIO0 - DIO7 for changes. If detected, data is transmitted with DIO data only. Any samples queued waiting for transmission will be sent first.	0 - 0xFF [bitfield]	0 (disabled)
IR (v1.xA0*)	I/O Settings	**Sample Rate.** Set/Read sample rate. When set, this parameter causes the module to sample all enabled inputs at a specified interval.	0 - 0xFFFF [x 1 msec]	0
IA (v1.xA0*)	I/O Settings {I/O Line Passing}	**I/O Input Address**. Set/Read addresses of module to which outputs are bound. Setting all bytes to 0xFF will not allow any received I/O packet to change outputs. Setting address to 0xFFFF will allow any received I/O packet to change outputs.	0 - 0xFFFFFFFFFFFFFFFF	0xFFFFFFFF FFFFFFFF
T0 - T7 (v1.xA0*)	I/O Settings {I/O Line Passing}	**(D0 - D7) Output Timeout.** Set/Read Output timeout values for lines that correspond with the D0 - D7 parameters. When output is set (due to I/O line passing) to a non-default level, a timer is started which when expired will set the output to it default level. The timer is reset when a valid I/O packet is received.	0 - 0xFF [x 100 ms]	0xFF
P0	I/O Settings {I/O Line Passing}	**PWM0 Configuration**. Select/Read function for PWM0 pin.	0 - 2 0 = Disabled 1 = RSSI 2 = PWM Output	1
P1 (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM1 Configuration**. Select/Read function for PWM1 pin.	0 - 2 0 = Disabled 1 = RSSI 2 = PWM Output	0
M0 (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM0 Output Level**. Set/Read the PWM0 output level.	0 - 0x03FF	-
M1 (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM1 Output Level**. Set/Read the PWM1 output level.	0 - 0x03FF	-
PT (v1.xA0*)	I/O Settings {I/O Line Passing}	**PWM Output Timeout.** Set/Read output timeout value for both PWM outputs. When PWM is set to a non-zero value: Due to I/O line passing, a time is started which when expired will set the PWM output to zero. The timer is reset when a valid I/O packet is received.]	0 - 0xFF [x 100 ms]	0xFF
RP	I/O Settings {I/O Line Passing}	**RSSI PWM Timer.** Set/Read PWM timer register. Set the duration of PWM (pulse width modulation) signal output on the RSSI pin. The signal duty cycle is updated with each received packet and is shut off when the timer expires.]	0 - 0xFF [x 100 ms]	0x28 (40d)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Diagnostics

Table 3-07. **XBee®/XBee-PRO® Commands - Diagnostics**

AT Command	Command Category	Name and Description	Parameter Range	Default
VR	Diagnostics	**Firmware Version**. Read firmware version of the RF module.	0 - 0xFFFF [read-only]	Factory-set
VL (v1.x80*)	Diagnostics	**Firmware Version - Verbose**. Read detailed version information (including application build date, MAC, PHY and bootloader versions). The VL command has been deprecated in version 10C9. It is not supported in firmware versions after 10C8	-	-

Table 3-07. XBee®/XBee-PRO® Commands - Diagnostics

AT Command	Command Category	Name and Description	Parameter Range	Default
HV (v1.x80*)	Diagnostics	**Hardware Version**. Read hardware version of the RF module.	0 - 0xFFFF [read-only]	Factory-set
DB	Diagnostics	**Received Signal Strength**. Read signal level [in dB] of last good packet received (RSSI). Absolute value is reported. (For example: 0x58 = -88 dBm) Reported value is accurate between -40 dBm and RX sensitivity.	0x17-0x5C (XBee) 0x24-0x64 (XBee-PRO) [read-only]	-
EC (v1.x80*)	Diagnostics	**CCA Failures.** Reset/Read count of CCA (Clear Channel Assessment) failures. This parameter value increments when the module does not transmit a packet because it detected energy above the CCA threshold level set with CA command. This count saturates at its maximum value. Set count to “0” to reset count.	0 - 0xFFFF	-
EA (v1.x80*)	Diagnostics	**ACK Failures**. Reset/Read count of acknowledgment failures. This parameter value increments when the module expires its transmission retries without receiving an ACK on a packet transmission. This count saturates at its maximum value. Set the parameter to “0” to reset count.	0 - 0xFFFF	-
ED (v1.x80*)	Diagnostics	**Energy Scan**. Send ‘Energy Detect Scan’. ED parameter determines the length of scan on each channel. The maximal energy on each channel is returned and each value is followed by a carriage return. Values returned represent detected energy levels in units of -dBm. Actual scan time on each channel is measured as Time = [(2 ^ SD) * 15.36] ms. Total scan time is this time multiplied by the number of channels to be scanned.	0 - 6	-

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

AT Command Options

Table 3-08. XBee®/XBee-PRO® Commands - AT Command Options

AT Command	Command Category	Name and Description	Parameter Range	Default
CT	AT Command Mode Options	**Command Mode Timeout.** Set/Read the period of inactivity (no valid commands received) after which the RF module automatically exits AT Command Mode and returns to Idle Mode.	2 - 0xFFFF [x 100 ms]	0x64 (100d)
CN	AT Command Mode Options	**Exit Command Mode**. Explicitly exit the module from AT Command Mode.	--	--
AC (v1.xA0*)	AT Command Mode Options	**Apply Changes**. Explicitly apply changes to queued parameter value(s) and re-initialize module.	--	--
GT	AT Command Mode Options	**Guard Times**. Set required period of silence before and after the Command Sequence Characters of the AT Command Mode Sequence (GT+ CC + GT). The period of silence is used to prevent inadvertent entrance into AT Command Mode.	2 - 0x0CE4 [x 1 ms]	0x3E8 (1000d)
CC	AT Command Mode Options	**Command Sequence Character**. Set/Read the ASCII character value to be used between Guard Times of the AT Command Mode Sequence (GT+CC+GT). The AT Command Mode Sequence enters the RF module into AT Command Mode.	0 - 0xFF	0x2B ('+' ASCII)

* Firmware version in which the command was first introduced (firmware versions are numbered in hexadecimal notation.)

Command Descriptions

Command descriptions in this section are listed alphabetically. Command categories are designated within "< >" symbols that follow each command title. XBee®/XBee-PRO® RF Modules expect parameter values in hexadecimal (designated by the "0x" prefix).

All modules operating within the same network should contain the same firmware version.

A1 (End Device Association) Command

<Networking {Association}> The A1 command is used to set and read association options for an End Device.

Use the table below to determine End Device behavior in relation to the A1 parameter.

AT Command: ATA1

Parameter Range: 0 – 0x0F [bitfield]

Default Parameter Value: 0

Related Commands: ID (PAN ID), NI (Node Identifier), CH (Channel), CE (Coordinator Enable), A2 (Coordinator Association)

Minimum Firmware Version Required: v1.x80

Bit number	End Device Association Option
0 - ReassignPanID	0 - Will only associate with Coordinator operating on PAN ID that matches Node Identifier
	1 - May associate with Coordinator operating on any PAN ID
1 - ReassignChannel	0 - Will only associate with Coordinator operating on Channel that matches CH setting
	1 - May associate with Coordinator operating on any Channel
2 - AutoAssociate	0 - Device will not attempt Association
	1 - Device attempts Association until success Note: This bit is used only for Non-Beacon systems. End Devices in a Beaconing system must always associate to a Coordinator
3 - PollCoordOnPinWake	0 - Pin Wake will not poll the Coordinator for pending (indirect) Data
	1 - Pin Wake will send Poll Request to Coordinator to extract any pending data
4 - 7	[reserved]

A2 (Coordinator Association) Command

<Networking {Association}> The A2 command is used to set and read association options of the Coordinator.

Use the table below to determine Coordinator behavior in relation to the A2 parameter.

AT Command: ATA2

Parameter Range: 0 – 7 [bitfield]

Default Parameter Value: 0

Related Commands: ID (PAN ID), NI (Node Identifier), CH (Channel), CE (Coordinator Enable), A1 (End Device Association), AS Active Scan), ED (Energy Scan)

Minimum Firmware Version Required: v1.x80

Bit number	End Device Association Option
0 - ReassignPanID	0 - Coordinator will not perform Active Scan to locate available PAN ID. It will operate on ID (PAN ID).
	1 - Coordinator will perform Active Scan to determine an available ID (PAN ID). If a PAN ID conflict is found, the ID parameter will change.
1 - ReassignChannel	0 - Coordinator will not perform Energy Scan to determine free channel. It will operate on the channel determined by the CH parameter.
	1 - Coordinator will perform Energy Scan to find a free channel, then operate on that channel.
2 - AllowAssociate	0 - Coordinator will not allow any devices to associate to it.
	1 - Coordinator will allow devices to associate to it.
3 - 7	[reserved]

The binary equivalent of the default value (0x06) is 00000110. ‘Bit 0’ is the last digit of the sequence.

AC (Apply Changes) Command

AT Command: ATAC
Minimum Firmware Version Required: v1.xA0

<AT Command Mode Options> The AC command is used to explicitly apply changes to module parameter values. 'Applying changes' means that the module is re-initialized based on changes made to its parameter values. Once changes are applied, the module immediately operates according to the new parameter values.

This behavior is in contrast to issuing the WR (Write) command. The WR command saves parameter values to non-volatile memory, but the module still operates according to previously saved values until the module is re-booted or the CN (Exit AT Command Mode) command is issued.

Refer to the "AT Command - Queue Parameter Value" API type for more information.

AI (Association Indication) Command

AT Command: ATAI
Parameter Range: 0 - 0x13 [read-only]
Related Commands: AS (Active Scan), ID (PAN ID), CH (Channel), ED (Energy Scan), A1 (End Device Association), A2 (Coordinator Association), CE (Coordinator Enable)
Minimum Firmware Version Required: v1.x80

<Networking {Association}> The AI command is used to indicate occurrences of errors during the last association request.

Use the table below to determine meaning of the returned values.

Returned Value (Hex)	Association Indication
0x00	Successful Completion - Coordinator successfully started or End Device association complete
0x01	Active Scan Timeout
0x02	Active Scan found no PANs
0x03	Active Scan found PAN, but the Coordinator Allow Association bit is not set
0x04	Active Scan found PAN, but Coordinator and End Device are not configured to support beacons
0x05	Active Scan found PAN, but Coordinator ID (PAN ID) value does not match the ID of the End Device
0x06	Active Scan found PAN, but Coordinator CH (Channel) value does not match the CH of the End Device
0x07	Energy Scan Timeout
0x08	Coordinator start request failed
0x09	Coordinator could not start due to Invalid Parameter
0x0A	Coordinator Realignment is in progress
0x0B	Association Request not sent
0x0C	Association Request timed out - no reply was received
0x0D	Association Request had an Invalid Parameter
0x0E	Association Request Channel Access Failure - Request was not transmitted - CCA failure
0x0F	Remote Coordinator did not send an ACK after Association Request was sent
0x10	Remote Coordinator did not reply to the Association Request, but an ACK was received after sending the request
0x11	[reserved]
0x12	Sync-Loss - Lost synchronization with a Beaconing Coordinator
0x13	Disassociated - No longer associated to Coordinator
0xFF	RF Module is attempting to associate

AP (API Enable) Command

<Serial Interfacing> The AP command is used to enable the RF module to operate using a frame-based API instead of using the default Transparent (UART) mode.

AT Command: ATAP

Parameter Range:0 – 2

Parameter	Configuration
0	Disabled (Transparent operation)
1	API enabled
2	API enabled (with escaped characters)

Default Parameter Value:0

Minimum Firmware Version Required: v1.x80

Refer to the API Operation section when API operation is enabled (AP = 1 or 2).

AS (Active Scan) Command

<Network {Association}> The AS command is used to send a Beacon Request to a Broadcast (0xFFFF) and Broadcast PAN (0xFFFF) on every channel. The parameter determines the amount of time the RF module will listen for Beacons on each channel. A ‘PanDescriptor’ is created and returned for every Beacon received from the scan. Each PanDescriptor contains the following information:

AT Command: ATAS

Parameter Range: 0 – 6

Related Command: SD (Scan Duration), DL (Destination Low Address), DH (Destination High Address), ID (PAN ID), CH (Channel)

Minimum Firmware Version Required: v1.x80

CoordAddress (SH + SL parameters)<CR> (NOTE: If MY on the coordinator is set less than 0xFFFF, the MY value is displayed)
CoordPanID (ID parameter)<CR>
CoordAddrMode <CR>
  0x02 = 16-bit Short Address
  0x03 = 64-bit Long Address
Channel (CH parameter) <CR>
SecurityUse<CR>
ACLEntry<CR>
SecurityFailure<CR>
SuperFrameSpec<CR> (2 bytes):
  bit 15 - Association Permitted (MSB)
  bit 14 - PAN Coordinator
  bit 13 - Reserved
  bit 12 - Battery Life Extension
  bits 8-11 - Final CAP Slot
  bits 4-7 - Superframe Order
  bits 0-3 - Beacon Order
GtsPermit<CR>
RSSI<CR> (- RSSI is returned as -dBm)
TimeStamp<CR> (3 bytes)
<CR> (A carriage return <CR> is sent at the end of the AS command.

The Active Scan is capable of returning up to 5 PanDescriptors in a scan. The actual scan time on each channel is measured as Time = [(2 ^ (SD Parameter)) * 15.36] ms. Total scan time is this time multiplied by the number of channels to be scanned (16 for the XBee, 12 for the XBee-PRO).

NOTE: Refer the scan table in the SD description to determine scan times. If using API Mode, no <CR>'s are returned in the response. Refer to the API Mode Operation section.

BD (Interface Data Rate) Command

<Serial Interfacing> The BD command is used to set and read the serial interface data rate used between the RF module and host. This parameter determines the rate at which serial data is sent to the module from the host. Modified interface data rates do not take effect until the CN (Exit AT Command Mode) command is issued and the system returns the 'OK' response.

When parameters 0-7 are sent to the module, the respective interface data rates are used (as shown in the table on the right).

The RF data rate is not affected by the BD parameter. If the interface data rate is set higher than the RF data rate, a flow control configuration may need to be implemented.

AT Command: ATBD

Parameter Range:0 – 7 (standard rates)
0x80-0x3D090 (non-standard rates up to 250 Kbps)

Parameter	Configuration (bps)
0	1200
1	2400
2	4800
3	9600
4	19200
5	38400
6	57600
7	115200

Default Parameter Value:3

Non-standard Interface Data Rates:
Any value above 0x07 will be interpreted as an actual baud rate. When a value above 0x07 is sent, the closest interface data rate represented by the number is stored in the BD register. For example, a rate of 19200 bps can be set by sending the following command line "ATBD4B00". NOTE: When using Digi's X-CTU Software, non-standard interface data rates can only be set and read using the X-CTU 'Terminal' tab. Non-standard rates are not accessible through the 'Modem Configuration' tab.

When the BD command is sent with a non-standard interface data rate, the UART will adjust to accommodate the requested interface rate. In most cases, the clock resolution will cause the stored BD parameter to vary from the parameter that was sent (refer to the table below). Reading the BD command (send "ATBD" command without an associated parameter value) will return the value actually stored in the module's BD register.

Parameters Sent Versus Parameters Stored

BD Parameter Sent (HEX)	Interface Data Rate (bps)	BD Parameter Stored (HEX)
0	1200	0
4	19,200	4
7	115,200*	7
12C	300	12B
1C200	115,200	1B207

* The 115,200 baud rate setting is actually at 111,111 baud (-3.5% target UART speed).

CA (CCA Threshold) Command

<RF Interfacing> CA command is used to set and read CCA (Clear Channel Assessment) thresholds.

Prior to transmitting a packet, a CCA is performed to detect energy on the transmit channel. If the detected energy is above the CCA Threshold, the RF module will not transmit the packet.

AT Command: ATCA

Parameter Range: 0 – 0x50 [-dBm]

Default Parameter Value: 0x2C
(-44 decimal dBm)

Minimum Firmware Version Required: v1.x80

CC (Command Sequence Character) Command

<AT Command Mode Options> The CC command is used to set and read the ASCII character used between guard times of the AT Command Mode Sequence (GT + CC + GT). This sequence enters the RF module into AT Command Mode so that data entering the module from the host is recognized as commands instead of payload.

AT Command: ATCC
Parameter Range: 0 – 0xFF
Default Parameter Value: 0x2B (ASCII "+")
Related Command: GT (Guard Times)

The AT Command Sequence is explained further in the AT Command Mode section.

CE (Coordinator Enable) Command

<Networking {Association} The CE command is used to set and read the behavior (End Device vs. Coordinator) of the RF module.

AT Command: ATCE

Parameter Range:0 – 1

Parameter	Configuration
0	End Device
1	Coordinator

Default Parameter Value:0

Minimum Firmware Version Required: v1.x80

CH (Channel) Command

<Networking {Addressing}> The CH command is used to set/read the operating channel on which RF connections are made between RF modules. The channel is one of three addressing options available to the module. The other options are the PAN ID (ID command) and destination addresses (DL & DH commands).

AT Command: ATCH
Parameter Range: 0x0B – 0x1A (XBee) 0x0C – 0x17 (XBee-PRO)
Default Parameter Value: 0x0C (12 decimal)
Related Commands: ID (PAN ID), DL (Destination Address Low, DH (Destination Address High)

In order for modules to communicate with each other, the modules must share the same channel number. Different channels can be used to prevent modules in one network from listening to transmissions of another. Adjacent channel rejection is 23 dB.

The module uses channel numbers of the 802.15.4 standard.

Center Frequency = 2.405 + (CH - 11d) * 5 MHz (d = decimal)

Refer to the XBee/XBee-PRO Addressing section for more information.

CN (Exit Command Mode) Command

<AT Command Mode Options> The CN command is used to explicitly exit the RF module from AT Command Mode.

AT Command: ATCN

CT (Command Mode Timeout) Command

<AT Command Mode Options> The CT command is used to set and read the amount of inactive time that elapses before the RF module automatically exits from AT Command Mode and returns to Idle Mode.

Use the CN (Exit Command Mode) command to exit AT Command Mode manually.

AT Command: ATCT
Parameter Range:2 – 0xFFFF [x 100 milliseconds]
Default Parameter Value: 0x64 (100 decimal (which equals 10 decimal seconds))
Number of bytes returned: 2
Related Command: CN (Exit Command Mode)

D0 - D4 (DIOn Configuration) Commands

<I/O Settings> The D0, D1, D2, D3 and D4 commands are used to select/read the behavior of their respective AD/DIO lines (pins 20, 19, 18, 17 and 11 respectively).

Options include:

- Analog-to-digital converter
- Digital input
- Digital output

AT Commands:
ATD0, ATD1, ATD2, ATD3, ATD4

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	n/a
2	ADC
3	DI
4	DO low
5	DO high

Default Parameter Value:0

Minimum Firmware Version Required: 1.x.A0

D5 (DIO5 Configuration) Command

<I/O Settings> The D5 command is used to select/read the behavior of the DIO5 line (pin 15).

Options include:

- Associated Indicator (LED blinks when the module is associated)
- Analog-to-digital converter
- Digital input
- Digital output

AT Command: ATD5

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	Associated Indicator
2	ADC
3	DI
4	DO low
5	DO high

Default Parameter Value:1

Parameters 2–5 supported as of firmware version 1.xA0

D6 (DIO6 Configuration) Command

<I/O Settings> The D6 command is used to select/read the behavior of the DIO6 line (pin 16). Options include:

- RTS flow control
- Analog-to-digital converter
- Digital input
- Digital output

AT Command: ATD6

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	RTS Flow Control
2	n/a
3	DI
4	DO low
5	DO high

Default Parameter Value:0

Parameters 3–5 supported as of firmware version 1.xA0

D7 (DIO7 Configuration) Command

<I/O Settings> The D7 command is used to select/read the behavior of the DIO7 line (pin 12). Options include:

- CTS flow control
- Analog-to-digital converter
- Digital input
- Digital output
- RS485 TX Enable (this output is 3V CMOS level, and is useful in a 3V CMOS to RS485 conversion circuit)

AT Command: ATD7

Parameter Range:0 – 5

Parameter	Configuration
0	Disabled
1	CTS Flow Control
2	n/a
3	DI
4	DO low
5	DO high
6	RS485 TX Enable Low
7	RS485 TX Enable High

Default Parameter Value:1

Parameters 3-7 supported as of firmware version 1.x.A0

D8 (DI8 Configuration) Command

<I/O Settings> The D8 command is used to select/read the behavior of the DI8 line (pin 9). This command enables configuring the pin to function as a digital input. This line is also used with Pin Sleep.

AT Command: ATD8

Parameter Range:0 – 5
(1, 2, 4 & 5 n/a)

Parameter	Configuration
0	Disabled
3	DI

Default Parameter Value:0

Minimum Firmware Version Required: 1.xA0

DA (Force Disassociation) Command

<(Special)> The DA command is used to immediately disassociate an End Device from a Coordinator and reattempt to associate.

AT Command: ATDA

Minimum Firmware Version Required: v1.x80

DB (Received Signal Strength) Command

<Diagnostics> DB parameter is used to read the received signal strength (in dBm) of the last RF packet received. Reported values are accurate between -40 dBm and the RF module's receiver sensitivity.

AT Command: ATDB

Parameter Range [read-only]:
0x17-0x5C (XBee), 0x24-0x64 (XBee-PRO)

Absolute values are reported. For example: 0x58 = -88 dBm (decimal). If no packets have been received (since last reset, power cycle or sleep event), "0" will be reported.

DH (Destination Address High) Command

<Networking {Addressing}> The DH command is used to set and read the upper 32 bits of the RF module's 64-bit destination address. When combined with the DL (Destination Address Low) parameter, it defines the destination address used for transmission.

An module will only communicate with other modules having the same channel (CH parameter), PAN ID (ID parameter) and destination address (DH + DL parameters).

AT Command: ATDH

Parameter Range: 0 – 0xFFFFFFFF

Default Parameter Value: 0

Related Commands: DL (Destination Address Low), CH (Channel), ID (PAN VID), MY (Source Address)

To transmit using a 16-bit address, set the DH parameter to zero and the DL parameter less than 0xFFFF. 0x000000000000FFFF (DL concatenated to DH) is the broadcast address for the PAN.

Refer to the XBee/XBee-PRO Addressing section for more information.

DL (Destination Address Low) Command

<Networking {Addressing}> The DL command is used to set and read the lower 32 bits of the RF module's 64-bit destination address. When combined with the DH (Destination Address High) parameter, it defines the destination address used for transmission.

AT Command: ATDL
Parameter Range: 0 - 0xFFFFFFFF
Default Parameter Value: 0
Related Commands: DH (Destination Address High), CH (Channel), ID (PAN VID), MY (Source Address)

A module will only communicate with other modules having the same channel (CH parameter), PAN ID (ID parameter) and destination address (DH + DL parameters).

To transmit using a 16-bit address, set the DH parameter to zero and the DL parameter less than 0xFFFF. 0x000000000000FFFF (DL concatenated to DH) is the broadcast address for the PAN.

Refer to the XBee/XBee-PRO Addressing section for more information.

DN (Destination Node) Command

<Networking {Identification}> The DN command is used to resolve a NI (Node Identifier) string to a physical address. The following events occur upon successful command execution:

AT Command: ATDN
Parameter Range: 20-character ASCII String
Minimum Firmware Version Required: v1.x80

1. DL and DH are set to the address of the module with the matching NI (Node Identifier).
2. 'OK' is returned.
3. RF module automatically exits AT Command Mode.

If there is no response from a modem within 200 msec or a parameter is not specified (left blank), the command is terminated and an 'ERROR' message is returned.

DP (Disassociation Cyclic Sleep Period) Command

<Sleep Mode (Low Power)>

AT Command: ATDP
Parameter Range: 1 – 0x68B0 [x 10 milliseconds]
Default Parameter Value:0x3E8 (1000 decimal)
Related Commands: SM (Sleep Mode), SP (Cyclic Sleep Period), ST (Time before Sleep)
Minimum Firmware Version Required: v1.x80

NonBeacon Firmware

End Device - The DP command is used to set and read the time period of sleep for cyclic sleeping remotes that are configured for Association but are not associated to a Coordinator. (i.e. If a device is configured to associate, configured as a Cyclic Sleep remote, but does not find a Coordinator; it will sleep for DP time before reattempting association.) Maximum sleep period is 268 seconds (0x68B0). DP should be > 0 for NonBeacon systems.

EA (ACK Failures) Command

<Diagnostics> The EA command is used to reset and read the count of ACK (acknowledgement) failures. This parameter value increments when the module expires its transmission retries without receiving an ACK on a packet transmission. This count saturates at its maximum value.

AT Command: ATEA
Parameter Range:0 – 0xFFFF
Minimum Firmware Version Required: v1.x80

Set the parameter to "0" to reset count.

EC (CCA Failures) Command

<Diagnostics> The EC command is used to read and reset the count of CCA (Clear Channel Assessment) failures. This parameter value increments when the RF module does not transmit a packet due to the detection of energy that is above the CCA threshold level (set with CA command). This count saturates at its maximum value.

Set the EC parameter to "0" to reset count.

AT Command: ATEC
Parameter Range:0 – 0xFFFF
Related Command: CA (CCA Threshold)
Minimum Firmware Version Required: v1.x80

ED (Energy Scan) Command

<Networking {Association}> The ED command is used to send an "Energy Detect Scan". This parameter determines the length of scan on each channel. The maximal energy on each channel is returned and each value is followed by a carriage return. An additional carriage return is sent at the end of the command.

AT Command: ATED
Parameter Range:0 – 6
Related Command: SD (Scan Duration), SC (Scan Channel)
Minimum Firmware Version Required: v1.x80

The values returned represent the detected energy level in units of -dBm. The actual scan time on each channel is measured as Time = [(2 ^ ED PARAM) * 15.36] ms.

Note: Total scan time is this time multiplied by the number of channels to be scanned. Also refer to the SD (Scan Duration) table. Use the SC (Scan Channel) command to choose which channels to scan.

EE (AES Encryption Enable) Command

<Networking {Security}> The EE command is used to set/read the parameter that disables/enables 128-bit AES encryption.

The XBee®/XBee-PRO® firmware uses the 802.15.4 Default Security protocol and uses AES encryption with a 128-bit key. AES encryption dictates that all modules in the network use the same key and the maximum RF packet size is 95 Bytes.

AT Command: ATEE	
Parameter Range:0 – 1	
Parameter	**Configuration**
0	Disabled
1	Enabled
Default Parameter Value:0	
Related Commands: KY (Encryption Key), AP (API Enable), MM (MAC Mode)	
Minimum Firmware Version Required: v1.xA0	

When encryption is enabled, the module will always use its 64-bit long address as the source address for RF packets. This does not affect how the MY (Source Address), DH (Destination Address High) and DL (Destination Address Low) parameters work

If MM (MAC Mode) > 0 and AP (API Enable) parameter > 0:
With encryption enabled and a 16-bit short address set, receiving modules will only be able to issue RX (Receive) 64-bit indicators. This is not an issue when MM = 0.

If a module with a non-matching key detects RF data, but has an incorrect key: When encryption is enabled, non-encrypted RF packets received will be rejected and will not be sent out the UART.

Transparent Operation --> All RF packets are sent encrypted if the key is set.

API Operation --> Receive frames use an option bit to indicate that the packet was encrypted.

FP (Force Poll) Command

<Networking (Association)> The FP command is used to request indirect messages being held by a Coordinator.

AT Command: ATFP
Minimum Firmware Version Required: v1.x80

FR (Software Reset) Command

<Special> The FR command is used to force a software reset on the RF module. The reset simulates powering off and then on again the module.

AT Command: ATFR
Minimum Firmware Version Required: v1.x80

GT (Guard Times) Command

<AT Command Mode Options> GT Command is used to set the DI (data in from host) time-of-silence that surrounds the AT command sequence character (CC Command) of the AT Command Mode sequence (GT + CC + GT).

The DI time-of-silence is used to prevent inadvertent entrance into AT Command Mode.

Refer to the Command Mode section for more information regarding the AT Command Mode Sequence.

AT Command: ATGT
Parameter Range:2 – 0x0CE4 [x 1 millisecond]
Default Parameter Value:0x3E8 (1000 decimal)
Related Command: CC (Command Sequence Character)

HV (Hardware Version) Command

<Diagnostics> The HV command is used to read the hardware version of the RF module.

AT Command: ATHV
Parameter Range:0 – 0xFFFF [Read-only]
Minimum Firmware Version Required: v1.x80

IA (I/O Input Address) Command

<I/O Settings {I/O Line Passing}> The IA command is used to bind a module output to a specific address. Outputs will only change if received from this address. The IA command can be used to set/read both 16 and 64-bit addresses.

Setting all bytes to 0xFF will not allow the reception of any I/O packet to change outputs. Setting the IA address to 0xFFFF will cause the module to accept all I/O packets.

AT Command: ATIA
Parameter Range:0 – 0xFFFFFFFFFFFFFFFF
Default Parameter Value:0xFFFFFFFFFFFFFFFF (will not allow any received I/O packet to change outputs)
Minimum Firmware Version Required: v1.xA0

IC (DIO Change Detect) Command

<I/O Settings> Set/Read bitfield values for change detect monitoring. Each bit enables monitoring of DIO0 - DIO7 for changes.

If detected, data is transmitted with DIO data only. Any samples queued waiting for transmission will be sent first.

AT Command: ATIC
Parameter Range:0 – 0xFF [bitfield]
Default Parameter Value:0 (disabled)
Minimum Firmware Version Required: 1.xA0

Refer to the “ADC and Digital I/O Line Support” sections of the “RF Module Operations” chapter for more information.

ID (Pan ID) Command

<Networking {Addressing}> The ID command is used to set and read the PAN (Personal Area Network) ID of the RF module. Only modules with matching PAN IDs can communicate with each other. Unique PAN IDs enable control of which RF packets are received by a module.

AT Command: ATID
Parameter Range: 0 – 0xFFFF
Default Parameter Value:0x3332 (13106 decimal)

Setting the ID parameter to 0xFFFF indicates a global transmission for all PANs. It does not indicate a global receive.

IO (Digital Output Level) Command

<I/O Settings> The IO command is used to set digital output levels. This allows DIO lines setup as outputs to be changed through Command Mode.

AT Command: ATIO
Parameter Range: 8-bit bitmap (where each bit represents the level of an I/O line that is setup as an output.)
Minimum Firmware Version Required: v1.xA0

IR (Sample Rate) Command

<I/O Settings> The IR command is used to set/ read the sample rate. When set, the module will sample all enabled DIO/ADC lines at a specified interval. This command allows periodic reads of the ADC and DIO lines in a non-Sleep Mode setup. A sample rate which requires transmissions at a rate greater than once every 20ms is not recommended.

AT Command: ATIR
Parameter Range: 0 - 0xFFFF [x 1 msec] (cannot guarantee 1 ms timing when IT=1)
Default Parameter Value:0
Related Command: IT (Samples before TX)
Minimum Firmware Version Required: v1.xA0

Example: When IR = 0x14, the sample rate is 20 ms (or 50 Hz).

IS (Force Sample) Command

<I/O Settings> The IS command is used to force a read of all enabled DIO/ADC lines. The data is returned through the UART.

When operating in Transparent Mode (AP=0), the data is retuned in the following format:

AT Command: ATIS
Parameter Range: 1 - 0xFF
Default Parameter Value:1
Minimum Firmware Version Required: v1.xA0

All bytes are converted to ASCII:
number of samples<CR>
channel mask<CR>
DIO data<CR> (If DIO lines are enabled<CR>
ADC channel Data<cr> <-This will repeat for every enabled ADC channel<CR>
<CR> (end of data noted by extra <CR>)

When operating in API mode (AP > 0), the command will immediately return an 'OK' response. The data will follow in the normal API format for DIO data.

IT (Samples before TX) Command

<I/O Settings> The IT command is used to set/ read the number of DIO and ADC samples to collect before transmitting data.

One ADC sample is considered complete when all enabled ADC channels have been read. The module can buffer up to 93 Bytes of sample data.

AT Command: ATIT
Parameter Range: 1 - 0xFF
Default Parameter Value:1
Minimum Firmware Version Required: v1.xA0

Since the module uses a 10-bit A/D converter, each sample uses two Bytes. This leads to a maximum buffer size of 46 samples or IT=0x2E.

When Sleep Modes are enabled and IR (Sample Rate) is set, the module will remain awake until IT samples have been collected.

IU (I/O Output Enable) Command

<I/O Settings> The IU command is used to disable/enable I/O UART output. When enabled (IU = 1), received I/O line data packets are sent out the UART. The data is sent using an API frame regardless of the current AP parameter value.

AT Command: ATIU	
Parameter Range:0 – 1	
Parameter	Configuration
0	Disabled – Received I/O line data packets will be NOT sent out UART.
1	Enabled – Received I/O line data will be sent out UART
Default Parameter Value:1	
Minimum Firmware Version Required: 1.xA0	

KY (AES Encryption Key) Command

AT Command: ATKY
Parameter Range:0 – (any 16-Byte value)
Default Parameter Value:0
Related Command: EE (Encryption Enable)
Minimum Firmware Version Required: v1.xA0

<Networking {Security}> The KY command is used to set the 128-bit AES (Advanced Encryption Standard) key for encrypting/decrypting data. Once set, the key cannot be read out of the module by any means.

The entire payload of the packet is encrypted using the key and the CRC is computed across the ciphertext. When encryption is enabled, each packet carries an additional 16 Bytes to convey the random CBC Initialization Vector (IV) to the receiver(s). The KY value may be "0" or any 128-bit value. Any other value, including entering KY by itself with no parameters, is invalid. All ATKY entries (valid or not) are received with a returned 'OK'.

A module with the wrong key (or no key) will receive encrypted data, but the data driven out the serial port will be meaningless. A module with a key and encryption enabled will receive data sent from a module without a key and the correct unencrypted data output will be sent out the serial port. Because CBC mode is utilized, repetitive data appears differently in different transmissions due to the randomly-generated IV.

When queried, the system will return an 'OK' message and the value of the key will not be returned.

M0 (PWM0 Output Level) Command

<I/O Settings> The M0 command is used to set/read the output level of the PWM0 line (pin 6).

Before setting the line as an output:
1. Enable PWM0 output (P0 = 2)
2. Apply settings (use CN or AC)

The PWM period is 64 µsec and there are 0x03FF (1023 decimal) steps within this period. When M0 = 0 (0% PWM), 0x01FF (50% PWM), 0x03FF (100% PWM), etc.

AT Command: ATM0
Parameter Range:0 – 0x03FF [steps]
Default Parameter Value:0
Related Commands: P0 (PWM0 Enable), AC (Apply Changes), CN (Exit Command Mode)
Minimum Firmware Version Required: v1.xA0

M1 (PWM1 Output Level) Command

<I/O Settings> The M1 command is used to set/read the output level of the PWM1 line (pin 7).

Before setting the line as an output:
1. Enable PWM1 output (P1 = 2)
2. Apply settings (use CN or AC)

AT Command: ATM1
Parameter Range:0 – 0x03FF
Default Parameter Value:0
Related Commands: P1 (PWM1 Enable), AC (Apply Changes), CN (Exit Command Mode)
Minimum Firmware Version Required: v1.xA0

MM (MAC Mode) Command

<Networking {Addressing}> The MM command is used to set and read the MAC Mode value. The MM command disables/enables the use of a Digi header contained in the 802.15.4 RF packet. By default (MM = 0), Digi Mode is enabled and the module adds an extra header to the data portion of the 802.15.4 packet. This enables the following features:

- ND and DN command support
- Duplicate packet detection when using ACKs
- "RR command
- "DIO/AIO sampling support

The MM command allows users to turn off the use of the extra header. Modes 1 and 2 are strict 802.15.4 modes. If the Digi header is disabled, ND and DN parameters are also disabled.

Note: When MM=0 or 3, application and CCA failure retries are not supported.

AT Command: ATMM

Parameter Range:0 – 3

Parameter	Configuration
0	Digi Mode (802.15.4 + Digi header)
1	802.15.4 (no ACKs)
2	802.15.4 (with ACKs)
3	Digi Mode (no ACKs)

Default Parameter Value:0

Related Commands: ND (Node Discover), DN (Destination Node)

Minimum Firmware Version Required: v1.x80

MY (16-bit Source Address) Command

<Networking {Addressing}> The MY command is used to set and read the 16-bit source address of the RF module.

By setting MY to 0xFFFF, the reception of RF packets having a 16-bit address is disabled. The 64-bit address is the module's serial number and is always enabled.

AT Command: ATMY

Parameter Range: 0 – 0xFFFF

Default Parameter Value: 0

Related Commands: DH (Destination Address High), DL (Destination Address Low), CH (Channel), ID (PAN ID)

NB (Parity) Command

<Serial Interfacing> The NB command is used to select/read the parity settings of the RF module for UART communications.

Note: the module does not actually calculate and check the parity; it only interfaces with devices at the configured parity and stop bit settings.

AT Command: ATNB

Parameter Range: 0 – 4

Parameter	Configuration
0	8-bit no parity
1	8-bit even
2	8-bit odd
3	8-bit mark
4	8-bit space

Default Parameter Value: 0

Number of bytes returned: 1

ND (Node Discover) Command

<Networking {Identification}> The ND command is used to discover and report all modules on its current operating channel (CH parameter) and PAN ID (ID parameter). ND also accepts an NI (Node Identifier) value as a parameter. In this case, only a module matching the supplied identifier will respond.

AT Command: ATND
Range: optional 20-character NI value
Related Commands: CH (Channel), ID (Pan ID), MY (Source Address), SH (Serial Number High), SL (Serial Number Low), NI (Node Identifier), NT (Node Discover Time)
Minimum Firmware Version Required: v1.x80

ND uses a 64-bit long address when sending and responding to an ND request. The ND command causes a module to transmit a globally addressed ND command packet. The amount of time allowed for responses is determined by the NT (Node Discover Time) parameter.

In AT Command mode, command completion is designated by a carriage return (0x0D). Since two carriage returns end a command response, the application will receive three carriage returns at the end of the command. If no responses are received, the application should only receive one carriage return. When in API mode, the application should receive a frame (with no data) and status (set to 'OK') at the end of the command. When the ND command packet is received, the remote sets up a random time delay (up to 2.2 sec) before replying as follows:

Node Discover Response (AT command mode format - Transparent operation):
MY (Source Address) value<CR>
SH (Serial Number High) value<CR>
SL (Serial Number Low) value<CR>
DB (Received Signal Strength) value<CR>
NI (Node Identifier) value<CR>
<CR> (This is part of the response and not the end of command indicator.)

Node Discover Response (API format - data is binary (except for NI)):
2 bytes for MY (Source Address) value
4 bytes for SH (Serial Number High) value
4 bytes for SL (Serial Number Low) value
1 byte for DB (Received Signal Strength) value
NULL-terminated string for NI (Node Identifier) value (max 20 bytes w/out NULL terminator)

NI (Node Identifier) Command

<Networking {Identification}> The NI command is used to set and read a string for identifying a particular node.

AT Command: ATNI
Parameter Range: 20-character ASCII string
Related Commands: ND (Node Discover), DN (Destination Node)
Minimum Firmware Version Required: v1.x80

Rules:

- Register only accepts printable ASCII data.
- A string can not start with a space.
- A carriage return ends command
- Command will automatically end when maximum bytes for the string have been entered.

This string is returned as part of the ND (Node Discover) command. This identifier is also used with the DN (Destination Node) command.

NO (Node Discover Options) Command

<Networking {Identification}> The NO command is used to suppress/include a self-response to Node Discover commands. When NO=1 a module doing a Node Discover will include a response entry for itself.

AT Command: ATNO
Parameter Range: "0-1
Related Commands: ND (Node Discover), DN (Destination Node)
Minimum Firmware Version Required: v1.xC5

NT (Node Discover Time) Command

<Networking {Identification}> The NT command is used to set the amount of time a base node will wait for responses from other nodes when using the ND (Node Discover) command. The NT value is transmitted with the ND command.

Remote nodes will set up a random hold-off time based on this time. The remotes will adjust this time down by 250 ms to give each node the ability to respond before the base ends the command. Once the ND command has ended, any response received on the base will be discarded.

AT Command: ATNT
Parameter Range: 0x01 - 0xFC [x 100 msec]
Default: 0x19 (2.5 decimal seconds)
Related Commands: ND (Node Discover)
Minimum Firmware Version Required: 1.xA0

P0 (PWM0 Configuration) Command

<I/O Setting {I/O Line Passing}> The P0 command is used to select/read the function for PWM0 (Pulse Width Modulation output 0). This command enables the option of translating incoming data to a PWM so that the output can be translated back into analog form.

With the IA (I/O Input Address) parameter correctly set, AD0 values can automatically be passed to PWM0.

AT Command: ATP0
The second character in the command is the number zero (“0”), not the letter “O”.

Parameter Range: 0 - 2

Parameter	Configuration
0	Disabled
1	RSSI
2	PWM0 Output

Default Parameter Value: 1

P1 (PWM1 Configuration) Command

<I/O Setting {I/O Line Passing}> The P1 command is used to select/read the function for PWM1 (Pulse Width Modulation output 1). This command enables the option of translating incoming data to a PWM so that the output can be translated back into analog form.

With the IA (I/O Input Address) parameter correctly set, AD1 values can automatically be passed to PWM1.

AT Command: ATP1

Parameter Range: 0 - 2

Parameter	Configuration
0	Disabled
1	RSSI
2	PWM1 Output

Default Parameter Value: 0

Minimum Firmware Version Required: v1.xA0

PL (Power Level) Command

<RF Interfacing> The PL command is used to select and read the power level at which the RF module transmits conducted power.

When operating in Europe, XBee-PRO 802.15.4 modules must operate at or below a transmit power output level of 10dBm. Customers have 2 choices for transmitting at or below 10dBm:

- Order the standard XBee-PRO module and change the PL command to "0" (10dBm),
- Order the International variant of the XBee-PRO module, which has a maximum transmit output power of 10dBm.

AT Command: ATPL

Parameter Range: 0 - 4

Parameter	XBee	XBee-PRO	XBee-PRO International variant
0	-10 dBm	10 dBm	PL=4: 10 dBm
1	-6 dBm	12 dBm	PL=3: 8 dBm
2	-4 dBm	14 dBm	PL=2: 2 dBm
3	-2 dBm	16 dBm	PL=1: -3 dBm
4	0 dBm	18 dBm	PL=0: -3 dBm

Default Parameter Value: 4

PR (Pull-up Resistor) Command

<Serial Interfacing> The PR command is used to set and read the bit field that is used to configure internal the pull-up resistor status for I/O lines. "1" specifies the pull-up resistor is enabled. "0" specifies no pull up.

AT Command: ATPR
Parameter Range: 0 – 0xFF
Default Parameter Value: 0xFF (all pull–up resistors are enabled)
Minimum Firmware Version Required: v1.x80

bit 0 - AD4/DIO4 (pin 11)
bit 1 - AD3/DIO3 (pin 17)
bit 2 - AD2/DIO2 (pin 18)
bit 3 - AD1/DIO1 (pin 19)
bit 4 - AD0/DIO0 (pin 20)
bit 5 - AD6/DIO6 (pin 16)
bit 6 - DI8 (pin 9)
bit 7 - DIN/CONFIG (pin 3)

For example: Sending the command "ATPR 6F" will turn bits 0, 1, 2, 3, 5 and 6 ON; and bits 4 & 7 will be turned OFF. (The binary equivalent of "0x6F" is "01101111". Note that 'bit 0' is the last digit in the bitfield.

PT (PWM Output Timeout) Command

<I/O Settings {I/O Line Passing}> The PT command is used to set/read the output timeout value for both PWM outputs.

When PWM is set to a non-zero value: Due to I/O line passing, a time is started which when expired will set the PWM output to zero. The timer is reset when a valid I/O packet is received.

AT Command: ATPT
Parameter Range: 0 – 0xFF [x 100 msec]
Default Parameter Value: 0xFF
Minimum Firmware Version Required: 1.xA0

RE (Restore Defaults) Command

<(Special)> The RE command is used to restore all configurable parameters to their factory default settings. The RE command does not write restored values to non-volatile (persistent) memory. Issue the WR (Write) command subsequent to issuing the RE command to save restored parameter values to non-volatile memory.

AT Command: ATRE

RN (Random Delay Slots) Command

<Networking & Security> The RN command is used to set and read the minimum value of the back-off exponent in the CSMA-CA algorithm. The CSMA-CA algorithm was engineered for collision avoidance (random delays are inserted to prevent data loss caused by data collisions).

AT Command: ATRN
Parameter Range: 0 – 3 [exponent]
Default Parameter Value: 0

If RN = 0, collision avoidance is disabled during the first iteration of the algorithm (802.15.4 - macMinBE).

CSMA-CA stands for "Carrier Sense Multiple Access - Collision Avoidance". Unlike CSMA-CD (reacts to network transmissions after collisions have been detected), CSMA-CA acts to prevent data collisions before they occur. As soon as a module receives a packet that is to be transmitted, it checks if the channel is clear (no other module is transmitting). If the channel is clear, the packet is sent over-the-air. If the channel is not clear, the module waits for a randomly selected period of time, then checks again to see if the channel is clear. After a time, the process ends and the data is lost.

RO (Packetization Timeout) Command

AT Command: ATRO	
Parameter Range:0 – 0xFF [x character times]	
Default Parameter Value: 3	

<Serial Interfacing> RO command is used to set and read the number of character times of inter-character delay required before transmission.

RF transmission commences when data is detected in the DI (data in from host) buffer and RO character times of silence are detected on the UART receive lines (after receiving at least 1 byte).

RF transmission will also commence after 100 Bytes (maximum packet size) are received in the DI buffer.

Set the RO parameter to '0' to transmit characters as they arrive instead of buffering them into one RF packet.

RP (RSSI PWM Timer) Command

AT Command: ATRP	
Parameter Range:0 – 0xFF [x 100 msec]	
Default Parameter Value: 0x28 (40 decimal)	

<I/O Settings {I/O Line Passing}> The RP command is used to enable PWM (Pulse Width Modulation) output on the RF module. The output is calibrated to show the level a received RF signal is above the sensitivity level of the module. The PWM pulses vary from 24 to 100%. Zero percent means PWM output is inactive. One to 24% percent means the received RF signal is at or below the published sensitivity level of the module. The following table shows levels above sensitivity and PWM values.

The total period of the PWM output is 64 µs. Because there are 445 steps in the PWM output, the minimum step size is 144 ns.

PWM Percentages

dB above Sensitivity	PWM percentage (high period / total period)
10	41%
20	58%
30	75%

A non-zero value defines the time that the PWM output will be active with the RSSI value of the last received RF packet. After the set time when no RF packets are received, the PWM output will be set low (0 percent PWM) until another RF packet is received. The PWM output will also be set low at power-up until the first RF packet is received. A parameter value of 0xFF permanently enables the PWM output and it will always reflect the value of the last received RF packet.

RR (XBee Retries) Command

AT Command: ATRR	
Parameter Range: 0 – 6	
Default: 0	
Minimum Firmware Version Required: 1.xA0	

<Networking {Addressing}> The RR command is used set/read the maximum number of retries the module will execute in addition to the 3 retries provided by the 802.15.4 MAC. For each XBee retry, the 802.15.4 MAC can execute up to 3 retries.

This values does not need to be set on all modules for retries to work. If retries are enabled, the transmitting module will set a bit in the Digi RF Packet header which requests the receiving module to send an ACK (acknowledgement). If the transmitting module does not receive an ACK within 200 msec, it will re-send the packet within a random period up to 48 msec. Each XBee retry can potentially result in the MAC sending the packet 4 times (1 try plus 3 retries). Note that retries are not attempted for packets that are purged when transmitting with a Cyclic Sleep Coordinator.

SC (Scan Channels) Command

<Networking {Association}> The SC command is used to set and read the list of channels to scan for all Active and Energy Scans as a bit field.

This affects scans initiated in command mode [AS (Active Scan) and ED (Energy Scan) commands] and during End Device Association and Coordinator startup.

AT Command: ATSC
Parameter Range: 1-0xFFFF [Bitfield] (bits 0, 14, 15 are not allowed when using the XBee-PRO)
Default Parameter Value: 0x1FFE (all XBee-PRO channels)
Related Commands: ED (Energy Scan), SD (Scan Duration)
Minimum Firmware Version Required: v1.x80

bit 0 - 0x0B	bit 4 - 0x0F	bit 8 - 0x13	bit 12 - 0x17
bit 1 - 0x0C	bit 5 - 0x10	bit 9 - 0x14	bit 13 - 0x18
bit 2 - 0x0D	bit 6 - 0x11	bit 10 - 0x15	bit 14 - 0x19
bit 3 - 0x0E	bit 7 - 0x12	bit 11 - 0x16	bit 15 - 0x1A

SD (Scan Duration) Command

<Networking {Association}> The SD command is used to set and read the exponent value that determines the duration (in time) of a scan.

End Device (Duration of Active Scan during Association) - In a Beacon system, set SD = BE of the Coordinator. SD must be set at least to the highest BE parameter of any Beaconing Coordinator with which an End Device or Coordinator wish to discover.

AT Command: ATSD
Parameter Range: 0 – 0x0F
Default Parameter Value: 4
Related Commands: ED (Energy Scan), SC (Scan Channel)
Minimum Firmware Version Required: v1.x80

Coordinator - If the 'ReassignPANID' option is set on the Coordinator [refer to A2 parameter], the SD parameter determines the length of time the Coordinator will scan channels to locate existing PANs. If the 'ReassignChannel' option is set, SD determines how long the Coordinator will perform an Energy Scan to determine which channel it will operate on.

Scan Time is measured as ((# of Channels to Scan) * (2 ^ SD) * 15.36ms). The number of channels to scan is set by the SC command. The XBee RF Module can scan up to 16 channels (SC = 0xFFFF). The XBee PRO RF Module can scan up to 12 channels (SC = 0x1FFE).

Examples: Values below show results for a 12-channel scan

If SD = 0, time = 0.18 sec	SD = 8, time = 47.19 sec
SD = 2, time = 0.74 sec	SD = 10, time = 3.15 min
SD = 4, time = 2.95 sec	SD = 12, time = 12.58 min
SD = 6, time = 11.80 sec	SD = 14, time = 50.33 min

SH (Serial Number High) Command

<Diagnostics> The SH command is used to read the high 32 bits of the RF module's unique IEEE 64-bit address.

The module serial number is set at the factory and is read-only.

AT Command: ATSH
Parameter Range: 0 – 0xFFFFFFFF [read-only]
Related Commands: SL (Serial Number Low), MY (Source Address)

SL (Serial Number Low) Command

<Diagnostics> The SL command is used to read the low 32 bits of the RF module's unique IEEE 64-bit address.

The module serial number is set at the factory and is read-only.

AT Command: ATSL
Parameter Range: 0 – 0xFFFFFFFF [read-only]
Related Commands: SH (Serial Number High), MY (Source Address)

SM (Sleep Mode) Command

<Sleep Mode (Low Power)> The SM command is used to set and read Sleep Mode settings. By default, Sleep Modes are disabled (SM = 0) and the RF module remains in Idle/ Receive Mode. When in this state, the module is constantly ready to respond to either serial or RF activity.

* The Sleep Coordinator option (SM=6) only exists for backwards compatibility with firmware version 1.x06 only. In all other cases, use the CE command to enable a Coordinator.

AT Command: ATSM

Parameter Range: 0 – 6

Parameter	Configuration
0	Disabled
1	Pin Hibernate
2	Pin Doze
3	(reserved)
4	Cyclic Sleep Remote
5	Cyclic Sleep Remote (with Pin Wake-up)
6	Sleep Coordinator*

Default Parameter Value: 0

SO (Sleep Mode Command)

Sleep (Low Power) Sleep Options Set/Read the sleep mode options.

Bit 0 - Poll wakeup disable

- 0 - Normal operations. A module configured for cyclic sleep will poll for data on waking.
- 1 - Disable wakeup poll. A module configured for cyclic sleep will not poll for data on waking.

Bit 1 - ADC/DIO wakeup sampling disable.

- 0 - Normal operations. A module configured in a sleep mode with ADC/DIO sampling enabled will automatically perform a sampling on wakeup.
- 1 - Suppress sample on wakeup. A module configured in a sleep mode with ADC/DIO sampling enabled will not automatically sample on wakeup.

AT Command: ATSO

Parameter Range:	0-4
Default Parameter Value:	
Related Commands: SM (Sleep Mode), ST (Time before Sleep), DP (Disassociation Cyclic Sleep Period, BE (Beacon Order)	

SP (Cyclic Sleep Period) Command

<Sleep Mode (Low Power)> The SP command is used to set and read the duration of time in which a remote RF module sleeps. After the cyclic sleep period is over, the module wakes and checks for data. If data is not present, the module goes back to sleep. The maximum sleep period is 268 seconds (SP = 0x68B0).

The SP parameter is only valid if the module is configured to operate in Cyclic Sleep (SM = 4-6). Coordinator and End Device SP values should always be equal.

To send Direct Messages, set SP = 0.

AT Command: ATSP

Parameter Range:	NonBeacon Firmware: 0-0x68B0 [x 10 milliseconds]
Default Parameter Value:	
Related Commands: SM (Sleep Mode), ST (Time before Sleep), DP (Disassociation Cyclic Sleep Period, BE (Beacon Order)	

NonBeacon Firmware

End Device - SP determines the sleep period for cyclic sleeping remotes. Maximum sleep period is 268 seconds (0x68B0).

Coordinator - If non-zero, SP determines the time to hold an indirect message before discarding it. A Coordinator will discard indirect messages after a period of (2.5 * SP).

ST (Time before Sleep) Command

<Sleep Mode (Low Power)> The ST command is used to set and read the period of inactivity (no serial or RF data is sent or received) before activating Sleep Mode.

NonBeacon Firmware

Set/Read time period of inactivity (no serial or RF data is sent or received) before activating Sleep Mode. ST parameter is only valid with Cyclic Sleep settings (SM = 4 - 5).

Coordinator and End Device ST values must be equal.

AT Command: ATST	
Parameter Range:	NonBeacon Firmware: 1 – 0xFFFF [x 1 millisecond]
Default Parameter Value:	
Related Commands: SM (Sleep Mode), ST (Time before Sleep)	

T0 - T7 ((D0-D7) Output Timeout) Command

AT Commands: ATT0 – ATT7
Parameter Range:0 – 0xFF [x 100 msec]
Default Parameter Value:0xFF
Minimum Firmware Version Required: v1.xA0

<I/O Settings {I/O Line Passing}> The T0, T1, T2, T3, T4, T5, T6 and T7 commands are used to set/read output timeout values for the lines that correspond with the D0 - D7 parameters. When output is set (due to I/O line passing) to a non-default level, a timer is started which when expired, will set the output to its default level. The timer is reset when a valid I/O packet is received. The Tn parameter defines the permissible amount of time to stay in a non-default (active) state. If Tn = 0, Output Timeout is disabled (output levels are held indefinitely).

VL (Firmware Version - Verbose)

AT Command: ATVL
Parameter Range:0 – 0xFF [x 100 milliseconds]
Default Parameter Value: 0x28 (40 decimal)
Minimum Firmware Version Required: v1.x80 – v1.xC8

<Diagnostics> The VL command is used to read detailed version information about the RF module. The information includes:
application build date; MAC, PHY and bootloader versions; and build dates. This command was removed from firmware 1xC9 and later versions.

VR (Firmware Version) Command

AT Command: ATVR
Parameter Range: 0 – 0xFFFF [read only]

<Diagnostics> The VR command is used to read which firmware version is stored in the module.

XBee version numbers will have four significant digits. The reported number will show three or four numbers and is stated in hexadecimal notation. A version can be reported as "ABC" or "ABCD". Digits ABC are the main release number and D is the revision number from the main release. "D" is not required and if it is not present, a zero is assumed for D. "B" is a variant designator. The following variants exist:

- "0" = Non-Beacon Enabled 802.15.4 Code
- "1" = Beacon Enabled 802.15.4 Code

WR (Write) Command

AT Command: ATWR

<(Special)> The WR command is used to write configurable parameters to the RF module's non-volatile memory. Parameter values remain in the module's memory until overwritten by subsequent use of the WR Command.

If changes are made without writing them to non-volatile memory, the module reverts back to previously saved parameters the next time the module is powered-on.

NOTE: Once the WR command is sent to the module, no additional characters should be sent until after the “OK/r” response is received.

API Operation

By default, XBee®/XBee-PRO® RF Modules act as a serial line replacement (Transparent Operation) - all UART data received through the DI pin is queued up for RF transmission. When the module receives an RF packet, the data is sent out the DO pin with no additional information.

Inherent to Transparent Operation are the following behaviors:

- If module parameter registers are to be set or queried, a special operation is required for transitioning the module into Command Mode.
- In point-to-multipoint systems, the application must send extra information so that the receiving module(s) can distinguish between data coming from different remotes.

As an alternative to the default Transparent Operation, API (Application Programming Interface) Operations are available. API operation requires that communication with the module be done through a structured interface (data is communicated in frames in a defined order). The API specifies how commands, command responses and module status messages are sent and received from the module using a UART Data Frame.

API Frame Specifications

Two API modes are supported and both can be enabled using the AP (API Enable) command. Use the following AP parameter values to configure the module to operate in a particular mode:

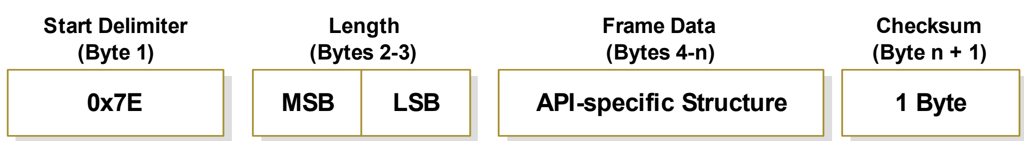
- AP = 0 (default): Transparent Operation (UART Serial line replacement)
  API modes are disabled.
- AP = 1: API Operation
- AP = 2: API Operation (with escaped characters)

Any data received prior to the start delimiter is silently discarded. If the frame is not received correctly or if the checksum fails, the data is silently discarded.

API Operation (AP parameter = 1)

When this API mode is enabled (AP = 1), the UART data frame structure is defined as follows:

Figure 3-01. UART Data Frame Structure:

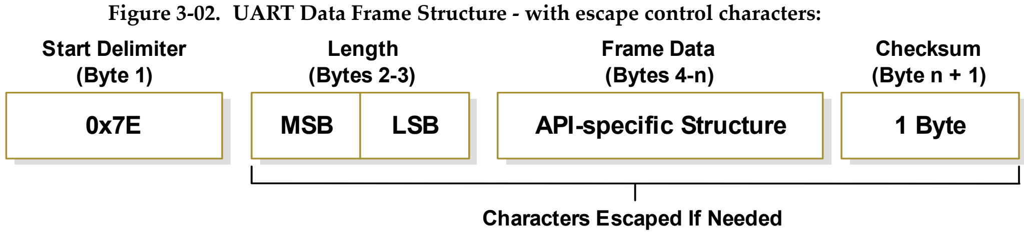


MSB = Most Significant Byte, LSB = Least Significant Byte

API Operation - with Escape Characters (AP parameter = 2)

When this API mode is enabled (AP = 2), the UART data frame structure is defined as follows:

Figure 3-02. UART Data Frame Structure - with escape control characters:



MSB = Most Significant Byte, LSB = Least Significant Byte

Escape characters. When sending or receiving a UART data frame, specific data values must be escaped (flagged) so they do not interfere with the UART or UART data frame operation. To escape an interfering data byte, insert 0x7D and follow it with the byte to be escaped XOR'd with 0x20.

Data bytes that need to be escaped:

- 0x7E – Frame Delimiter
- 0x7D – Escape
- 0x11 – XON
- 0x13 – XOFF

Example - Raw UART Data Frame (before escaping interfering bytes):
0x7E 0x00 0x02 0x23 0x11 0xCB

0x11 needs to be escaped which results in the following frame:
0x7E 0x00 0x02 0x23 0x7D 0x31 0xCB

Note: In the above example, the length of the raw data (excluding the checksum) is 0x0002 and the checksum of the non-escaped data (excluding frame delimiter and length) is calculated as: 0xFF - (0x23 + 0x11) = (0xFF - 0x34) = 0xCB.

Checksum

To test data integrity, a checksum is calculated and verified on non-escaped data.

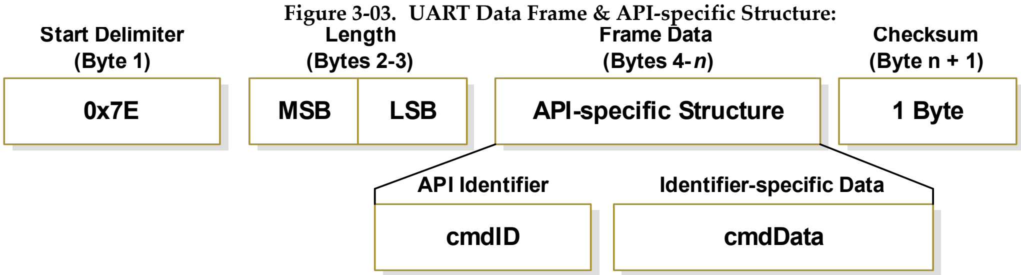
To calculate: Not including frame delimiters and length, add all bytes keeping only the lowest 8 bits of the result and subtract from 0xFF.

To verify: Add all bytes (include checksum, but not the delimiter and length). If the checksum is correct, the sum will equal 0xFF.

API Types

Frame data of the UART data frame forms an API-specific structure as follows:

Figure 3-03. UART Data Frame & API-specific Structure:

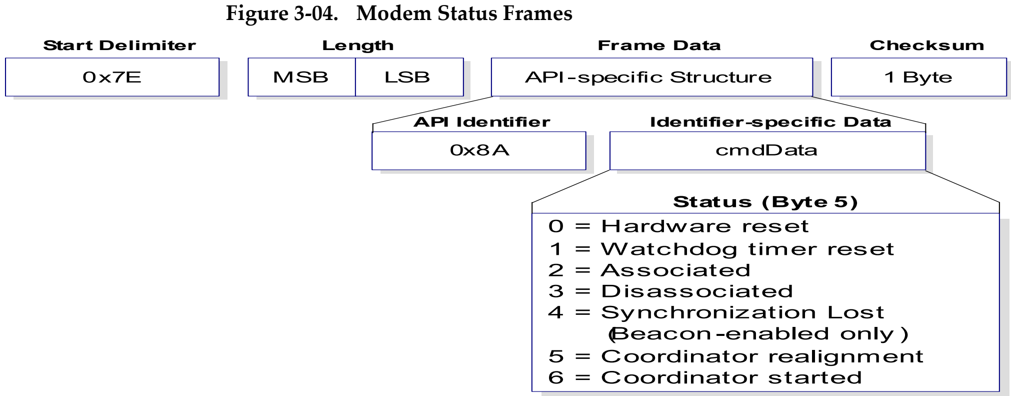


The cmdID frame (API-identifier) indicates which API messages will be contained in the cmdData frame (Identifier-specific data). Refer to the sections that follow for more information regarding the supported API types. Note that multi-byte values are sent big endian.

Modem Status

API Identifier: 0x8A
RF module status messages are sent from the module in response to specific conditions.

Figure 3-04. Modem Status Frames



AT Command

API Identifier Value: 0x08

The "AT Command" API type allows for module parameters to be queried or set. When using this command ID, new parameter values are applied immediately. This includes any register set with the "AT Command - Queue Parameter Value" (0x09) API type.

Figure 3-05. AT Command Frames

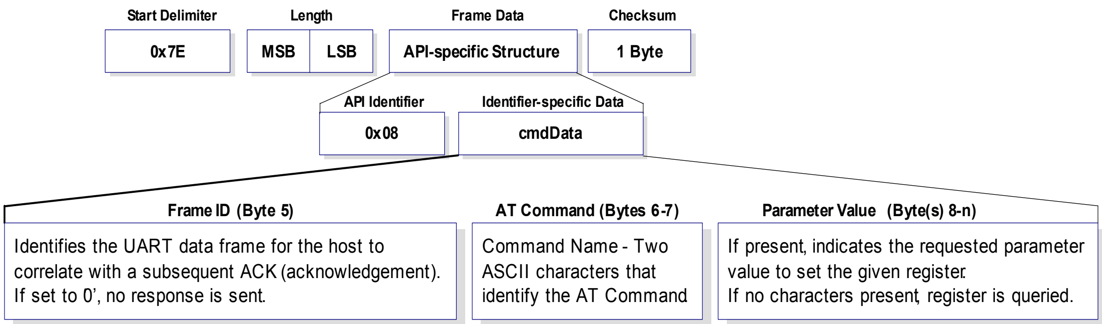
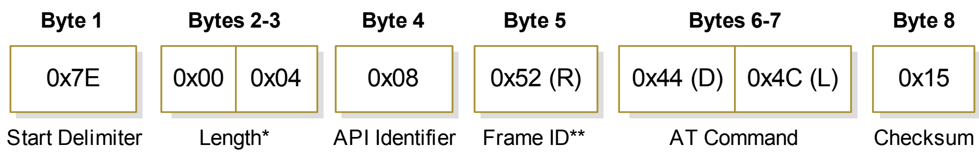


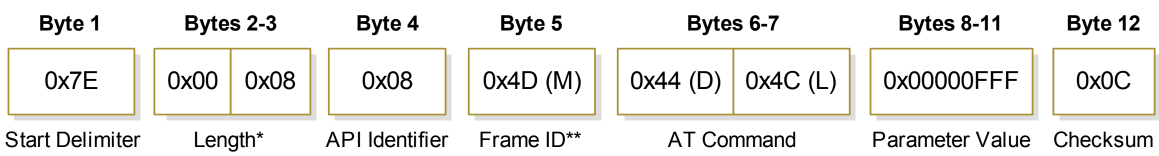
Figure 3-06. Example: API frames when reading the DL parameter value of the module.



** Length [Bytes] = API Identifier + Frame ID + AT Command*

*** "R" value was arbitrarily selected.*

Figure 3-07. Example: API frames when modifying the DL parameter value of the module.



** Length [Bytes] = API Identifier + Frame ID + AT Command + Parameter Value*

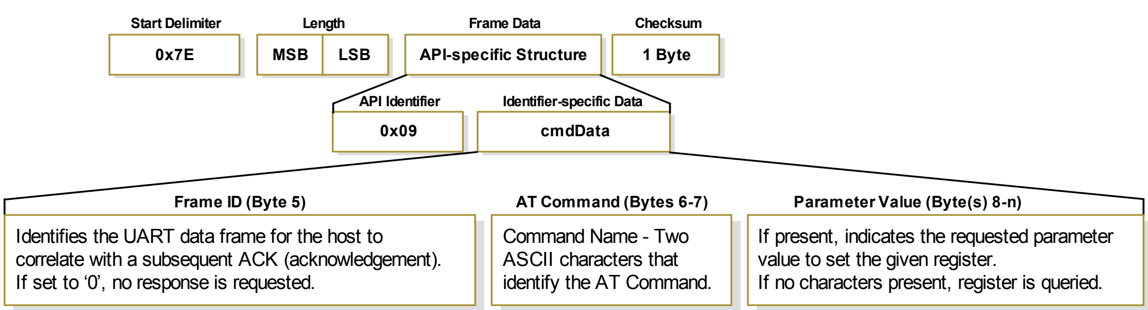
*** "M" value was arbitrarily selected.*

AT Command - Queue Parameter Value

API Identifier Value: 0x09

This API type allows module parameters to be queried or set. In contrast to the "AT Command" API type, new parameter values are queued and not applied until either the "AT Command" (0x08) API type or the AC (Apply Changes) command is issued. Register queries (reading parameter values) are returned immediately.

Figure 3-08. AT Command Frames
(Note that frames are identical to the "AT Command" API type except for the API identifier.)



AT Command Response

API Identifier Value: 0x88

Response to previous command.

In response to an AT Command message, the module will send an AT Command Response message. Some commands will send back multiple frames (for example, the ND (Node Discover) and AS (Active Scan) commands). These commands will end by sending a frame with a status of ATCMD_OK and no cmdData.

Figure 3-09. AT Command Response Frames.

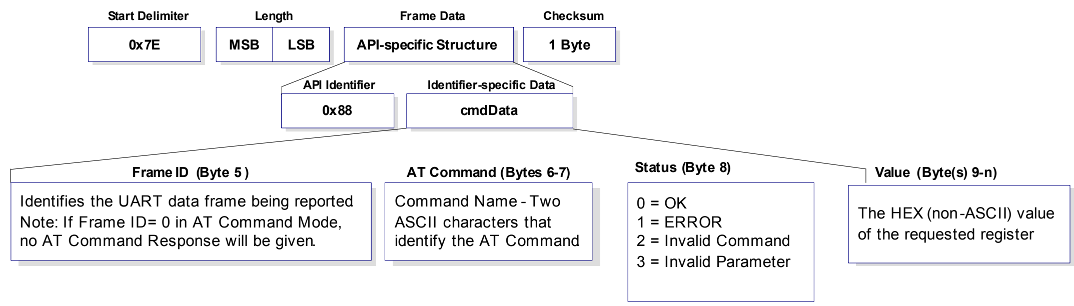
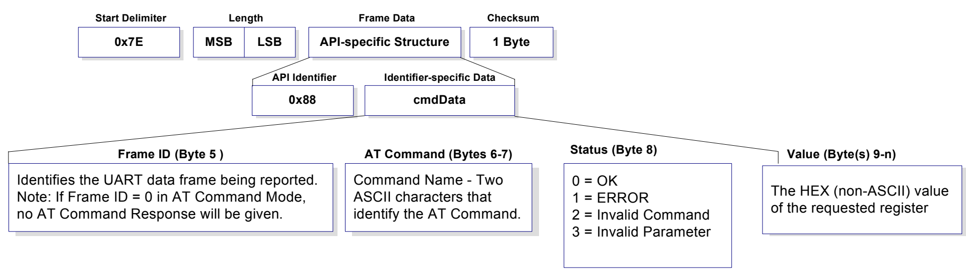


Figure 3-10. AT Command Response Frames.

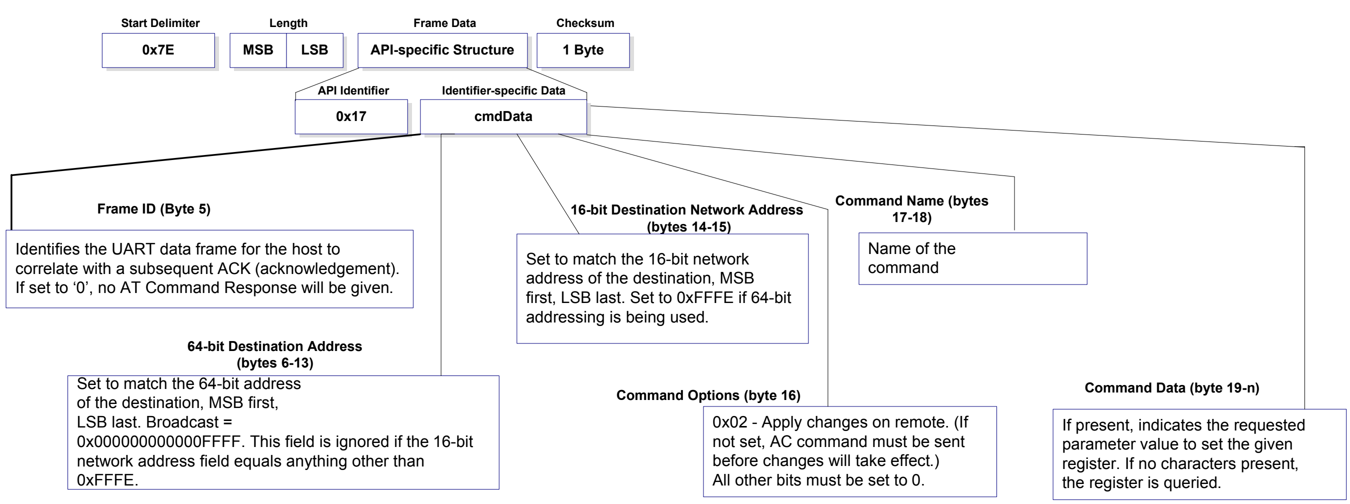


Remote AT Command Request

API Identifier Value: 0x17

Allows for module parameter registers on a remote device to be queried or set

Figure 3-11. Remote AT Command Request

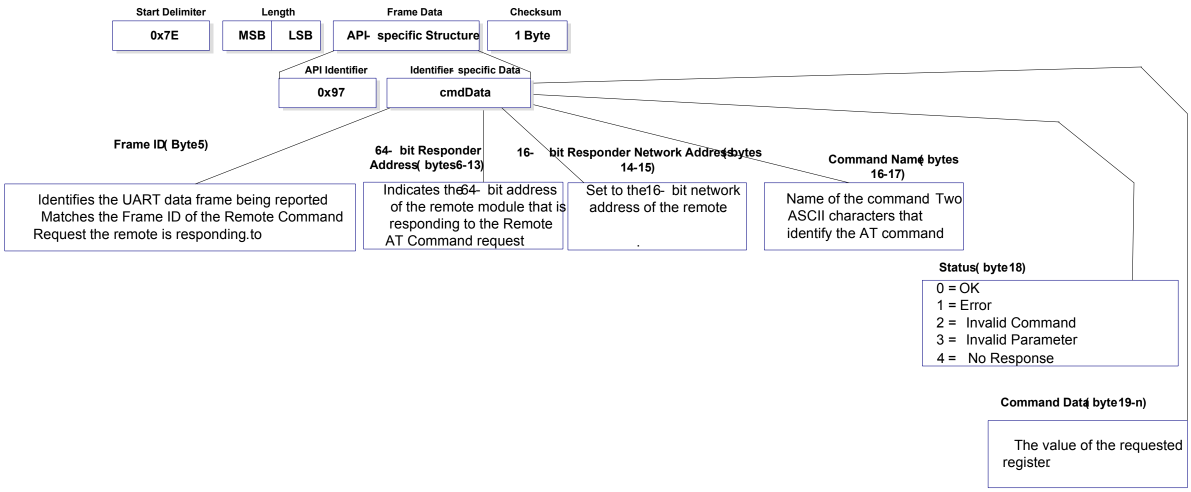


Remote Command Response

API Identifier Value: 0x97

If a module receives a remote command response RF data frame in response to a Remote AT Command Request, the module will send a Remote AT Command Response message out the UART. Some commands may send back multiple frames--for example, Node Discover (ND) command.

Figure 3-12. Remote AT Command Response.

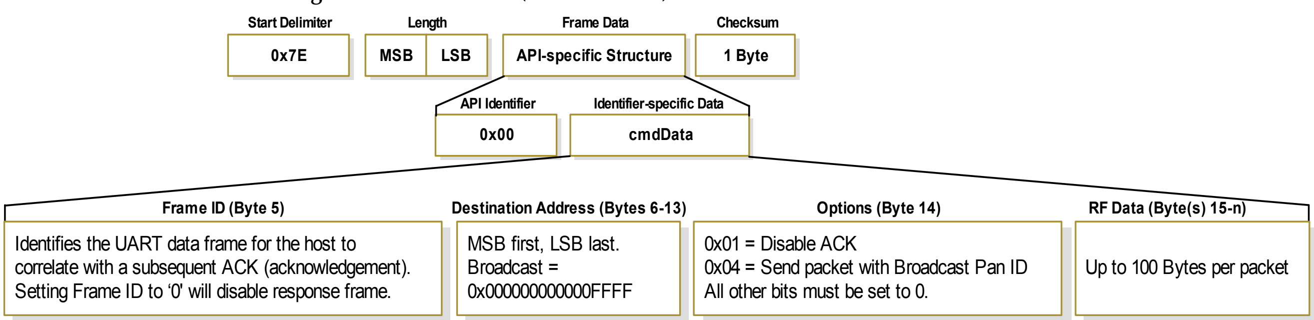


TX (Transmit) Request: 64-bit address

API Identifier Value: 0x00

A TX Request message will cause the module to send RF Data as an RF Packet.

Figure 3-13. TX Packet (64-bit address) Frames

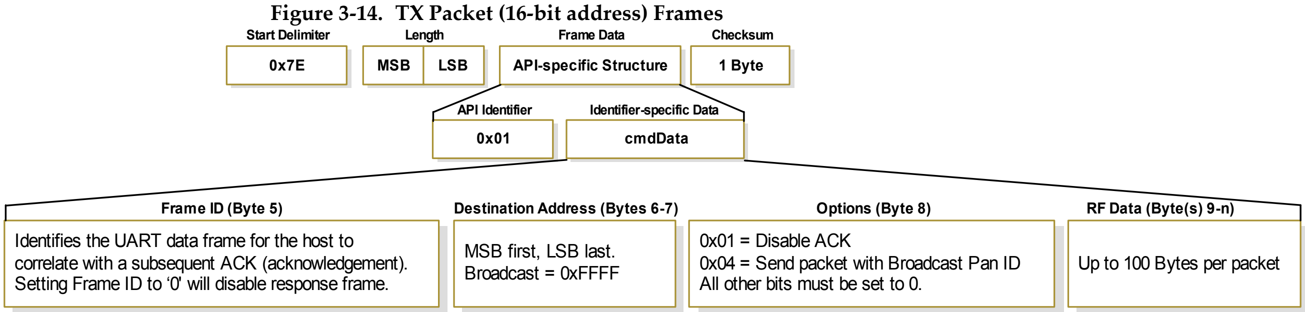


TX (Transmit) Request: 16-bit address

API Identifier Value: 0x01

A TX Request message will cause the module to send RF Data as an RF Packet.

Figure 3-14. TX Packet (16-bit address) Frames

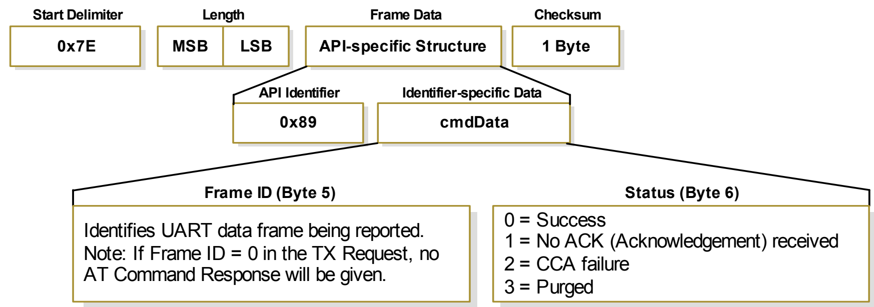


TX (Transmit) Status

API Identifier Value: 0x89

When a TX Request is completed, the module sends a TX Status message. This message will indicate if the packet was transmitted successfully or if there was a failure.

Figure 3-15. TX Status Frames



NOTES:

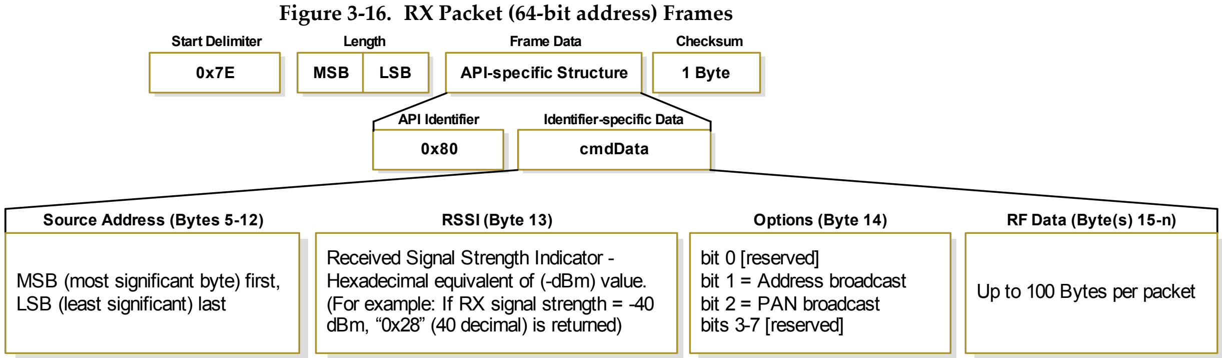
- "STATUS = 1" occurs when all retries are expired and no ACK is received.
- If transmitter broadcasts (destination address = 0x000000000000FFFF), only "STATUS = 0 or 2" will be returned.
- "STATUS = 3" occurs when Coordinator times out of an indirect transmission. Timeout is defined as (2.5 x SP (Cyclic Sleep Period) parameter value).

RX (Receive) Packet: 64-bit Address

API Identifier Value: 0x80

When the module receives an RF packet, it is sent out the UART using this message type.

Figure 3-16. RX Packet (64-bit address) Frames

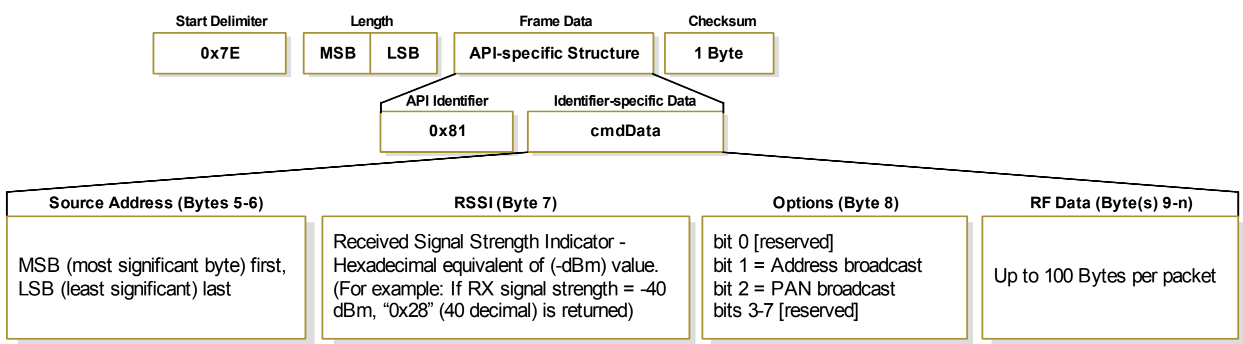


RX (Receive) Packet: 16-bit Address

API Identifier Value: 0x81

When the module receives an RF packet, it is sent out the UART using this message type.

Figure 3-17. RX Packet (16-bit address) Frames



Appendix A: Agency Certifications

United States (FCC)

XBee®/XBee-PRO® RF Modules comply with Part 15 of the FCC rules and regulations. Compliance with the labeling requirements, FCC notices and antenna usage guidelines is required.

To fulfill FCC Certification requirements, the OEM must comply with the following regulations:

1. The system integrator must ensure that the text on the external label provided with this device is placed on the outside of the final product [Figure A-01].
2. XBee®/XBee-PRO® RF Modules may only be used with antennas that have been tested and approved for use with this module [refer to the antenna tables in this section].

OEM Labeling Requirements

WARNING: The Original Equipment Manufacturer (OEM) must ensure that FCC labeling requirements are met. This includes a clearly visible label on the outside of the final product enclosure that displays the contents shown in the figure below.

Figure 4-01. Required FCC Label for OEM products containing the XBee®/XBee-PRO® RF Module

Contains FCC ID: OUR-XBEE/OUR-XBEEPRO**

The enclosed device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (*i.*) this device may not cause harmful interference and (*ii.*) this device must accept any interference received, including interference that may cause undesired operation.

* The FCC ID for the XBee is “OUR-XBEE”. The FCC ID for the XBee-PRO is “OUR-XBEEPRO”.

FCC Notices

IMPORTANT: The XBee®/XBee-PRO® RF Module has been certified by the FCC for use with other products without any further certification (as per FCC section 2.1091). Modifications not expressly approved by Digi could void the user's authority to operate the equipment.

IMPORTANT: OEMs must test final product to comply with unintentional radiators (FCC section 15.107 & 15.109) before declaring compliance of their final product to Part 15 of the FCC Rules.

IMPORTANT: The RF module has been certified for remote and base radio applications. If the module will be used for portable applications, the device must undergo SAR testing.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation.

If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures: Re-orient or relocate the receiving antenna, Increase the separation between the equipment and receiver, Connect equipment and receiver to outlets on different circuits, or Consult the dealer or an experienced radio/TV technician for help.

FCC-Approved Antennas (2.4 GHz)

XBee/XBee-PRO RF Modules can be installed using antennas and cables constructed with standard connectors (Type-N, SMA, TNC, etc.) if the installation is performed professionally and according to FCC guidelines. For installations not performed by a professional, non-standard connectors (RPSMA, RPTNC, etc) must be used.

The modules are FCC-approved for fixed base station and mobile applications on channels 0x0B - 0x1A (XBee) and 0x0C - 0x17 (XBee-PRO). If the antenna is mounted at least 20cm (8 in.) from nearby persons, the application is considered a mobile application. Antennas not listed in the table must be tested to comply with FCC Section 15.203 (Unique Antenna Connectors) and Section 15.247 (Emissions).

XBee RF Modules (1 mW): XBee Modules have been tested and approved for use with all of the antennas listed in the tables below (Cable-loss IS NOT required).

XBee-PRO RF Modules (60 mW): XBee-PRO Modules have been tested and approved for use with the antennas listed in the tables below (Cable-loss IS required when using antennas listed in the second table.

The antennas in the tables below have been approved for use with this module. Digi does not carry all of these antenna variants. Contact Digi Sales for available antennas.

Antennas approved for use with the XBee®/XBee-PRO® RF Modules (Cable-loss is not required.)

Part Number	Type (Description)	Gain	Application*	Min. Separation
A24-HASM-450	Dipole (Half-wave articulated RPSMA - 4.5”)	2.1 dBi	Fixed/Mobile	20 cm
A24-HABSM	Dipole (Articulated RPSMA)	2.1 dBi	Fixed	20 cm
A24-HABUF-P5I	Dipole (Half-wave articulated bulkhead mount U.FL. w/ 5” pigtail)	2.1 dBi	Fixed	20 cm
A24-HASM-525	Dipole (Half-wave articulated RPSMA - 5.25")	2.1 dBi	Fixed/Mobile	20 cm
A24-QI	Monopole (Integrated whip)	1.5 dBi	Fixed	20 cm

Antennas approved for use with the XBee RF Modules (Cable-loss is required)

Part Number	Type (Description)	Gain	Application*	Min. Separation	Required Cable-loss
Omni-Directional Class Antennas					
A24-Y6NF	Yagi (6-element)	8.8 dBi	Fixed	2 m	1.7 dB
A24-Y7NF	Yagi (7-element)	9.0 dBi	Fixed	2 m	1.9 dB
A24-Y9NF	Yagi (9-element)	10.0 dBi	Fixed	2 m	2.9 dB
A24-Y10NF	Yagi (10-element)	11.0 dBi	Fixed	2 m	3.9 dB
A24-Y12NF	Yagi (12-element)	12.0 dBi	Fixed	2 m	4.9 dB
A24-Y13NF	Yagi (13-element)	12.0 dBi	Fixed	2 m	4.9 dB
A24-Y15NF	Yagi (15-element)	12.5 dBi	Fixed	2 m	5.4 dB
A24-Y16NF	Yagi (16-element)	13.5 dBi	Fixed	2 m	6.4 dB
A24-Y16RM	Yagi (16-element, RPSMA connector)	13.5 dBi	Fixed	2 m	6.4 dB
A24-Y18NF	Yagi (18-element)	15.0 dBi	Fixed	2 m	7.9 dB
Omni-Directional Class Antennas					
A24-C1	Surface Mount	-1.5 dBi	Fixed/Mobile	20 cm	-
A24-F2NF	Omni-directional (Fiberglass base station)	2.1 dBi	Fixed/Mobile	20 cm	
A24-F3NF	Omni-directional (Fiberglass base station)	3.0 dBi	Fixed/Mobile	20 cm	
A24-F5NF	Omni-directional (Fiberglass base station)	5.0 dBi	Fixed/Mobile	20 cm	
A24-F8NF	Omni-directional (Fiberglass base station)	8.0 dBi	Fixed	2 m	
A24-F9NF	Omni-directional (Fiberglass base station)	9.5 dBi	Fixed	2 m	0.2 dB
A24-F10NF	Omni-directional (Fiberglass base station)	10.0 dBi	Fixed	2 m	0.7 dB
A24-F12NF	Omni-directional (Fiberglass base station)	12.0 dBi	Fixed	2 m	2.7 dB
A24-F15NF	Omni-directional (Fiberglass base station)	15.0 dBi	Fixed	2 m	5.7 dB
A24-W7NF	Omni-directional (Base station)	7.2 dBi	Fixed	2 m	
A24-M7NF	Omni-directional (Mag-mount base station)	7.2 dBi	Fixed	2 m	
Panel Class Antennas					
A24-P8SF	Flat Panel	8.5 dBi	Fixed	2 m	1.5 dB
A24-P8NF	Flat Panel	8.5 dBi	Fixed	2 m	1.5 dB
A24-P13NF	Flat Panel	13.0 dBi	Fixed	2 m	6 dB
A24-P14NF	Flat Panel	14.0 dBi	Fixed	2 m	7 dB
A24-P15NF	Flat Panel	15.0 dBi	Fixed	2 m	8 dB
A24-P16NF	Flat Panel	16.0 dBi	Fixed	2 m	9 dB

Antennas approved for use with the XBee®/XBee-PRO® RF Modules (Cable-loss is required)

Part Number	Type (Description)	Gain	Application*	Min. Separation	Required Cable-loss
A24-C1	Surface Mount	-1.5 dBi	Fixed/Mobile	20 cm	-
A24-Y4NF	Yagi (4-element)	6.0 dBi	Fixed	2 m	8.1 dB
A24-Y6NF	Yagi (6-element)	8.8 dBi	Fixed	2 m	10.9 dB
A24-Y7NF	Yagi (7-element)	9.0 dBi	Fixed	2 m	11.1 dB
A24-Y9NF	Yagi (9-element)	10.0 dBi	Fixed	2 m	12.1 dB
A24-Y10NF	Yagi (10-element)	11.0 dBi	Fixed	2 m	13.1 dB
A24-Y12NF	Yagi (12-element)	12.0 dBi	Fixed	2 m	14.1 dB
A24-Y13NF	Yagi (13-element)	12.0 dBi	Fixed	2 m	14.1 dB
A24-Y15NF	Yagi (15-element)	12.5 dBi	Fixed	2 m	14.6 dB
A24-Y16NF	Yagi (16-element)	13.5 dBi	Fixed	2 m	15.6 dB
A24-Y16RM	Yagi (16-element, RPSMA connector)	13.5 dBi	Fixed	2 m	15.6 dB
A24-Y18NF	Yagi (18-element)	15.0 dBi	Fixed	2 m	17.1 dB
A24-F2NF	Omni-directional (Fiberglass base station)	2.1 dBi	Fixed/Mobile	20 cm	4.2 dB
A24-F3NF	Omni-directional (Fiberglass base station)	3.0 dBi	Fixed/Mobile	20 cm	5.1 dB
A24-F5NF	Omni-directional (Fiberglass base station)	5.0 dBi	Fixed/Mobile	20 cm	7.1 dB
A24-F8NF	Omni-directional (Fiberglass base station)	8.0 dBi	Fixed	2 m	10.1 dB
A24-F9NF	Omni-directional (Fiberglass base station)	9.5 dBi	Fixed	2 m	11.6 dB
A24-F10NF	Omni-directional (Fiberglass base station)	10.0 dBi	Fixed	2 m	12.1 dB
A24-F12NF	Omni-directional (Fiberglass base station)	12.0 dBi	Fixed	2 m	14.1 dB
A24-F15NF	Omni-directional (Fiberglass base station)	15.0 dBi	Fixed	2 m	17.1 dB
A24-W7NF	Omni-directional (Base station)	7.2 dBi	Fixed	2 m	9.3 dB
A24-M7NF	Omni-directional (Mag-mount base station)	7.2 dBi	Fixed	2 m	9.3 dB
A24-P8SF	Flat Panel	8.5 dBi	Fixed	2 m	8.6 dB
A24-P8NF	Flat Panel	8.5 dBi	Fixed	2 m	8.6 dB
A24-P13NF	Flat Panel	13.0 dBi	Fixed	2 m	13.1 dB
A24-P14NF	Flat Panel	14.0 dBi	Fixed	2 m	14.1 dB
A24-P15NF	Flat Panel	15.0 dBi	Fixed	2 m	15.1 dB
A24-P16NF	Flat Panel	16.0 dBi	Fixed	2 m	16.1 dB
A24-P19NF	Flat Panel	19.0 dBi	Fixed	2 m	19.1 dB

*** If using the RF module in a portable application** (For example - If the module is used in a handheld device and the antenna is less than 20cm from the human body when the device is operation): The integrator is responsible for passing additional SAR (Specific Absorption Rate) testing based on FCC rules 2.1091 and FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields, OET Bulletin and Supplement C. The testing results will be submitted to the FCC for approval prior to selling the integrated unit. The required SAR testing measures emissions from the module and how they affect the person.

RF Exposure

WARNING: To satisfy FCC RF exposure requirements for mobile transmitting devices, a separation distance of 20 cm or more should be maintained between the antenna of this device and persons during device operation. To ensure compliance, operations at closer than this distance is not recommended. The antenna used for this transmitter must not be co-located in conjunction with any other antenna or transmitter.

The preceding statement must be included as a CAUTION statement in OEM product manuals in order to alert users of FCC RF Exposure compliance.

Europe (ETSI)

The XBee RF Modules have been certified for use in several European countries. For a complete list, refer to www.digi.com

If the XBee RF Modules are incorporated into a product, the manufacturer must ensure compliance of the final product to the European harmonized EMC and low-voltage/safety standards. A Declaration of Conformity must be issued for each of these standards and kept on file as described in Annex II of the R&TTE Directive.

Furthermore, the manufacturer must maintain a copy of the XBee user manual documentation and ensure the final product does not exceed the specified power ratings, antenna specifications, and/or installation requirements as specified in the user manual. If any of these specifications are exceeded in the final product, a submission must be made to a notified body for compliance testing to all required standards.

OEM Labeling Requirements

The 'CE' marking must be affixed to a visible location on the OEM product.

CE Labeling Requirements

The CE mark shall consist of the initials "CE" taking the following form:

- If the CE marking is reduced or enlarged, the proportions given in the above graduated drawing must be respected.
- The CE marking must have a height of at least 5mm except where this is not possible on account of the nature of the apparatus.
- The CE marking must be affixed visibly, legibly, and indelibly.

Restrictions

Power Output: When operating in Europe, XBee-PRO 802.15.4 modules must operate at or below a transmit power output level of 10dBm. Customers have two choices for transmitting at or below 10dBm:

a. Order the standard XBee-PRO module and change the PL command to 0 (10dBm)

b. Order the International variant of the XBee-PRO module, which has a maximum transmit output power of 10dBm (@ PL=4).

Additionally, European regulations stipulate an EIRP power maximum of 12.86 dBm (19 mW) for the XBee-PRO and 12.11 dBm for the XBee when integrating antennas.

France: Outdoor use limited to 10 mW EIRP within the band 2454-2483.5 MHz.

Norway: Norway prohibits operation near Ny-Alesund in Svalbard. More information can be found at the Norway Posts and Telecommunications site (www.npt.no).

Declarations of Conformity

Digi has issued Declarations of Conformity for the XBee RF Modules concerning emissions, EMC and safety. Files can be obtained by contacting Digi Support.

Important Note:

Digi does not list the entire set of standards that must be met for each country. Digi customers assume full responsibility for learning and meeting the required guidelines for each country in their distribution market. For more information relating to European compliance of an OEM product incorporating the XBee RF Module, contact Digi, or refer to the following web sites:

CEPT ERC 70-03E - Technical Requirements, European restrictions and general requirements: Available at www.ero.dk/.

R&TTE Directive - Equipment requirements, placement on market: Available at www.ero.dk/.

Approved Antennas

When integrating high-gain antennas, European regulations stipulate EIRP power maximums. Use the following guidelines to determine which antennas to design into an application.

XBee-PRO RF Module

The following antenna types have been tested and approved for use with the XBee Module:

Antenna Type: Yagi
RF module was tested and approved with 15 dBi antenna gain with 1 dB cable-loss (EIRP Maximum of 14 dBm). Any Yagi type antenna with 14 dBi gain or less can be used with no cable-loss.

Antenna Type: Omni-directional
RF module was tested and approved with 15 dBi antenna gain with 1 dB cable-loss (EIRP Maxi-

mum of 14 dBm). Any Omni-directional type antenna with 14 dBi gain or less can be used with no cable-loss.

Antenna Type: Flat Panel
RF module was tested and approved with 19 dBi antenna gain with 4.8 dB cable-loss (EIRP Maximum of 14.2 dBm). Any Flat Panel type antenna with 14.2 dBi gain or less can be used with no cable-loss.

XBee-PRO RF Module (@ 10 dBm Transmit Power, PL parameter value must equal 0, or use International variant)

The following antennas have been tested and approved for use with the embedded XBee-PRO RF Module:

- Dipole (2.1 dBi, Omni-directional, Articulated RPSMA, Digi part number A24-HABSM)
- Chip Antenna (-1.5 dBi)
- Attached Monopole Whip (1.5 dBi)

The RF modem encasement was designed to accommodate the RPSMA antenna option.

Canada (IC)

Labeling Requirements

Labeling requirements for Industry Canada are similar to those of the FCC. A clearly visible label on the outside of the final product enclosure must display the following text:

Contains Model XBee Radio, IC: 4214A-XBEE
Contains Model XBee-PRO Radio, IC: 4214A-XBEEPRO

The integrator is responsible for its product to comply with IC ICES-003 & FCC Part 15, Sub. B - Unintentional Radiators. ICES-003 is the same as FCC Part 15 Sub. B and Industry Canada accepts FCC test report or CISPR 22 test report for compliance with ICES-003.

Japan

In order to gain approval for use in Japan, the XBee RF module or the International variant of the XBee-PRO RF module (which has 10 dBm transmit output power) must be used.

Labeling Requirements

A clearly visible label on the outside of the final product enclosure must display the following text:

ID: 005NYCA0378

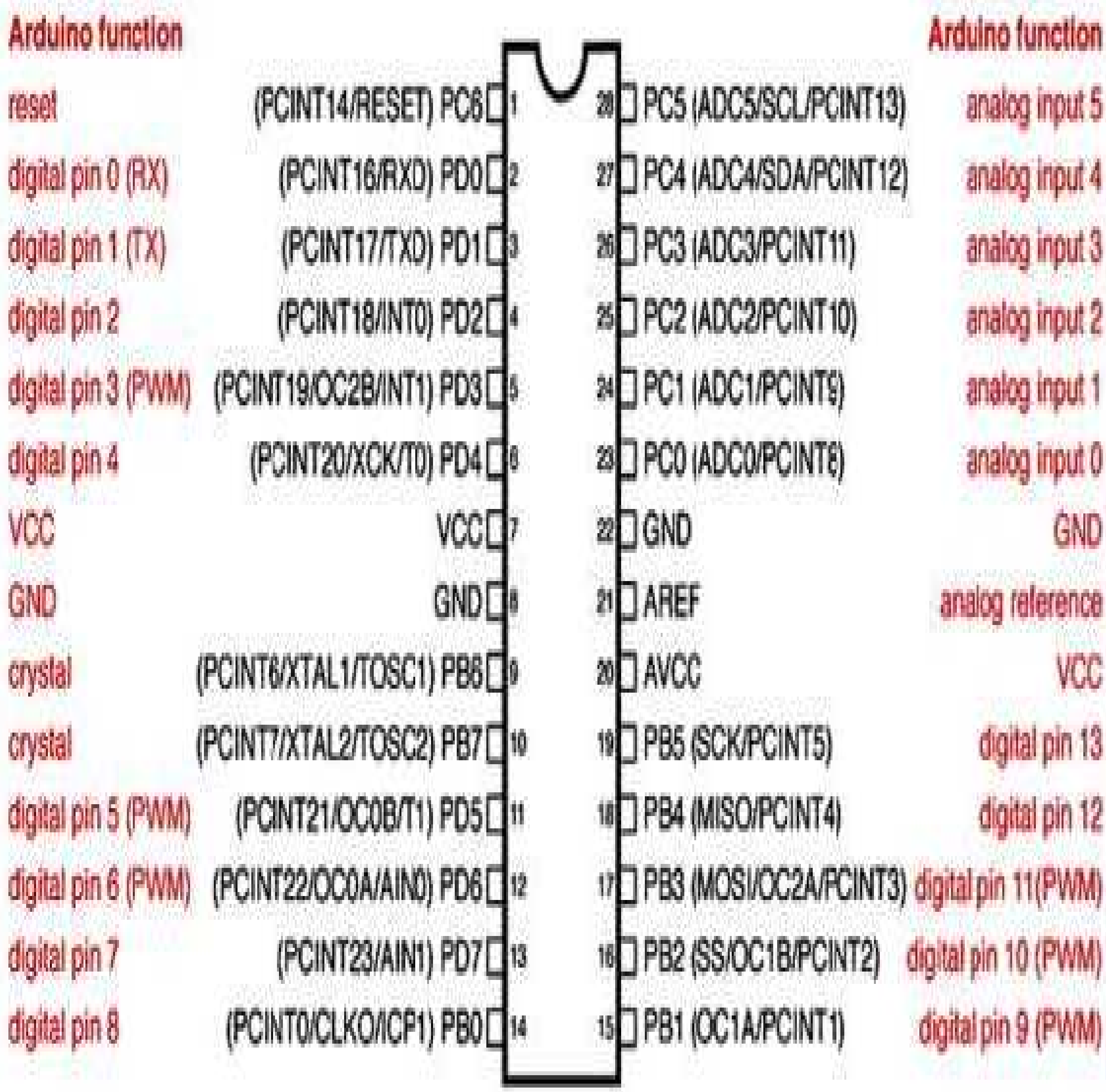
Appendix B. Additional Information

1-Year Warranty

XBee®/XBee-PRO® RF Modules from Digi Intenational, Inc. (the "Product") are warranted against defects in materials and workmanship under normal use, for a period of 1-year from the date of purchase. In the event of a product failure due to materials or workmanship, Digi will repair or replace the defective product. For warranty service, return the defective product to Digi, shipping prepaid, for prompt repair or replacement.

The foregoing sets forth the full extent of Digi's warranties regarding the Product. Repair or replacement at Digi's option is the exclusive remedy. THIS WARRANTY IS GIVEN IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, AND DIGI SPECIFICALLY DISCLAIMS ALL WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. IN NO EVENT SHALL DIGI, ITS SUPPLIERS OR LICENSORS BE LIABLE FOR DAMAGES IN EXCESS OF THE PURCHASE PRICE OF THE PRODUCT, FOR ANY LOSS OF USE, LOSS OF TIME, INCONVENIENCE, COMMERCIAL LOSS, LOST PROFITS OR SAVINGS, OR OTHER INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PRODUCT, TO THE FULL EXTENT SUCH MAY BE DISCLAIMED BY LAW. SOME STATES DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES. THEREFORE, THE FOREGOING EXCLUSIONS MAY NOT APPLY IN ALL CASES. This warranty provides specific legal rights. Other rights which vary from state to state may also apply.

ATmega168/328 Pin Mapping



Digital Pins 11,12 & 13 are used by the ICSP header for MISO, MOSI, SCK connections (Atmega168 pins 17,18 & 19). Avoid low-impedance loads on these pins when using the ICSP header.

Window power DC Motor LH

Quick Details

Place of Origin	Taiwan	Brand Name:	Rebeck	Model Number:	HY-2740A
Type:	DC Motor	Use	Window	Motor	Brushless
Voltage	12V	Car Window:	Automobile parts		

Packaging & Delivery

Packaging Detail: 20pcs/ctn.

Delivery Detail: 30-45 days

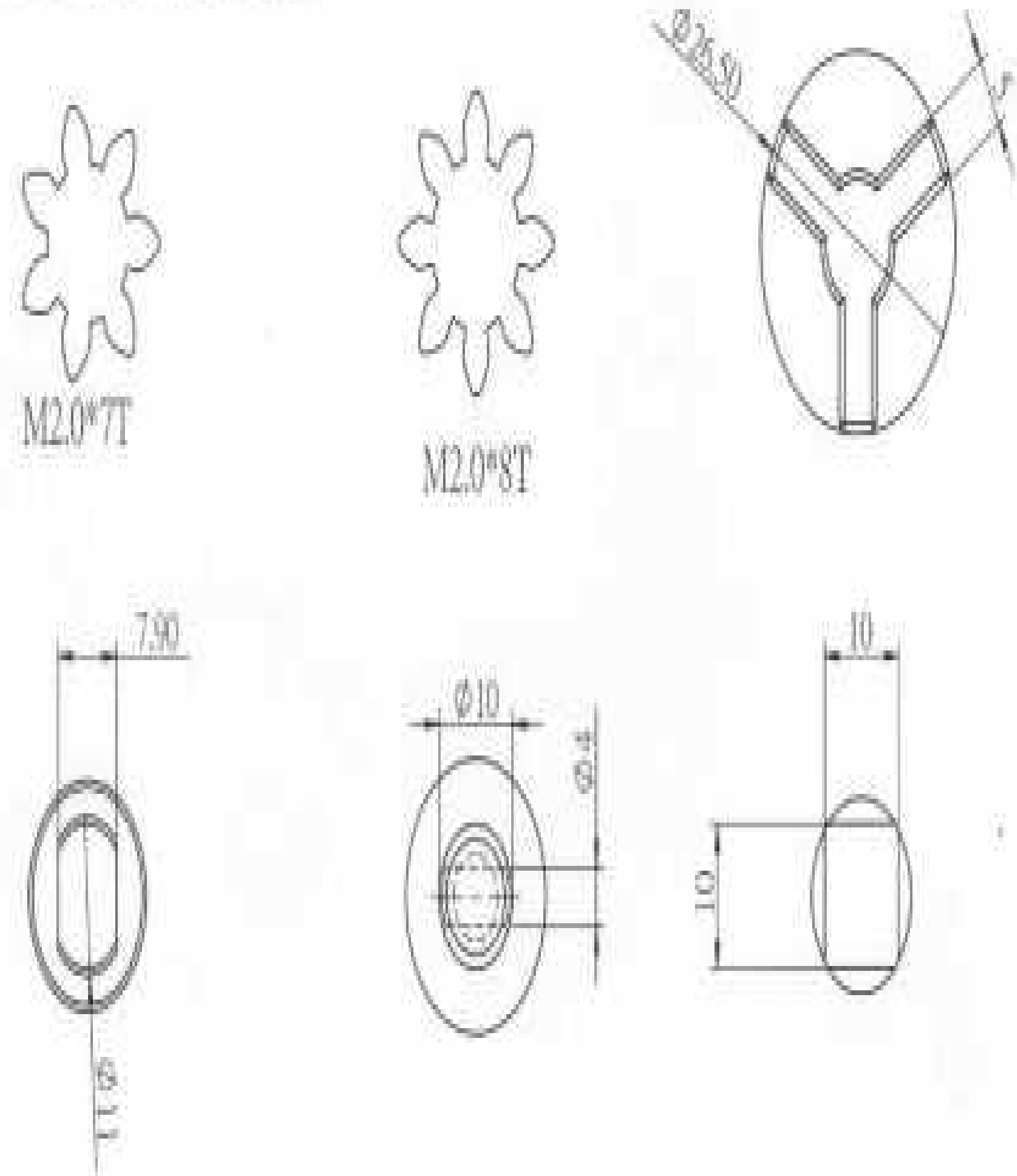
Specifications

Key Features:
For ASIA type power window motor.
Noise<52db

1.Stall: 10 +/-2.5Nm, 30A (max) for 12V, 15A (max) for 24V.
2.For automation products ...etc.
3.DC12V 24V(option).
4.Rated Speed: 80 +/-10 rpm
5.Insulation resistance: 1M ohm min.
6.Low Noise<52dbA
7.OEM ODM.

Window power DC Motor LH

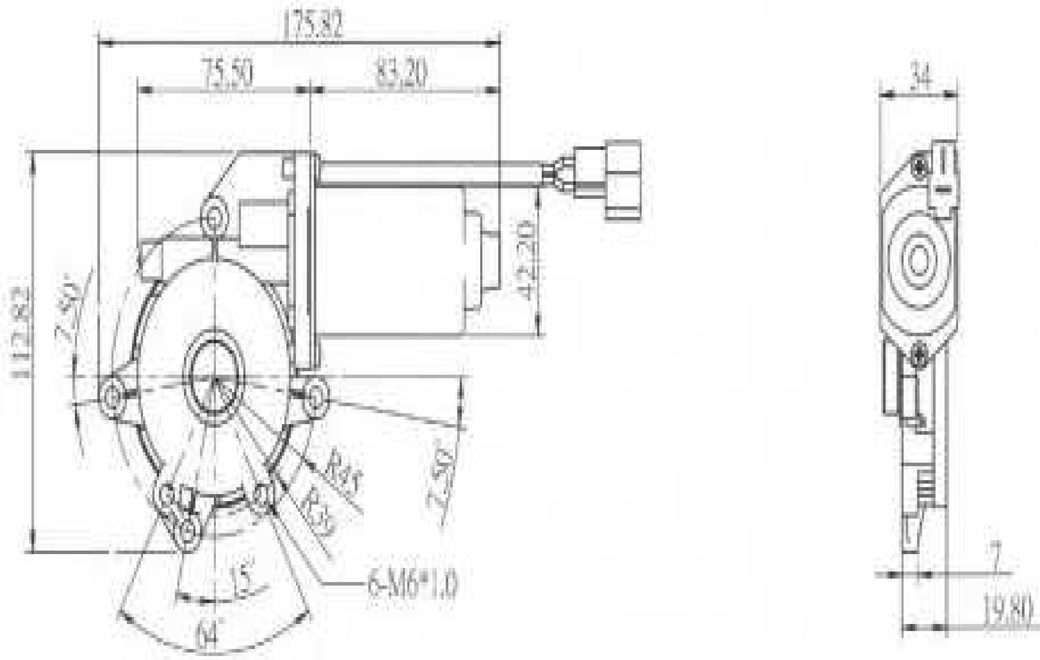
AVAILABLE PINION:



*CUSTOMIZE PINION IS WELCOME.

Window power DC Motor LH

HY-2740A SERIES GEAR MOTOR



MOTOR SPECIFICATION		
RATED VOLTAGE	DC 12V AT MOTOR TERMINAL	DC 24V AT MOTOR TERMINAL
NO LOAD CURRENT	3A MAX	2A MAX
NO LOAD SPEED	90±10 RPM	90±10 RPM
RATED LOAD 3 N*m	9A MAX	4.5A MAX
	62±10 RPM	62±10 RPM
STALL	10±2.5 N*m	10±2.5 N*m
	30A MAX	15A MAX
INSULATION RESISTANCE	1M Ohm min	1M Ohm min
DIELECTRIC STRENGTH	AC 600V BETWEEN CASING AND TERMINAL FOR 1 SEC	