Mechatronics Workshop July 2013

Part I

CONTENTS

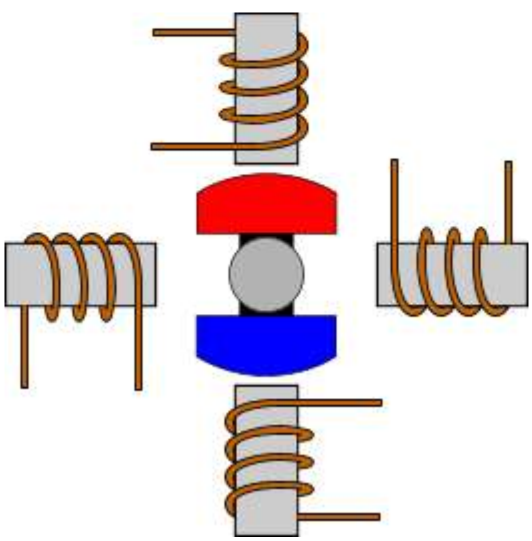
1. MOTORS

1.1 Stepper motor

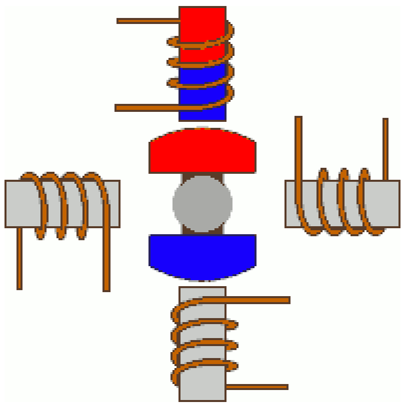
First of all, a stepper motor is a motor. This means, that it converts electrical power into mechanical power. The main difference between them and all the other motors, is the way they revolve. Unlike other motors, stepper motors does not continuously rotate! Instead, they rotate in steps (from which they got the name). Each step is a fraction of a full circle. This fraction depends mostly from the mechanical parts of the motor, and from the driving method. The stepper motors also differs in the way they are powered. Instead of an AC or a DC voltage, they are driven (usually) with pulses. Each pulse is translated into a degree of rotation. For example, an 1.8^o stepper motor, will revolve its shaft 1.8^o on every pulse that arrives. Often, due to this characteristic, stepper motors are called also digital motors.

A very basic stepper motor

As all motors, the stepper motors consists of a stator an a rotor. The rotor carries a set of permanent magnets, and the stator has the coils. The very basic design of a stepper motor would be as follows:



There are 4 coils with 90^o angle between each other fixed on the stator. The way that the coils are interconnected, will finally characterize the type of stepper motor connection. In the above drawing, the coils are not connected together. The above motor has 90^o rotation step. The coils are activated in a cyclic order, one by one. The rotation direction of the shaft is determined by the order that the coils are activated. The following animation demonstrates this motor in operation. The coils are energized in series, with about 1sec interval. The shaft rotates 90^o each time the next coil is activated:

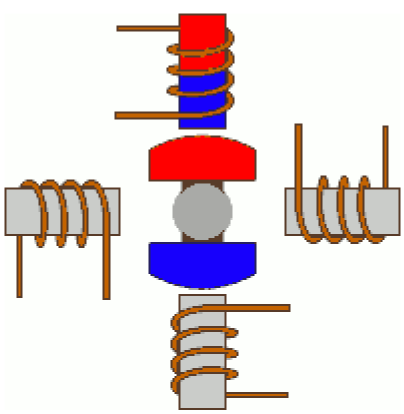


Driving modes

In this section, it will explain the various ways that the coils are energized, and the results on the motors shaft.

Wave drive or Single-Coil Excitation

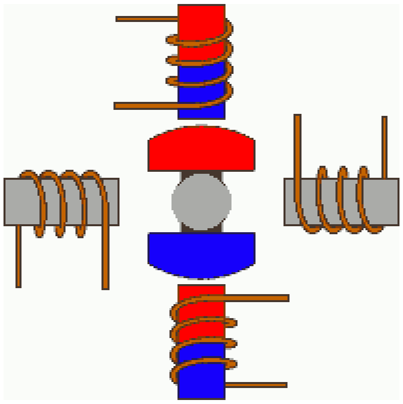
The first way is the one described previously. This is called **Single-Coil Excitation**, and means that only one coil is energized each time. This method is rarely used, generally when power saving is necessary. It provides less than half of the nominal torque of the motor, therefore the motor load cannot be high.



This motor will have 4 steps per full cycle, that is the nominal number of steps per cycle.

Full step drive

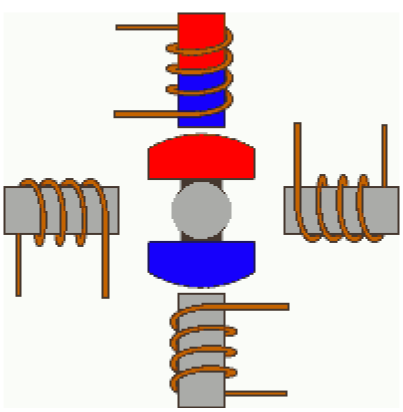
The second and most often used method, is the **Full step drive**. According to this method, the coils are energized in pairs. According to the connection of the coils (series or parallel) the motor will require double the voltage or double the current to operate that needs when driving with Single-Coil Excitation. Yet, it produces 100% the nominal torque of the motor.



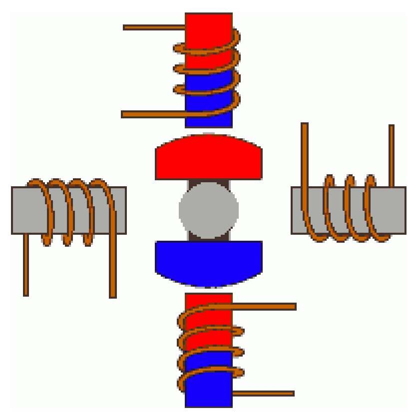
This motor will have 4 steps per full cycle, that is the nominal number of steps per cycle.

Half stepping

This is a very interesting way to achieve double the accuracy of a positioning system, without changing anything from the hardware! According to this method, all coil pairs can be energized simultaneously, causing the rotor to rotate half the way as a normal step. This method can be single-coil or two-coil excitation as well. The following animations make this clear:



Single-Coil excitation



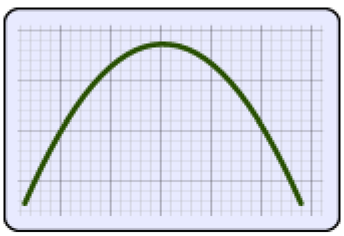
Two-Coil excitation

With this method, the same motor will have double the steps per revolutions, thus double the accuracy in positioning systems. For example, this motor will have 8 steps per cycle!

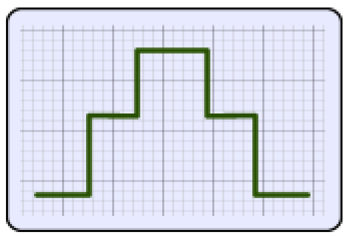
Microstepping

Microstepping is the most common method to control stepper motors nowadays. The idea of microstepping, is to power the coils of the motor NOT with pulses, but with a waveform similar to a sin waveform. This way, the positioning from one step to the other is smoother, making the stepper motor suitable to be used for high accuracy applications such as CNC positioning systems. Also, the stress of the parts connected on the motor, as well as the stress on the motor itself is significantly decreased. With microstepping, a stepper motor can rotate almost continuous, like simple DC motors.

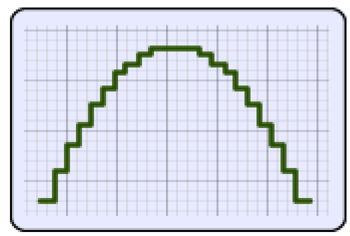
The waveform that the coils are powered with, is similar to an AC waveform. Digital waveforms can also be used. here are some examples:



Powering with sine wave

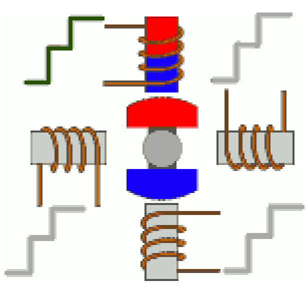


Powering with digital signal



Powering with high resolution digital signal

The microstepping method is actually a power supply method, rather than coil driving method. Therefore, the microstepping can be applied with single-coil excitation and full step drive. The following animation demonstrated this method:

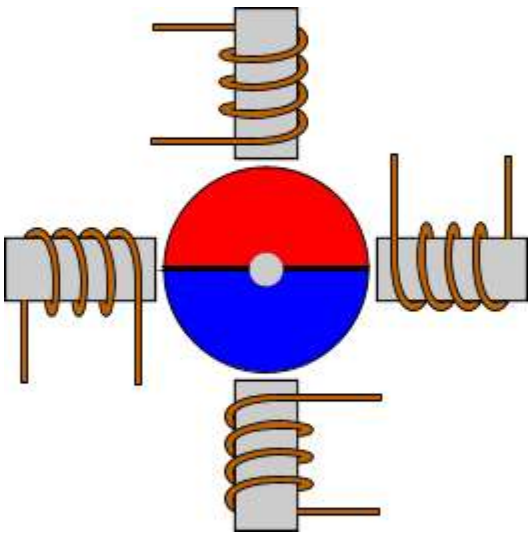


Although it seems that the microstepping increases the steps even further, usually this does not happen. In high accuracy applications, trapezoidal gears are used to increase the accuracy. This method is used to ensure smooth motion.

Stepper motor types

Permanent Magnet Stepper Motor (PM)

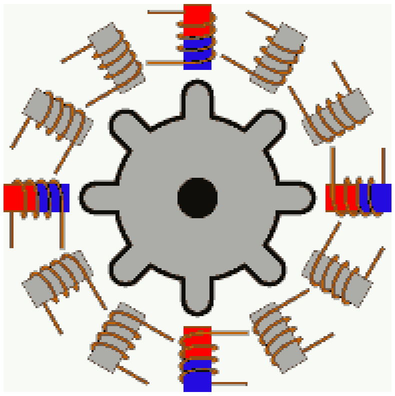
The first and most basic type of stepper motors is the Permanent Magnet (PM). The rotor of the PM motor carries a permanent magnet with 2 or more poles, in a shape of disk. The operation is exactly the one described above. The stator coils will attract or repulse the permanent magnet on the rotor and will generate the torque. Here is a sketch of a PM motor:



PM stepper motors have usually step angle from 45^o to 90^o.

Variable Reluctance Stepper Motor (VR)

The VR motor does not have a permanent magnet on the rotor. Instead, the rotor is made of soft iron, and performs a teethed disk like a gear. The stator has more than 4 coils. The coils are energized in opposite pairs, and will attract the rotor. The lack of a permanent magnet has a negative affect on the torque that is significantly decreased. But it has a great advantage. These motors have no detent torque. The detent torque, is the torque generated by the rotor permanent magnets that are magnetized to the stator's armature, when no current flows within the coils. You can easily understand what this torque is, if you try to rotate an unconnected stepper motor by hand (NOT a VR stepper). You will feel the distinctive "clicks" of each step of the motor. Actually, what you feel is the detent torque that pulls the magnets against the armature of the stator. Here is an animation of a VR stepper motor in operation:



VR stepper motors have usually step angle from 5^o to 15^o.

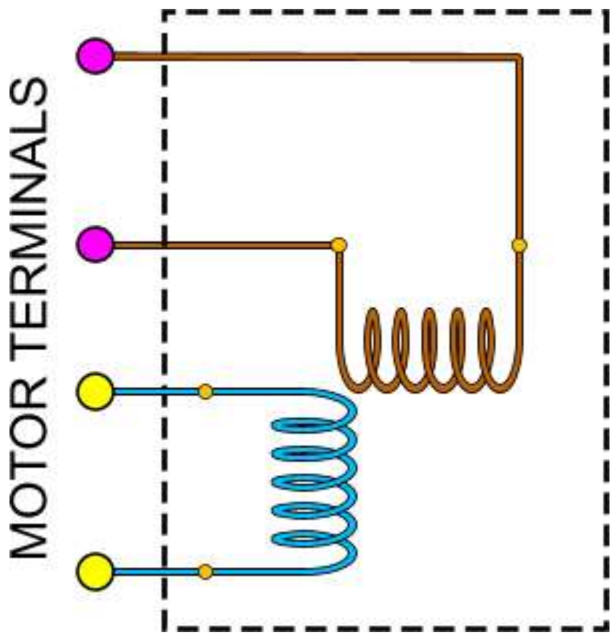
Coil connections

Stepper motors are actually multiphase motors. The more the coils, the more the phases. The more the phases, the smoother the operation of the motor and the higher the price. The torque is irrelevant to the number of phases. The most common type of stepper motor is the two-phase. Two phases, is the minimum number of phases needed for a stepper motor to operate. What you need to make clear here, is that the number of phases does not necessarily set the number of coils. If for example each phase has 2 coil **pairs**, and the motor is a 2-phase motor, the number of coils will be 8. That has to do only with the mechanical characteristic of the motor. To simplify things, i will explain the simplest 2-phase motor with one coil pair per phase.

There are basically 3 different connection types for a 2-phase stepper motor. The coils are interconnected and according the connection, a different number of wires are used to connect the motor to the controller.

Bipolar motor

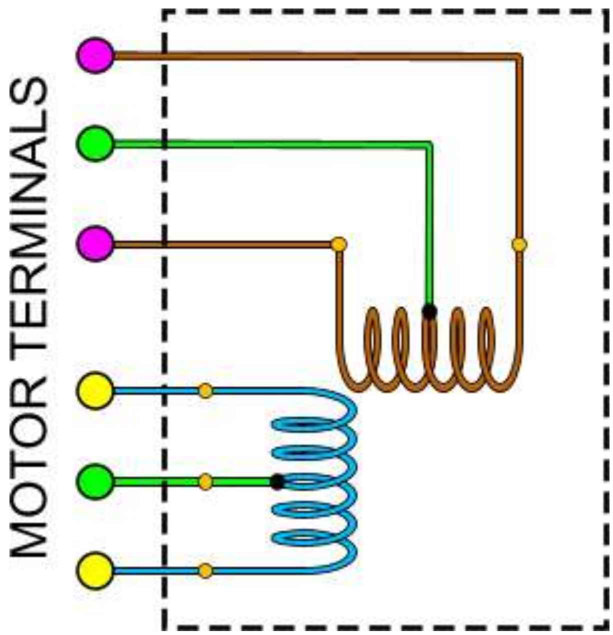
This configuration is the most simple. 4 wires are used to connect the motor to the controller. The coils are internally connected either in series or parallel. This is an example of a bipolar stepper motor:

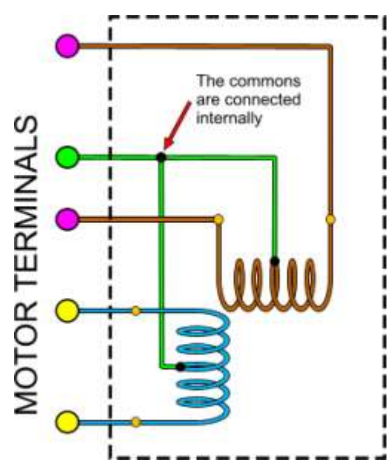


The motor has 4 terminals. The two yellow terminals (**the colors i use are NOT according to standards!!!**) are for powering the horizontal coils, while the two purple terminals are for powering the vertical coils. The problem with this configuration is that, if someone wants to change the magnetic polarity, the only way to do this is by changing the current direction. This means that the driver circuit will have to be complicated, for example with a H-bridge.

Unipolar motor

In a bipolar motor, a common wire is connected to the point where the two coils are connected together:





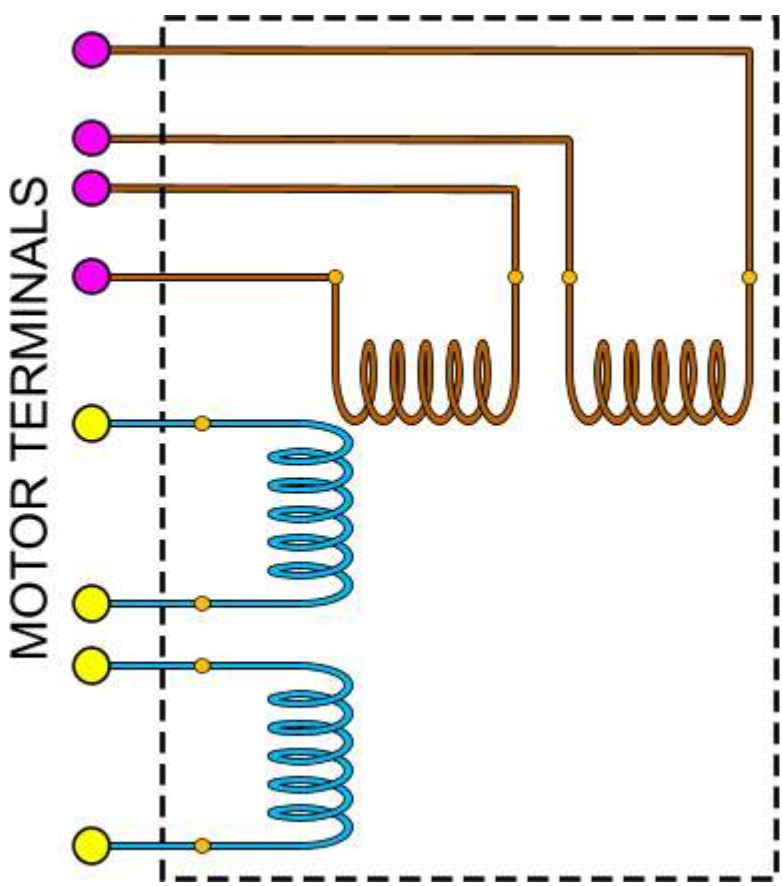
A unipolar motor with 5 terminals

With this common wire, the magnetic poles can now easily be changed. Suppose for example that we connect the common wire to the ground. By powering once the first end of the coil and once the other end, the magnetic poles are changed. This means that the circuit for a bi-directional motor application is very simply, usually with only two transistors per phase. A major drawback is that, each time, only half of the available coil windings are used. This is like the motor is driven with single-coil excitation. Therefore, the torque generated is always about half the torque that would have be generated if both coils were powered. In other words, unipolar motors needs double the space as a bipolar motor, to provide the same torque. The unipolar motor can be used as a bipolar motor, simply by leaving the common wire unconnected.

Unipolar motors may have 5 or 6 terminal wires. The drawing above demonstrates a unipolar motor with 6 wires. There are situations though, that the two common wires are internally connected. In this case, the motor will have 5 wire terminals.

8-lead stepper

This is the most flexible stepper motor in terms of connection modes. All coils have wire terminals for both sides:



This motor can be connected with any connection possible. It can be connected as a 5 or 6 leads unipolar, as bipolar with series windings, as bipolar with parallel windings, or as bipolar with single winding per phase for lower current applications.

1.2 How RC Servos Works

What is an RC Servo?

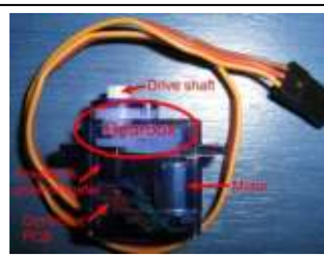
An RC servo

RC Servos are very popular mechanisms in the world of RC models. No matter if this is a train model, or a car, or a boat, plane or helicopter, there must be at least one servo hidden somewhere within the constructions.

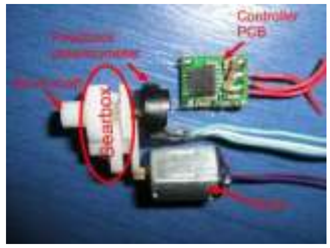
RC Servos are used to convert electrical signal into polar or linear movement. A simple example is the steering system of an RC car. When signal is transmitted from the control to the car, this signal is decoded and sent to a servo. According to this signal, the servo will rotate it's drive shaft for some degrees, and this rotation is translated into wheel steering.

The reason that makes those servos vary handy is that, they have a very easy (and universal) way of driving them with a simple PWM circuit, they can achieve from low to higher torques, enough to move almost everything needed in an RC model, they are very compact and reliable, and most of all, they come with very low prices according to their specifications.

The anatomy of an RC Servo



The anatomy of an RC servo



The servo with the guts out

The vast majority of RC servos are composed with he same blocks:

- **The controller circuit:** This is the "brain" of the Servo. This circuit is responsible to read the user's input signal (pulses) and translate it into a motor revolution in such a way, that the drive shaft will be rotated to the desired position.
- **The feedback potentiometer:** The shaft of the potentiometer is attached to the drive shaft of the servo. When the drive shaft rotates, so does the potentiometer. In that way, each and every rotation angle of the drive shaft, corresponds to a different resistance of the potentiometer. By reading the potentiometers' resistance, the controller is able to know the exact angle of the drive shaft of the servo.
- **The motor:** This is usually a small high speed DC motor controlled by a H-bridge circuit attached to the servos' controller.
- **The gearbox:** The gearbox will drive the motor's revolution to the drive shaft. Also, the rpm will be significantly reduced and the torque will be increased. The torque is one of the main characteristics of RC servos.
- **The drive shaft:** When all of the above operate in perfect harmony, the drive shaft will be rotated with accuracy to the user's requested angle.

Different types of RC Servos

There are lot of different RC servos made from many companies. The basic differences that will increase or decrease the cost are:

- **Precision:** How accurately will the servo translate the input signal into drive shaft position
- **Speed:** how fast can this translation be made
- **Strength:** What torque can achieve during rotation
- **Break strength:** With how much load can be the servos' drive shaft be loaded without loosing it's position

- **Motion type:** How does the drive shaft moves. it could be circular (like motors) or linear (like pistons)
- **Size and Weight:** An important consideration when used in small planes or helicopters. Typically, smaller servos have lower torque.
- **Bearing type:** Standard servos have bushings supporting the main shaft, heavy duty servos typically have one or two ball bearings supporting the main shaft.
- **Gearbox type:** In common, nylon gears are used for the gearbox. For heavy duty servos, there are also metallic gears. Karbonite gears are rather new to the market and offers higher strength than nylon gears (5 times stronger or more) and very high durability, but they are still expensive. The most durable are the titanium gears. They are much more lighter than the metallic gears and in some cases they are more durable than them. Thus, they can achieve higher torques and speeds.
- **Motor type:** The standard motor used in servos is a three pole ferrite motor. For some high speed servos, five poles core-less motors are used. For heavy duty servos, heavy duty core-less motors are used.

According to your application, you should carefully choose the most appropriate servo. For example, an expensive and heavy metal-geared high torque servo could be inappropriate for controlling a helicopter's fin, but it could be an one-way solution for the steering system of a racing car, that the torque loads are very high and a lot of vibrations are sent from the wheels to the servo.

Analog and digital servos

There are two types of servos in the market, the analog and the digital servos. There is no difference in how the servo is controlled by the user. The main difference is how the motor is driven by the servo controller.

The motor of an analog servo would receive a signal from the servo controller (AKA amplifier) at about 30 to 50 times a second. And this is the position refresh speed of the servo. On the other hand, digital servos can achieve position refresh rates up to 400 times per second.

By updating the motor position that often, the digital servo can deliver full torque from the beginning of movement and increases the holding power of the servo, about 3 times higher! The quick refresh also allows the digital servo to have a tighter dead-band. Moreover, the response of the servo is significantly increased, and in conjunction to the increased holding power and the faster max torque delivery, the digital servos can accurately set and hold a position on the shaft.

Digital servos can be programmed for direction of rotation, center and end points, fail-safe option, speed, and dead bandwidth adjustment. You do not need to worry about programming as most of the digital servos operate like normal servos out of the box and require no programming.

A main drawback of digital servos is that they are much more expensive than analog servos, and require more power from your batteries.

Theory of operation

The block diagram of the automation for an RC servo

The servo is actually an implementation of an **ACS** (**A**utomated **C**ontrol**S**ystem). When no input signal is detected from the controller, the servo does just nothing. When an input signal is driven, the following actions are taken:

- The controller will decode the signal into a reference voltage. Each voltage corresponds to different drive-shaft position
- The controller will read the drive shaft position by reading the feedback potentiometers' voltage.
- A comparison shall be made between those two voltages. If the potentiometers' voltage is greater than the reference voltage, the motor shall be rotated one way. If it is less than the reference voltage, the motor shall be rotated the other way. Then, the comparison shall be made again.
- If after the comparison the two voltages are equal, this means that the required position has been achieved and no more actions should be taken
- At any time, the servo is never idle. It always check if the drive shaft has change position due to any external interference. If it does, the controller will try to correct the position. Therefore, the input signal should always be driven to the servo if the desired position needs to be held.

RC Servo connectors

It would be very nice to have one type of universal connector that all manufacturers would use, but this is yet not true. Although nowadays standards are trying to be settled, still there are servos with different connectors and color codes. Therefore, it is highly recommended, before you proceed connecting a servo or experimenting with it, to check first what each wire does.

Following we have a table with some known manufacturers and the color code that they follow. Not that servos have 3 wires that comes out: One wire that goes to the positive of the power supply, one that goes to the negative of the power supply, and another one with the input signal.

Manufacturer	**Positive**	**Negative**	**Signal**
Airtronics (Obsolete)	RED	BLACK (in the middle)	BLACK, WHITE or BLUE
Airtronics / Sanwa (Obsolete)	RED	BLACK	WHITE or YELLOW
Airtronics / Sanwa	RED	BLACK	BLUE or YELLOW
Futaba	RED	BLACK	WHITE
Hitec	RED	BLACK	YELLOW
Japan Radio	RED	BROWN	ORANGE
Tower Hobbies	RED	BLACK	WHITE
Kyosho / Pulsar	RED	BLACK	YELLOW

If you cannot find your servo on the above table, or cannot find the manufacturer, you should get some help from the following general information:

- The vast majority of modern servos have the positive wire in the middle (just to avoid damaging the controller in case of reverse plug insertion)
- Most older Futaba servos use a "G" type plug.
- Modern Futaba "J" connectors have a little polarization slot or tab
- Some old Airtronics connectors have a gray or white strip on the positive wire
- The old Airtronics connectors have three ridges on top
- In general, BLACK or BROWN should be negative, RED should be positive and BLUE or WHITE or YELLOW should be the signal

How to control an RC Servo

A very simple PWM servo controller circuit to test our servo in the labs

The power supply of servos is usually from **4.6 to 6 volts**, and that could vary between manufacturers and types. For maximum torque and speed achievements, you should supply the servo with it's maximum nominal voltages.

As mentioned before, servos are controlled with a PWM signal driven to their signal wire. A PWM signal has three parameters that characterizes it: The first is the amplitude (or peak to peak voltage) of the signal. You should use from 3 to 5 volts for your signal, according to it's specifications. The second is the frequency. In PWM, the frequency is usually fixed to a value. For analog servos the frequency is**30-50 Hz**, and for digital servos it is **300 to 400 Hz**.

The third and most critical value is the positive pulse with of the PWM, AKA "duty cycle". The width of the pulse will have a direct result into the drive shaft position. In other words, to control the position of a servo, you should change the duration of the positive pulse of the PWM signal driven to the signal wire of the servo...

The translation of pulse width to drive shaft position is not easily to be made. It depends on the manufacturer and the type of servo. It is a good beginning to say that the pulse width duration for a full drive shaft move should be within the range of **1mSec to 2mSec**. If we take for example a rotary servo, a PWM with positive pulse width 1mSec would cause the shaft to revolve fully left. A 2mSec positive pulse width would cause the drive shaft to revolve fully right. 1.5mSec pulse width would cause the shaft to turn to the middle of the revolution area.

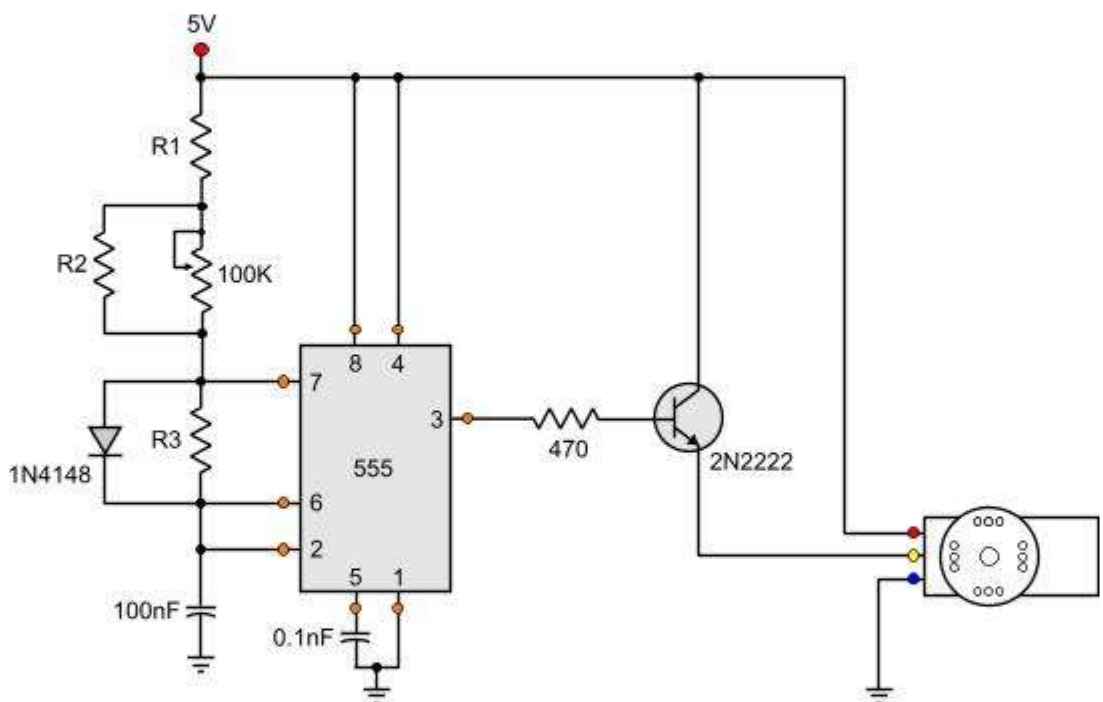
There are of course manufacturers that have different min and max pulse width duration values. But those differences slightly differs from the range of 1 to 2 mSec.

An RC Servo in the lab

And here is an example. Using a very simple PWM circuit, we will control an RC servo. This is the best circuit in terms of flexibility and simplicity that i have came up with. It is able to change it's frequency, its highest and it's lowest pulse width duration by just changing one component each time! With the addition of 3 potentiometers (instead of three set-up resistors) the circuit can change all the above characteristics with just a screw driver!

The circuit

Following, i have added the above circuit schematic diagram.



As you can see, the circuit is a 555 connected as astable multivibrator. The servo is controlled through a 2N2222 transistor directly connected to it's signal wire. You should add a resistor if your RC needs lower signal voltage, and also you should take care about the supply voltage of your servo. If it is powered with lower than 5V, you should add a zener diode accordingly.

There are 3 componnents, three resistors in the circuit that have no value, the **R1**, the **R2** and the **R3**. Those components are the ones that changes the characteristics of the output signal. The resistor **R3** is the one that will change the **PWM frequency**. In my test circuit, this resistor is 470K, and this results in an oscillation of about 35Hz.

The second resistor is the **R1**. By changing the value of this resistor, it results to the lower positive pulse duration. In my test circuit, this resistor is chosen to be **6.9K** (two resistors in series, one 2.2K and one 4.7K) and as a result i get about 0.6mSec minimum pulse duration.

The third and last resistor is the **R2**. By changing it's value, it results to the maximum positive pulse duration. I have chosen a **33K** resistor. The maximum pulse duration that i get with this resistor is about 2.5mSec.

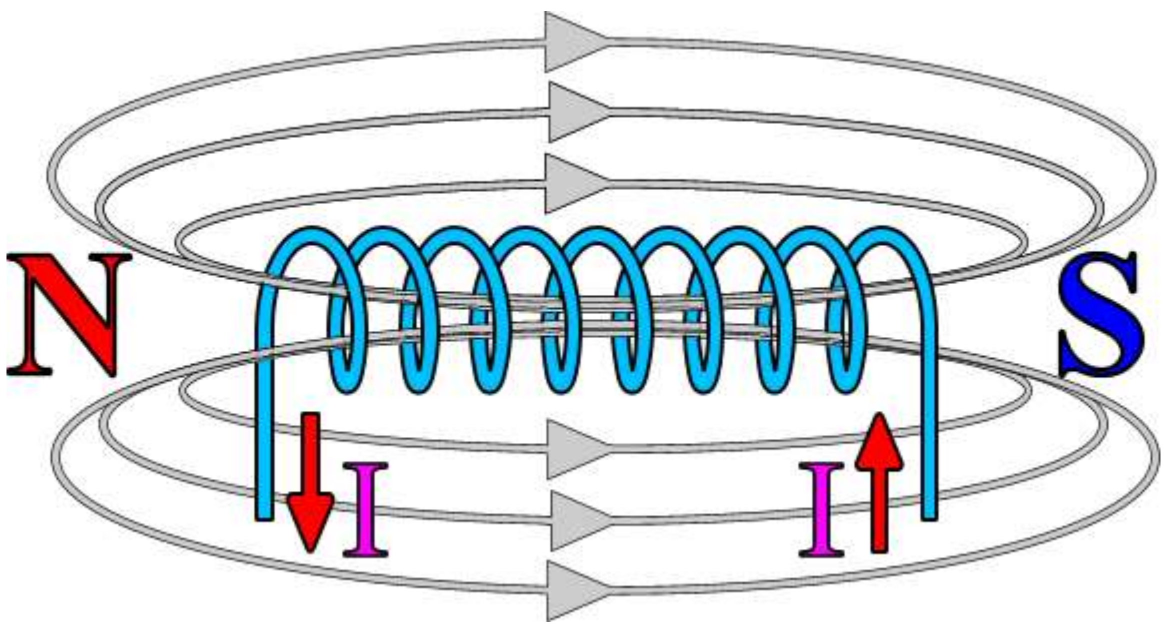
As you can see, this is a very flexibly circuit. If you change the R1 and R2 resistors with a rheostat, then you will be able to change the minimum and maximum angle of the drive shaft by simply changing those rheostats. Isn't that something for such a simply circuit!

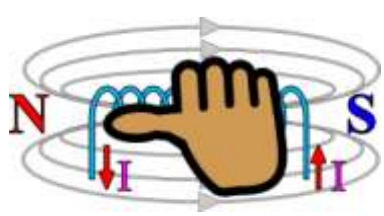
1.3 How DC Motors are made and how they work

In the following article, explained the principles of operation of a brushed DC motor with permanent magnets. Also showed how a DC motor (with permanent magnets) is made and what is inside in such a motor.

The Ampere's rule (the right-hand screw rule)

It is Frenchman Andre-Marie Ampere (1775–1836), a mathematician and physicist, who discovered what happens to a wire winded in a coil when current flows within. The current will generate a magnetic field around the coil, as shown in the following drawing:

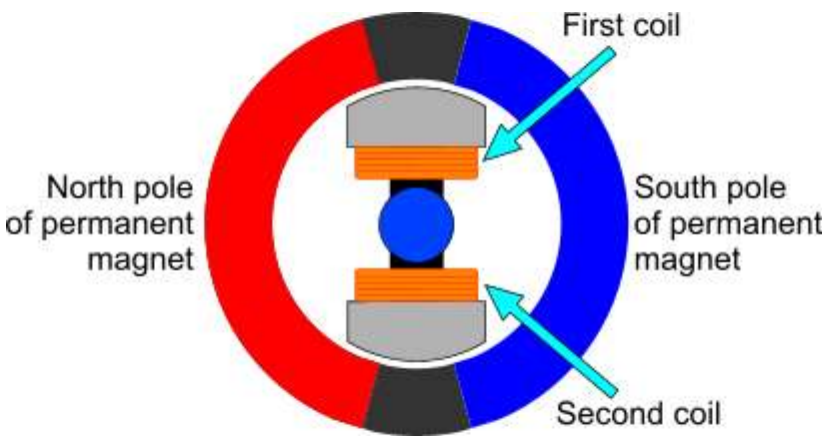




The "right-hand screw rule"

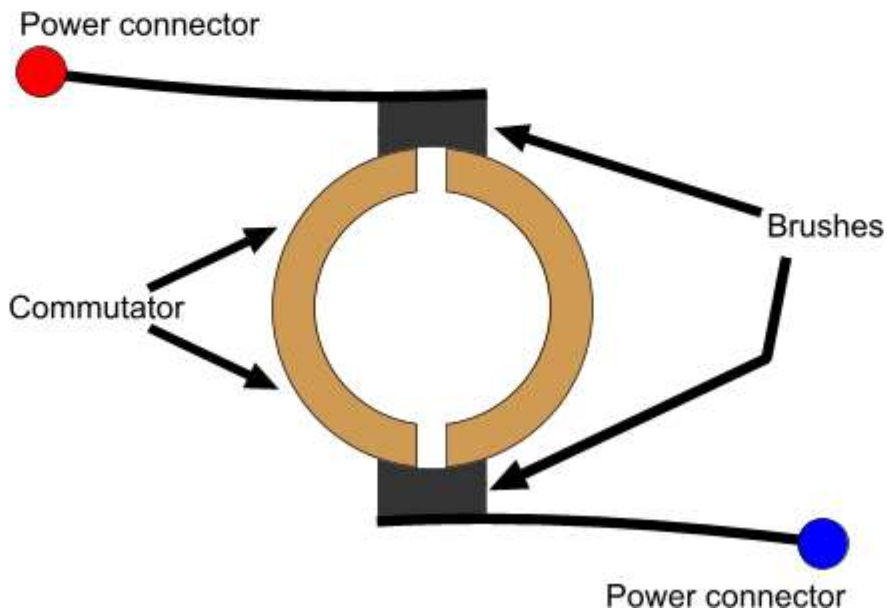
Using your right hand, you can find out the direction of the magnetic lines as well as the North pole orientation. Close your fist and hold your thumb upwards, like thumbs-up. If you had the coil inside your hand and your fingers (except the thumb) was showing the direction of the current, then the thumb shows the direction of the magnetic lines as well as the orientation of the North pole. This is called "the right-hand screw rule".

The basic DC motor has actually two windings and two permanent magnets. The coils are powered from the commutator and the brushes. We will see these two later on. For now, you only need to know that during a full cycle of the rotor, the current that runs through each winding change direction once. Thus, each electromagnet will change its magnetic polarity. Moreover, the windings of the two magnets are winded in reversed direction. Thus, when one electromagnet is North, the other is South and vice versa. Look at the following drawing of the basic DC motor:

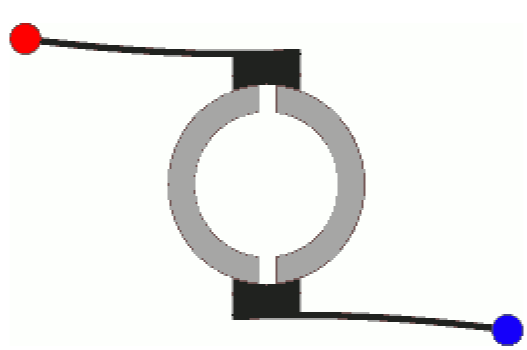


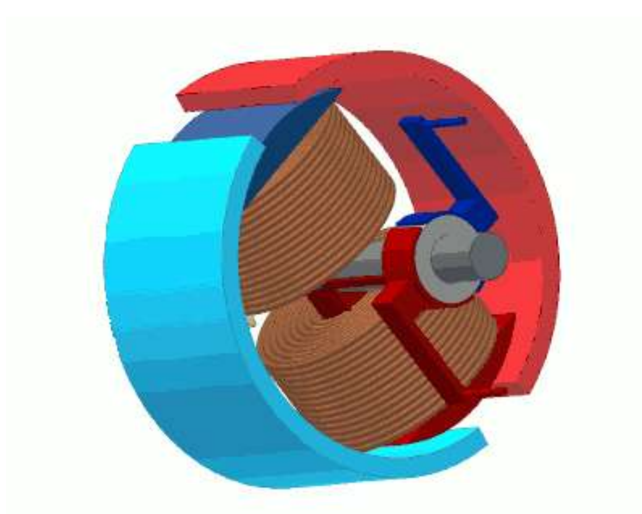
The commutator and the brushes of a DC motor

This kind of DC motor is called "Brushed DC motor". Why? Because it uses brushes... The brushes are the way that the motor provides the coils with power, and the geometrical characteristics and position of the brushes (and the commutator of course) will be responsible for changing the magnetic field of the two electromagnets according to the position of the rotor. So, how this is done? The brushes are two metallic pieces that act like springs. On one side, they have a piece of conductive material, usually made of carbon to stand against friction. On the other side, they have the pin that the power supply is applied to the motor. The brushes are pushed (by the spring action of the metallic part) against the commutator. The commutator is a metallic ring, also conductive and able to stand friction, that is divided in two parts. The following drawing explains how these parts are:



The commutator is fixed on the shaft of the motor. Each semi-ring has one pole of each coil. Giving thus power to both half-rings, is like giving power to the coils. But while the shaft of the motor rotates, the commutator rotates as well. This causes the poles of the power supply provided to the coils to change. This change of the electric poles, has an affect on the magnetic poles as well. The current direction is changed and - due to the rule of the right-hand screw - the poles of the electromagnets will also change. The following two animations indicates this procedure. The left one shows the brushes and the commutator from above, while the right one shows how the electric and magnetic polarity is changed.





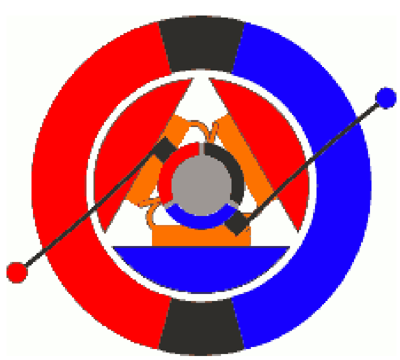
Notice how each part of the commutator changes polarity as it rotates. This is the basic operation of the DC motor. Notice also, that there is one moment that the commutator is short-circuited. During this time, the motor produces no power at all, and also the short-circuit can cause several damages due to over current. This of course does not happen in real life.

Real life is different

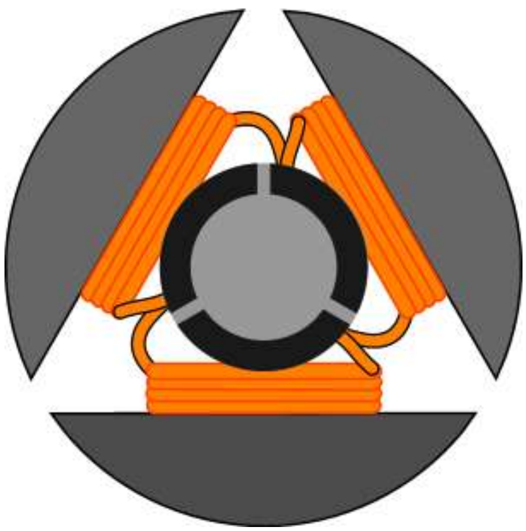
This is a schematic drawing of the coil arrangement of a real motor.

Indeed it is. Nevertheless, the theory of operation is absolutely the same as above. What changes is the number of coils. Instead of 2, there are actually 3 coils that takes part. These 3 coils will solve the following 3 problems: First of all, there is no more this position that the commutators are short-circuited, and the motor will provide all the time torque, without the problems from over-current. Also, while in operation, always two or three coils will be active and interact with the permanent magnets. And because the coils have 120^o angle between them, the torque provided by the motor is much more smooth and never falls to 0. Finally, if the motor had 2 coils and it was stopped in this position where the commutator is short-circuited, it would be impossible to start it again.

Of course, the 3 coils require now a different construction of the commutator. It is composed by 3 pieces instead of two, and the gaps are in circular pastern with 120^o angle. The brushes are again two. The following animation shows how the real motor with the 3 coils works:

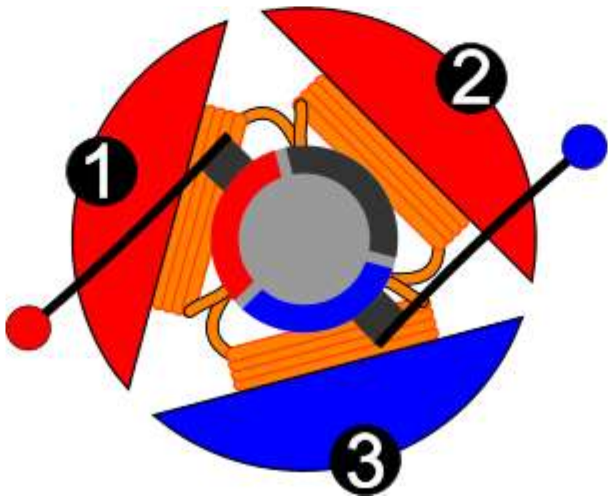


The way that the armature changes magnetic polarity is not that easy to understand as in the simple motor with 2 electromagnets. To understand the operation, you need to know first of all **how the electromagnets are internally connected**. The following image indicates this connection:

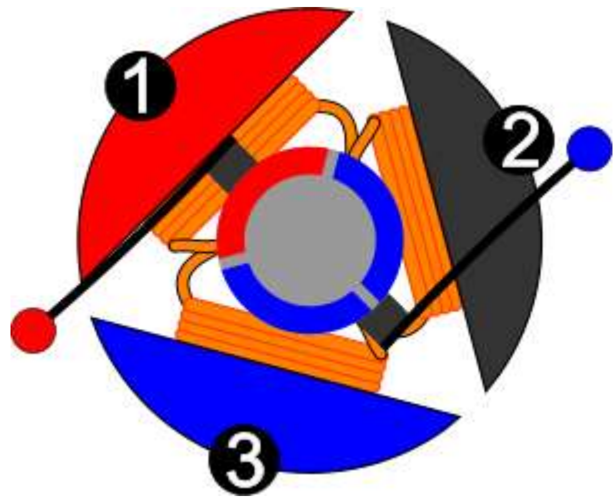


All electromagnets are winded with the same direction of rotation. Now, we have to distinguish two different situations as the motor rotates, The first situation, is when a brush is between two collectors. At this moment, all collectors are having power. During this time, one coil will have the same polarity between its poles, thus, this coil will NOT produce a magnetic a field as no current flows within.

The other situation is when one commutator piece has no power. This happens most of the time during the rotation of the motor. This commutator piece will act as a bridge for the two coils, that have one wire connected on it. Thus, these two coils will be considered as connected in series! And because their windings -as said before- have the same direction, they will both produce a magnetic field of the same magnetic polarity. The following two images indicates these two situations.



The piece of commutator that is black has no power. It acts like a bridge for coils 1 and 2. These coils are connected in series and they generate the same magnetic polarity.



All commutators have power. This time, coil 2 has both its ends to the same electric polarity - NEGATIVE. Thus, coil 2 will produce no magnetic field at all.

How Brushless Motors Work (BLDC Motors)

This motor could be characterized as the modern kind of DC motor. The letters BLDC means **B**rush-**L**ess **D**irect**C**urrent. So, these motors have no brushes. It is better to start learning from the simplest motors.

How are the Brushless DC (BDLC) motors made?

PC fans use BLDCs for their silent operation and reliability

The controller circuit for PC fans is so small, it can fir on the back side of the motor!

The brushless motor, unlike the DC brushed motor, has the permanent magnets glued on the rotor. It has usually 4 magnets around the perimeter. The stator of the motor is composed by the electromagnets, usually 4 of them, placed in a cross pattern with 90^o angle between them. The major advantage of the brushless motors is that, due to the fact that the rotor carries only the permanent magnets, it needs of NO power at all. No connection needs to be done with the rotor, thus, no brush-commutator pair needs to be made! This is how the brushless motors took their name from. This feature gives the brushless motor great increament in reliability, as the brushes wear off very fast. Moreover, brushless motors are more silent and more efficient in terms of power consumption.

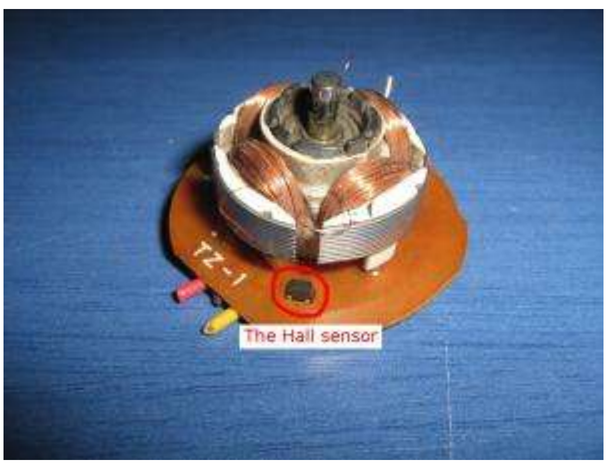
A brushless motor has yet another major difference from the brushed motors. In the theory of operation of the brushed DC motors with permanent magnets, i explain how the commutator is made and how the coils changes polarity during rotation. But brushless motors have no commutator nor brushes. Thus, there is actually no way of knowing where each time the rotor is.

Well actually they do know. There are several ways to find out where the rotor is. Sometimes they use rotary encoders along with their controllers and they know exactly the angle that the rotor is. Others use pairs of Hall sensors while most of them use just one Hall sensor. You can learn more information about the Hall sensor in this page. The Hall sensor is placed in an appropriate position. It can sense if in front of it is the North or the South pole. The Hall sensor will then transmit this signal to the controller of the motor. The controller will then switch on or off the appropriate coils needed in order to provide the torque. And that's the way it goes...

As you understand, this is a major drawback of brushless motors. They need of a controller circuitry to operate. Yet when reliability is required, this motor is the most suitable. The following video demonstrates exactly how a typical (and very popular type) of a brushless motor is made:

How the brushless motors work?

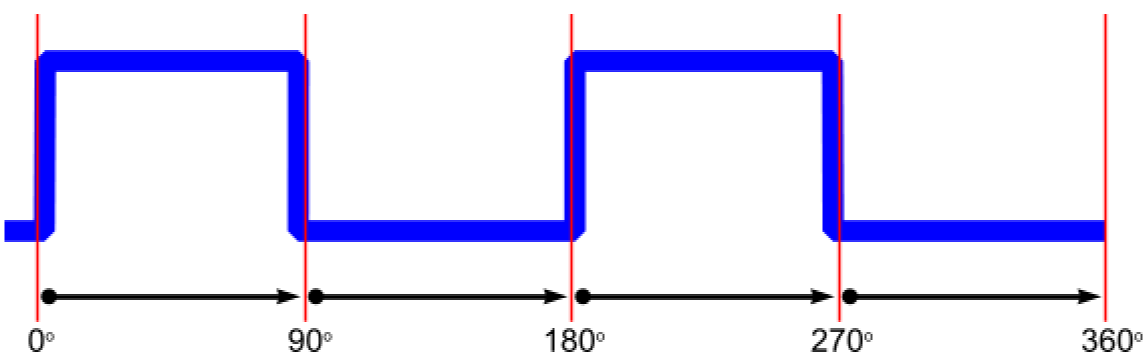
The trick of operation in BLDC motors is the **Hall sensor** that is attached to the stator. It faces the magnets perpendicularly and can distinguish if the North or South pole is in front of it. The following image shows this Hall senor. The photo is taken from a PC fan (yes, PC fans do have BLDCs!):



To better understand the operation of the Hall sensor in respect to the rotor position, i will show you an animation with only 2 magnetic poles and 2 coils. The magnetic poles are both South poles:

The Hall sensor is this little component under the right electromagnet. When it senses the South pole, it keeps the coils turned off. When the sensor senses no magnetic field (or could be also the South pole), then it turns on the coils. The coils have both the same magnetic polarity which is North. So they pull the opposite pole and torque is then created.

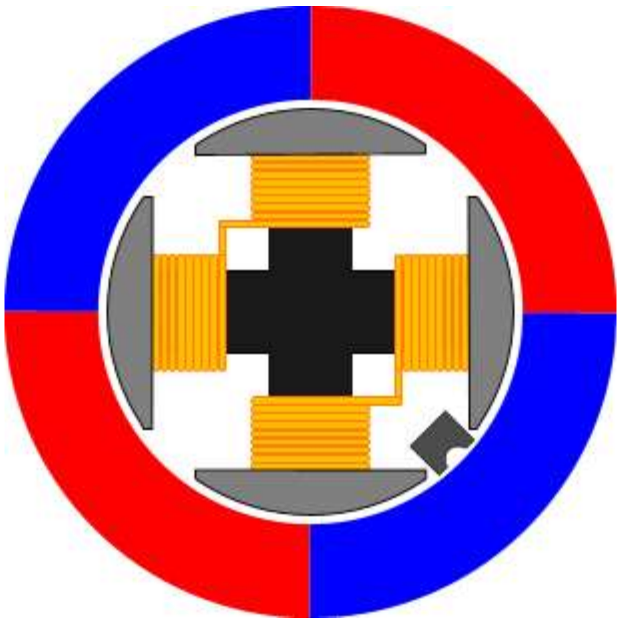
If you put a probe to the Hall sensor and watch the signal, then you will discover that during a full rotation of the rotor, the Hall sensor is two times HIGH and two times LOW. The waveform on oscilloscope would be like this one:



Yet another great advantage for the brushless motors. This very signal that is used to control the coils, can be used as is for measuring the speed of the motor! It can also be used to see if the motor is functional or not! Actually, this signal is exactly the one that comes out from the third wire from the PC fans that have 3 (or 4 wires)! These fans do not have any extra circuitry to measure the speed of the motor. They use the signal from the Hall sensor. Each revolution will generate 2 pulses. With a simple frequency measuring circuitry, someone can measure precisely the rpm of the motor.

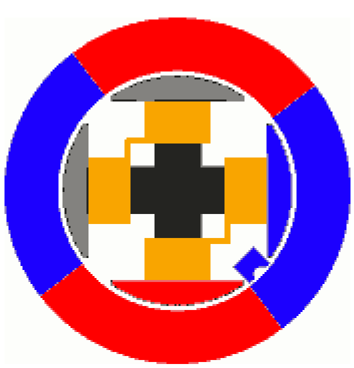
A real brushless motor has 4 coils

I explained above the operation principle of a brushless motor with 2 coils and 2 permanent magnets. Yet, in real life, BLDCs have usually 4 coils and 4 magnets. Also, the Hall sensor is able not only to see if a magnetic field is in front of it, but also to distinguish if this is the North or the South pole. This is how a real BLDC motor looks like:



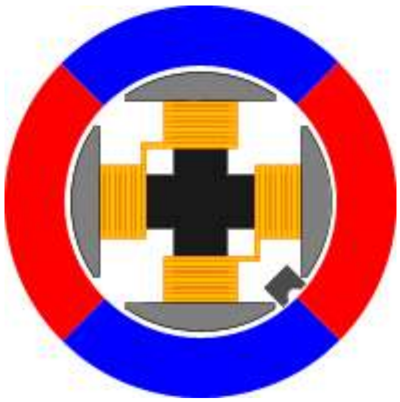
Around the perimeter of the rotor, there are 4 magnets in N-S-N-S patten. Also, there are 4 coils. The windings of the coils are not all of the same direction. 2 neighbor coils can never have the same magnetic polarity. The coils are connected in pairs, either each one with it's opposite coils, or there in two pairs or neighbor coils like shown on the above drawing.

The simplest operation cycle is, according to the pole that is in front of the Hall sensor, the controller will turn on or off the appropriate coil pair. The following animation demonstrates this cycle of operation:



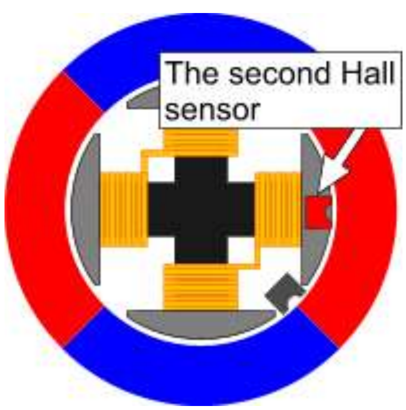
And when the Hall sensor is between the two poles?

I had this question myself. What will happen if the rotor is stopped in a position where the Hall sensor is exactly between two different poles? Look for example the following drawing:



It may happen... Now the Hall sensor cannot sense exactly which pole is in front of it. Well, this is actually not a big deal... Suppose that the sensor senses the wrong pole and gives power to the wrong coils. What will happen? For a fraction of a millisecond the motor will try to rotate the wrong way. But a few degrees of rotation will bring the correct pole in front of the Hall sensor and it will immediately change the coils. Thus, the motor will then turn on the correct rotation.

But what if the motor controls a critical load and this backwards rotation, even if it is under 5^o must NOT occur? There is a solution for this, but it requires the use of another Hall sensor. The second sensor will be placed with 45^odifference from the first one:



Now, even if the first Hall sensor cannot get a proper reading, the second Hall sensor can clearly distinguish the magnetic pole. The controller will accept as "correct reading" the one that comes from the sensor with the most intense signal.

The Sensorless BLDCs

Yet another variation of the brushless motors. Using a Hall sensor will result in an increase of the overall price of the motor. Moreover, there are situations that a sensor cannot be used, as for example in submersible pumps, or in applications where the wiring must be kept to minimum. In such applications, the sensorless BLDC can be used instead. The operation of such motor is based on the BEMF effect. The BEMF (**B**ack **E**lectro-**M**agnetic **F**orce) is inducted by the movement of a permanent magnet in front of a stator coil.

There are two problems that must be solved for the proper operation of the motor. First of all, the rotation direction. As no sensor is used, the controller cannot know where the rotor is stopped at any time. Thus, the rotation direction that the motor will start is -at least for the first degrees of rotation- coin toss. The other problem is the zero detection. The controller does not know when to change the polarity of the coils, as there is no sensor to sense when the permanent magnet pole crosses a specific point.

There are special designed controller chips to solve these problems. The chips will use the characteristics of the BEMF and the voltage generated on the coils from the BEMF effect. For example, the current produced on a coil due to BEMF will change its polarity, if the rotation of the permanent magnet is changed. Also, the amplitude of the produced waveform is proportional to the speed of the rotors, and the phase of the waveform depends on the position of the permanent magnet in respect to the coil. Yet, this is not the proper article to discuss about sensorless BLDCs in details.

How PC Fans Work

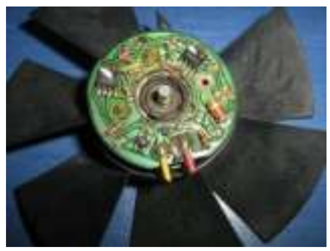
The vast majority of PCs has at least one of them. They carry the heavy load to keep your PC cool and functional, either by providing fresh air in the box, or by forcing the hot air to leave a hot surface by pushing cool air. Read the following article to learn how the BLDC PC Fans operates...

What is inside a PC fan?

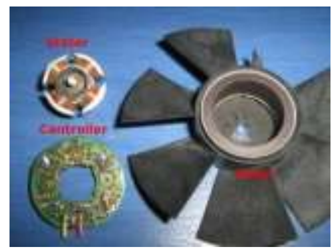
There are may types of PC fans that are assembled in different ways. In this article, i will explain the basic and most common fan type. The fan that i study is a 3-wire 4 coils 80mm fan rotating at 2200 rpm. Then i will explain some other common fans.

First of all i had to disassemble the fan. I am not the right person to disassemble something for the first time due to lack of patience. During the disassembling, i broke some parts of the housing and a fin. Still i did not find any way of easy disassembling. I suppose that the fan i chosen (and maybe many others) are NOT to be disassembled and re-assembled. Anyway, let's see what's inside a PC fan:

A victim in the name of science



Removing the fins from the housing, the controller is revealed



The rotor, the stator and the controller

It is more than obvious that the PC fan is not rotated from a simple DC motor. It has the permanent magnets fixed on the rotor, the stator carries the coils, there are no brushes, it has a controller... the sun is shining... it is of course a brushless motor. I have written a detailed theory about brushless motors. You can find it in the "Theory of operation of brushless motors" page.

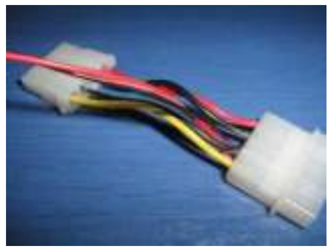
Some different PC fan types

As long as the motor is concerned, i suppose that all PC fans use brushless motors. There are several reasons that a brushless motor should be used, among them is the reliability, the power efficiency and the rpm feedback. So the motor type would not be the proper way to categorize PC fans. Instead, i will categorize them with the most obvious characteristic: their connector.

There are actually 3 different types of PC fans. Those with a 2-pin connector, those with a 3-pin connector and those with a 4-pin connector. Let's see them one by one:

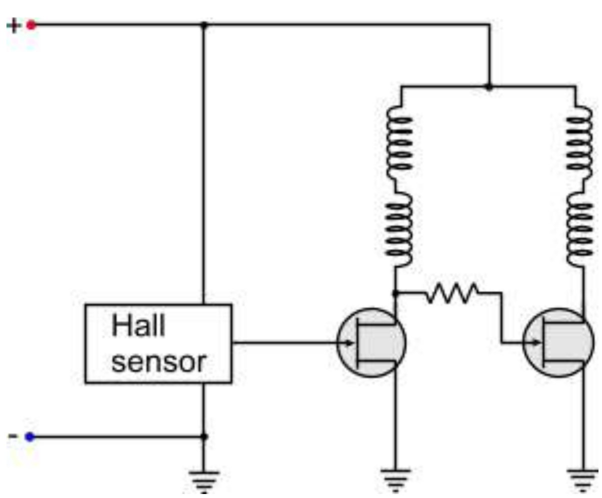
2-wire PC Fans

A 2-wire PC fan



These fans have usually a male-female molex 4-pins connector from where their power supply is drawn.

These are the oldest and most simple PC fans. Only two wires comes out out of the fan controller, the positive and the negative. Giving power to the fan, it will rotate at full speed. The internal diagram of a typical two-wire fan is as follows:



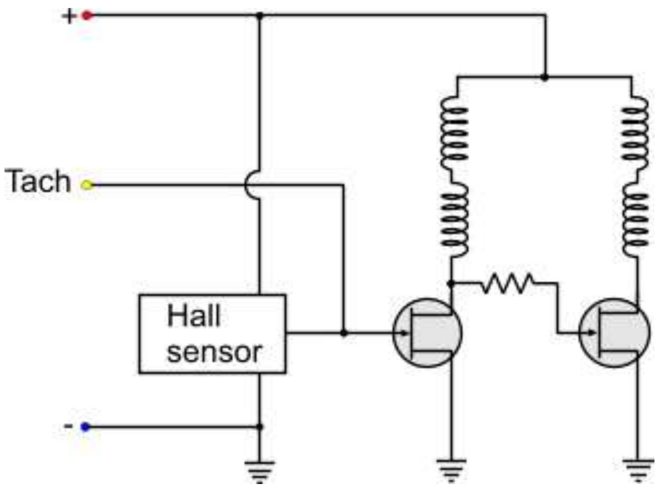
The connector of a 2-wire fan has a red and a black cable. The red cable goes to the positive of the power supply and the black to the negative. Usually, for more flexibility, they have a male-female 4-wire molex power connector. In one end of the connector the fan is connected in parallel with the 12V (YELLOW - BLACK). Therefore, the fan is powered normally and the cable of the PSU can be used to power another device.

3-wire PC Fans

A 3-wire PC fan

Yet another 3-wire PC fan with different wire colors

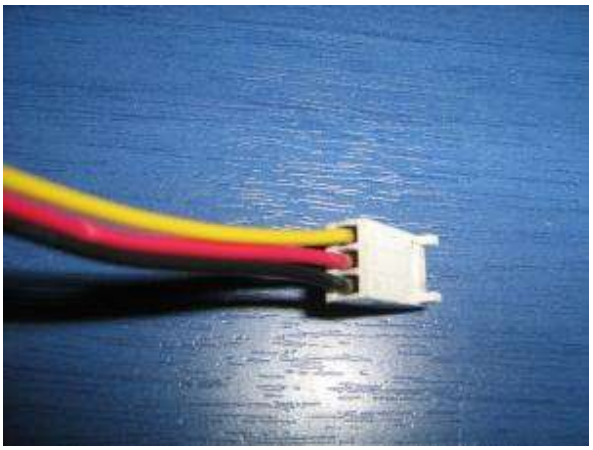
A very common type of PC fan. These fans introduced the "tacho" for the first time. The first two wires are the power supply of the fan. The third wire, comes directly from the output of the Hall sensor. This output generates 2 pulses per one revolution of a fan. The fan is then connected to the motherboard. From the third wire, the motherboard can "read" the tacho of the fan and see if the fan is running and with how many RPMs! It is a great innovation! If the motherboard sees no pulses or very low rpm, then the characteristic buzzer sounds to inform the operator that something is not ok. The internal diagram of a typical three-wire fan is as follows:



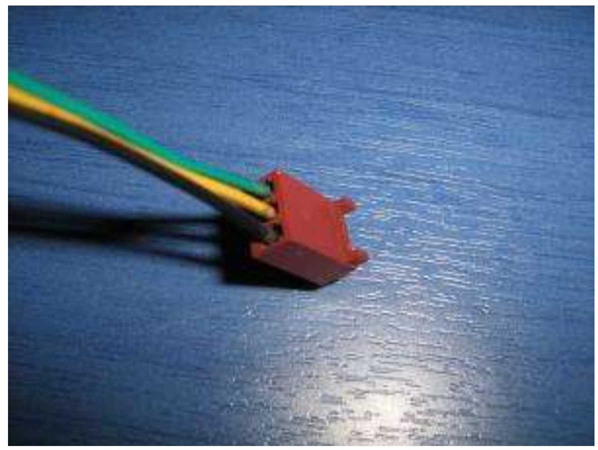
It seems that for once more, the manufacturers did not have the same wire provider, or their wire providers did not have the same colored-plastic provider... Two fans with 3-wire connectors may not have the same wire colors. Thus, instead of using the colors to distinguish the function, better go with the connector that is standard. No matter what color the cable has, it will be plugged in the same motherboard connector! So,**as you look from the key-side of the connector, number 1 is the most left pin**

:

- **1:** Negative power supply
- **2:** Positive power supply
- **3:** Tacho



BLACK: Negative
RED: Positive
YELLOW: Tacho

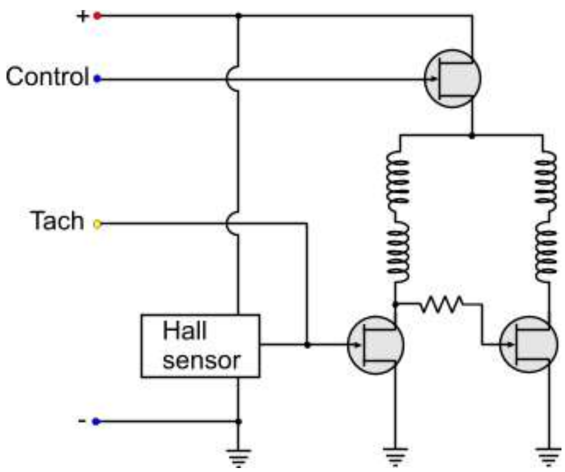


BLACK: Negative
YELLOW: Positive
GREEN: Tacho

4-wire PC Fan

This is the most modern type of PC fan. This fan is designed to be controlled with a PWM signal and increase or decrease its RPM. All fans actually can be controlled with PWM, but this particular type can also provide tacho feedback simultaneously, something that the 3-wire fan cannot do -under normal circumstances. The 3-wire fan powers the Hall sensor and the controller from the same line that the coils are powered. Thus, if someone tries to send PWM pulses to the coils of a 3-wire fan, the same pulses will arrive at the controller. The controller will then malfunction, because it needs constant current to operate. As a result, the third wire will not provide correct readings.

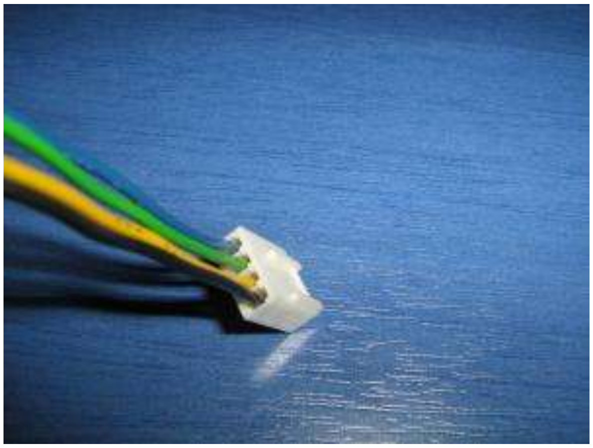
Unlike the 3-wire fans, the 4-wire fans have a slight change that eliminates this problem. The controller and the Hall sensor are always powered with constant current. A transistor (fet) is placed before the coils. The base of the transistor is actually the fourth wire. So, the PWM pulses are driving the transistor. The coils receive these pulses through the transistor, but the controller along with the Hall sensor are not affected at all. This change can be seen in the internal diagram of a typical 4-wire fan:



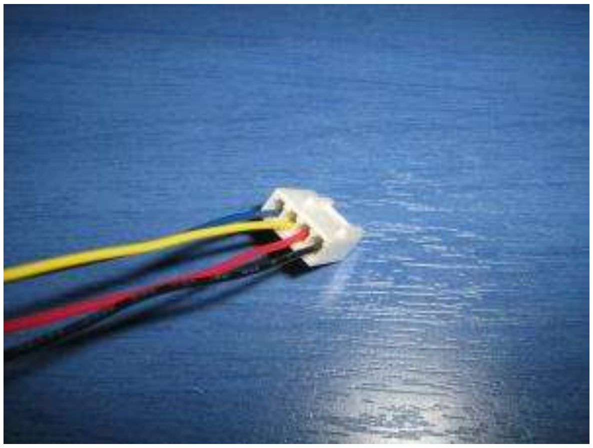
Usually, the diagram is more complicated than this. This is to give you an idea about the principle of operation of the PC PWM Fans (as used to be called). The controller actually checks the PWM input pulses and sends pulses to the transistor accordingly. If the PWM Duty cycle is bellow a threshold value, then the fan either shuts down, or it remains in a stable 'LOW" rpm. There are also fans that even with 0% duty cycle, they keep on running at this 'LOW' speed. This is usually done in critical applications that even if the external controller fails to operate, the internal fan controller will bypass the signal and will keep the fan running.

As for the pinout... Just do not trust the colors. **As you look from the key-side of the connector, number 1 is the most left**:

- **1:** Negative power supply
- **2:** Positive power supply
- **3:** Tacho
- **4:** PWM control



BLACK: Negative
YELLOW: Positive
GREEN: Tacho
BLUE: PWM Control



BLACK: Negative
RED: Positive
YELLOW: Tacho
BLUE: PWM Control

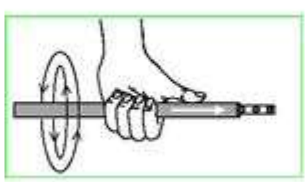
1.4 Induction Motors

How Does An A.C. Motor Rotate?

An electric motor is used for the conversion of electrical energy into mechanical energy. This conversion of electrical power to mechanical energy takes place in the rotating part of the motor. A D.C. Motor is called as Conduction motor, but an A.C. Motor is called as Induction Motor.

Induction Motor Design Principle

We all know that an electric motor is used for the conversion of electrical energy into mechanical energy. This mechanical energy may be used for the pumping of liquid from one place to other by using pumps or even to blow air by blowers or ceiling fans. The conversion of electrical power to mechanical energy takes place in the rotating part of the motor. In D.C. Motors, the electric power is conducted directly to the armature (the rotating part) through brushes & commutator. Thus we can say a D.C. Motor as a conduction motor. But in case of an A.C. Motor, the rotor does not receive electric power by conduction, but by Induction. Thus they are called as induction motors. This can be compared with the secondary winding of a transformer. These induction motors are also called as rotating transformers. Of all motors, it is generally a 3-phase or a poly-phase induction motor is used in a larger extent in many industries



The Direction of rotation of an Electric motor is given by Fleming's Left Hand rule:

- It shows the relation between the direction of "thrust" on a conductor carrying a "current" in a "magnetic field".
- Keep the Thumb, Index finger & the Middle finger of the left hand at right angles to each other.The ***F***irst finger or the index finger indicates the direction of the ***F***ield.
- The se***C***ond finger or the middle finger represents the direction of the ***C***urrent.
- The ***TH***umb represents the direction of the ***TH***rust or the direction of motion of the conductor.

Also other important Law is the Faraday's Law Of Electro Magnetic Induction.There are 3 important rules/laws of electro magnetic induction.They are as follows:

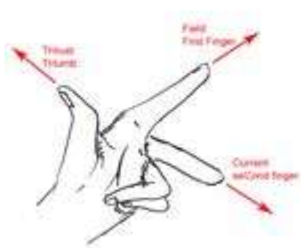
1. An EMF is induced in a coil whenever the flux through the coil changes with time.

2. The magnitude of induced EMF is directly proportional to the rate of change of flux.

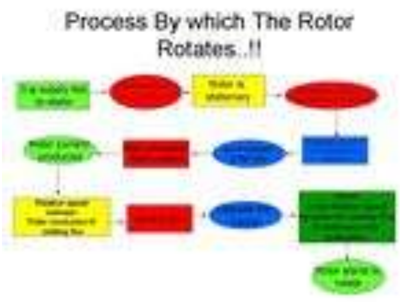
3. The direction of the EMF is such as to oppose the change in flux.

These basic Laws govern the working of an electric motor. Remembering all the above laws, let us find out how the rotor rotates..!

- **Why Does A Rotor Rotate?**

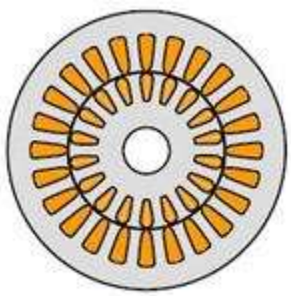


If a 3-phase supply is fed to the stator windings of a 3-phase motor, *a magnetic flux of constant magnitude, rotating at synchronous speed is set up*. At this point, the rotor is stationary. The rotating magnetic flux passes through the air gap between the stator & rotor and sweeps past the stationary rotor conductors. *This rotating flux, as it sweeps, cuts the rotor conductors, thus causing an e.m.f to be induced in the rotor conductors*. As per the *Faraday's law of electromagnetic induction*, it is this relative motion between the rotating magnetic flux and the stationary rotor conductors, which induces an e.m.f on the rotor conductors. Since the rotor conductors are shorted and form a closed circuit, the induced e.m.f produces a rotor current whose direction is given by *Lenz's Law*, is such as to oppose the cause producing it. In this case, the cause which produces the rotor current is the relative motion between the rotating magnetic flux and the stationary rotor conductors. Thus to reduce the relative speed, the rotor starts to rotate in the same direction as that of the rotating flux on



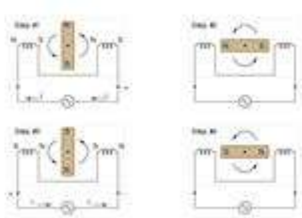
the stator windings, trying to catch it up. The frequency of the induced e.m.f is same as the supply frequency.

Cogging Of Induction Motors



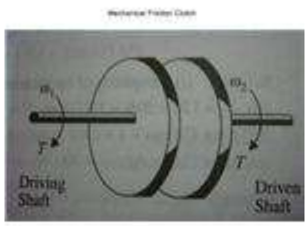
Sometimes, when the supply voltage is low, the squirrel cage induction motor refuses to start. This happens when the number of stator teeth and the number of the rotor teeth is equal, thus causing a magnetic locking between the stator and the rotor. This phenomenon is other-wise called as teeth-locking or Magnetic locking. This problem can be overcome by having the number of rotor slots prime to the stator slots.

Plugging of Motor



The Induction motor can be stopped immediately by just interchanging any two of the stator leads. When an induction motor is rotating at a high speed, during emergency if situation arises that the motor has to be stopped immediately, can be done by interchanging any 2 leads of the stator supply. By doing this, it reverses the direction of the revolving flux, which produces a torque in the reverse direction, thus causing a breaking effect on the rotor. This breaking period is called the "Plugging" period.

Analogy with the Mechanical Clutch



The Rotor Cu loss = Slip * Rotor Input

This is evident by considering the working of mechanical clutch, used in automobiles. By visualizing the figure pf plate clutch, it is evident that the torque on the drive shaft must be equal to the torque on the driven shaft. Further, it should be emphasized that the these two torques are the one and the same, because the torque is caused by the friction between the two plates. Let $1 and $2 be the angular velocities on these two shafts assuming the plate clutch is slipping.

Then input = T*ω1

Output= T* ω 2

But ω 2 = ω 1*(1-s)

So output = T* ω 1*(1-s)

Loss = T* ω 1 – T* ω 2

Loss = T* ω 1 – T ω 1*(1-s)

Loss = s * T ω 1

Thus

Loss = slip * input.

Advantages & Disadvantages

<u>Advantages of A.C. Induction Motors:</u>

1. It has a simple design, low initial cost, rugged construction almost unbreakable

2. The operation is very simple with almost very less maintenance as there are no brushes.

3. The efficiency of these motors is very high, as there are no frictional losses, with reasonably good power factor.

4. The control gear for the starting purpose of these motors is minimum and thus simple and reliable operation.

Disadvantages of A.C. Induction Motors:

1. The speed control of these motors is not easy without some loss in efficiency.

2. As the load on the motor increases, the speed decreases.

3. The starting torque is inferior when compared to D.C. Motors.

1. Induction motors

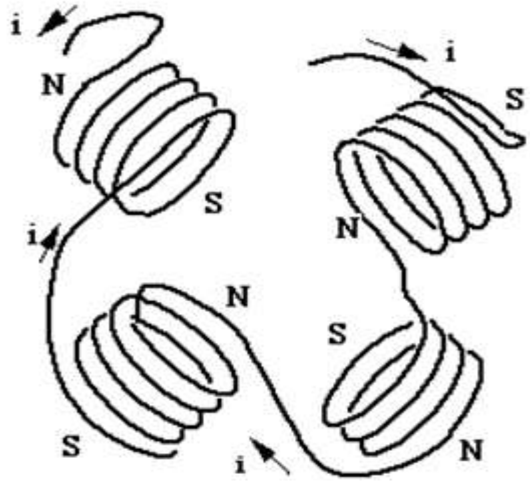
No modern home should be without one – or maybe a dozen. You'll find an induction motor in the fan, fridge, washing machine, dishwasher, clothes drier, and the little pump that circulates water in the fish tank to stop the water turning green and the fish going belly-up. Chances are there's also one in the air conditioner – unless it's a particularly high-tech one.

Advantages:
• Cheap
• Quiet
• Long lasting
• Creates no interference

Disadvantages:
• Wants to turn at constant speed (50Hz divided by half the number of poles)
• Cannot turn faster than 1500rpm (4-pole motor)
• Draws a massive starting current, or is inefficient, or both
• Kind of big and bulky for the power it develops

This one came out of a fan.

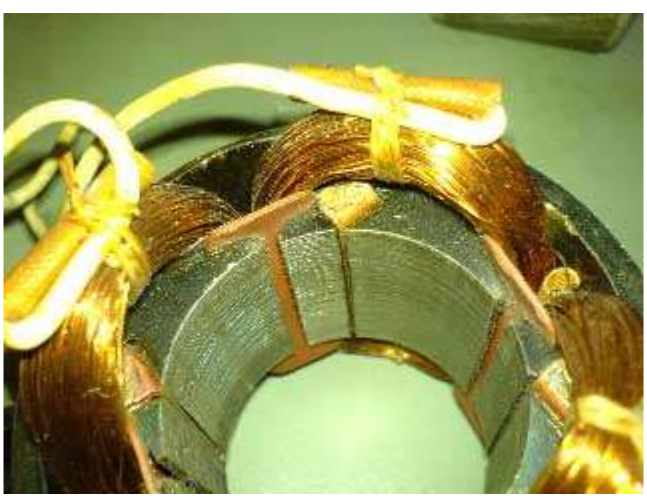
Actually, the bearings and end-caps of the motor have already been removed. (In retrospect, I should have used something more delicate than an axe to disassemble the fan.) We can pull the rotor out and this is what we're left with. There are four windings, and they are all simply in series.



Well, not quite simply – the current comes in the white wire, then the first winding (top right) is clockwise, the next one (bottom right) is anticlockwise, bottom left is clockwise again, top left is anticlockwise, then out the other white wire. So, imagine a positive half-cycle of the mains, with the current actually coming in that first wire. The first winding produces a north pole facing in; the second a south pole facing in; etc, like this: N-S-N-S.

Half a mains cycle later (10 ms) the current has reversed and so must the magnetic sense of the poles, which are now: S-N-S-N. The rotor is an electrical conductor, and therefore tries to follow this field. To do so it has to rotate through 90 degrees. The rotor thus takes two full cycles of the mains (40 ms) to make a complete rotation, and so revolves at 1500 rpm. At least, it would if it could keep up with the rotating field. But it can't, quite, and in fact it's only because it's slipping behind that any torque is developed at all. So, it rotates a bit slower than 1500 rpm (typically 1440 rpm) depending on how much torque it is being called upon to produce.

Note that the motor, as described so far, could rotate happily clockwise or anticlockwise. This kind of motor therefore needs some kind of internal cleverness to ensure it only turns in the right direction. This is achieved, in this motor, by the use of shaded poles.



Notice the winding at the top of the picture. See how there is a small additional pole (or set of iron laminations) off to the left of the main pole. It's excited by the same winding as the main pole, but is "shaded" from it by a thick copper band that wraps around the laminations and acts like a shorted electrical turn. The current induced in this band by the magnetic field generates a phase shift so that the shaded pole can generate a small component of magnetic field at right angles to the main field, and with the correct phase to ensure the fan turns the right way (otherwise the fan would suck instead of blowing).

So in fact our induction motor is using induction already, and we haven't even got to the rotor yet!

Now we look at the rotor. This is a real disappointment – it looks nothing like the "squirrel cage" in the text book! Where's the squirrel supposed to go, for starters?

What's happened here is that the rotor is actually made up of a stack of disc-shaped laminations of soft iron. That's right – it's solid. This concentrates the magnetic field (generated by the windings) into the region where it will do the most good (the conducting bars of the rotor).

You can actually see the edges of the bars that run along the axis of the rotor, but they're at an angle of maybe 30 degrees to the shaft. What's going on here? Bad day at the factory? Chances are it's been designed that way to reduce *cogging torque*. If the bars ran parallel to the axis, the torque would rise and fall as each bar passed under the windings. By slanting the bars, the torque is kept more uniform as the rotor turns.

Now let's look at a different type of induction motor.

This induction motor came out of an astronomical telescope. It was part of the photographic film transport, and needed to be able to turn both forwards and backwards. It therefore has two separate windings, and four wires coming out. One winding is fed directly from the mains (or *"line"* as our US colleagues call it); the other is fed through a capacitor that provides the necessary 90 degree phase shift. Swap the windings over, or reverse the connections to one of the windings, and the motor goes the other way.

No surprises when we take it apart, although note a very different winding pattern to the previous motor. It has more poles, and therefore turns slower.

Once again, the rotor is solid, and we can't see what's inside. The aluminium plate at the end of the rotor has been stamped and turned up into a series of small fins to make a crude cooling fan. (This wasn't necessary with our first motor – it kept itself cool by the simple expedient of placing itself in the middle of, well, a fan.)

Since astronomical telescopes no longer use film, we may as well cut the rotor in half and see if there's a squirrel in there.

No squirrel, but a magnificent set of aluminium conducting bars, just like in the text books. If you think of the rotor bars as forming (via the end rings) a single-turn secondary winding of a transformer, the primary of which (the windings on each pole) has some 50 ~ 100 turns, it is clear that the current through the rotor bars can be very high – as much as 100 amps for a 240 watt motor. This explains the need for really chunky bars!

One disadvantage of the shaded pole motor is that the *starting torque* is rather low. This doesn't matter for something like a fan, where the load when stationary is almost zero. For other applications, like a washing machine, it would be a disaster. Such motors therefore use a capacitor to generate the required phase shift for the quadrature windings, as in this example.

Induction motors also come in other variations, but the two described above are the most common in domestic use.

For serious grunt, however, you need a *three-phase* induction motor. This takes advantage of the fact that commercial 3-phase power is delivered by three conductors, each of which carries a 50 Hz sine wave with 120 degrees of phase shift relative to the other two. A 3-phase motor simply places three windings at 120 degree intervals around the casing, and a rotating magnetic field is automatically produced. Three-phase induction motors are the "workhorse" of industry, with large units having ratings well in excess of a megawatt.

Sydney's new Millenium trains use 3-phase induction motors, each rated at 226 kW, breaking away from the traditional DC motors used on Tangara trains and earlier models. However, since the overhead power to the train is 1500 volts DC, each Millenium train must use an *inverter* to create the three AC phases to feed to its motors.

2. Wireless Transmitter and Receiver

Description: DRA887TX and DRA887TX are low cost ASK transmitter modules Pair which are based on RFIC which minimizes the board size and improve the stability against nterferences. The transmitter modules work in very wide voltage range so they are very suiable for battery-driven applications. DRA886RX is a type of high sensitive ASK receiver which works at 3.6~5.5V. It can be used together with DRA887TX to construct simple and short range wireless control system.

DRA887TX Transmitter Features

- Category : ASK transmitter module
- Features : Frequency Range: 433MHz
- Output power : 10-17dBm
- Tx current : 24mA

- Temperature : -20~+70C
- Supply voltage: 1.5~5.5V

DRA886RX Receiver Features

- Category: ASK receiver module
- Features : Frequency Range: 433MHz
- Sensitivity :-107dBm
- Rx current : 4mA
- Temperature : -20~+70C
- Supply voltage: 3.6~5.5V

Amplitude Shift Keying

Amplitude Shift Keying (ASK) is the digital modulation technique. In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes. In ASK, the amplitude of the carrier assumes one of the two amplitudes dependent on the logic states of the input bit stream. This modulated signal can be expressed as:

$$x_c(t) = \begin{cases} 0 & \text{symbol "0"} \\ A\cos \omega_c t & \text{symbol "1"} \end{cases}$$

Note that the modulated signal is still an on-off signal.

Amplitude shift keying (ASK) in the context of digital signal communications is a modulation process, which imparts to a sinusoid two or more discrete amplitude levels. These are related to the number of levels adopted by the digital message. For a binary message sequence there are two levels, one of which is typically zero. Thus the modulated waveform consists of bursts of a sinusoid. Figure 1 illustrates a binary ASK signal (lower), together with the binary sequence which initiated it (upper). Neither signal has been band limited.

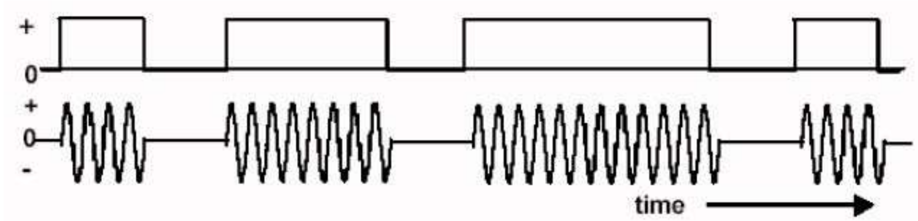


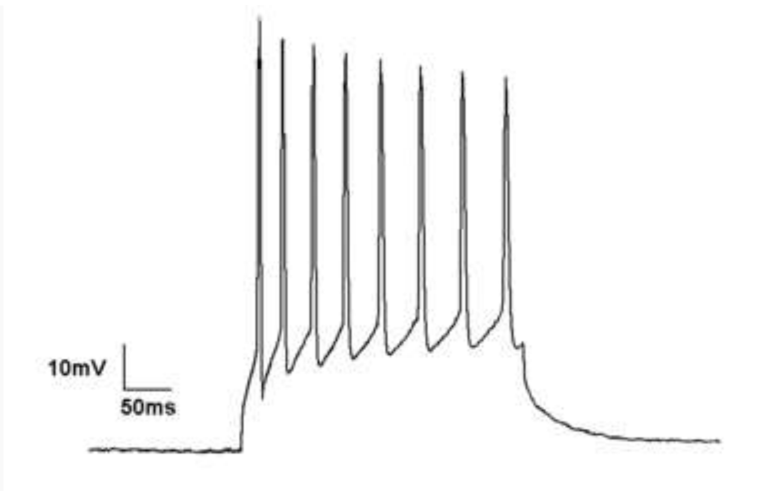
Fig: an ASK signal (below) and the message (above)

There are sharp discontinuities shown at the transition points. These result in the signal having an unnecessarily wide bandwidth. Band limiting is generally introduced before transmission, in which case these discontinuities would be 'rounded off'. The band limiting may be applied to the digital message, or the modulated signal itself. The data rate is often made a sub-multiple of the carrier frequency. This has been done in the waveform of Fig.

One of the disadvantages of ASK, compared with FSK and PSK, for example, is that it has not got a constant envelope. This makes its processing (eg, power amplification) more difficult, since linearity becomes an important factor. However, it does make for ease ofdemodulation with an envelope detector.With bandlimiting of the transmitted ASK neither of these demodulation methods (envelope detection or synchronous demodulation) would recover the original binary sequence; instead, their outputs would be a bandlimited side. Thus further processing by some sort of decision-making circuitry for example – would be necessary.

3. Human Interface and Bio Signal

Electrophysiology is the study of the electrical properties of biological cells and tissues. It involves measurements of voltage change or electric current on a wide variety of scales from single ion channel proteins to whole organs like the heart. In neuroscience, it includes measurements of the electrical activity of neurons, and particularly action potential activity. Recordings of large-scale electric signals from the nervous system such as electroencephalography, may also be referred to as electrophysiological recordings.[1]



"Current Clamp" is a common technique in electrophysiology. This is a whole-cell current clamp recording of a neuron firing due to it being depolarized by current injection

Definition and scope

Classical electrophysiological techniques

Electrophysiology is the science and branch of physiology that pertains to the flow of ions in biological tissues and, in particular, to the electrical recording techniques that enable the measurement of this flow. Classical electrophysiology techniques involve placing electrodes into various preparations of biological tissue. The principal types of electrodes are:

1. simple solid conductors, such as discs and needles (singles or arrays, often insulated except for the tip),
2. tracings on printed circuit boards, also insulated except for the tip, and
3. hollow tubes filled with an electrolyte, such as glass pipettes filled with potassium chloride solution or another electrolyte solution.

The principal preparations include:

1. living organisms,
2. excised tissue (acute or cultured),
3. dissociated cells from excised tissue (acute or cultured),
4. artificially grown cells or tissues, or
5. hybrids of the above.

If an electrode is small enough (micrometers) in diameter, then the electrophysiologist may choose to insert the tip into a single cell. Such a configuration allows direct observation and recording of the intracellular electrical activity of a single cell. However, at the same time such invasive setup reduces the life of the cell and causes a leak of substances across the cell membrane. Intracellular activity may also be observed using a specially formed (hollow) glass pipette containing an electrolyte. In this technique, the microscopic pipette tip is pressed against the cell membrane, to which it tightly adheres by an interaction between glass and lipids of the cell membrane. The electrolyte within the pipette may be brought into fluid continuity with the cytoplasm by delivering a pulse of pressure to the electrolyte in order to rupture the small patch of membrane encircled by the pipette rim (whole-cell recording). Alternatively, ionic continuity may be established by "perforating" the patch by allowing exogenous pore-forming agent within the electrolyte to insert themselves into the membrane patch (perforated patch recording). Finally, the patch may be left intact (patch recording).

The electrophysiologist may choose not to insert the tip into a single cell. Instead, the electrode tip may be left in continuity with the extracellular space. If the tip is small enough, such a configuration may allow indirect observation and recording of action potentials from a single cell, and is termed single-unit recording. Depending on the preparation and precise placement, an extracellular configuration may pick up the activity of several nearby cells simultaneously, and this is termed multi-unit recording.

As electrode size increases, the resolving power decreases. Larger electrodes are sensitive only to the net activity of many cells, termed local field potentials. Still larger electrodes, such as uninsulated needles and surface electrodes used by clinical and surgical neurophysiologists, are sensitive only to certain types of synchronous activity within populations of cells numbering in the millions.

Other classical electrophysiological techniques include single channel recording and amperometry.

Optical electrophysiological techniques

Optical electrophysiological techniques were created by scientists and engineers to overcome one of the main limitations of classical techniques. Classical techniques allow observation of electrical activity at approximately a single point within a volume of tissue. Essentially, classical techniques singularize a distributed phenomenon. Interest in the spatial distribution of bioelectric activity prompted development of molecules capable of emitting light in response to their electrical or chemical environment. Examples are voltage sensitive dyes and fluorescing proteins.

After introducing one or more such compounds into tissue via perfusion, injection or gene expression, the 1 or 2-dimensional distribution of electrical activity may be observed and recorded.

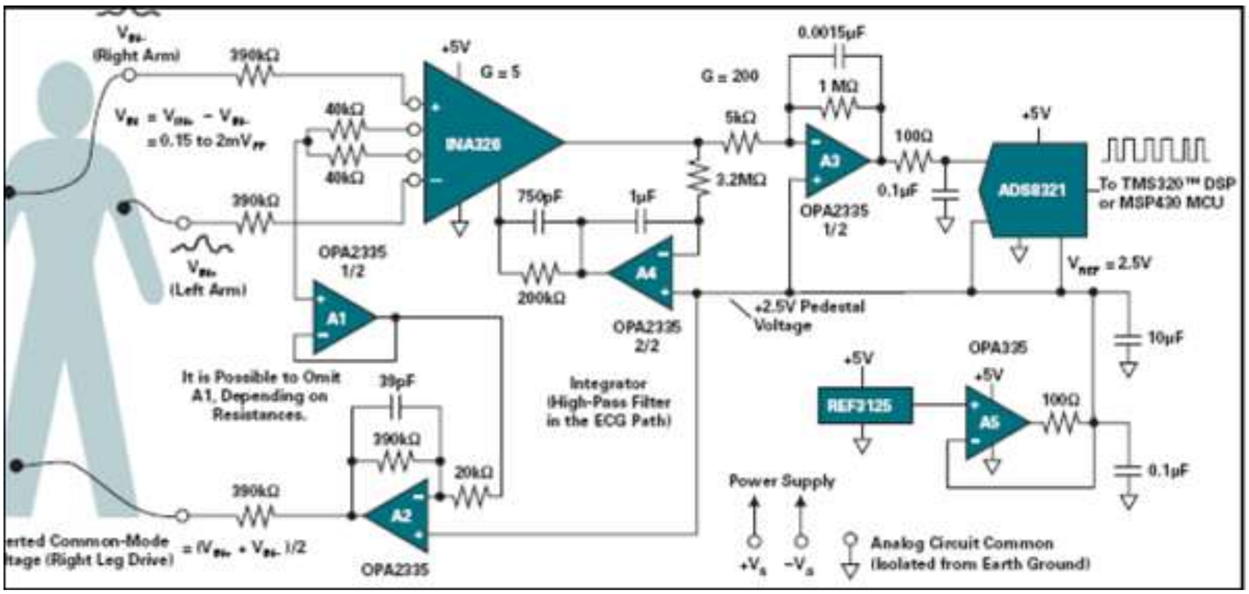
Many particular electrophysiological readings have specific names:

- Electrocardiography - for the heart
- Electroencephalography - for the brain
- Electrocorticography - from the cerebral cortex
- Electromyography - for the muscles
- Electrooculography - for the eyes
- Electroretinography - for the retina
- Electroantennography - for the olfactory receptors in arthropods
- Audiology - for the auditory system

Intracellular recording

Intracellular recording involves measuring voltage and/or current across the membrane of a cell. To make an intracellular recording, the tip of a fine (sharp) microelectrode must be inserted inside the cell, so that the membrane potential can be measured. Typically, the resting membrane potential of a healthy cell will be -60 to -80 mV, and during an action potential the membrane potential might reach +40 mV. In 1963, Alan Lloyd Hodgkin and Andrew Fielding Huxley won the Nobel Prize in Physiology or Medicine for their contribution to understanding the mechanisms underlying the generation of action potentials in neurons. Their experiments involved intracellular recordings from the giant axon of Atlantic squid (Loligo pealei), and were among the first applications of the "voltage clamp" technique. Today, most microelectrodes used for intracellular recording are glass micropipettes, with a tip diameter of < 1 micrometre, and a resistance of several megaohms. The micropipettes are filled with a solution that has a similar ionic composition to the intracellular fluid of the cell. A chlorided silver wire inserted in to the pipet connects the electrolyte electrically to the amplifier and signal processing circuit. The voltage measured by the electrode is compared to the voltage of a reference electrode, usually a silver chloride-coated silver wire in contact with the extracellular fluid around the cell. In general, the smaller the electrode tip, the higher its electrical resistance, so an electrode is a compromise between size (small enough to penetrate a single cell with minimum damage to the cell) and resistance (low enough so that small neuronal signals can be discerned from thermal noise in the electrode tip).

Circuit Diagram of ECG Amplifier.



4 Recording Audio Signals

With this circuit, you can **record your voice and play back** the same for 20 seconds. The **voice recorder circuit** is ideal for door phones, automatic answering devices etc. APR 9301 is used in the circuit which is a data storage and retrieval IC without any micro controller programming.

The IC requires minimum components to create a voice recorder. The IC has non volatile flash memory technology with 100K recording cycles and 100 year message retention capacity. The IC utilizes the Invox proprietary analog / multi level flash non volatile memory cells that can store more than 256 voltage levels. It requires a single 5 volt supply and operates in 25 mA current.

Mode of operation

1. Record Mode

The LED glows when the IC records the voice obtained through the Mic. A single voice message up to 20 seconds can be recorded. The IC remains in the recorded mode as long as the RecL pin 27 is grounded. Recoding will be terminated with the last memory when 20 seconds is over. The Speaker driver will automatically mutes in the recording mode. By changing the value of the OscR resistor R1 it is possible to increase the recording period as follows.

1. R1 52K 20 Sec.
2. R1 67 K 24 Sec
3. R1 89K 30 Sec

Play back Mode

By pressing the play back switch, the play mode starts from the beginning of the message. The input section will be muted during play back.

Standby Mode

After completing the Record or Play back function, the IC will enters into the standby mode.

Sampling frequency

20 Sec 6.4 KHz

24 Sec 5.3 KHz

30 Sec 4 KHz

28 Pin IC requires IC base.

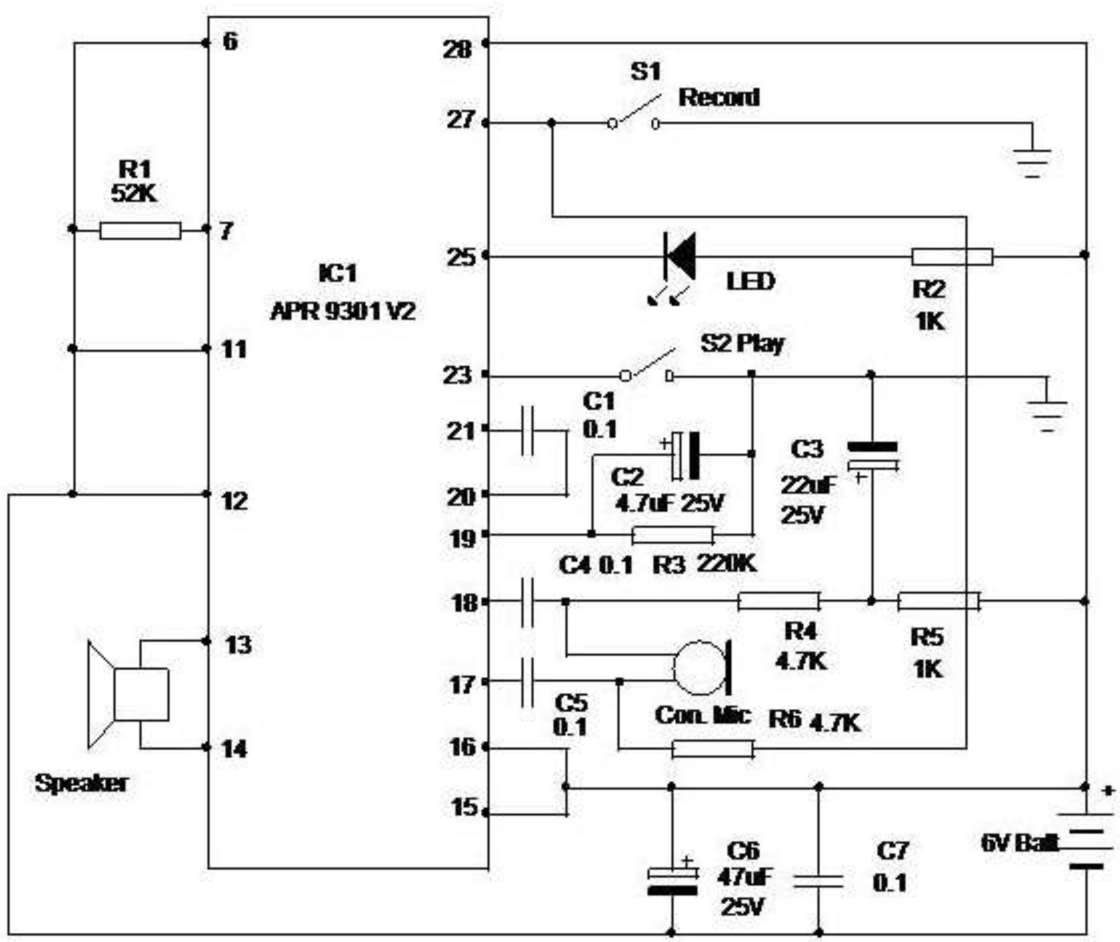
Recording

Press ,switch S1 and speak through the Mic or record music. LED will glow in the recording mode. Open S1 after recording. Use a small condenser Mic

Play back

Close S2. Recorded message will be heard from the speaker. Use a 2 inch 8 Ohms speaker.

Power supply 5 Volt regulated supply or 6 volt battery.


6
28
S1
Record
27
R1
52K
7
IC1
APR 9301 V2
25
LED
R2
1K
11
S2 Play
23
C1
0.1
21
C2
4.7uF 25V
C3
22uF
25V
20
12
19
C4 0.1
R3
220K
18
R4
4.7K
R5
1K
13
17
C5
0.1
Con. Mic
R6
4.7K
14
16
Speaker
15
C6
47uF
25V
C7
0.1
6V Batt

5. Function Generator Construction and Testing

A function generator is a instruments that delivers a choice of different waveforms whose frequency are adjustable over a wide range. The most common output waveforms are sine, square, triangular, pulse-train wave's .The frequency of the waveforms may be adjusted from a fraction of a 10Hz to several hundred kHz.

Objectives

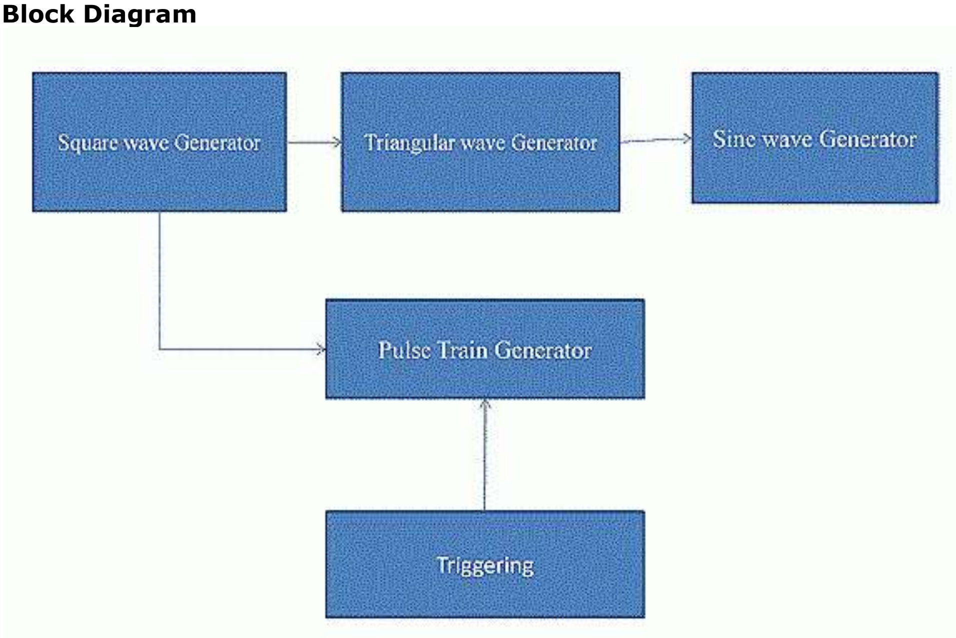
1. Design and construction of a square wave generator with minimum distortion.
2. Design and construction of a triangle wave generator with minimum distortion.
3. Design and construction of a sine wave generator with minimum distortion.
4. Design and construction of a pulse train generator with minimum distortion.
5. Design and construction of a complete function generator using IC with minimum distortion.
6. Design and construction of AM modulator with minimum distortion.
7. Design and construction of a FM modulator with minimum distortion.
8. Performance and cost analysis.

Methodology

1. Study about the different types of signal.
2. Study about the different types of function generators.
3. Study about the theory/operation of the different types of function generators.
4. Design about the different types of function generators.
5. Construction and performance test of a function generator.

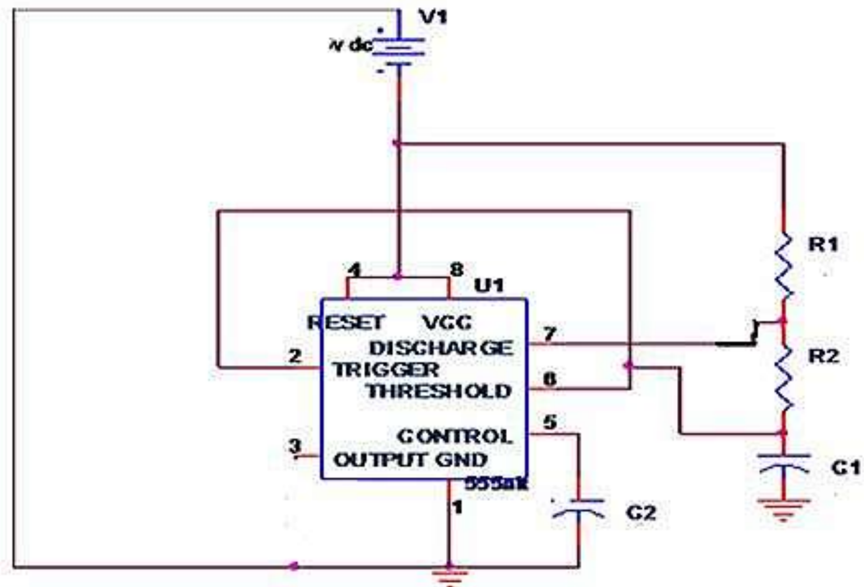
DESIGN AND CONSTRUCTION OF DISCRETE FUNCTION GENERATOR

Block Diagram

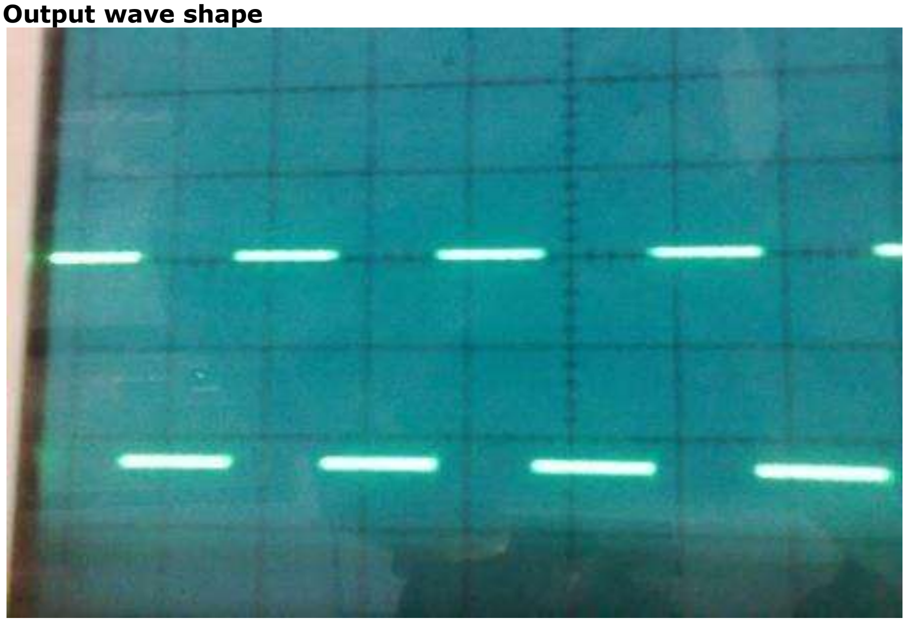


Square wave generator

Circuit diagram



Output wave shape



Results

Calculated value

W=0.693(R1+R2) C =0.693(20k+1k) 0.1μF =1.455ms

T=0.693(R1+2R2) C =0.693(20k+2k) 0.1μF =1.5ms

f =1.44 / (R1+2R2) =655Hz.

Experimental Value

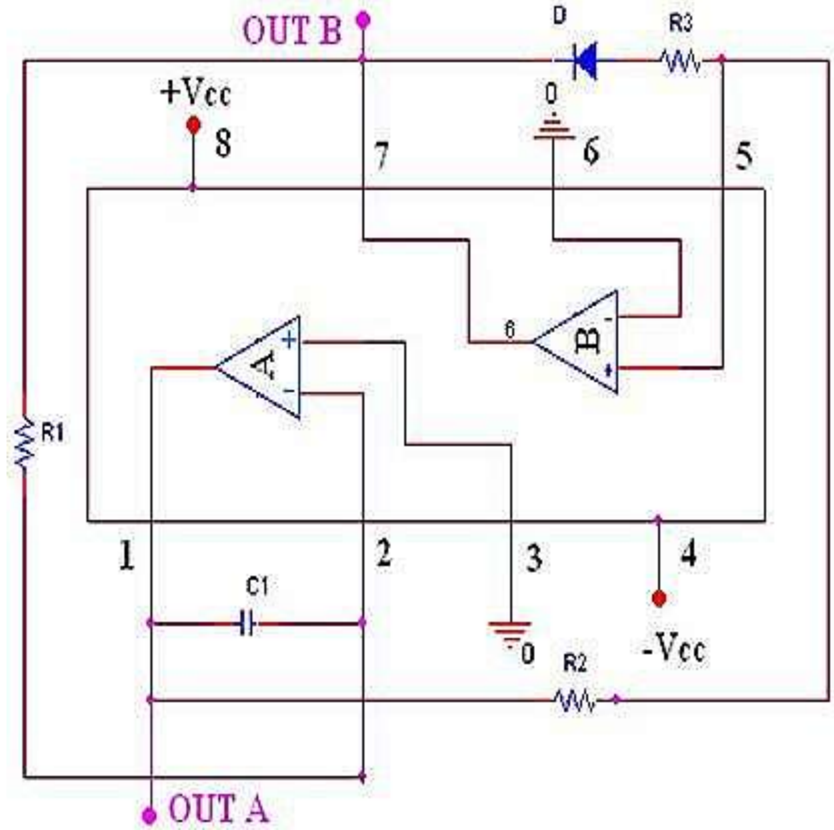
T = 1.4ms

f = 714Hz

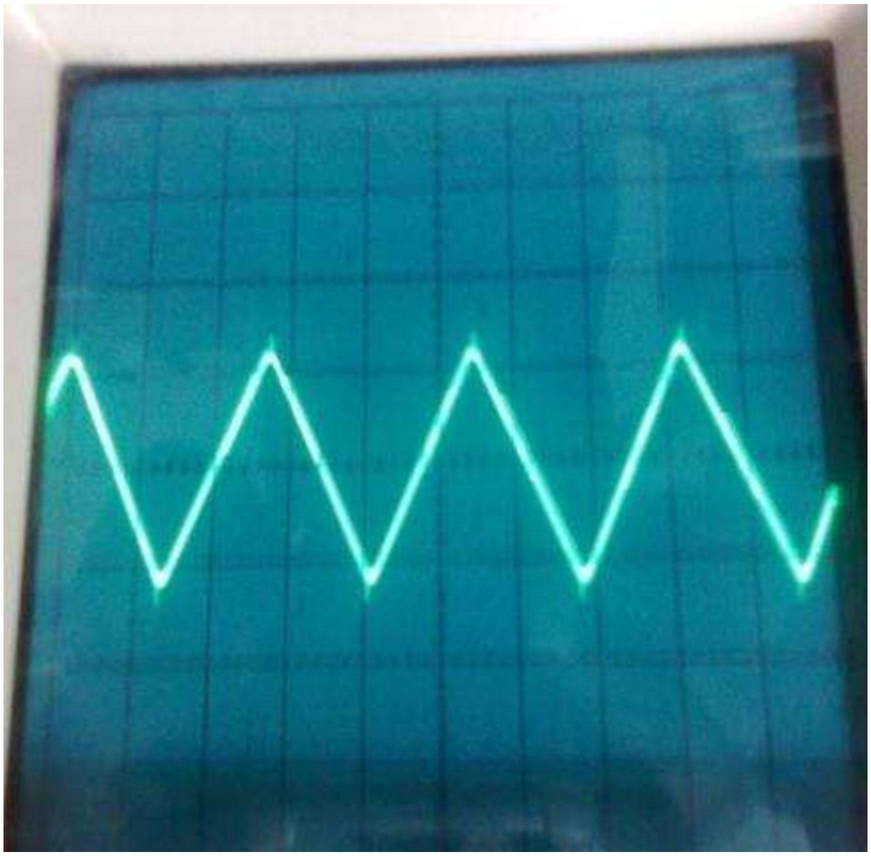
Vm = 1.15v (p-p)

Triangular wave generator

Circuit diagram



Output wave shape



Results

Calculated value

P=PR/R=2.8

Frequency of oscillation is given by,

f=P/4RC=800Hz.

T=1.25ms

Experimental Value

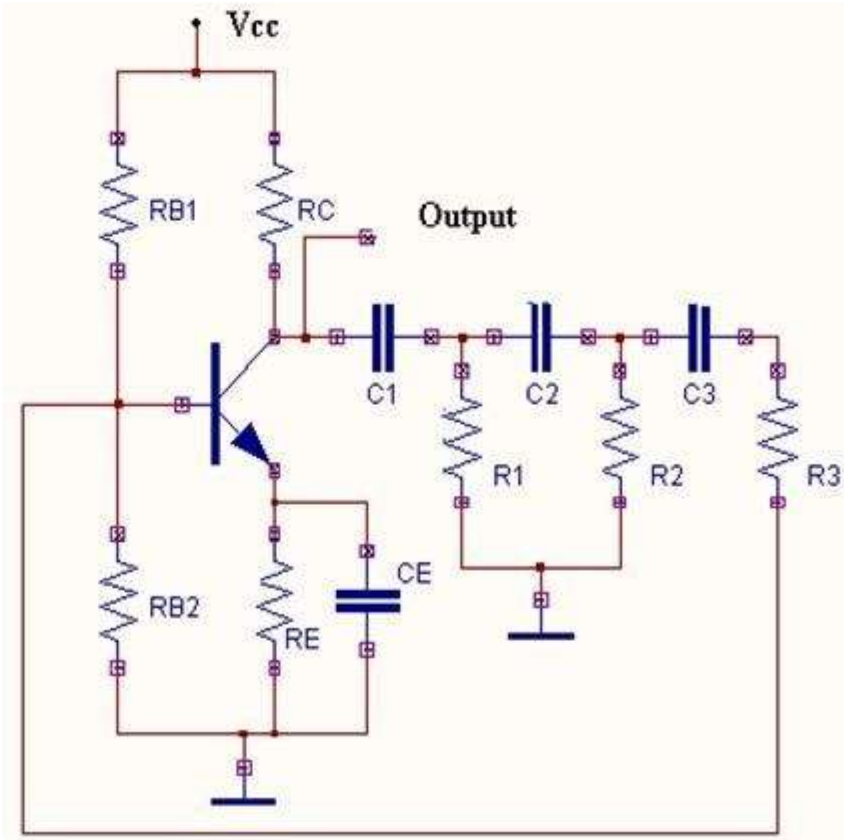
T =1.3ms

f =769Hz

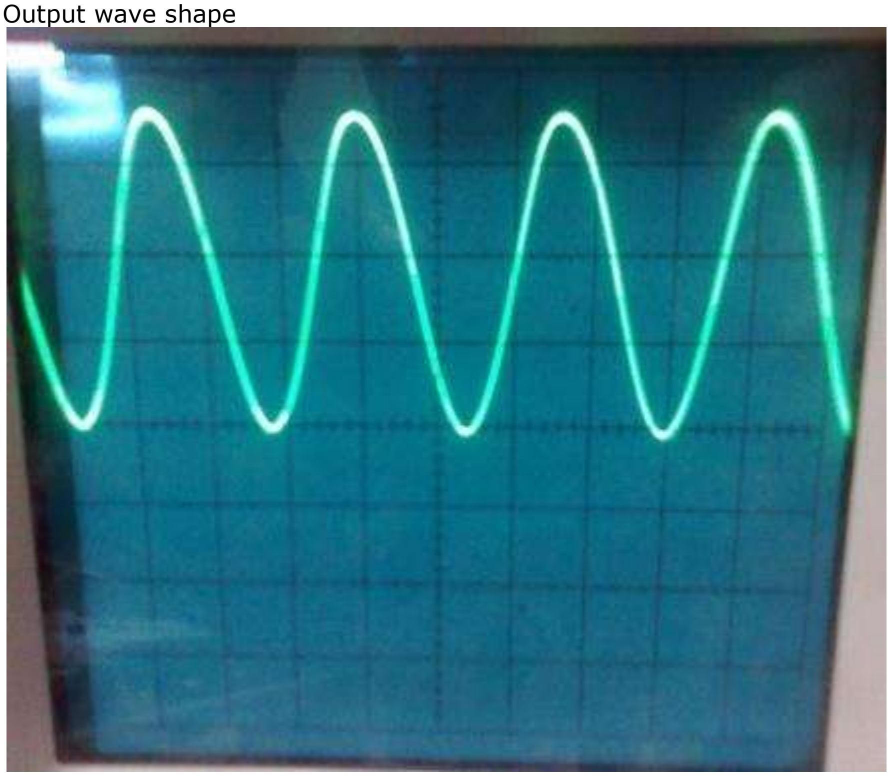
Vm = 0.5v (p-p)

Sine Wave Generator

Circuit diagram



Output wave shape



Results

Calculated value

The frequency of oscillation of RC Phase Shift Oscillator is given by ,

f =1/(2πRC*6^0.5)=628Hz.

T=1.59ms

Experimental Value

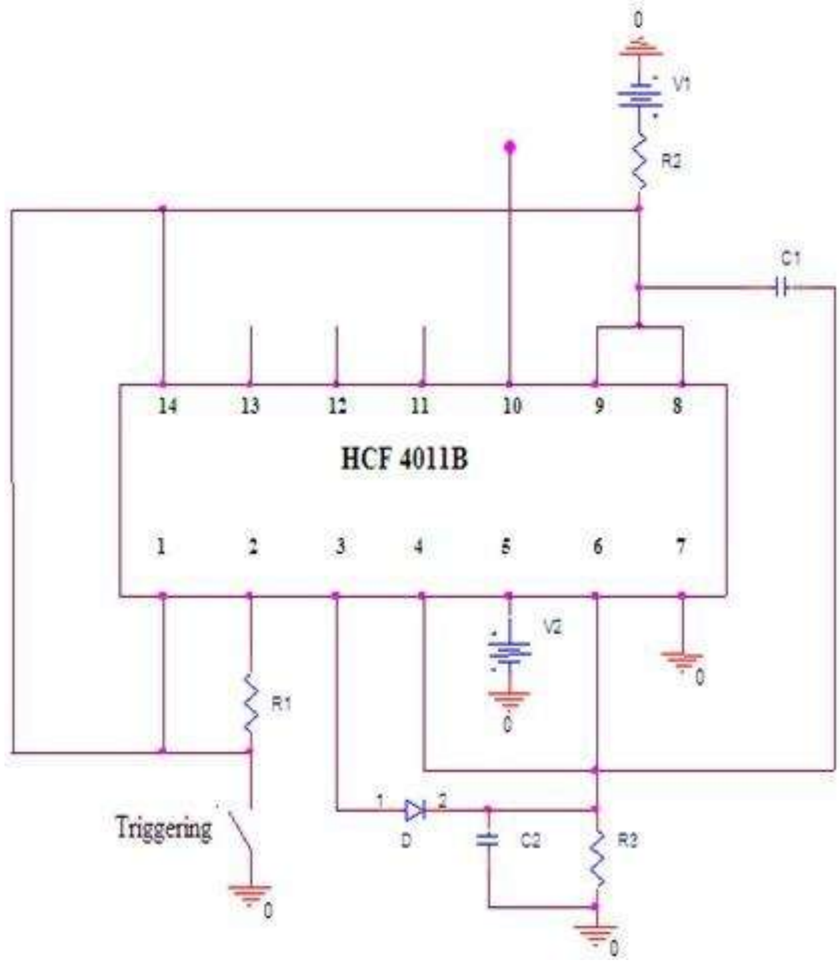
f=625Hz

T=1.6ms

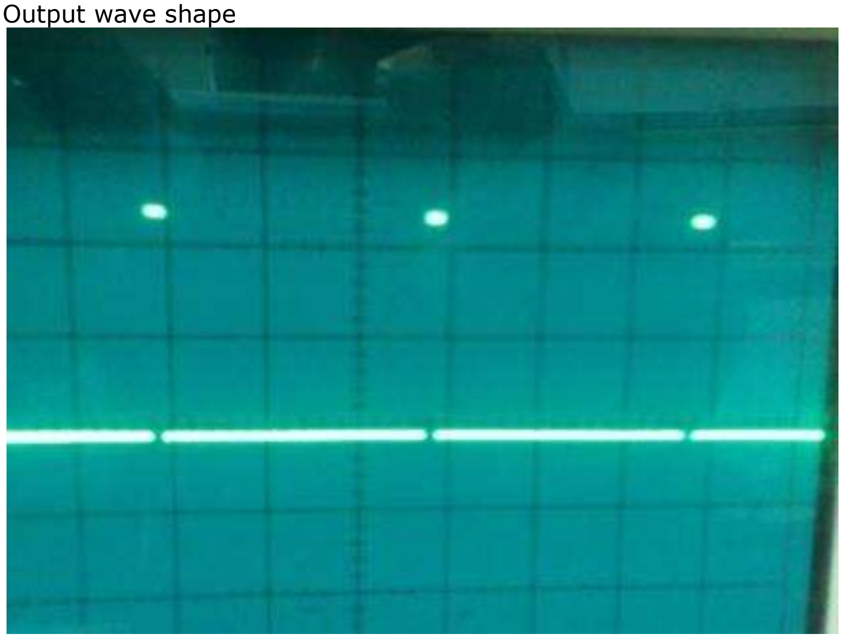
Vm = 0.4v (p-p)

Pulse train wave generator

Circuit diagram



Output wave shape



Results

Calculated value

W=0.693R1C1 =69.3μs

T=W+0.693(R2+R3) C1 =1.12ms

f =1/T =890Hz.

Experimental Value

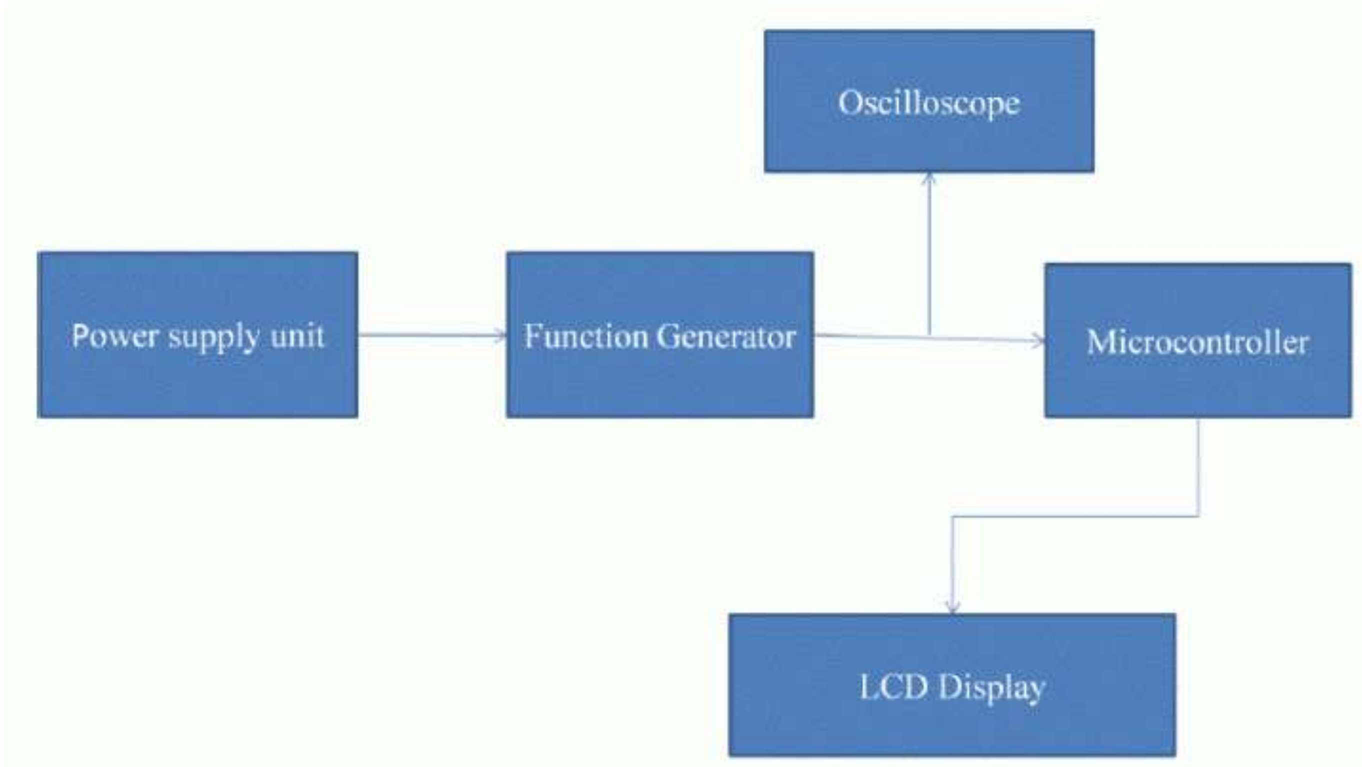
W=75μs.

T=1.2ms.

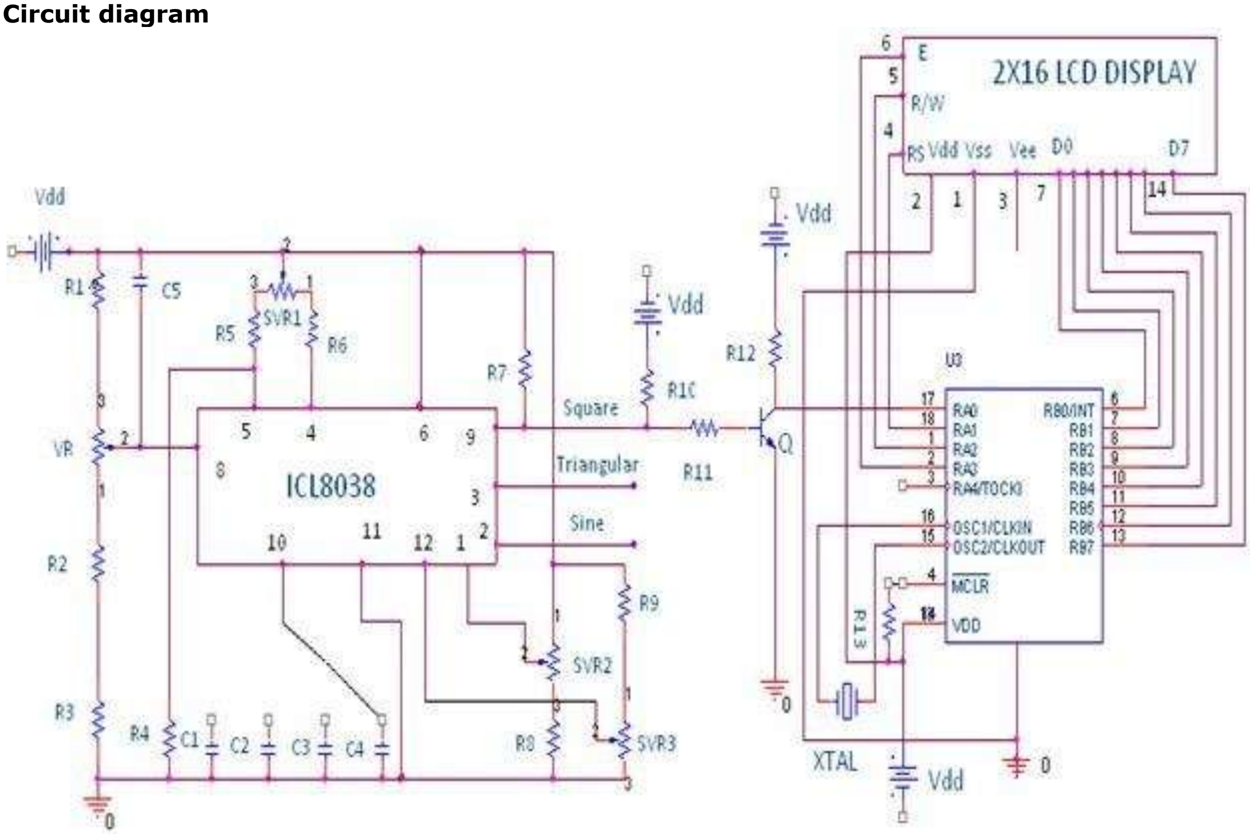
f=1/T=830Hz

Vm=1.2v (p-p).

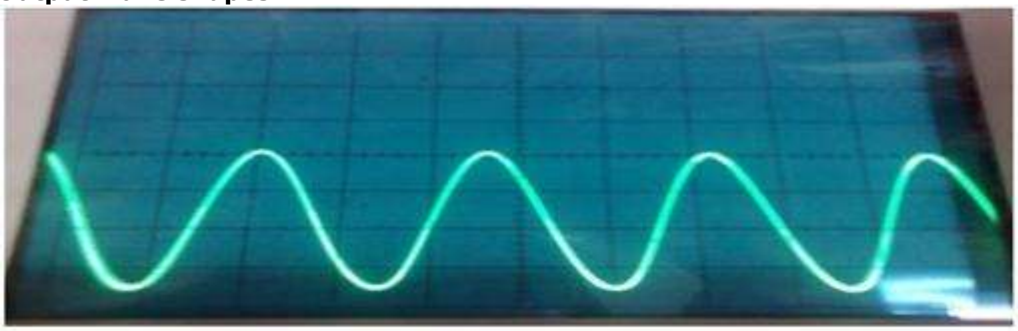
DESIGN AND CONSTRUCTION OF MICROCONTROLLER BASED FUNCTION GENERATOR

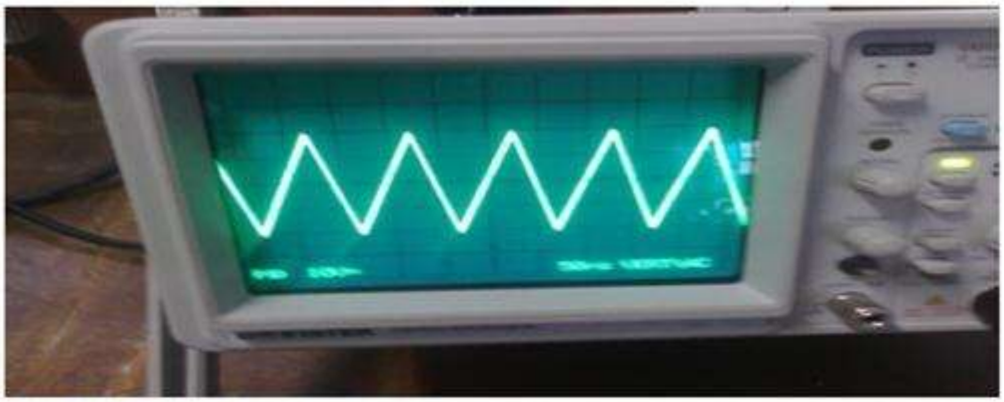


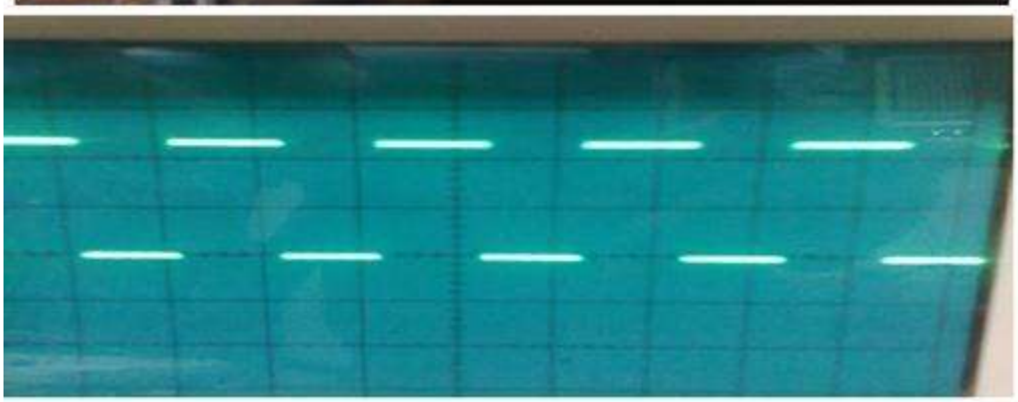
Circuit diagram



Output wave shapes







Frequency range

1Hz-80kHz

1Hz-10kHz

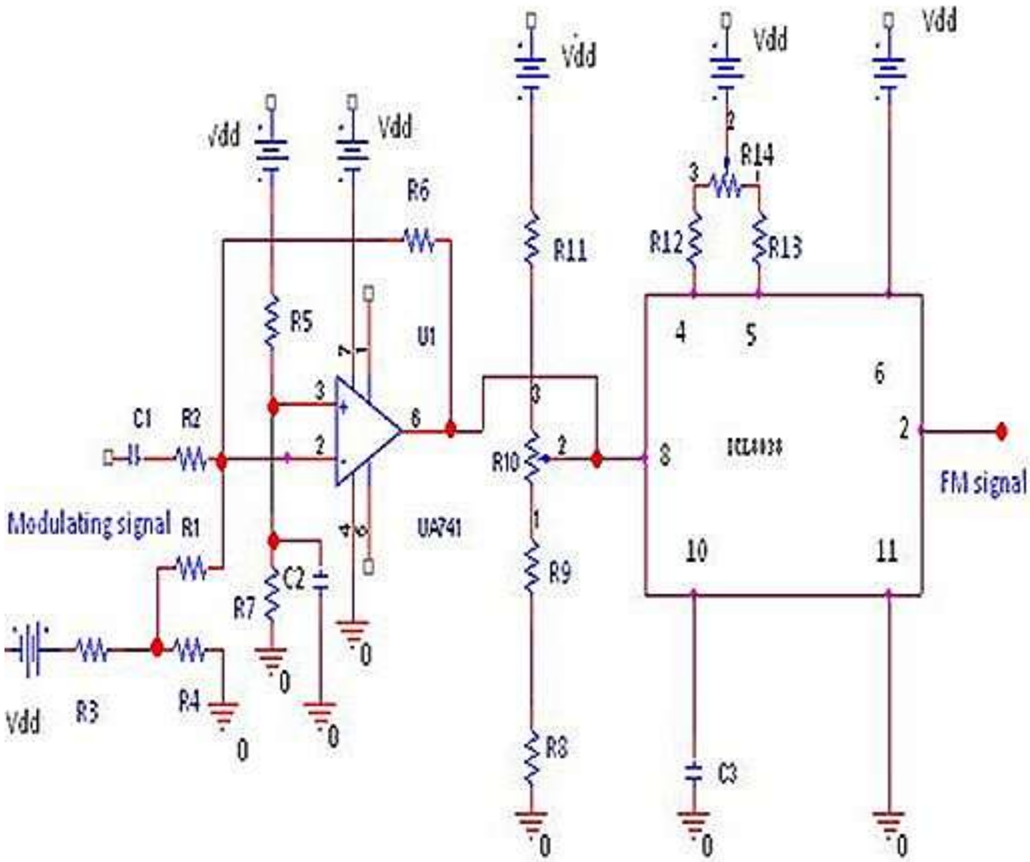
1Hz-1kHz

1Hz-100Hz

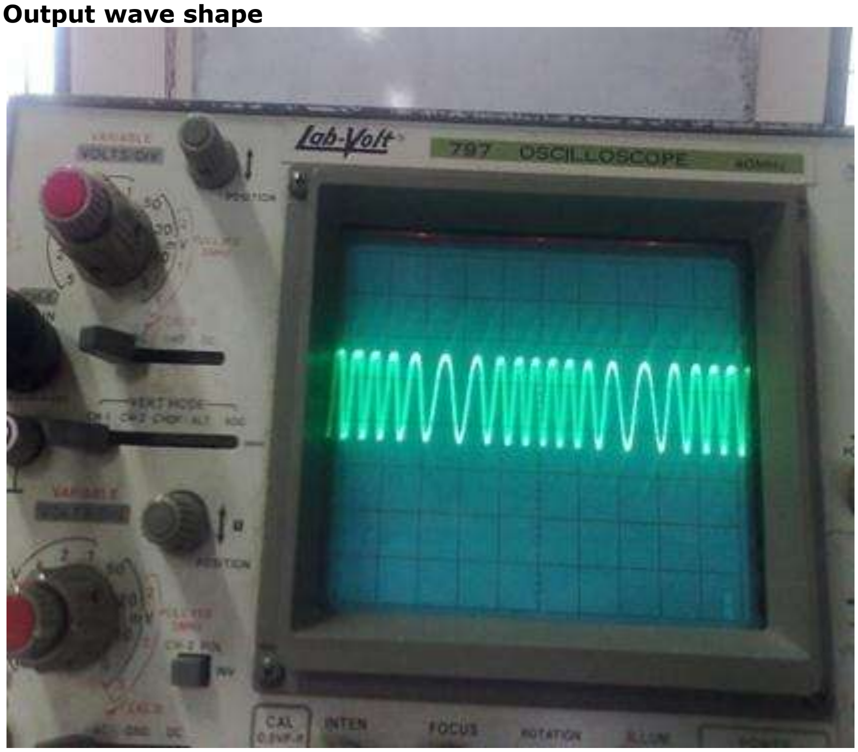
DESIGN AND CONSTRUCTION OF MODULATORS

Frequency Modulator

Circuit diagram



Output wave shape



Result

Frequency of modulating signal, fm = 1kHz

Frequency of carrier signal, fc = 20kHz

Maximum modulated frequency, f(max) = 4.76kHz

Minimum modulated frequency, f(min) = 2.86kHz

The frequency deviation, Δf = 1.90kHz

Modulation index, m = 1.90

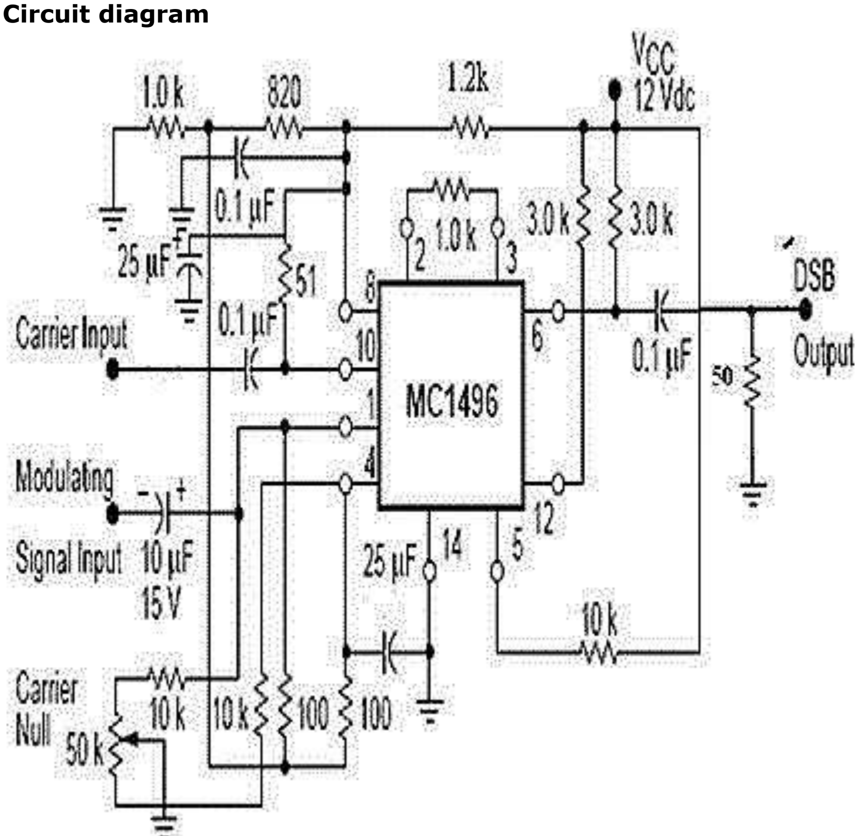
Amplitude of the FM modulated wave, Vfm = 10v(p-p)

Average carrier Power, Pc = 1w

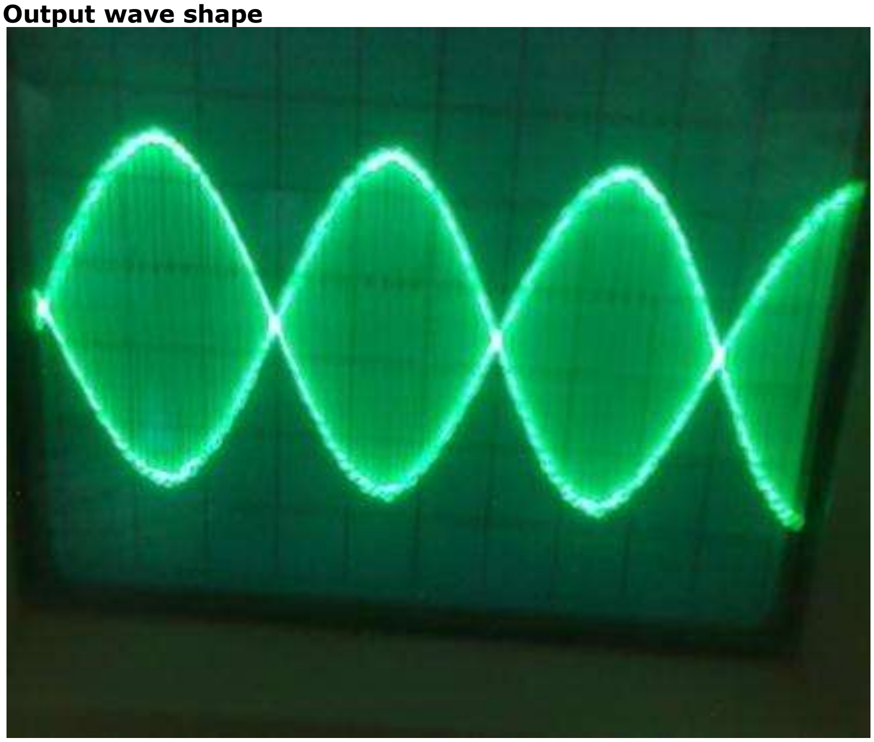
Total power of the modulated wave, Pt = Pc = 1w

AM modulator

Circuit diagram



Output wave shape



Results

Peak amplitude of the modulating waveform voltage, Vm =10v (p-p)

Peak amplitude of the carrier signal voltage, Vc = 10v (p-p)

Frequency of modulating signal, fm = 300Hz

Frequency of carrier signal, fc = 10 kHz

Modulating index, M = 1

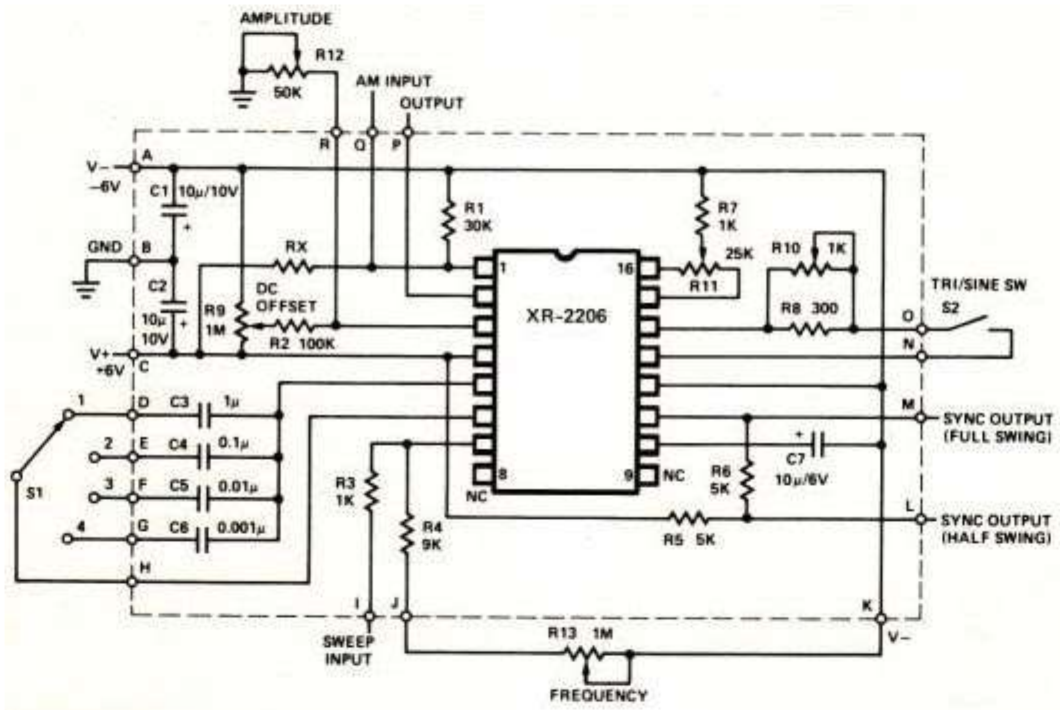
Carrier power, Pc = 1w

Total power, Pt = 1.5w

CONCLUSION

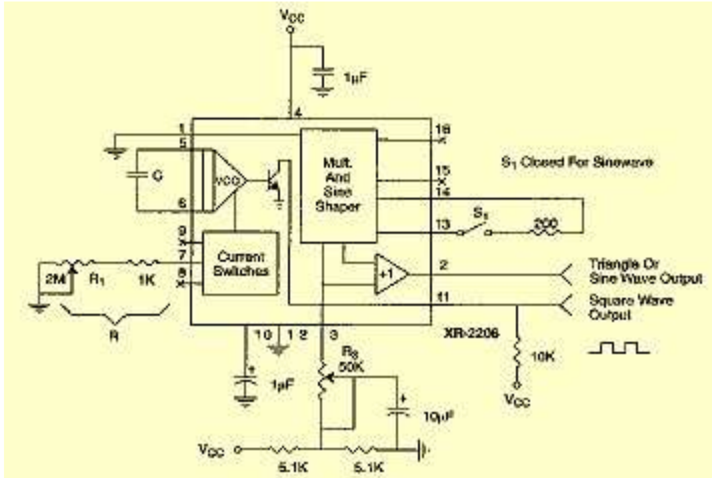
To design, construct and performance test of function generator is the basic purpose of our project. Our project work is already completed. The constructed circuit is very nicely working. It can be used to test and align all types of transmitters and receivers, to measure frequency and to generate a signal, waveform or noise source. Signal generators can use AC energy, audio frequency (AF) and radio frequency (RF) to function. They are generally used in designing, testing, troubleshooting, and repairing electronic or electro acoustic devices. By studying books, searching internet, discussing with our teacher we got an idea about the work.

Working Circuit Diagram of Function Generator using IC XR-2206



Description of Function Generator with XR2206

For measurement purposes in the electronics laboratory is needed again and again signals of different frequency and waveforms. A common function generator provides sine, for example, triangular and square waves. The frequency must be adjustable and at least cover the low frequency range. The low-cost IC XR2206 provides a very simple function generator with only a few external components. XR2206 data sheet provides complete basic circuit for a simple function generator. It requires an operating voltage of 12 V and delivers sine and square wave signals. Instead of the sine wave output is obtained after opening of S1 a triangular output wave. XR2206 IC contains an internal VCO (Voltage Controlled Oscillator, Voltage Controlled Oscillator) with triangular and rectangular output. The capacitor C and the power to determine the frequency at pin 7. With a pot of 2 megohms and a fixed resistor of 1 kOhm variation gives a ratio of 1 to 2000 and may include a range of 10 Hz to 20 kHz sweep.

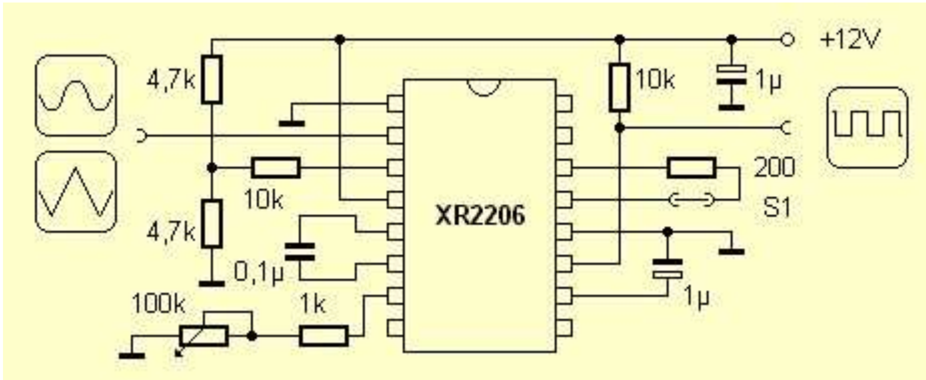


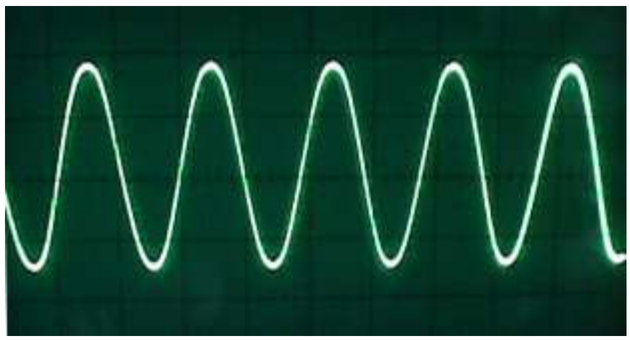
A sine-shaping network makes the triangular signal of the VCO, a sinusoidal signal that can be picked up at the pin 2. At pin 3 to set the exact medium voltage and the output amplitude. The additional output at pin 11 also delivers a square wave with the same frequency.

The actual sample structure differs in some details from the data sheet. Thus, only a frequency ratio of 1 was chosen to 100, so a finer adjustment is possible. With the frequency-determining capacitor of 0.1 uF an adjustment range of 100 Hz is reached to 10 kHz. The frequency is changed by using a variable resistor.
The amplitude setting at pin 3 is connected with fixed resistors, so the output voltage is always the same. The switching sine / triangle was achieved with a jumper. On the board, the outputs of the circuit were placed in small wire loops, where the signals can be picked up directly with alligator clips.

The sample design renounces everything that is not absolutely necessary. Many attempts have come out with this simple circuit. But there are some points that could improve it take to build an almost professional function generator. All required circuit details are shown in the datasheet.

Basic Diagram of 2206 Function Generator





6. Counter

In digital logic and computing, a **counter** is a device which stores (and sometimes displays) the number of times a particular event or process has occurred, often in relationship to a clock signal.

Electronic counters

In electronics, counters can be implemented quite easily using register-type circuits such as the flip-flop, and a wide variety of classifications exist:

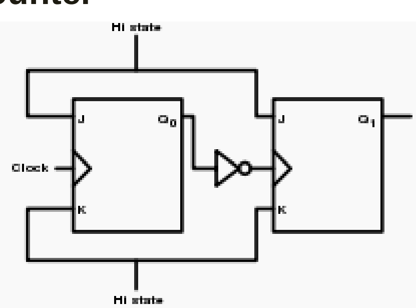
- Asynchronous (ripple) counter – changing state bits are used as clocks to subsequent state flip-flops
- Synchronous counter – all state bits change under control of a single clock
- Decade counter – counts through ten states per stage
- Up/down counter – counts both up and down, under command of a control input
- Ring counter – formed by a shift register with feedback connection in a ring
- Johnson counter – a *twisted* ring counter
- Cascaded counter
- modulas counter.

Each is useful for different applications. Usually, counter circuits are digital in nature, and count in natural binary. Many types of counter circuits are available as digital building blocks, for example a number of chips in the 4000 series implement different counters.

Occasionally there are advantages to using a counting sequence other than the natural binary sequence—such as the binary coded decimal counter, a linear feedback shift register counter, or a Gray-codecounter.

Counters are useful for digital clocks and timers, and in oven timers, VCR clocks, etc.[1]

Asynchronous (ripple) counter



Asynchronous counter created from two JK flip-flops

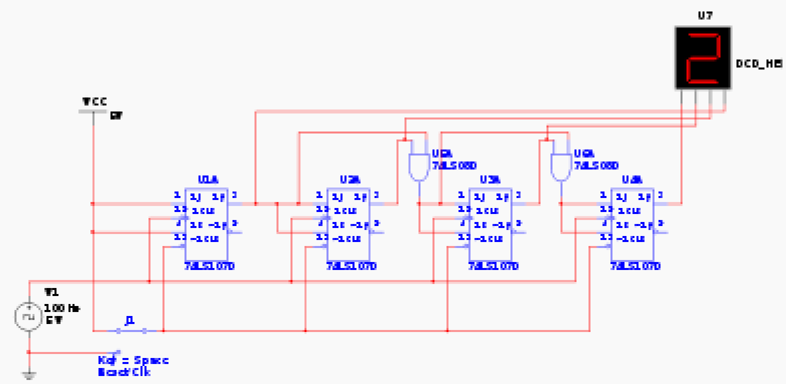
An asynchronous (ripple) counter is a single JK-type flip-flop, with its J (data) input fed from its own inverted output. This circuit can store one bit, and hence can count from zero to one before it overflows (starts over from 0). This counter will increment once for every clock cycle and takes two clock cycles to overflow, so every cycle it will alternate between a transition from 0 to 1 and a transition from 1 to 0. Notice that this creates a new clock with a 50% duty cycle at exactly half the frequency of the input clock. If this output is then used as the clock signal for a similarly arranged D flip-flop (remembering to invert the output to the input), one will get another 1 bit counter that counts half as fast. Putting them together yields a two-bit counter:

Cycle	Q1	Q0	(Q1:Q0)dec
0	0	0	0
1	0	1	1
2	1	0	2
3	1	1	3
4	0	0	0

You can continue to add additional flip-flops, always inverting the output to its own input, and using the output from the previous flip-flop as the clock signal. The result is called a ripple counter, which can count to $2^n - 1$ where *n* is the number of bits (flip-flop stages) in the counter. Ripple counters suffer from unstable outputs as the overflows "Ripple" from stage to stage, but they do find frequent application as dividers for clock signals, where the instantaneous count is unimportant, but the division ratio overall is (to clarify this, a 1-bit counter is exactly equivalent to a divide by two circuit; the output frequency is exactly half that of the input when fed with a regular train of clock pulses).

The use of flip-flop outputs as clocks leads to timing skew between the count data bits, making this ripple technique incompatible with normal synchronous circuit design styles.

Synchronous counter



A 4-bit synchronous counter using JK flip-flops

Synchronous Counters

In synchronous counters, the clock inputs of all the flip-flops are connected together and are triggered by the input pulses. Thus, all the flip-flops change state simultaneously (in parallel). The circuit below is a 3-bit synchronous counter. The J and K inputs of FF0 are connected to HIGH. FF1 has its J and K inputs connected to the output of FF0, and the J and K inputs of FF2 are connected to the output of an AND gate that is fed by the outputs of FF0 and FF1. A simple way of implementing the logic for each bit of an ascending counter (which is what is depicted in the image to the right) is for each bit to toggle when all of the less significant bits are at a logic high state. For example, bit 1 toggles when bit 0 is logic high; bit 2 toggles when both bit 1 and bit 0 are logic high; bit 3 toggles when bit 2, bit 1 and bit 0 are all high; and so on.

Synchronous counters can also be implemented with hardware finite state machines, which are more complex but allow for smoother, more stable transitions.

Hardware-based counters are of this type.

Decade counter

A decade counter is one that counts in decimal digits, rather than binary. A decade counter may have each digit binary encoded (that is, it may count in binary-coded decimal, as the 7490 integrated circuit did) or other binary encodings (such as the bi-quinary encoding of the 7490 integrated circuit). Alternatively, it may have a "fully decoded" or one-hot output code in which each output goes high in turn (the 4017 is such a circuit). The latter type of circuit finds applications inmultiplexers and demultiplexers, or wherever a scanning type of behavior is useful. Similar counters with different numbers of outputs are also common.

The decade counter is also known as a mod-counter when it counts to ten (0, 1, 2, 3, 4, 5, 6, 7, 8, 9). A Mod Counter that counts to 64 stops at 63 because 0 counts as a valid digit.

Up/down counter

A counter that can change state in either direction, under the control of an up or down selector input, is known as an up/down counter. When the selector is in the up state, the counter increments its value. When the selector is in the down state, the counter decrements the count.

Ring counter[

A ring counter is a circular shift register which is initiated such that only one of its flip-flops is the state one while others are in their zero states.

A ring counter is a Shift Register (a cascade connection of flip-flops) with the output of the last one connected to the input of the first, that is, in a ring. Typically, a pattern consisting of a single bit is circulated so the state repeats every n clock cycles if n flip-flops are used. It can be used as a cycle counter of n states.

Johnson counter

A Johnson counter (or switchtail ring counter, twisted-ring counter, walking-ring counter, or Moebius counter) is a modified ring counter, where the output from the last stage is inverted and fed back as input to the first stage.[2][3][4] The register cycles through a sequence of bit-patterns, whose length is equal to twice the length of the shift register, continuing indefinitely. These counters find specialist applications, including those similar to the decade counter, digital-to-analog conversion, etc. They can be implemented easily using D- or JK-type flip-flops.

Computer science counters

In computability theory, a **counter** is considered a type of memory. A counter stores a single natural number (initially zero) and can be arbitrarily long. A counter is usually considered in conjunction with afinite-state machine (FSM), which can perform the following operations on the counter:

- Check whether the counter is zero
- Increment the counter by one.
- Decrement the counter by one (if it's already zero, this leaves it unchanged).

The following machines are listed in order of power, with each one being strictly more powerful than the one below it:

1. Deterministic or non-deterministic FSM plus two counters
2. Non-deterministic FSM plus one stack
3. Non-deterministic FSM plus one counter
4. Deterministic FSM plus one counter
5. Deterministic or non-deterministic FSM.

For the first and last, it doesn't matter whether the FSM is a deterministic finite automaton or a nondeterministic finite automaton. They have power. The first two and the last one are levels of the Chomsky hierarchy.

The first machine, an FSM plus two counters, is equivalent in power to a Turing machine. See the article on counter machines for a proof.

Mechanical counters

Mechanical counter wheels showing both sides. The bump on the wheel shown at the top engages the ratchet on the wheel below every turn.

Several mechanical counters

Long before electronics became common, mechanical devices were used to count events. These are known as tally counters. They typically consist of a series of disks mounted on an axle, with the digits 0 through 9 marked on their edge. The right most disk moves one increment with each event. Each disk except the left-most has a protrusion that, after the completion of one revolution, moves the next disk to the left one increment. Such counters were originally used to control manufacturing processes, but were later used as odometers for bicycles and cars and in tape recorders and fuel dispensers. One of the largest manufacturers was the Veeder-Root company, and their name was often used for this type of counter.[5]

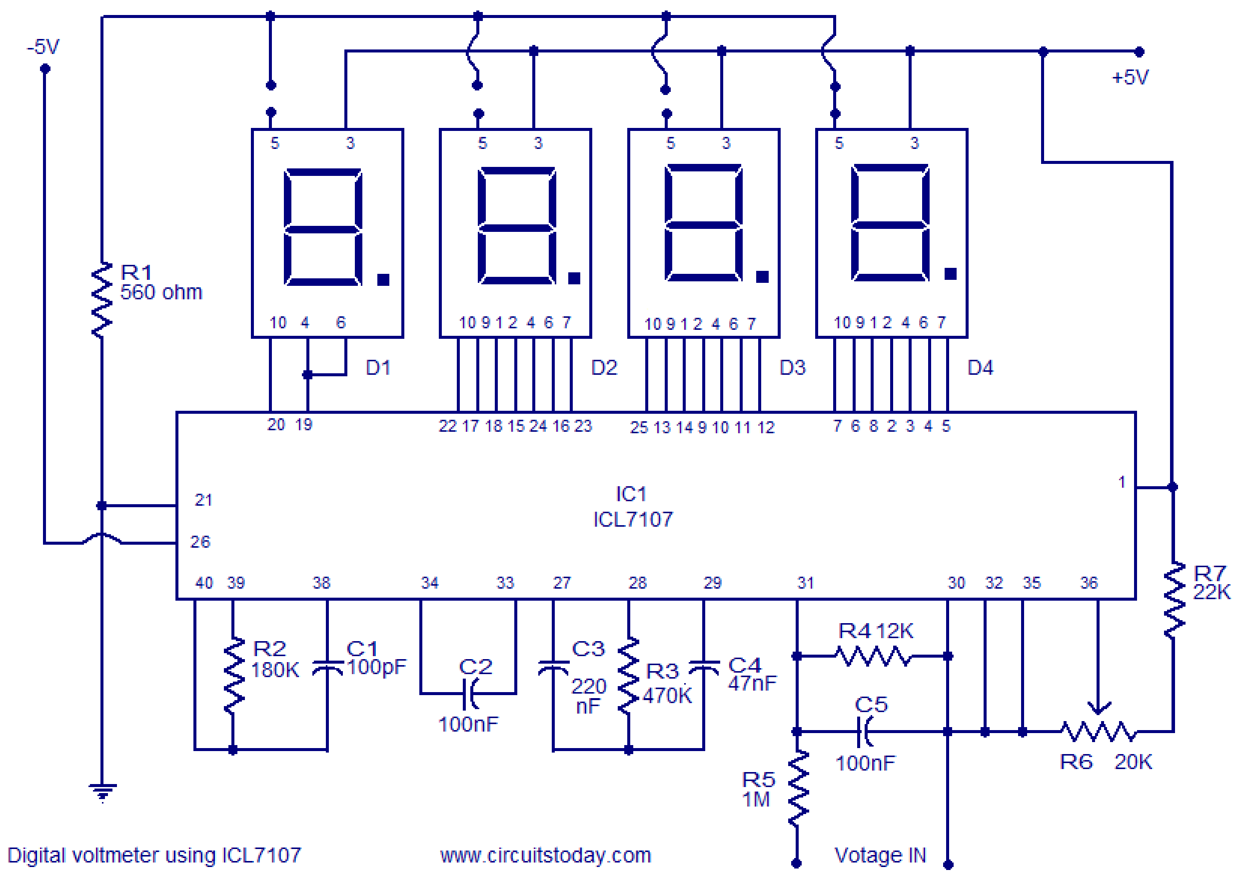
7. Digital voltmeter using ICL7107

Description.

The circuit given here is of a very useful and accurate digital voltmeter with LED display using the ICL7107 from Intersil. The ICL7107 is a high performance, low power, 3.5 digit analog to digital converter. The IC includes internal circuitry for seven segment decoders, display drivers, reference voltage source and a clock. The power dissipation is less than 10mW and the display stability is very high.

The working of this electronic circuit is very simple. The voltage to be measured is converted into a digital equivalent by the ADC inside the IC and then this digital equivalent is decoded to the seven segment format and then displayed. The ADC used in ICL7107 is dual slope type ADC. The process taking place inside our ADC can be stated as follows. For a fixed period of time the voltage to be measured is integrated to obtain a ramp at the output of the integrator. Then a known reference voltage of opposite polarity is applied to the input of the integrator and allowed to ramp until the output of integrator becomes zero. The time taken for the negative slope to reach zero is measured in terms of the IC's clock cycle and it will be proportional to the voltage under measurement. In simple words, the input voltage is compared to an internal reference voltage and the result is converted in a digital format.
The resistor R2 and C1 are used to set the frequency of IC's internal clock. Capacitor C2 neutralizes the fluctuations in the internal reference voltage and increases the stability of the display.R4 controls the range of the voltmeter. Right most three displays are connected so that they can display all digits. The left most display is so connected that it can display only "1" and "-".The pin5(representing the dot) is connected to ground only for the third display and its position needs to be changed when you change the range of the volt meter by altering R4. (R4=1.2K gives 0-20V range, R4=12K gives 0-200V range).

Circuit diagram.



Notes.

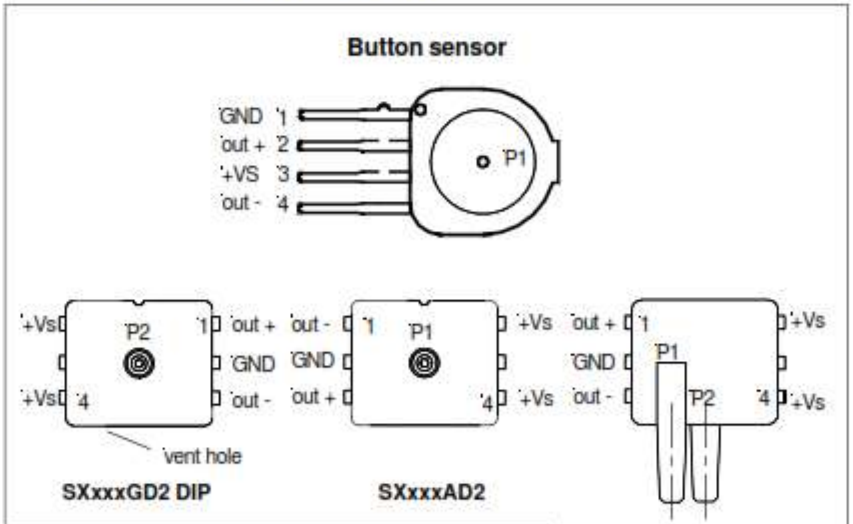
- Assemble the circuit on a good quality PCB.
- The circuit can be powered from a +/_5V dual supply.
- For calibration, power up the circuit and short the input terminals. Then adjust R6 so that the display reads 0V.
- The ICL7107 is a CMOS device and it is very sensitive to static electricity. So avoid touching the IC pins with your bare hands.
- The seven segment displays must by common anode type.
- Assembled this circuit few years back and it is still working fine.

8. SENSORS

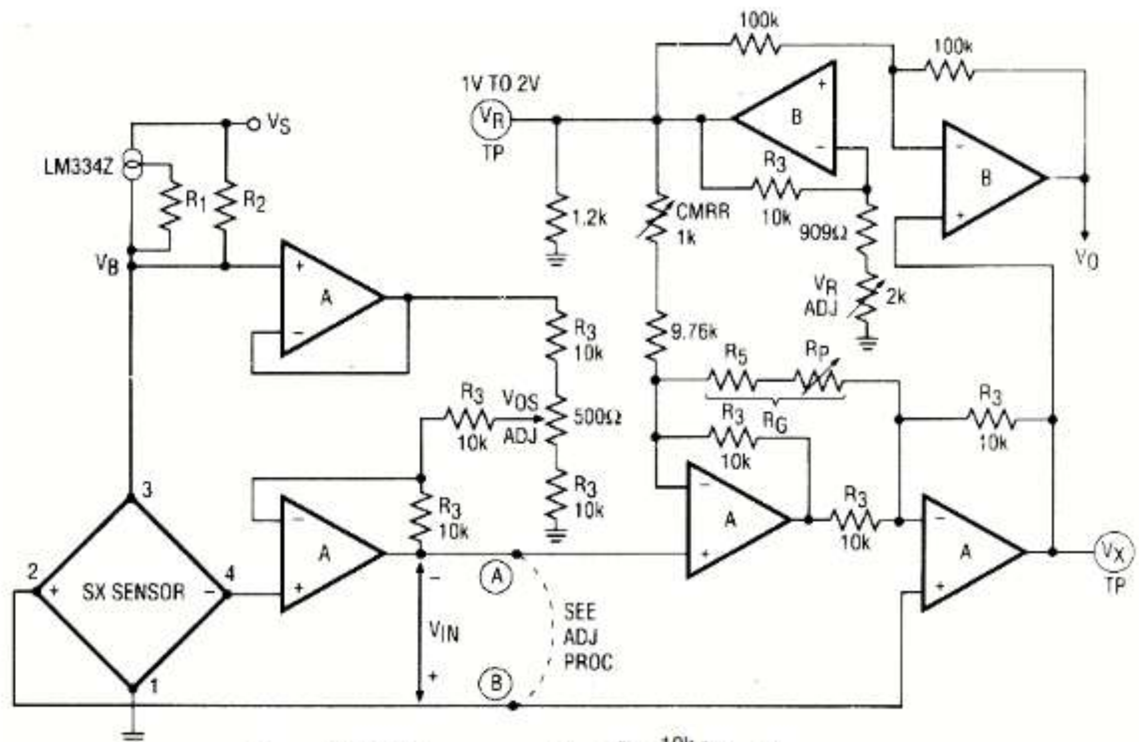
Pressure Sensors

The SX Series pressure Sensors provide the lowest cost components for measuring pressures up to 150 psi. TheseSensors are designed for use with non-corrosive, non-ionic media, such as air and dry gases. Convenient pressure ranges are available to measure differential, gauge, and absolute pressures from 0 psi to 1 psi (SX01) up to 0 psi to 150 psi SX150 . The Absolute (A) devices have an internal vacuum reference and an output voltage proportional to absolute pressure. The differential (D) devices allow application of pressure to either side of the diaphragm and can be used for gauge or differential pressure measurements. This product is packaged in either the standard low cost chip carrier "button" package, a plastic ported "N" package, or a DIP package. All packages are designed for applications where the sensing element is integral to the OEM equipment. These packages can be o-ring sealed, epoxied, and/or clamped onto a pressure fitting.

ELECTRICAL CONNECTION



The polarity indicated is for pressure applied to:		
SX...	:	P1 (forward gage)
SX...AD2	:	P1 (forward gage)
SX...GD2	:	P2 (backward gage)
SX...DD4	:	P2 (backward gage)



A = LT1014CN

B = LM10CN

$$V_O = 4\left[1 + \frac{10k}{R_G}\right] V_{IN} + V_R$$

Resistors labled R_3 are 5-Element Resistor Arrays 10 kΩ. Two required

Figure V: Button Sensor Amplifier Circuit

Force Sensor

Description: This is a small force sensitive resistor. It has a 0.16" (4 mm) diameter active sensing area. This FSR will vary its resistance depending on how much pressure is being applied to the sensing area. The harder the force, the lower the resistance. When no pressure is being applied to the FSR, its resistance will be larger than 1MΩ, with full pressure applied the resistance will be 2.5kΩ.

Two pins extend from the bottom of the sensor with 0.1" pitch making it bread board friendly.

These sensors are simple to set up and great for sensing pressure, but they aren't incredibly accurate. Use them to sense if it's being squeezed, but you may not want to use it as a scale.

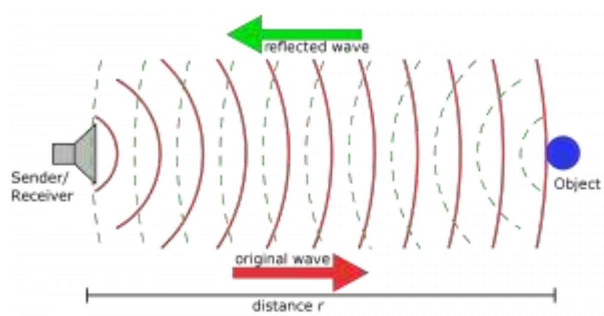
Dimensions:

- Overall length: 1.75"
- Overall width: 0.28"
- Sensing area: 0.3"

ULTRASONIC DISTANCE SENSOR

The theory behind ultrasonic ranging is quite simple. Typically a short ultrasonic burst is transmitted from the transmitter. When there is an object in the path of the ultrasonic pulse, some portion of the transmitted ultrasonic wave is reflected and the ultrasonic receiver can detect such echo. By measuring the elapsed time between the sending and the receiving of the signal along with the knowledge of the speed of sound in the medium, the distance between the receiver and the object can be calculated. The picture below (source: Wikipedia) illustrates this basic principal:

Ultrasonic Ranging (Courtesy of Wikipedia)



We can use separate transducers for transmitter and receiver. It is possible to multiplex the transmission and receiving with a single transducer (e.g. Maxbotix range finders), but the design would be significantly more complex.

Ultrasonic Transducer

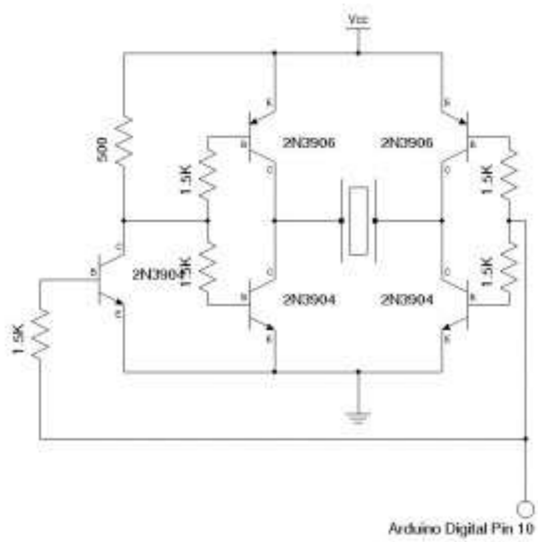
There are quite a few ultrasonic transducers to choose from, and the main criteria are the resonant frequency, radiation pattern and sensitivity. Generally speaking, these parameters affect the measurement in the following ways: a higher resonant frequency can provide finer details of the surroundings due to the shorter wavelength. A more directional radiation pattern can also enhance the resolution of the measurement. Sensitivity affects the efficiency of the transducer and also attributes to the SNR (signal to noise ratio).

The 24KHz transducers shown in the picture below. These transducers are very inexpensive (around a dollar each, and even cheaper when on sale) but effective. With properly designed circuits these sensors can easily achieve a range of more than 20 feet. Of course, using the higher priced 40 kHz sensors should achieve even better performance.

24 kHz Ultrasonic Transducers

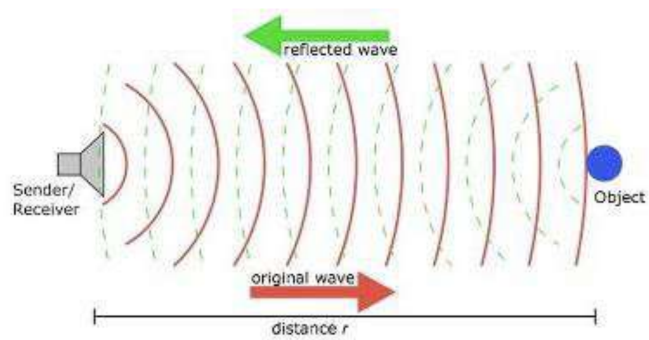
The Transmitter

The ultrasonic transmitter is powered from ATmega328′s counter 1 PWM output (chip pin 16 and Arduino digital pin 10). In order to achieve the maximum output power of the transducer for a given supply voltage, below is the bridged output design as shown in the schematics:

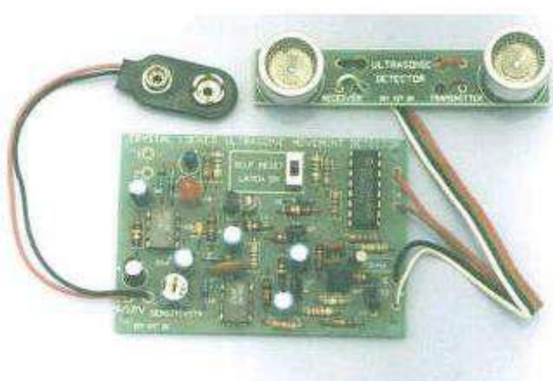


Ultrasonic Transmitter

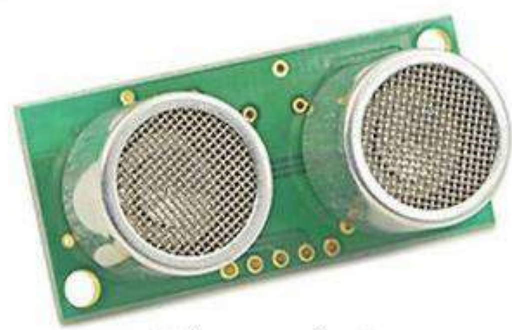
This bridged circuit produces an output voltage roughly twice the Vcc. I used +5V for Vcc and the result is already quite good (more than 20 feet of range). For even longer range measurement, you can safely increase this driving voltage to around 12 Volts as most ultrasonic transducers can be driven with voltage as high as 20 to 30 volts. If you increase the voltage significantly above 5V however, you will have to change the transistors to allow more power dissipation. With 2N3904 and 2N3906 the transistors get warm during normal operation and would heat up drastically with voltage above 6V.



Working (emitting waves)

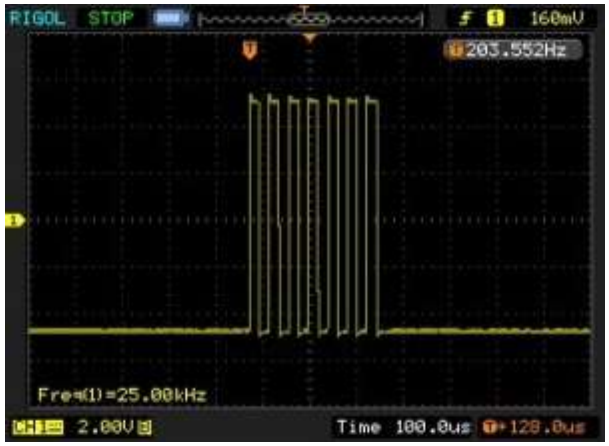


Circuitry



Ultrasonic Sensor

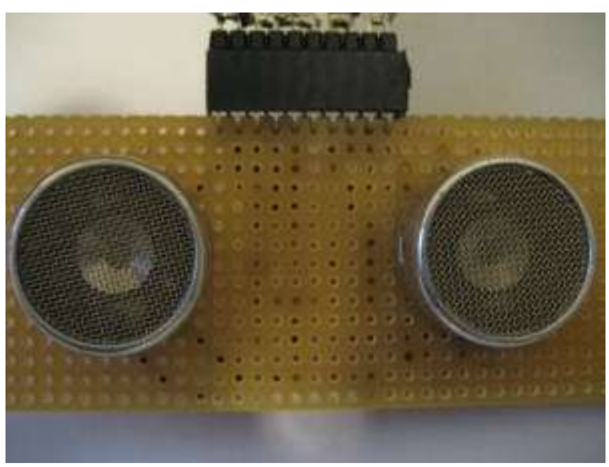
Here is the output of the ultrasonic burst measured at the output transducer's terminals:



Output Waveform

The small "ladders" at the half-way voltage point in the output waveform is due to the slight added delay of the inverted signal stage due to the use of an extra NPN transistor. To obtain purer rectangular wave form and reduce switching loss, a PNP transistor with similar timing parameters can be used on the side that is directly connected to the driving signal. For this application though, the waveform is more than adequate and the added switching loss is negligible.

The transmitter and receiver transducers can be mounted on a circuit board with approximately one inch of spacing (see below).



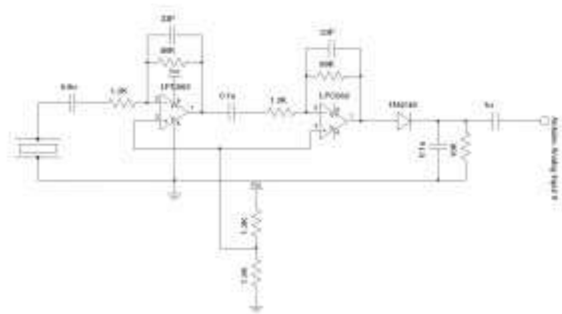
Ultrasonic Range Sensor

The Receiver

The performance of the range sensor is largely determined by the sensitivity of the receiver for a given transmitter power level. Because the received signal is usually very weak (less than 1 mV), a high gain low noise amplifier is needed to ensure optimal performance.

Following is a two stage inverted band-pass amplifier design (see below). Each stage has a gain of around 67 (36.5 dB) and the circuit has a combined voltage gain of 73 dB. The operational amplifier used is National's LPC662. In general, any operational amplifier with a sufficient gain bandwidth product should work just as well.

Each stage has a band-pass filter that is centered around the operating frequency (24 kHz). Because the amplifier has a very high gain, we must pay special attention to the circuit layout in order to prevent parasitic oscillation. The connection between the receiver transducer and the circuit input (6.8n capacitor) needs to be shielded to reduce noise and unwanted coupling.



Ultrasonic Receiver

Because we are using a single power supply the output voltage of the opamp is centered at around Vcc/2 (2.5V). In order to make it easier to process the echo, a diode (IN4148), capacitor (0.1uF) and resistor (10k) are used to demodulate the signal and a coupling capacitor (1uF) is used to rid the demodulated signal of the DC component.

You can see the demodulated envelope waveform from the following oscilloscope screenshots (you can ignore the frequency measurement as these signals are none-periodical the frequency readings are meaningless). The higher amplitude waveforms in both images are the results of the ultrasonic burst, the lower amplitude waveforms are from the echo. In the first screenshot on the left, two echoes can be seen.

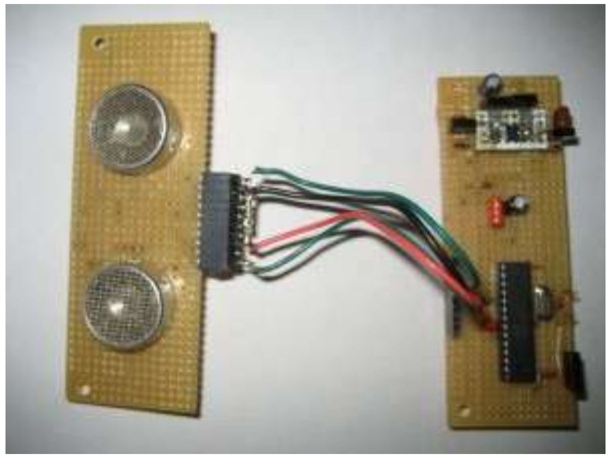
Echo and the demodulated waveform 1

Echo and the demodulated waveform 2

The following screenshot shows the relationship between the ultrasonic pulses (measured from ATmega328 pin 16) from the transmitter and the demodulated echo output. One key observation is that the received signal takes much longer time to fade then the original pulse duration and thus we must add in some delay after the transmission of the ultrasonic pulses. A delay of 1 to 2 millisecond is typical. With a 1 millisecond delay, the shortest measurable distance is around 30 centimeters or one foot.

Demodulated Echo

And here is a picture of the finished project.



Ultrasonic Range Finder

Range Calculation

Since the measured distance is a function of the time interval between the time at which the pulse is transmitted and the time at which the echo is received, we need to detect the echo.

Empirically, we can measure the peak of the received echo and use the time displacement to calculate the distance. We assume that the strongest echo comes from the closest object (this may not always be true as the reflectivity of different objects are different, but generally achieves very good results in real-world situations) and thus the peak measurement corresponds to the closest object's position.