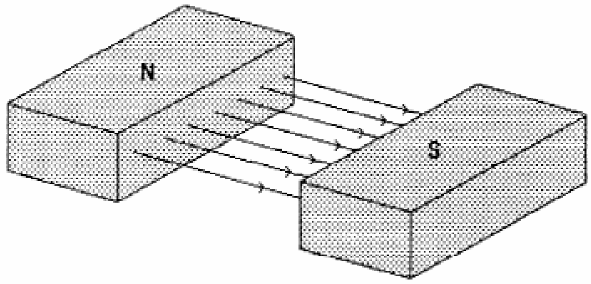
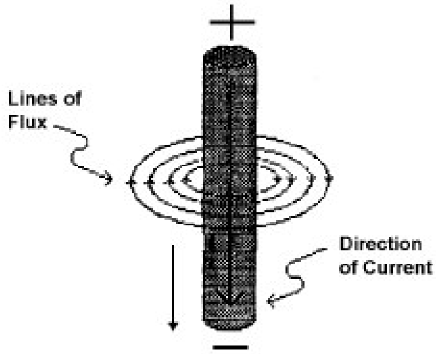
2. DC Motors and Their Drivers

Basics of a DC Motor

Magnetic strength is determined by the density of magnetic flux, which flows from the North pole to the South pole.



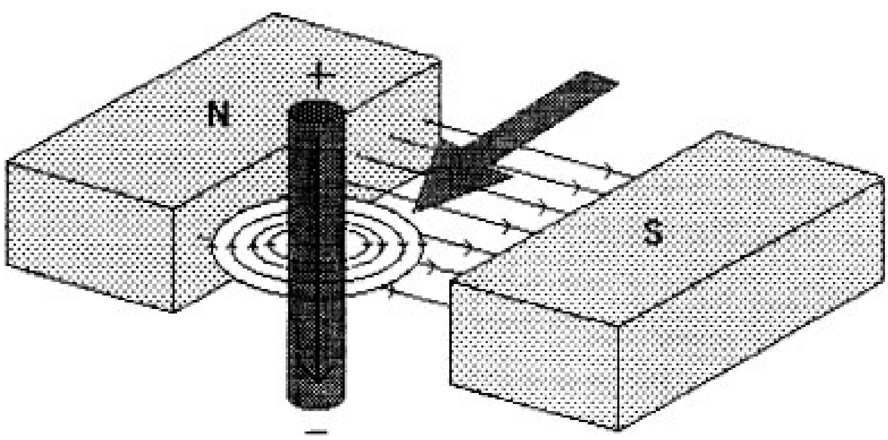
When current flows through a wire, a magnetic flux is generated around the wire according to the right hand rule, assuming current flows from +ve to –ve and the flux direction N to S.



Basics of a DC Motor (con't)

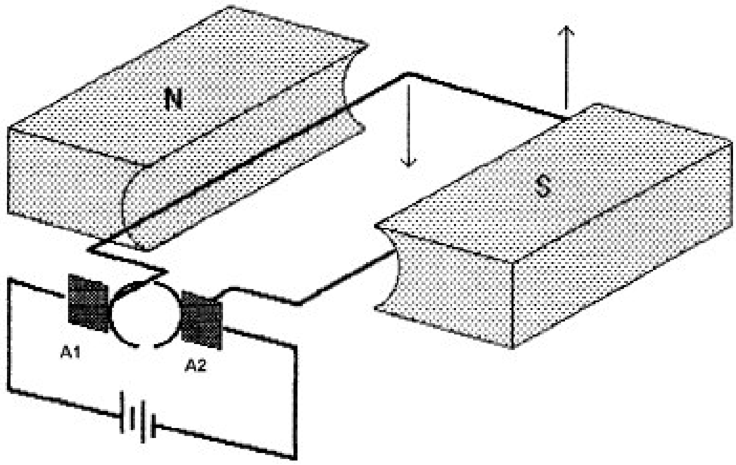
When live wire (with DC current flowing) is placed into a magnetic field, a force is generated, which will push the wire to side where the magnetic flux is weaker.

The force generated is proportional to the strength of the magnetic flux, Φ and the current flowing in the wire, I.



Basics of a DC Motor (con't)

When this effect is optimised and configured in a loop, with a brush to change the flow of current in the wire, the resultant linear motion can be transformed into a rotational motion and the linear force transformed into effective torque.



Basics of a DC Motor (con't)

The torque generated can be calculated as:

$$T = K_t \Phi_F I_A$$

where

T = Torque $\quad$ K_t = Torque constant

Φ_F = Field Flux $\quad$ I_A = Armature current

The rotational speed of the motor is determined by:

$$N = (E_T - I_A R_A) / K_V \Phi_F$$

where

N = speed $\quad$ E_T = terminal voltage

I_A = Armature current $\quad$ R_A = armature resistance

K_V = voltage constant $\quad$ Φ_F = Field Flux

In practice, the wire will be wound into a core of multiple loops.

General Motor Drives

2 main characteristics of the DC motor are:

- Speed is proportional to the applied voltage
- Current is proportional to the load carried by the motor.

Thus, in order to control the motor performance, logically speaking, we should be controlling the voltage being sent to the motor, with sufficient current limit from the source.

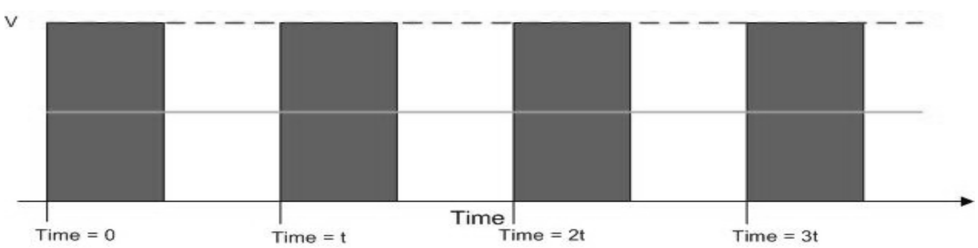
This is not done in practice, as variable analog voltage output with large current is not available, and is not practical.

The solution is to efficiently control the power being sent to the motor through the PWM method.

Introduction to Pulse Width Modulation (PWM)

A PWM signal consists of a fixed frequency logic pulse train with controllable duty cycle.

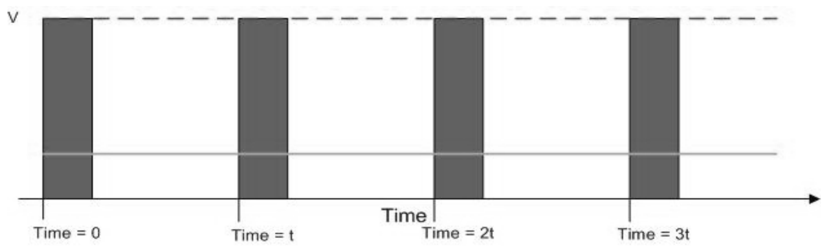
Imagine a normal clock signal, i.e. 50% duty cycle, as shown below is sent to an electronic switch.



The blue section will be the switch-on period. If applied voltage is V, then the equivalent voltage is V/2, as shown by the green line, which is 50% of V.

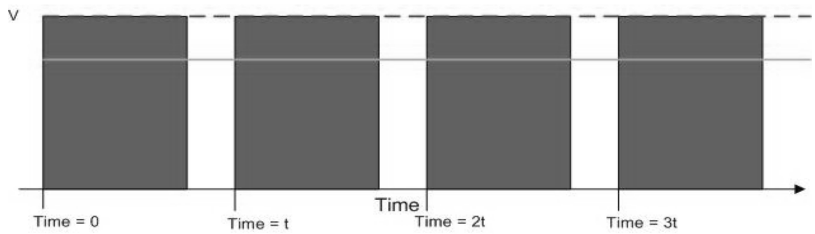
PWM (con't)

If a lower duty cycle is set, say 25%, then the PWM signal will look like this.



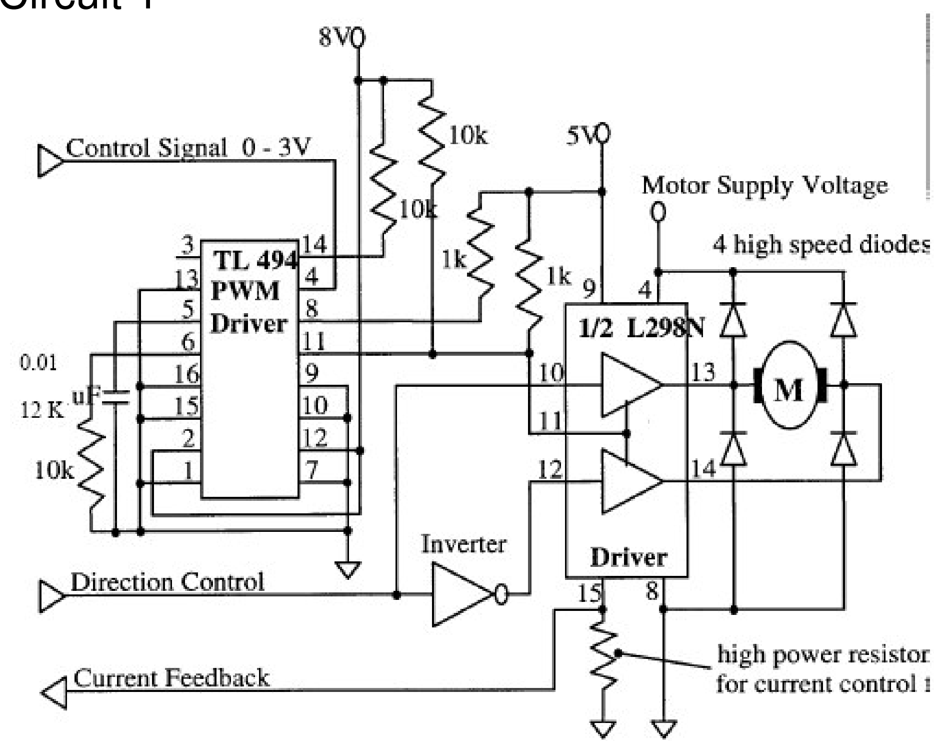
The equivalent output voltage shall then be V/4.

If a higher duty cycle of 75% is used, then the output will be similar to 3V/4.



PWM (con't)

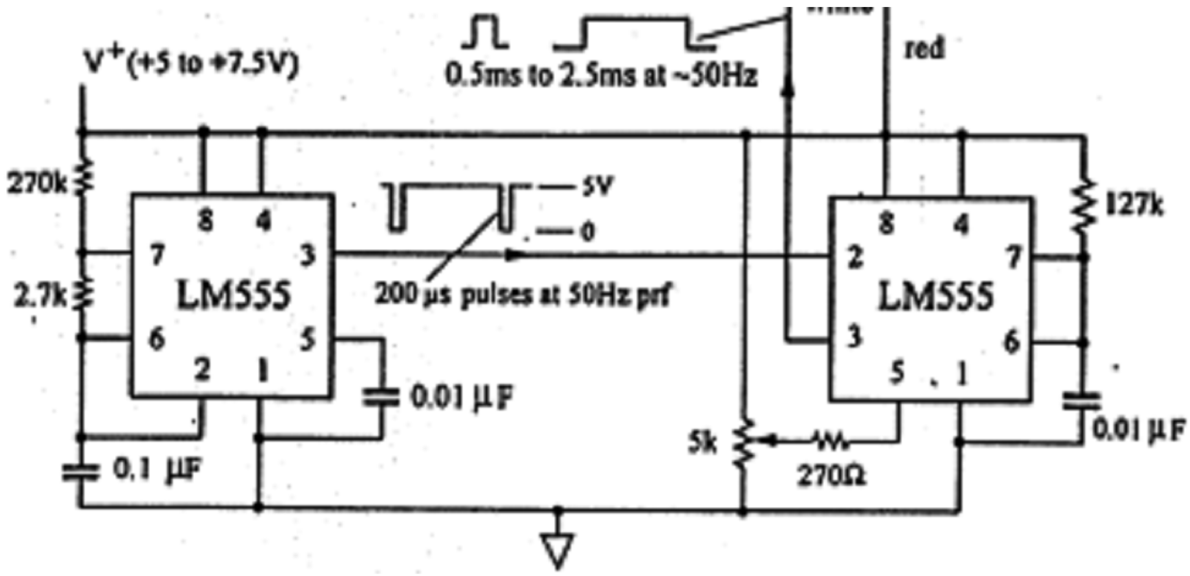
PWM Circuit 1



PWM (con't)

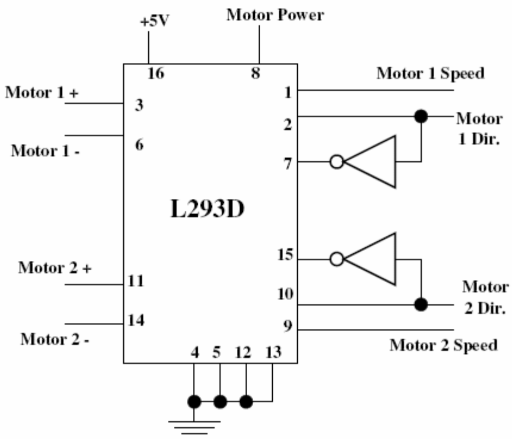
PWM Circuit 2

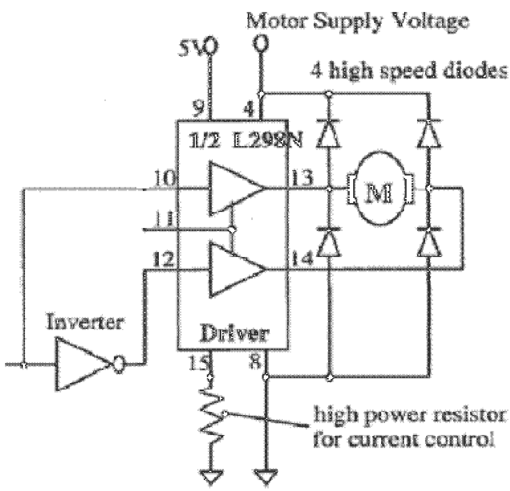
Using 2 LM555 timer chips. PWM is controlled by 5Kohm variable resistor.



PWM (con't)

PWM signals can also be generated by many Microcontrollers directly, without having to build external circuitries. For such situations, only the driver circuits need be incorporated. Examples of Driver chips are the L293D and the L298N.



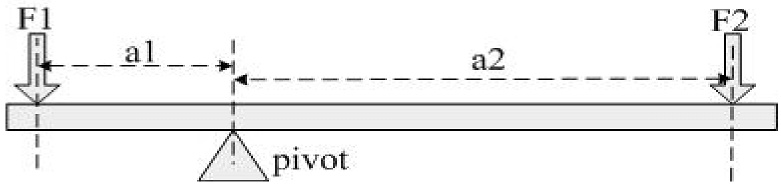


Gears & Gearbox

Principles of operation for gear trains are similar to that of the lever. In the lever system, the balancing force is inversely proportional to the moment arm, as shown below.

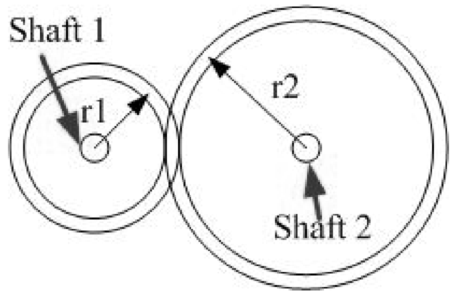
In equilibrium:

$$F1.a1 = F2.a2$$



Gears are normally used to change the output torque and speed of a rotary actuator.

The input shaft is connected to the actuator and normally to a smaller gear. The output shaft connects to the wheel or linkages and a bigger gear.



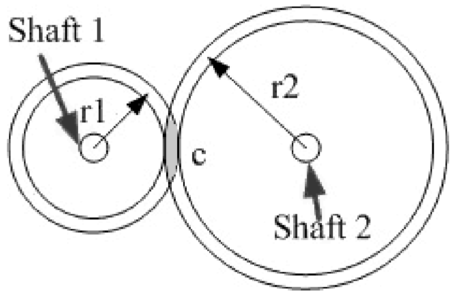
Gears & Gearbox (con't)

If Shaft 1 = input shaft & Shaft 2 = output shaft

Let T1 = input torque, T2 = output torque

w1 = input rotational speed, and

w2 =output rotational speed



Then,

$w2 = w1 \times r1 / r2$, and $T2 = T1 \times r2 / r1$

Thus, if $r2 > r1$ then

$w2 < w1$, and $T2 > T1$

The gears can be appended to create gear trains to achieve higher magnification factors, but the efficiency can take a beating !!

Huge gear trains can have efficiency as low as 20%, due to friction, etc.

Multiple gears placed in plenary manner may increase the efficiency slightly.

2.2 RC Servo Motors

A Servo is a small device that has an output shaft. This shaft can be positioned to specific angular positions by sending the servo a coded signal. As long as the coded signal exists on the input line, the servo will maintain the angular position of the shaft. As the coded signal changes, the angular position of the shaft changes. In practice, servos are used in radio controlled airplanes to position control surfaces like the elevators and rudders. They are also used in radio controlled cars, puppets, and of course, robots.

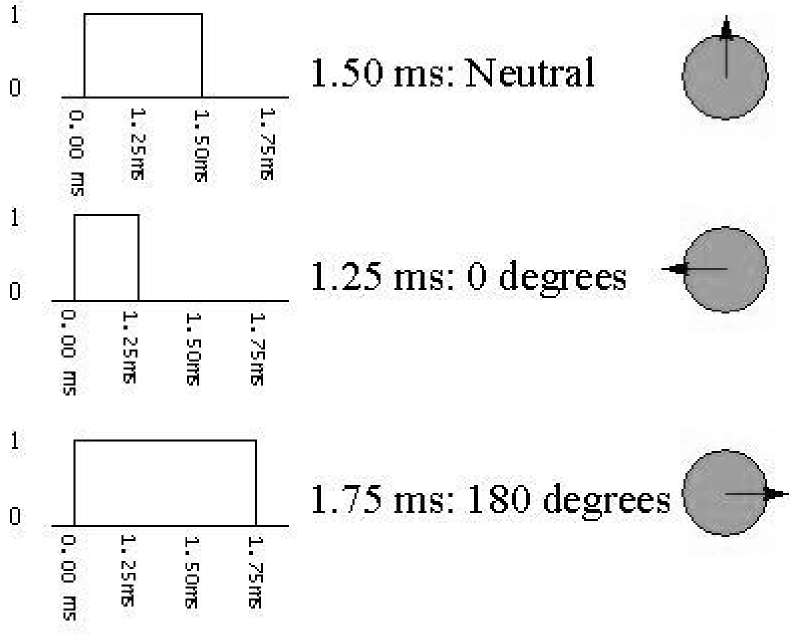
Servos are extremely useful in robotics. The motors are small, as you can see by the picture on the right, have built in control circuitry, and are extremely powerful for their size. A standard servo such as the Futaba S-148 has 42 oz/inches of torque, which is pretty strong for its size. It also draws power proportional to the mechanical load. A lightly loaded servo, therefore, doesn't consume much energy. The guts of a servo motor are shown in the picture below. You can see the control circuitry, the motor, a set of gears, and the case. You can also see the 3 wires that connect to the outside world. One is for power (+5volts), ground, and the white wire is the control wire.

So, how does a servo work? The servo motor has some control circuits and a potentiometer (a variable resistor) that is connected to the output shaft. In the picture above, the pot can be seen on the right side of the circuit board. This pot allows the control circuitry to monitor the current angle of the servo motor. If the shaft is at the correct angle, then the motor shuts off. If the circuit finds that the angle is not correct, it will turn the motor the correct direction until the angle is correct. The output shaft of the servo is capable of traveling somewhere around 180 degrees. Usually, it is somewhere in the 210 degree range, but it varies by manufacturer. A normal servo is used to control an angular motion of between 0 and 180 degrees. A normal servo is mechanically not capable of turning any farther due to a mechanical stop built on to the main output gear.

The amount of power applied to the motor is proportional to the distance it needs to travel. So, if the shaft needs to turn a large distance, the motor will run at full speed. If it needs to turn only a small amount, the motor will run at a slower speed. This is called proportional control.

How do you communicate the angle at which the servo should turn? The control wire is used to communicate the angle. The angle is determined by the duration of a pulse that is applied to the control wire. This is called Pulse Coded Modulation. The servo expects to see a pulse every 20 milliseconds (.02 seconds). The length of the pulse will determine how far the motor turns. A 1.5 millisecond pulse, for example, will make the motor turn to the 90 degree position (often called the neutral position). If the pulse is shorter than 1.5 ms, then the motor will turn the shaft to closer to 0 degrees. If the pulse is longer than 1.5ms, the shaft turns closer to 180 degrees.

As you can see in the picture, the duration of the pulse dictates the angle of the output shaft (shown as the green circle with the arrow). Note that the times here are illustrative and the actual timings depend on the motor manufacturer. The principle, however, is the same.



Hacking a Servo

This section is going to describe how to take an RC servo and make it into an excellent gear-head motor. The changes are quite easy to do, once you have seen the insides. This modification is known to work quite well on Futaba S-148 servos, which are commonly available.

The theory behind this hack is to make the servo think that the output shaft is always at the 90 degree mark. This is done by removing the feedback sensor, and replacing it with an equivalent circuit that creates the same readings as the sensor being at 90 degrees. Thus, giving it the signal for 0 degrees will cause the motor to turn on full speed in one direction. The signal for 180 degrees will cause the motor to go the other direction. Since the feedback from the output shaft is disconnected, the servo will continue in the appropriate direction as long as the signal remains.

As for the details, there are actually only two modifications to make to the servo.

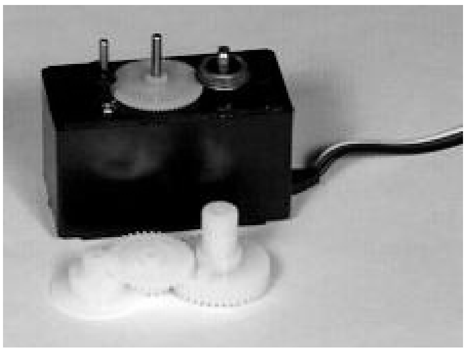
1. Replace the position sensing potentiometer with an equivalent resistor network
2. Remove the mechanical stop from the output shaft

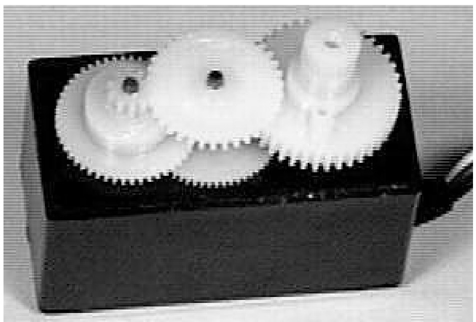
Here are the steps. You will need a few supplies

1. small philips screwdriver for opening the case
2. a soldering iron
3. a desoldering pump or solder wick for removing the potentiometer
4. a sharp knife or wire cutters for removing the mechanical stop
5. Two 2.2k resistors (actually, anything between 2.2k and 3.3k will work, as long as they are equal values)

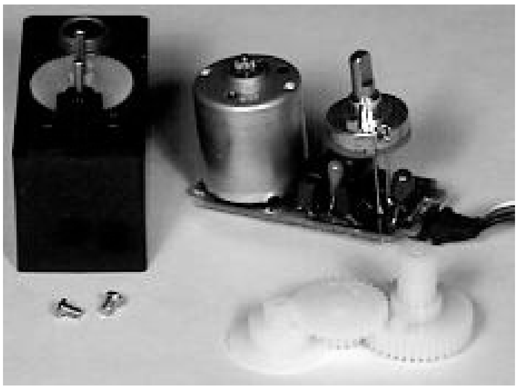
The following steps will help you make the modifications.

- Open the case by removing the 4 screws located at the bottom of the servo. The bottom plate should come off easily. Remove the top of the case. You will find a set of gears under the top case, a several blobs of white grease. Try hard to save the grease by leaving it on the gears.
- Be careful to note how the gears are arranged, and remove them from the top of the servo. I usually place them as they are supposed to sit. The large fine tooth gear in the middle does not need to be removed. See the picture below.

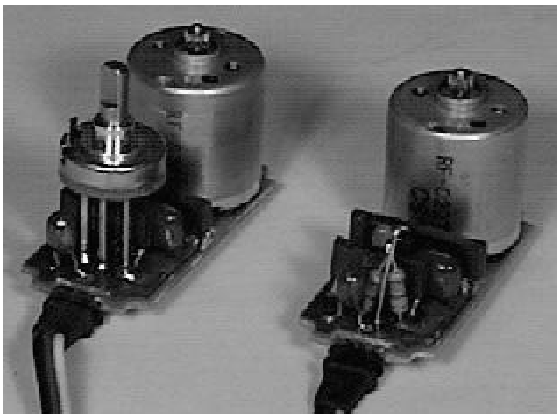




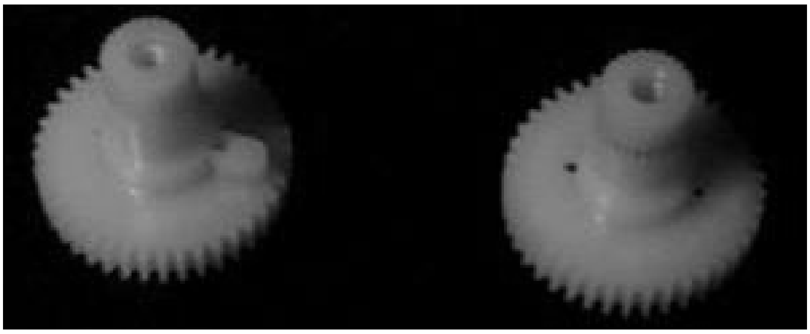
- Locate and remove the two small philips head screws on the left shaft in the picture above. These screws go through the top case and into the drive motor.
- Next, you need to remove the circuit board from the case. To do this, you will probably need to press down hard on the brass shaft on the right side. This is the top of the position potentiometer. I find that pressing that brass shaft against the edge of the workbench helps push it through.
- From the bottom, very carefully pry up on opposing corners of the circuit board. The board should slide out with the motor and potentiometer attached. You should end up with the following parts on the table.



- Now for the actual modifications. You will need to de-solder the potentiometer from the board. I usually cut the long leads off a quarter inch or so from the bottom. I then use solder wick on the back side of the board.
- Once the pot has been removed, you need to wire in the resistor network in its place. To do this, place the resistors side by side and twist one pair of leads. Solder them together, but leave one of the leads long enough to make a 3 wire part. Then replace the pot with this 3 wire pot. As seen in the picture below, the pot has been replaced by the resistor network. The unmodified unit is on the left, while the right unit was after modification.



- Now, reassemble the circuit board into the case. Note that the pot is now missing, so only the motor will protrude through the top of the case.
- Before reinstalling the gears, you will need to modify the gear with the output shaft so the mechanical stop is removed. The mechanical stop is a small tab of plastic on the lower gear surface. In the picture below, you can see the tab on the left gear. This should be cut down flush with the surface. Try to get all of the tab removed, as is shown with the gear on the right side.



- Replace the gears as they were when you took the motor apart, replace the top of the case, the bottom plate, and the two screws.
- Your done!

The motor should now be able to turn all the way around. Connect a control horn, and carefully apply enough pressure to make the horn turn around. Feel for any mechanical problems, such as a gear catching on the cut off section of the tab. You should not feel any catching or resistance. It would be best not to play with turning the servo by hand too much. This device is not intended to be driven from the output shaft, and it may cause undo wear and tear on the servo motor.