

CATCH ME IF YOU CAN¹

A MECHATRONICS

DEMONSTRATION PROJECT
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1. ABSTRACT

The goal of this project was to create a device that would model the physical laws in projectile motion. Using electronic and mechanical devices (mechatronics), a projectile launcher was built. This launcher will be used in a high school physics classroom to demonstrate the laws of projectile motion. When an appropriate angle (20 to 65 degrees) is entered in the software program the basic stamp raises the platform, computes the correct distance for the “catcher” and finally launches the ball towards the target. It was found that the device was consistently accurate for angles from 20 to 30 degrees. When other factors were included in the formula, the accuracy was extended from 20 to 65 degrees. It was discovered that errors in the creation of the device and the limits of the basic stamp were likely to affect the outcome of this experiment.

2. INTRODUCTION

When objects are thrown or fired from the Earth's surface their trajectory can easily be determined by using the laws of physics. These laws govern the distance that a projectile will travel across the surface of the Earth. By changing the angle at which a projectile will launch, one can determine the maximum distance that it will travel for a given velocity. One military application of this can be found in the field of artillery. When the initial velocity can be determined, it is relatively easy to determine the correct distance that a shell will travel. These calculations are typically very accurate however error does exist. One error that must be taken into account is air resistance which acts as a retarding force on the projectile. Another possible error is the Coriolis Effect that is caused due to Earth's rotation. This effect is only a serious consideration when a projectile is in the air for an extended period of time.

3. STANDARDS CORRELATION

This project meets the New York State Education Department Physics Standards in the following way;

Science Standards-Commencement Level

Key Idea 4:

4.1 Energy exists in many forms, and when these forms change energy is conserved.

- describe and explain the exchange among potential energy, kinetic energy, and internal energy for simple mechanical systems, such as a pendulum, a roller coaster, a spring, a freely falling object.
- observe and explain energy conversions in real-world situations

Key Idea 5:

5.1 Explain and predict different patterns of motion of objects (e.g., linear and uniform circular motion, velocity and acceleration, momentum and inertia).

- sketch the theoretical path of a projectile

5.1f The path of a projectile is the result of the simultaneous effect of the horizontal and vertical components of its motion; these components act independently.

5.1g A projectile's time of flight is dependent upon the vertical component of its motion.

5.1h The horizontal displacement of a projectile is dependent upon the horizontal component of its motion and its time of flight.

4. BACKGROUND

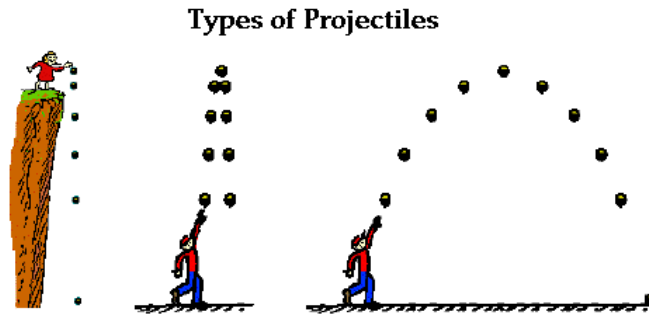
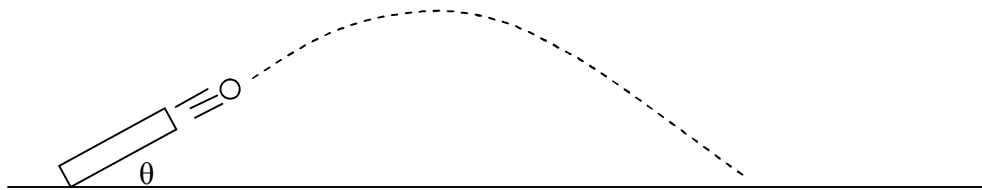


Illustration 1. Projectile Motion

Projectile Motion describes the motion of an object, in at least two dimensions, and experiences that force of gravity in the vertical direction. The motion of a projectile can be analyzed separately as two independent motions, horizontal and vertical. A projectile launched at some angle θ and initial velocity V_o will have a horizontal velocity component of $V_o \cos \theta$ and a vertical velocity component of $V_o \sin \theta$.



A projectile's horizontal velocity is constant because it experiences no net force in the horizontal direction. A projectile's vertical velocity is not constant as it experiences a net force downward, equal to the weight of the object. This net force results in an acceleration according to Newton's 2nd law and is equal to 9.8 m/s^2 downward. For the case when the launch height is equal to the landing height, the time of flight can be found by first finding the time the projectile takes to reach its maximum height. The vertical velocity of the projectile is zero at this point and this fact can be used with the equation that describes the velocity of an accelerated object to find the time.

$$V = V_{oy} + at = 0$$

and solving for t....

$$t = \frac{V_{oy}}{g}$$

The time of flight will then be two times the time found above.

$$t = \frac{2V_{oy}}{g} = \frac{2V_o \sin \theta}{g}$$

The time of flight can now be used with the equation that describes the horizontal displacement to find the range of the projectile.

$$x = V_o x t = \frac{V_o \cos \theta (2V_o \sin \theta)}{g}$$

Using the trig identity $\sin 2\theta = 2\cos \theta \sin \theta$ we can rewrite the range as follows.

$$x = \frac{V_o^2 \sin 2\theta}{g}$$

This is the final formula used in the PBASIC code to launch the ball to a given range.

4. EQUIPMENT USED

This project required the use of several mechanical and electronic components.

A) Launcher

The mechanical device used to launch the golf ball is a converted Wilson Putting Pal (shown below).



Illustration 3. The launcher

Inside the putting cup there is a solenoid which is a magnetic coil that pulls back a metallic “plunger” when current is present in the coil. When the switch is engaged the current is cut off and the plunger is propelled forward due to a spring located behind it. This force is applied to the golf ball causing it to be expelled from the front of the launcher.

In order to change the angle at which the golf ball is released, a constructed platform was connected to a DC motor and a potentiometer. The Wilson Putting Pal was then secured to the top of this platform. The potentiometer changes the voltage applied to a circuit by modifying the resistance. By attaching the potentiometer and DC motor to a hinge at the back of the platform, the varying voltage of the potentiometer could be used to determine the angle at which the DC motor had raised the platform.

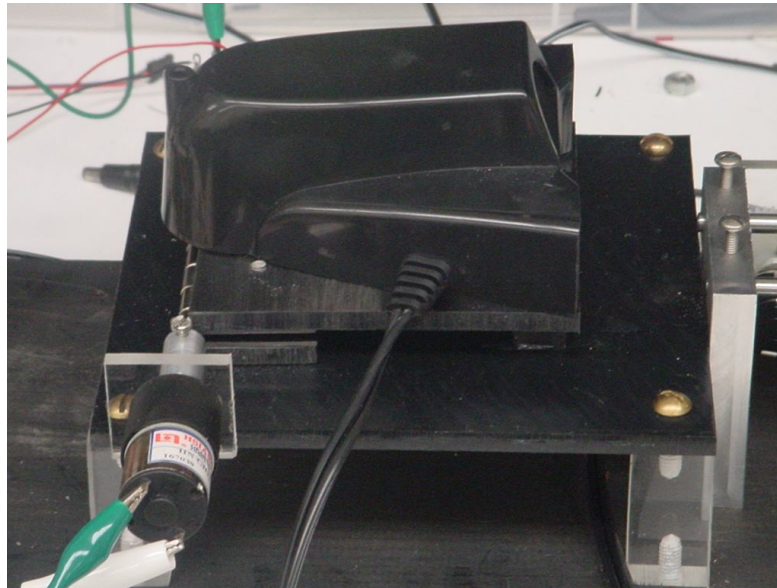


Illustration 4. The launcher and the platform.

B) Catcher

In order to “catch” the golf ball a track was built. The catcher was constructed from a piece of lucite with ball bearings drilled into it. These ball bearings allowed the catcher to move freely along two supporting metal rods. The catcher was driven by a servo motor (shown below), with a gear attached, which was used to move the catcher to a specific point along the track.



Illustration 5. Servo Motor

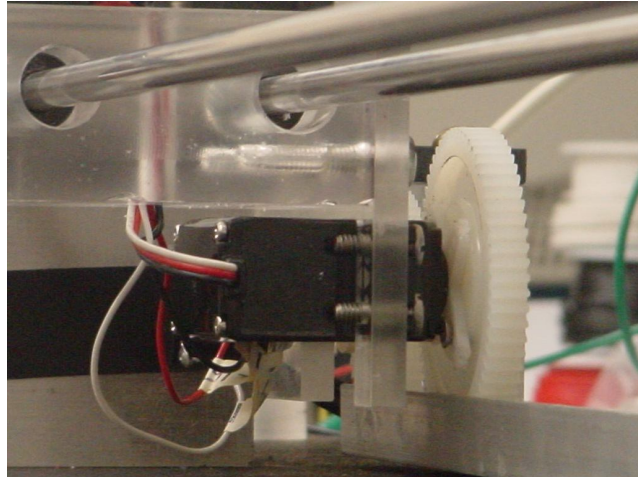


Illustration 6. Servo Motor connected to catcher

A potentiometer (shown on next page) was used to determine the correct distance along the track to place the catcher based on human or computer input. The potentiometer changes the voltage applied to a circuit by modifying the resistance. By using another gear to connect the potentiometer to the track we were able to correlate a specific voltage to the distance from the launcher.

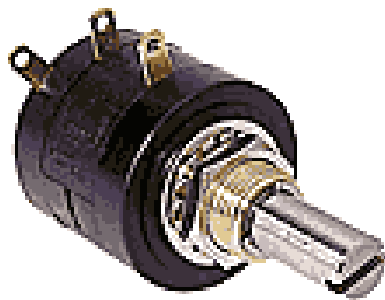


Illustration 7. Potentiometer

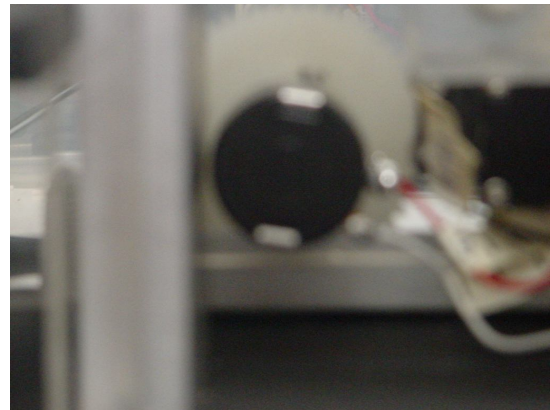


Illustration 8. Potentiometer connected to catcher.

C) Control

As with the majority of experiments in the field of mechatronics, control is the key element in the experiment. Control systems allow us to initiate an action based on a set of defined variables. The main control system in this experiment is the Basic Stamp 2 micro-controller. This micro-controller allows for the monitoring and control as many as 16 input or output devices.

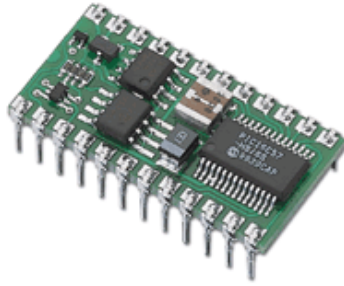


Illustration 9. The Basic Stamp.

The following table lists the pin assignments used on the Basic Stamp and the corresponding circuit element.

Basic Stamp I/O Pin	Pin Assignment
P0	Chip select for ramp position ADC
P1	Clock signal for ramp position ADC
P2	Digital output from ramp position ADC
P3	Chip select for cart position ADC
P4	Clock signal for cart position ADC
P5	Digital output from cart position ADC
P6	Servo motor control
P7	Ramp motor output A
P9	Ramp motor output B
P8	Ball launch switch

Most of the circuitry required for the experiment was built on a breadboard. An image of the breadboard is shown below.

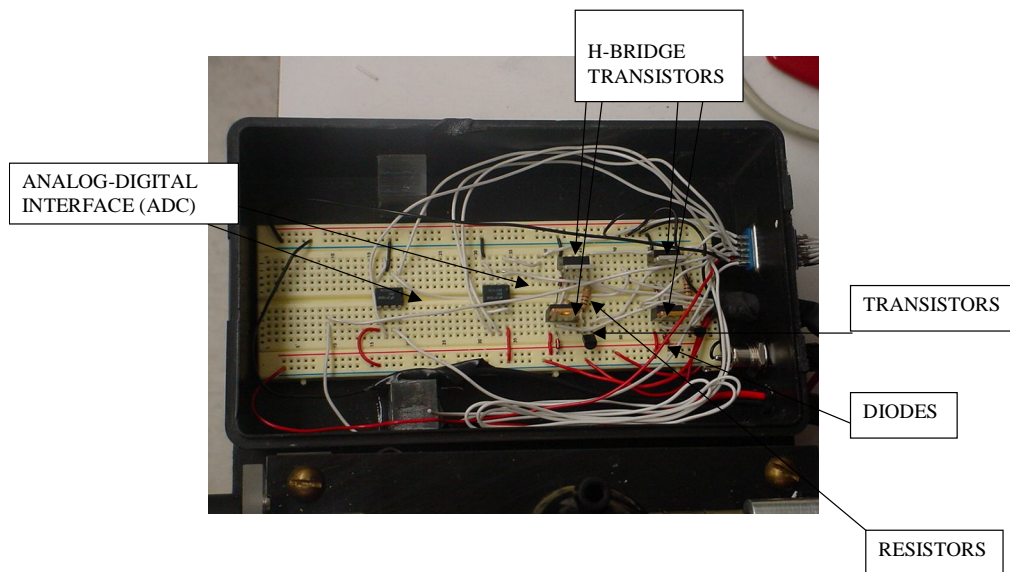


ILLUSTRATION 10. The Breadboard with components.

I) H-BRIDGE TRANSISTORS

In order to control the direction of the DC Motor, an H-Bridge had to be constructed. An H-Bridge is a series of transistors (electric switches) that allows the flow of current to pass in a particular direction. By alternating the flow of current through the H-Bridge, the direction in which the DC motor rotated could be controlled.

II) Diodes

Diodes allow current to flow in only one direction. They were used to prevent voltage spikes in the circuit.

III) ADC 0831

The ADC 0831 is an analog to digital converter. In this experiment we will need to convert to digital input and output in order to determine angle and distance. The ADC 0831 has 8 pins but can only control one 1 output or input device at a time.

IV) Resistors

Resistors are used to lower the current in the circuit in order not exceed the maximum current tolerance of the other components on the breadboard.

V) Solid State Relay

One important control device that is not on the breadboard is the solid state relay. The relay is a switch that is located inside a black box. One end of the power cord is connected to the power supply (AC wall socket) while the other end is connected to the launcher. The socket in the middle of the box is connected to the breadboard. When the ball is to be launched, the basic stamp will send an electronic signal to the relay (switch) and the ball will be launched.



Illustration 11. Solid State Relay.

5. EXPERIMENT

Procedure: Verification of Projectile Motion Formula

Goals:

1. Students will relate the angle of release to the maximum horizontal distance that the projectile travels.
2. Students will identify the angle (45^0) of maximum horizontal displacement.

Procedure:

1. Connect BS2 to the breadboard by using the DB-15 adapter and to a computer using a DB-9 serial cable.
2. Download the *CatchMeIfYouCan.bs2* file to the BS2
3. At the prompt, the student will enter the desired angle (20-65 degrees) in the window.
4. The BS2 will elevate the platform to the desired angle, student will be instructed to place golf ball in launcher.
5. The BS2 will determine the proper distance to move the “catcher” on the track. The servo motor will move “catcher” to calculated position.
6. Ball will be launched and will land on catcher.

Results:

It was determined that the projectile launcher was accurate for angles from 20 to 30 degrees. When tested at these angles the ball constantly hit the catcher. However at angles above 30 degrees, the ball was consistently short of the catcher, which was correctly placed based at the calculated distance. This effect was more pronounced as the angle increased. We believed that this effect was due to the position of the golf ball in the launcher. At high angles, the motor was unable to produce the velocity (3 meters/second), required to propel the golf ball. We changed the formula so that the range of the catcher was reduced by the angle of the launcher minus twenty five. After further testing it was determined that the apparatus was now accurate between the angles of 20 and 65 degrees.

6. UNCERTAINTY ANALYSIS

A) Floating Point Calculations

One unavoidable error in this experiment is due to the limitations of the BS2. The BS2 is unable to make floating point calculations, such as including the decimal point placement in a calculated number. This means that many calculated numbers will not be rounded off correctly. It has been determined in this experiment that this could lead to an error in distance of up to three centimeters. In order to round numbers off to an acceptable level, another limitation of the BS2 comes into play. The largest variable that can be stored in the BS2 is a “word” which has a numerical range of 0-65,535. This indicates that the highest level of precision in this experiment cannot exceed the thousandth placement.

B) Initial Velocity of the Golf Ball

In this experiment the initial velocity of the golf ball is assumed to be a constant. In fact the initial velocity of the ball is highly influenced by the voltage applied to the solenoid in the launcher. Since the voltage applied to the solenoid can vary in small amounts, the initial velocity of the golf ball will have a range of values. Since the velocity of the ball is not being determined in this experiment, it cannot be used in the formula. In order to account for this range of velocities, a larger “catcher” has been used. This will allow for variations in initial velocity.

C) Mechanical Hinge

The hinge that was constructed to open the platform allows for some “play” in the angle of the platform (see image below). When the platform is raised to the desired angle, the hinge is unable to hold that angle exactly due to the mass of the platform, golf ball and launcher. This results in a small drop in the position of the platform before the golf ball is released.



Illustration 12. The mechanical hinge.

7. PROJECT COSTS

ITEM	SUPPLIER	PART NUMBER	UNIT COST	QUANTITY	TOTAL
Ping Pong Balls	Sports Authority	N/A	1.99	1	1.99
Foam Golf Balls	Sports Authority	N/A	2.99	1	2.99
Al Angle 48"	Home Depot	N/A	3.35	1	3.35
Putting Pal	Sports Authority	N/A	12.99	1	12.99
14.5 deg Spur Gear, 32 pitch, 52 teeth	McMaster	57655K48	4.09	1	4.09
14.5 deg Spur Gear Rack, 32 pitch,	McMaster	57655K62	4.78	4	19.12
Self Aligning Ball Bearings 1/4 ID	McMaster	6489K61	14.83	2	29.66
14.5 deg Spur Gear, 32 pitch, 62 teeth	McMaster	57655K49	6.27	1	6.27
Hardened Steel Shaft 48" x 1/4"	McMaster	6061K71	22.66	2	45.32
Analog-Digital Converter (ADC0831)	Parallax	ADC0831	6	2	12
TIP 42 Transistor (PNP)	Radio Shack	276-2027	1.49	2	2.98
1K Ohm Resistors	Parallax	150-01020	0.15	4	0.6
Zener Diodes	Parallax	1N4002	0.5	4	2.00
NPN Transistor	Radio Shack	2N2222	0.69	2	1.38
NPN Transistor	Radio Shack	TIP120	1.49	2	2.98
Futaba S148 Servo Motor	Parallax	S148	12	1	12.00
DC Motor	Jameco	N/A	21.95	1	21.95
10 Turn (10K) Potentiometer	Digikey	3590	13.38	1	13.38
100 K Potentiometer	Digikey	91	9.02	1	9.02
Wood (1x10x60)	Sids Hardware	N/A	7.99	1	7.99
				Total	212.06

8. SUGGESTED PROJECTS

1. Determine the relationship between the angle of release and launch velocity.
2. Use sensors to verify the maximum height of the golf ball at different angles.
3. Account for discrepancy between launch height and catcher platform.

9. REFERENCES

1. The Physics Classroom and Mathsoft Engineering & Education, Inc., The Physics Classroom, Accessed August 8, 2003, <http://www.physicsclassroom.com/Default.html>.
2. Hewitt, Paul, Conceptual Physics, Prentice Hall, 2001.
3. Parallax home page, Accessed August 8, 2003, <http://www.parallax.com>
4. Pasco Scientific resource for physics equipment, Accessed July 25, 2003, <http://www.pasco.com>
5. Basic Analog and Digital Student Guide, Parallax Inc., 2003

Appendix I. P-Basic Code

```

SMART Program Summer 2003
' Funded by The National Science Foundation
' Polytechnic University
' Mechanical Engineering
'
' Catch Me If You Can
'
' Professor Vikram Kapila
' John Luvera   Montville Township High School Montville, NJ
' Mike McDonnell Midwood High School       Brooklyn, NY
'
*****
'{$STAMP BS2}
'{$PBASIC 2.5}
*****
*****
'declaration of constants and variables used

ramp_position_cs      CON    0      'Chip select for Ramp A to D
ramp_position_clk     CON    1      'ADC Clock for ramp
ramp_position_input   CON    2      'ADC position input for ramp
cart_position_cs      CON    3      'Chip select for Cart A to D
cart_position_clk     CON    4      'ADC Clock for ramp
cart_position_input   CON    5      'ADC position input for ramp
servo_motor           CON    6      'Servo motor pin
ramp_motorA           CON    7      'Motor input A
ramp_motorB           CON    8      'Motor input B
launch                CON    9      'Solid state relay for launcher
Vosqr                 CON   900     'Initial Velocity squared (3*3*100)
g                     CON   10     'Acceleration of gravity in m/s^2

Ready    VAR    Bit    'Var to check when ball is on launcher
Angle    VAR    Byte   'Var for Angle input from user
PotAngle VAR    Word   'var to set pot for a given angle
PotRange VAR    Word   'var to set pot for a calculated range
Sine2Theta VAR   Word   'var for sin (2*Angle)
Range    VAR    Word   'var for range
datain   VAR    Byte   'var to store either angle of incline or position of cart

*****
*****
initial:                                'Inialization of Ramp and Ball Catcher

    LOW ramp_motorB                      'set both motor inputs to 0
    LOW ramp_motorA
    
```

```

HIGH ramp_position_cs      'Convert analog value from pot to digital
LOW ramp_position_cs      'Check current position of ramp and set to
LOW ramp_position_clk      'zero degrees if not at zero
PULSOUT ramp_position_clk, 210
SHIFTIN ramp_position_input, ramp_position_clk, MSBPOST, [datain\8]

DEBUG "Welcome to the 'Catch Me If You Can' Projectile Motion Demo.", CR, CR

IF datain < 31 THEN Main      'Check if at zero TEMPORARILY
COMMENTED
IF datain > 35 THEN Zero_Ramp

Zero_Ramp:                  'Lower Motor
LOW ramp_motorA
HIGH ramp_motorB
PAUSE 10

Main:

DEBUG "Please enter the angle of launch and the computer will calculate and set the
range.", CR
DEBUG "The angle must be >=20 and <= 65 degrees.", CR
DEBUGIN DEC Angle

IF Angle > 65 OR Angle < 20 THEN Main      ' Check to make sure angle is in
range

PotAngle = (((Angle - 20) * 55) / 50 )      'Convert Angle to corresponding pot value
'PotAngle = (Angle * 11) / 10 - 22
GOSUB Set_Ramp_Angle      'Set ramp angle
GOSUB Calc_Range          'Calculate range

IF Angle >= 30 THEN Range = Range - (Angle - 30) 'Range adjustment for angles >
30

'PotRange = (((Range * 165) / 105) + 36 )      'Convert Range to corresponding pot
value
PotRange = (((Range * 85) / 125) + 156 )
GOSUB Set_Range          'Set cart to calculated range
GOSUB Launch_Ball        'Launch Ball

PAUSE 1000

GOSUB Lower_Ramp          'Lower Ramp
GOTO Main                'Restart

*****
*****
' Subroutines

```

```
*****
*****
```

Lower_Ramp:

```
LOW ramp_motorA
HIGH ramp_motorB
PAUSE 10
```

```
HIGH ramp_position_cs      'Get Current Reading on pot
LOW ramp_position_cs
LOW ramp_position_clk
PULSOUT ramp_position_clk, 210
SHIFTIN ramp_position_input, ramp_position_clk, MSBPOST, [datain\8]
```

```
IF datain > 31 THEN Lower_Ramp
RETURN
```

```
*****
*****
```

Launch_Ball:

```
DEBUG "Place ball on launcher and press 1 to continue.", CR
DEBUGIN Ready
IF Ready = 1 THEN
  HIGH launch
  PAUSE 100
  LOW launch
  DEBUG CR, "Ball is Launched.", CR
RETURN
ENDIF
```

GOTO Launch_ball

```
*****
*****
```

Set_Ramp_Angle:

```
LOW ramp_motorB      'Raise Ramp
HIGH ramp_motorA
PAUSE 50
LOW ramp_motorB      'Stop Motor
LOW ramp_motorA
```

```
HIGH ramp_position_cs      'Get Current Reading on pot
LOW ramp_position_cs
LOW ramp_position_clk
PULSOUT ramp_position_clk, 210
SHIFTIN ramp_position_input, ramp_position_clk, MSBPOST, [datain\8]
```

```
IF datain <= PotAngle THEN Set_Ramp_Angle
LOW ramp_motorA      'Stop Motor
LOW ramp_motorB
DEBUG "Ramp is raised to given angle.", CR
```

RETURN

```
*****
*****
```

Calc_Range:

```
Sine2Theta = SIN(2 * Angle * 128 / 180) * 100 / 127
Range = Vosqr / 100 * Sine2Theta / g
DEBUG "Angle= ", DEC Angle, CR
DEBUG "Range = ", DEC Range, CR
```

RETURN

```
*****
*****
```

Set_Range:

```
HIGH cart_position_cs           'Get Current Reading on pot
LOW cart_position_cs
LOW cart_position_clk
PULSOUT cart_position_clk, 210
SHIFTIN cart_position_input, cart_position_clk, MSBPOST, [datain\8]

IF datain < PotRange THEN      'motor needs to go forward
DO
  PULSOUT servo_motor,937
  PAUSE 20
  HIGH cart_position_cs       'Get Current Reading on pot
  LOW cart_position_cs
  LOW cart_position_clk
  PULSOUT cart_position_clk, 210
  SHIFTIN cart_position_input, cart_position_clk, MSBPOST, [datain\8]

LOOP UNTIL datain >= PotRange
ELSE                            'motor nees to go backward
DO
  PULSOUT servo_motor,637
  PAUSE 20
  HIGH cart_position_cs       'Get Current Reading on pot
  LOW cart_position_cs
  LOW cart_position_clk
  PULSOUT cart_position_clk, 210
  SHIFTIN cart_position_input, cart_position_clk, MSBPOST, [datain\8]

LOOP UNTIL datain <= PotRange
ENDIF
```

RETURN

Appendix II. Circuit Schematics

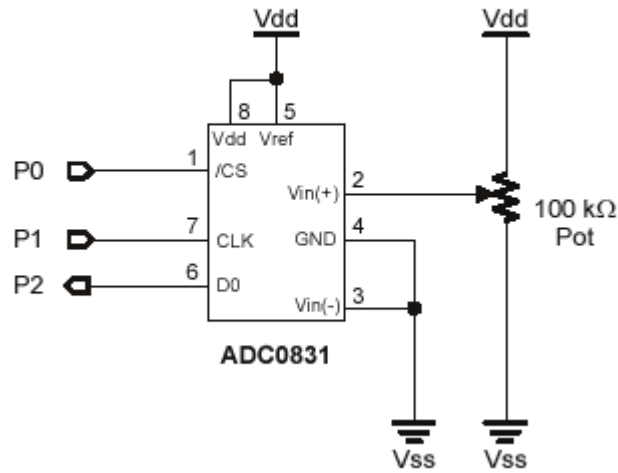


Figure A1 – General ADC Schematic

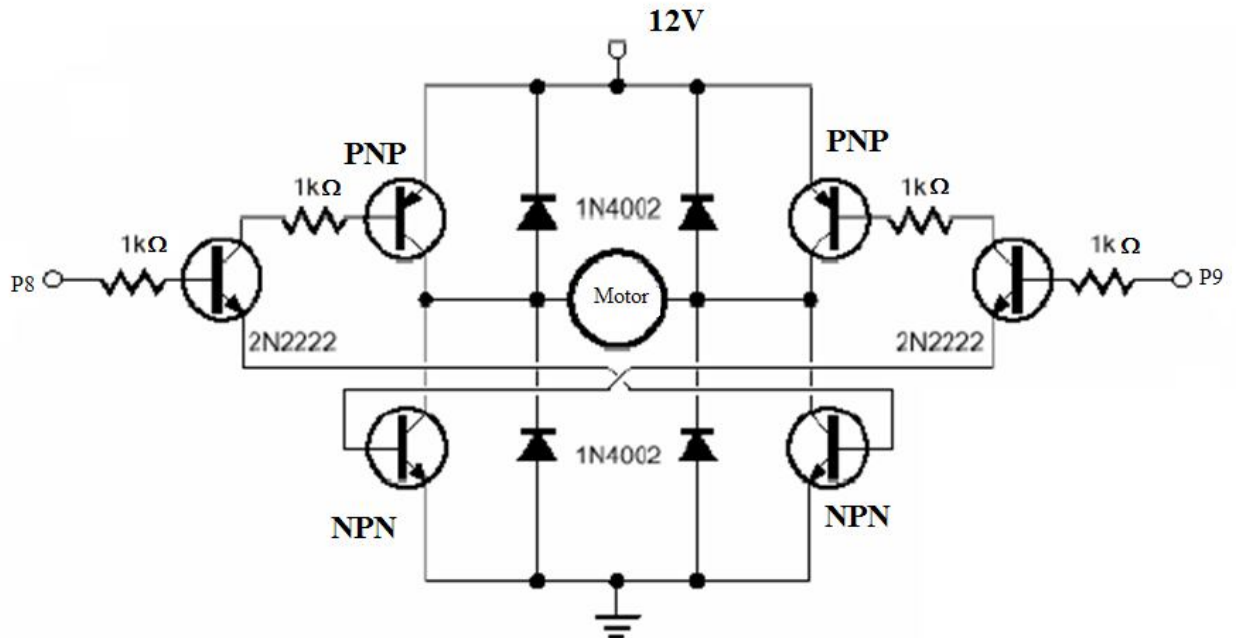


Figure A2: Schematic for H-Bridge