# Design and Animation of Automated Alternative Solar Water Heater System at the BRAC University Roof Top by Using SolidWorks and Implement the Controller Using GAL Technology

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May, 2012


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# DECLARATION

We hereby declare that this thesis report has been written based only on the works and results found by ourselves. Designing work of the Automated Alternative Solar Hot Water System which is on top of BRAC University. This thesis, neither in whole nor in part, has been previously submitted for any degree.

Signature of Supervisor

Signature of Author

# ACKNOWLEDGEMENTS

We are very thankful to our thesis coordinator Dr. AKM Abdul Malek Azad, Associate Professor, Department of Electrical and Electronic Engineering, BRACUniversity for guiding us throughout our thesis work. Special thanks for helping us by giving appropriate advice with the system devices, system designing, circuit works and other documentation. Special regards to our project engineer, Mr. TahsinFarazfor being with us through the whole thesis part with his extreme hard works and innovative ideas. Also thanks to IshtiaqAsad for giving me support. I have worked extremely hard on the thesis and hopefully my work will be appreciated by our supervisor.

# Abstract

The objective of the thesis is to design the “alternative Solar Water Heater with Automated control system”, which is developed by CARG at the roof top UB building, using “SolidWorks 2012” software. Initially, I made a 2D model of the roof top project in SolidWorks. The sketch will consist of geometry and dimensions to define the size and location of the system. The dimensions in the sketch can be controlled independently. Finally, that drawing will be created of the designed model. Views are automatically generated from the SolidWorks model (3D) and notes, dimensions and tolerance can be easily added to the drawing as needed.

# Contents

# CHAPTER I

# INTRODUCTION

## 1.1 Overview

The sun has produced energy for billions of years. Solar energy is the sun's rays (solar radiation) that reach the earth. Solar energy can be converted into other forms of energy, such as heat and electricity. In the 1830s, the British astronomer John Herschel used a solar thermal collector box to cook food during an expedition to Africa. Today, people use the sun's energy for lots of things such as heating houses, providing energy for cars, and, and having it as an extra energy source Heat water - for use in homes, buildings, or swimming pools. Heat spaces- inside greenhouses, homes, and other buildings.

After the 1973 oil embargo, there was a resurgence of interest in solar energy. Faced with a possibility of scarce oil resources, the United States government allocated $400 million per year, from a mere $1 million per year, for solar energy research. The expenditure is small compared to the expenditure on nuclear research. Currently, there is a need for allocating increased resources in solar research. Compared to the old forms of delectable energy (coal, oil, nuclear), solar energy offers a clean renewable form of energy. This presentation will provide an overview of the past, present and future of solar energy.

For the last few years, we have been observing that Natural incidents like these are occurring very frequently and the affect is getting higher and higher. These are the indicators of the global climatic changes for which we, the humans are responsible only. The current rate of consumption of resources and the resulting burden on the environment are not sustainable: in spite of technical improvements, growth in resource consumption has often outstripped progress on the environment or productivity increases. There is likely to be an even greater tendency in this direction as certain countries such as China or India become more industrially advanced. The risk of resources running out and the pollution caused by their use thus pose an ever-greater threat to our environment. Natural resources are under increasing pressure, threatening public health and development. Water shortages, soil exhaustion, loss of forests, air and water pollution, and degradation of coastlines afflict many areas. As the world's population grows, improving living standards without destroying the environment is a global challenge.

Most developed economies currently consume resources much faster than they can regenerate. Most developing countries with rapid population growth face the urgent need to improve living standards. As we humans exploit nature to meet present needs, we are destroying resources needed for the future. This also takes us to the time rapidly when we shall be seeing our non-existence.

## 1.2 What is Solar Energy and Need of Solar Energy Application

Solar energy is the radiant light and heat from the Sun that has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar radiation along with secondary solar resources such as wind and wave power, hydroelectricity and biomass account for most of the available renewable energy on Earth. Only a minuscule fraction of the available solar energy is used.

In this time we are in great need of renewable energy. Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which is renewable (naturally replenished) .The radiated energy from the sun, is the largest source of renewable energy available from earth. If we can make the proper utilization of this radiated energy then we can not only keep our environment cleaner but also preserve our limited natural resources for longer period. In recent time the developed and the developing world have concentrated much on the utilization of solar energy. Solar PV electricity, solar thermal electricity, solar powered vehicle, solar water heater and many more applications of solar energy in the field of agriculture have been developed.

## 1.3 A Focus on Bangladesh

Bangladesh is a small country with a huge population of more than 150 million. The large population creates a lot of problem in our country. The failure to meet the demand of electricity is such a major problem in this country. We may focus on some recent facts related to this criterion.

- According to the annual report of PDB, tin year 2009 the peak demand was 6000 MW in summer
- The generation was 4500 MW
- There was a shortage of 1500 MW of electricity
- 80 million people do not have access to electricity
- Remaining 70 million people of course having unreliable power
- Maximum generation in the last month was 4268 MW
- Maximum generation in this year has been 4606 MW in April
- The demand was always higher than 5000 MW

From these facts we can conclude that we are lacking a lot of electricity. That's why we need a very quick alternative solution which can be of course solar energy.

## 1.4 Reason of Using Alternative Solar Hot Water System?

The need of hot water in our country is increasing in our country day by day as we are becoming more dependent on our industrial sector. About 500 gallons of hot water is needed daily in the tanneries and in pharmaceuticals. Glass, Ceramic and other factories also need hot water for their production. Beside it has been now a great necessity of hot water supply in the hospitals as well as in hotels. Today all these hot waters are coming from either electric or gas based water heating system. This leads to a lot of consumption of our limited resources. It also creates pressure on the power generation. To reduce the pressure on the power sector where we already have a lot of crisis, we need an alternative water heating system that provides continuous hot water supply without consumption of electricity. The Alternative Solar Hot Water System is just the solution we are looking for.

# CHAPTER II

# SYSTEM OVERVIEW

## 2.1 Description of the System

According to achieve the objective of our project be successful, our system should be able to supply hot water to the user by using the radiated energy from the sun. So the main appliance of the system is a Solar Water Heater which transforms energy of sunrays to heat and produce hot water. But this Solar Water Heater can provide hot water only if there is sufficient energy available. And sufficient energy is only available when there is the sun available. If the sun is not available then the hot water cannot be supplied. We may not get sun for continuous days in the time of winter or the rainy season. So to improve the efficiency of the system we added a series of Hot Water Storage Tanks of high capacity. This storage tanks can store the hot water produced by the Solar Water Heater for three days (72 hours) so that we shall be able to supply hot water for some time in spite of having the sun available. The user will be having the supply from these Storage tanks. This surely improves the system's performance on a high scale in a tropical country like Bangladesh where consecutive unavailability of the sun is not naturally expected. We still have an Electric Water Heater as the backup water supplier. If the solar system fails to supply hot water then the supply would be getting from the Electric Heater so that there would be no interruption in the supply. All the water transportation and supplying would be controlled by the controller circuit with the help of Electromagnetic Valves, Temperature Sensors, Water Level Detectors etc. There comes the collaboration between a solar system and an embedded system.

## 2.2 System Components

The Alternative Solar Hot water System that we implemented on the roof top of BRACUniversity for our thesis is comprised with these appliances –

1. Solar Water Heater (1 unit of 150 Liters Capacity)
2. Hot Water Storage Tank (1 unit of 300 Liters Capacity)
3. Electromagnetic Valve (5 units)
4. Temperature Sensor (2 units)
5. Water Level Detector (2 units)
6. Electric Water Heater (1 unit of 40 Liters Capacity)
7. LCD display (1 unit)
8. Power Supply 24 volts (1 unit)
9. 24 volts Relay (5 units)
10. GAL Chip

We also needed the plumbing materials for the setup of the system and the electronic and circuitry materials for the controller setup and testing

## 2.3 The Solar Water Heater

The Solar Water Heater is the main equipment of the Alternative Solar Hot Water System. This Heater has the ability to absorb energy from the abundant rays of the sun and turn this energy into heat. By this transformed heat the water gets heated. For our thesis purpose we have used one Solar Water Heater having the capacity of 150 Liters.

The Solar Water Heater has two parts. One is the solar collector and the other is the water tank.

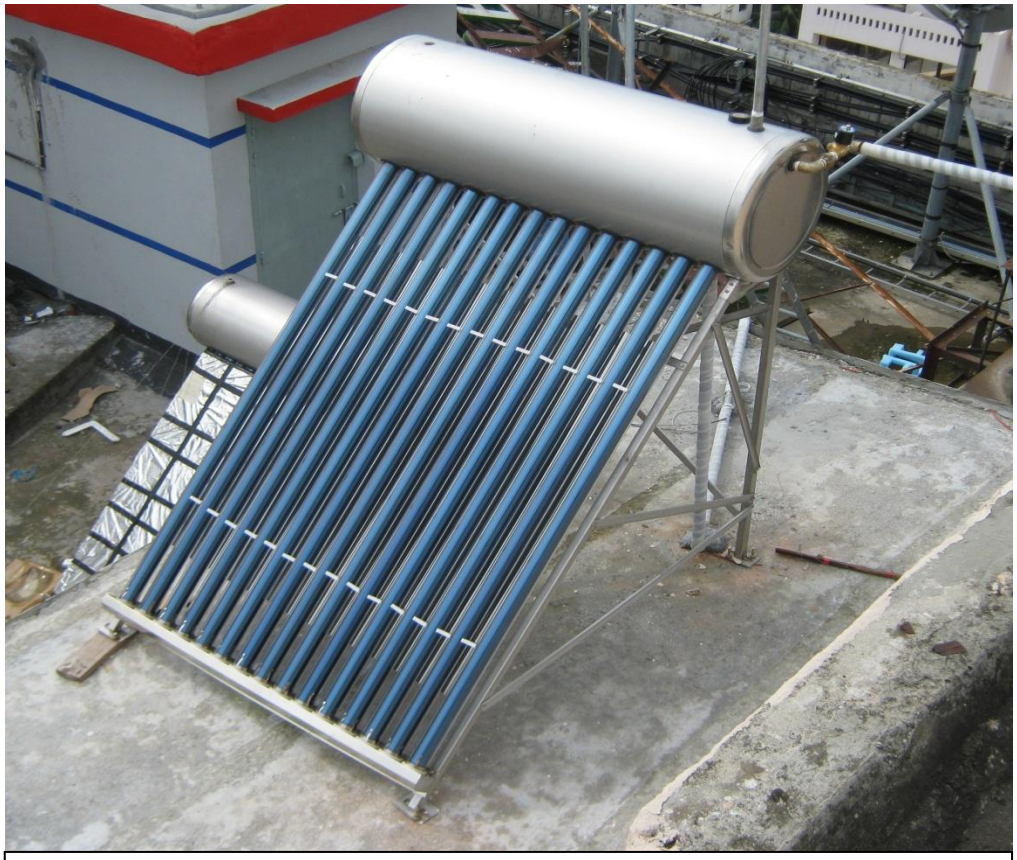


Figure 2.1 : Solar Water Heater installed on the roof of BRACUniversity

## 2.3.1 Working Principle

The working principle of the Solar Water Heater is based on the rules of closed loop Thermosyphone system. Thermosyphon refers to a method of passive heat exchange based on natural convection which circulates liquid without the necessity of a mechanical pump. In this case, the cold water comes and stored in the water tank. This water is circulated through the solar collector tubes. When these tubes are exposed to sun rays then they absorb heat and get heated internally. The water flowing through the tubes gets hot also. As the hot water has less density than the cold water, the hot water goes up to the water tank and cold water from the water tank comes down flowing through the evacuated tubes and this process goes on until all the water gets hot enough.

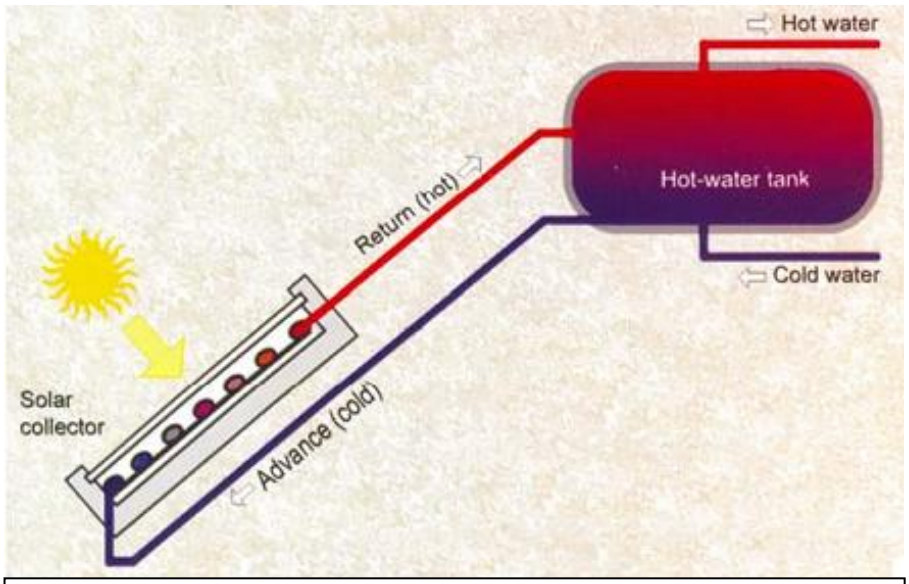



Figure 2.4 : working pronciple of Solar Water Heater

## 2.4 Hot Water Storage Tank

The Hot Water Storage Tank is the second most important and expensive material of the Solar Hot Water System. It's a special integrated water tank which is capable of keeping water without changing the temperature for maximum three days or 72 hours. This heat preservation is done mechanically without any power consumption. There would be multiple layers of heat insulation in the tank. There are many types of hot water storage tanks. But unfortunately we could manage none for its unavailability in Bangladesh. So we had to come up with another idea.

The water tank that comes with an evacuated tube solar water heater is actually an integrated thermal storage tank which has the capacity of preserving the water temperature for almost 72 hours. This naturally gives us the advantage to use the tank separately as the thermal storage tank. But the tank could not be separated from the collector tubes for its remaining holes. So we bought a 300 Liter capacitive evacuated tube solar water heater and thermally insulated the collector tubes with a layer of Asbestos wrapped up by Aluminum foil. That is how we got a Hot Water Storage Tank.

Figure 2.5 : 300 liter solar water heater with insulated collector on the roof top of BRACUniversity

## 2.5 Working Principle of the Whole System

From the previous two chapters we came to know about the instrumentation of the Alternative Solar Water System. In this chapter we are going to know how the whole system works under automated controlling system and how it provides the supply of water of required temperature to the user.

From the flowchart of the system we can see that the Solar Water Heater and the Electric Water Heater is getting cold water from the main supply water tank. This water is kept in the tank of Solar Water Heater and gets hot with the help of its collector. When the water is enough hot that means the temperature is equal to or above the required temperature then it is transferred to the Hot Water Storage Tank. The water transmission is controlled by a valve between the Solar Heater and the Storage Tank. The user gets hot water supply from the storage tank through another valve. If the water preserved in the Storage Tank gets cooler than the required temperature then this

supply valve gets closed. This time the user gets hot water supply from the backup electric heater through another valve. Simultaneously another valve attached with the Storage Tank gets opened and the relatively cold water of the Storage Tank flows back to the main supply tank so that no water is wasted. All these valves are automatically operated by the controller system.

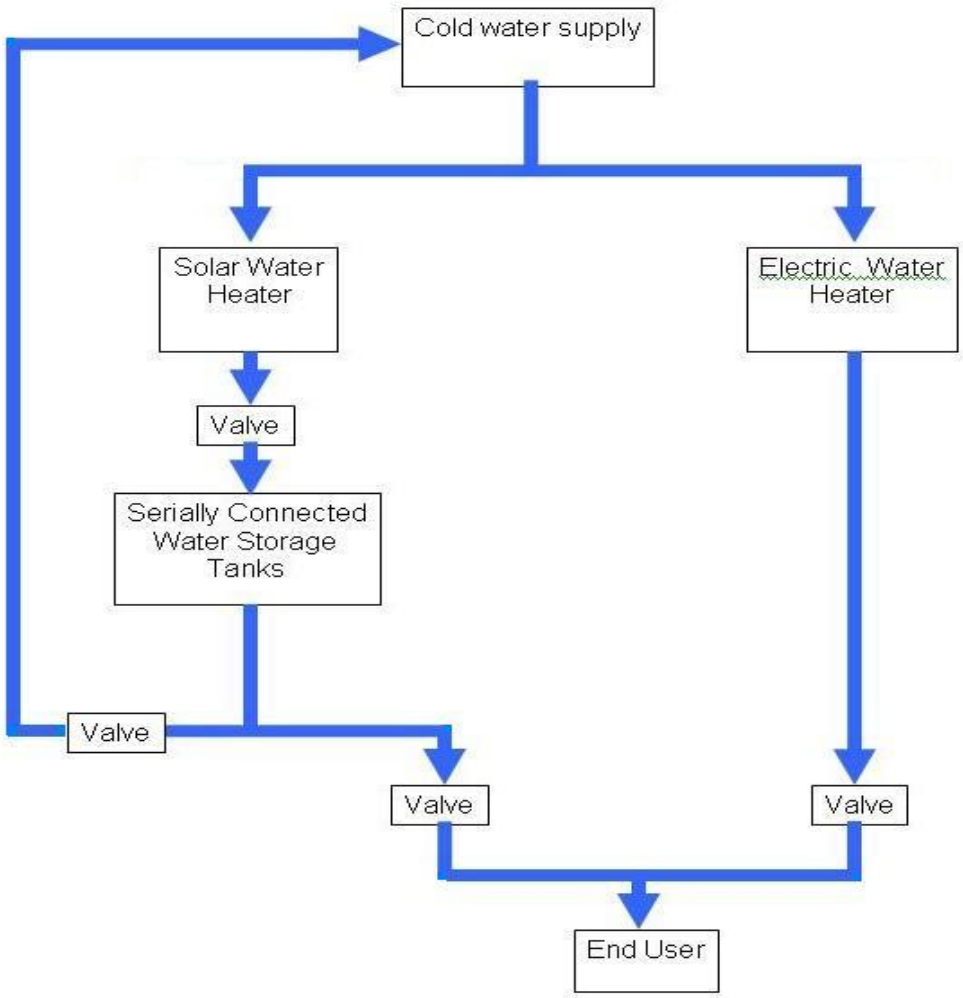



Figure 4.1 : Flowchart of the Alternative Hot Water System

From the flowchart of the system we can see that the Solar Water Heater and the Electric Water Heater is getting cold water from the main supply water tank. This water is kept in the tank of Solar Water Heater and gets hot with the help of its collector. When the water is enough hot that means the temperature is equal to or above the required temperature then it is transferred to the Hot Water Storage Tank. The water transmission is controlled by a valve between the Solar Heater and the Storage Tank.

The user gets hot water supply from the storage tank through another valve. If the water preserved in the Storage Tank gets cooler than the required temperature then this supply valve gets closed. This time the user gets hot water supply from the backup electric heater through another valve. Simultaneously another valve attached with the Storage Tank gets opened and the relatively cold water of the Storage Tank flows back to the main supply tank so that no water is wasted. All these valves are automatically operated by the controller system.

## 2.6Controlling of the System

The controlling of the whole system is based on several conditions. These conditions are derived from some parameters. For this case the most important parameters are the water temperature of the Solar Water Heater (T1) and the water temperature of the Hot Water Storage Tank (T2). Let's assume for the system the user's required water temperature should be To Celsius.

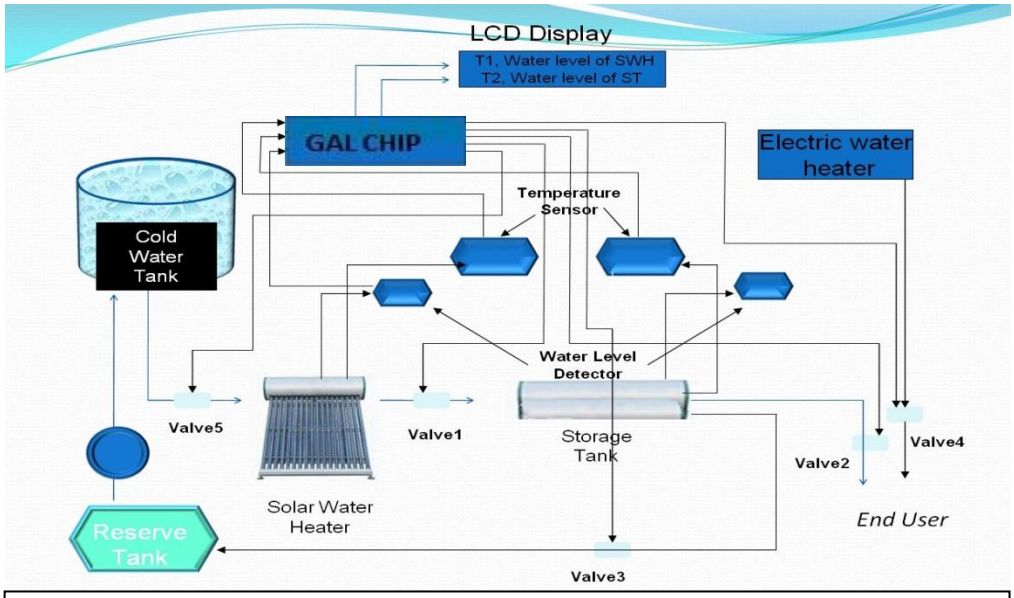



Figure 4.2: Block diagram of the whole system

Condition 1 : If T1 and T2 both are less than T, then the Valve1 and Valve 2 both are closed and the Valve 3 and Valve 4 are open. For this configuration no water is

transferred from Solar Water Heater to the Storage tank and the user gets hot water supply from the Electric Heater. If there is any cold water inside the storage tank then it will be drained out.

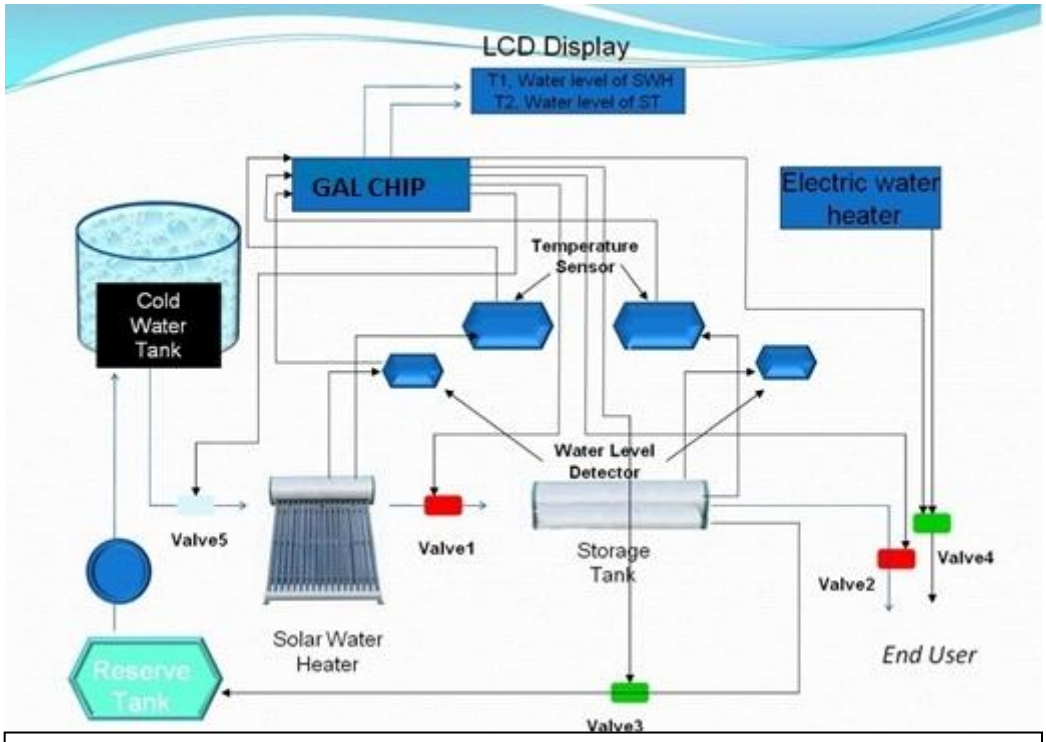



Figure 4.3 : Block diagram of condition 1 (T1<T, T2< T)

**Condition 2 :** If T1 is greater than T and T2 is less than T, then the Valve1 gets open while the Valve 2 remains closed. The Valve 3 and Valve 4 are also remaining open. For this configuration hot water is transferred from Solar Water Heater to the Storage tank but the user gets hot water supply from the Electric Heater. If there is any cold water inside the storage tank then it will be drained out.

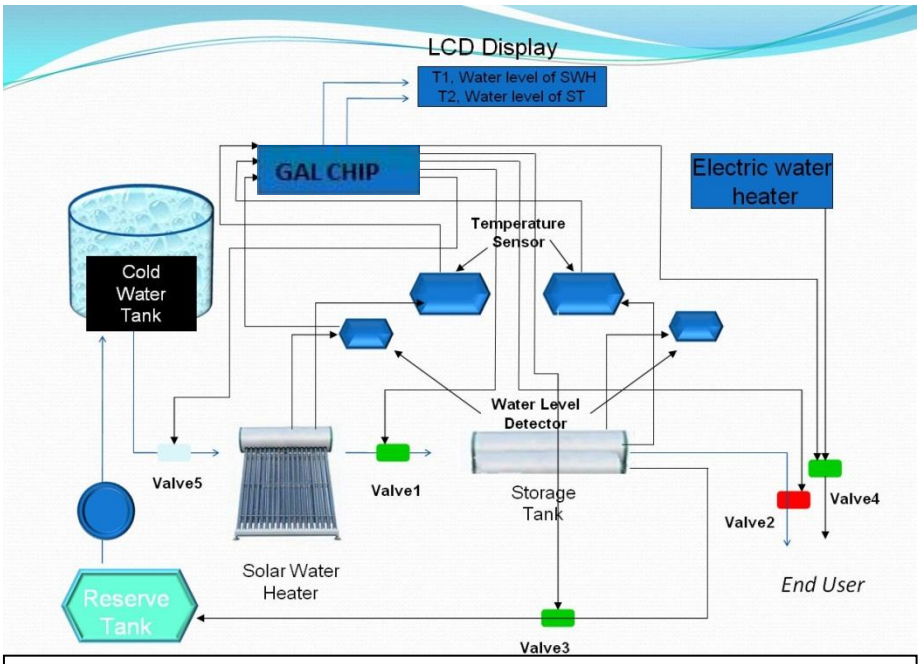



Figure 4.4 : Block diagram of condition 2 (T1>=T, T2< T)

**Condition 3 :** If T1 and T2 both are greater than T, then the Valve1 and Valve 2 both are open. This time the Valve 3 and Valve 4 get closed. In this case hot water is transferred from Solar Water Heater to the Storage tank and the user gets hot water supply from the Storage tank instead of Electric Heater. The drain path is also cold so that no water from the storage tank can be drained out.

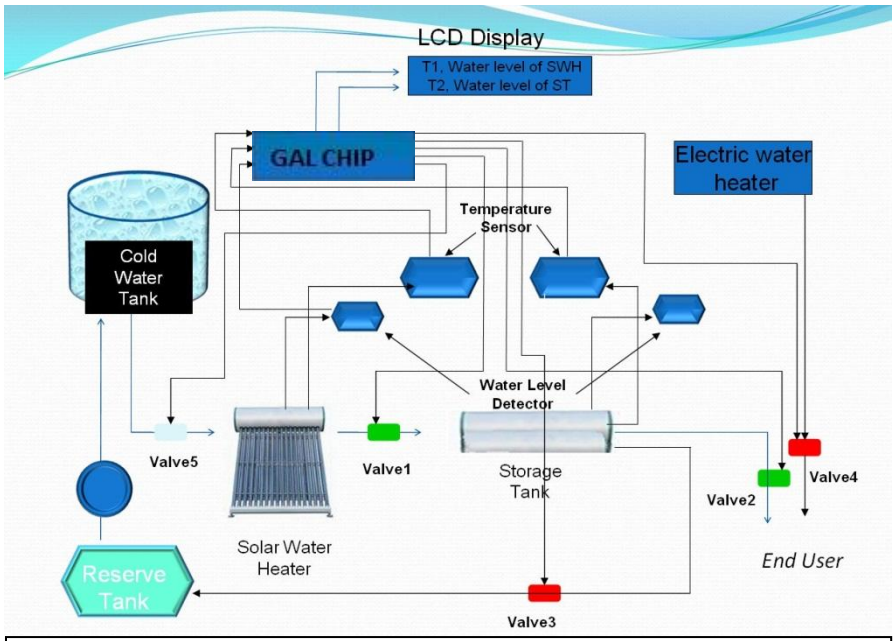



Figure 4.5 : Block diagram of condition 3 (T1>=T, T2>= T)

**Condition 4 :**If T1 is less than T but T2 is greater than T, then the Valve1 gets closed again while the Valve 2 remains open. This time the cold water from the Solar Heater cannot be transferred to the Storage Tank. The user gets the supply from the Storage Tank as the Valve 3 and Valve 4 are closed. No water is drained out from the storage tank.

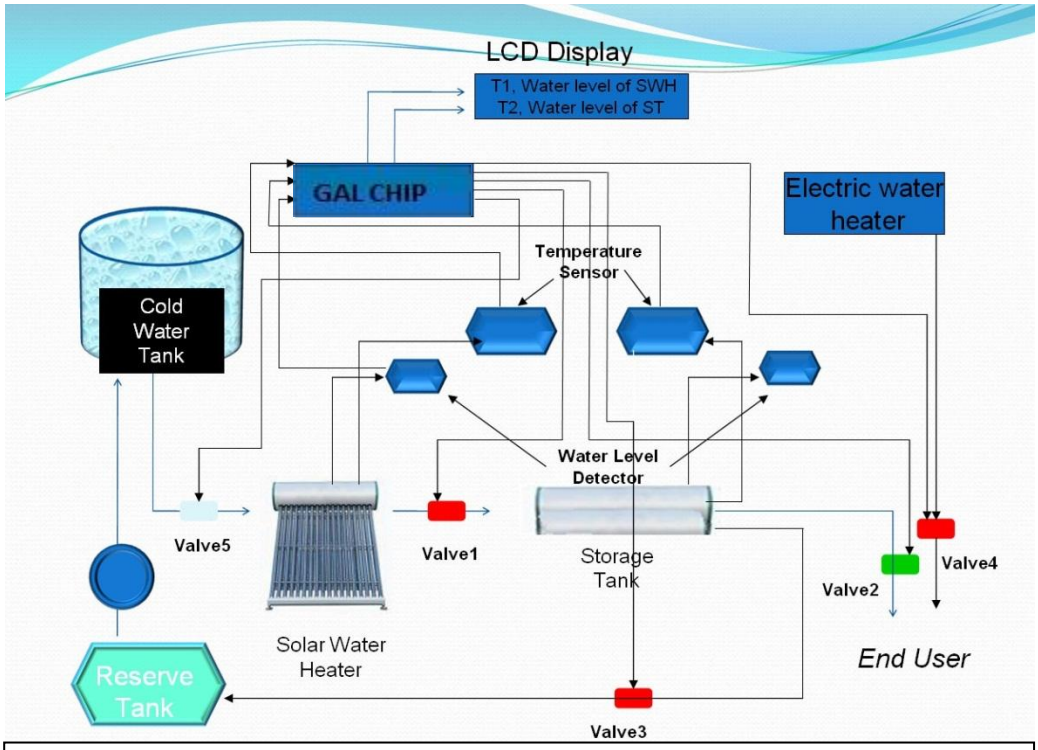



Figure 4.6 : Block diagram of condition 4 (T1<T, T2>= T)

Another condition is also applied here on the basis of the output of Water level Detector. There is another valve is attached between main cold water supply and the Solar Water Heater. When the Solar Heater Tank is empty only then this valve gets open and cold water fills up the Solar Heater tank. When the tank is full then the valve automatically gets off because we don't need to mix up cold water with the hot water inside.

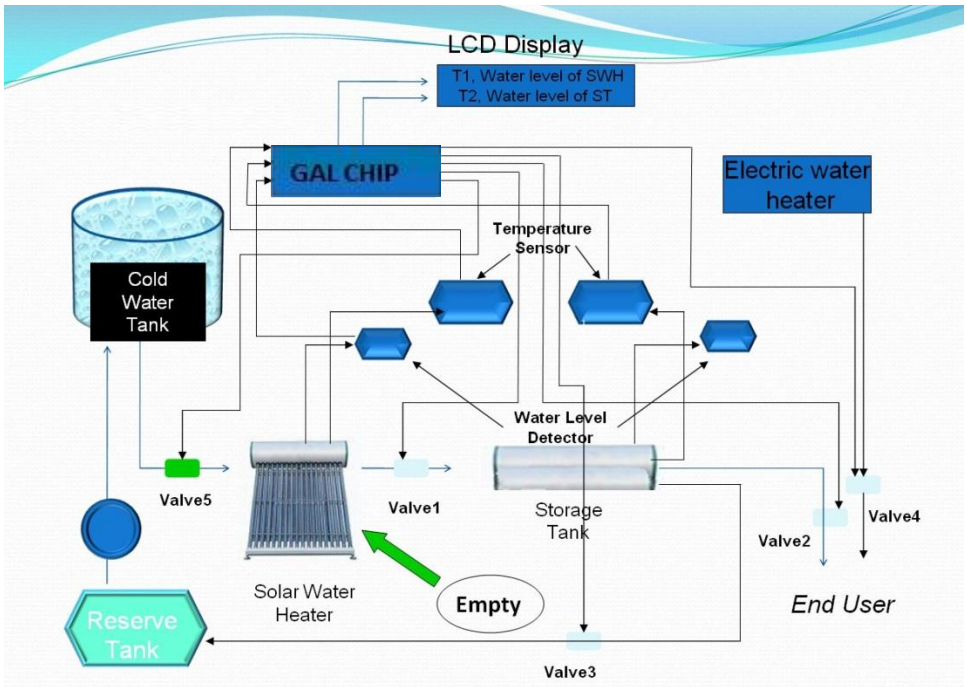



Figure 4.7: Block diagram of condition 5 (when the Solar Water Heater tank is empty)

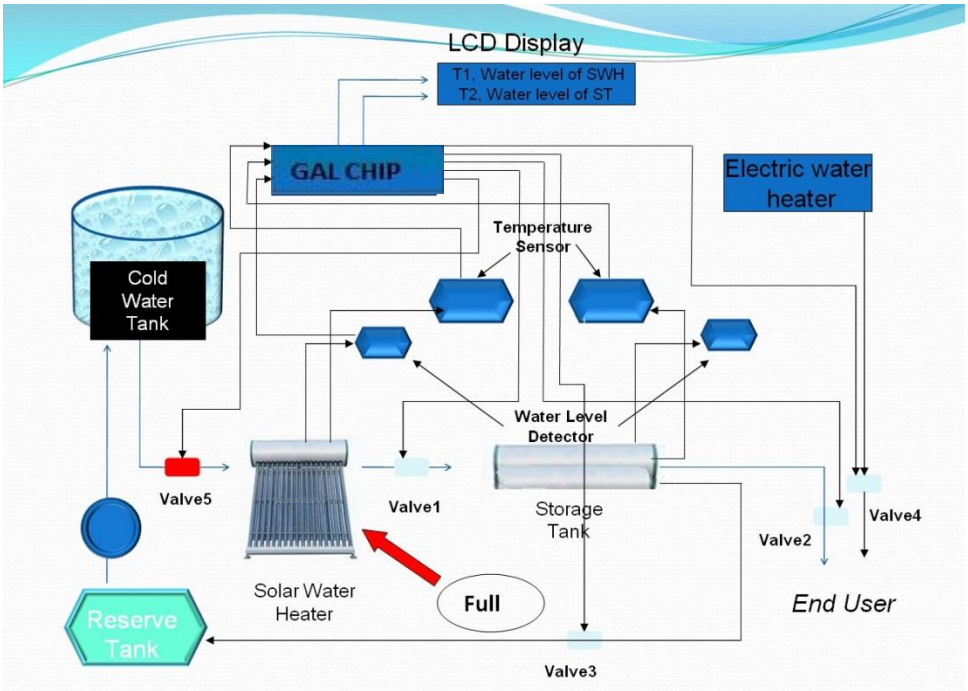



Figure 4.8: Block diagram of condition 5 (when the Solar Water Heater tank is full)

# CHAPTER: III

# GAL TECHNOLOGY

## 3.1 Overview

MODERN deep submicron fabrication technologies enable very high levels of integration such as a recent dual-core 1.7 billion-transistor chip. A highly promising approach to efficiently using these circuit resources is the integration of multiple processors onto a single chip (called a Chip Multiprocessor or CMP) to achieve higher performance through parallel processing. Chip multiprocessors can potentially also provide increased energy efficiency by allowing the clock frequency and supply voltage to be reduced together to dramatically reduce power dissipation during periods when full rate computation is not needed and conditions permit.


Figure 3.1: GAL Chip

Despite their promising benefits, complex systems built using deep submicron technologies encounter some unique challenges. One of the most critical is the design of the clocking system. Traditional globally synchronous clocking circuits have become increasingly difficult to design with growing chip sizes, clock rates, relative wire delays, and parameter variations. Additionally, high speed global clocks consume a signal can't portion of system power budgets and lack the flexibility to independently control the clock frequencies ofsub modules to achieve high energy efficiency. The globally

Asynchronous locally synchronous (GALS) clocking style separates processing blocks such that each block is clocked by an independent clock domain. This approach is a promisingstrategy to address global clock design challenges.GAL's systems are often highly energy efficient due to their simplified clock tree [4], and their enabling of joint clock and voltage scaling in system sub modules. However, GALS clocking typically also introduces a performance penalty due to additional communication latency between asynchronous domains.

We show that GALS chip multiprocessors under the right conditions can hide much of the GALS performance penalty and at the same time, take full advantage of its scalability and high energy efficiency. Along with a thorough investigation of GAL's effects on system performance, we show that such GALS chip multiprocessors have small performance penalties compared to corresponding synchronous systems. Furthermore, the small performance penalty can be completely eliminated by using sufficiently large FIFOs for inter-processor communication and programming without multiple-loop communication links. Scalability is enhanced due to the lack of a need for a global clock tree. In addition, the potential energy savings from joint clock and supply voltage scaling is increased in the common situation when workloads have unbalanced computational loads for each processor, therebyincreasing the probability processors can be tuned to savepower. This work is distinguished from previous GAL's multiprocessorevaluations [8] by not restricting the analysis to systems with global communication schemes.

An innovation of the PAL was the generic array logic device, or GAL, invented by Lattice Semiconductor in 1985. This device has the same logical properties as the PAL but can be erased and reprogrammed. The GAL is very useful in the prototyping stage of a design, when any bugs in the logic can be corrected by reprogramming. GALs are programmed and reprogrammed using a PAL programmer, or by using the in-circuit programming technique on supporting chips.

It’s actually a programmable logic device or PLD is an electronic component used to build reconfigurable digital circuits. Unlike a logic gate, which has a fixed function, a PLD has an undefined function at the time of manufacture. Before the PLD can be used in a circuit it must be programmed.

A device programmer is used to transfer the Boolean logic pattern into the programmable device. In the early days of programmable logic, every PLD manufacturer also produced a specialized device programmer for its family of logic devices. Later, universal device programmers came onto the market that supported several logic device families from different manufacturers. Today's device programmers usually can program common PLDs (mostly PAL/GAL equivalents) from all existing manufacturers. Common file formats used to store the Boolean logic pattern (fuses) are JEDEC, Altera POF (Programmable Object File), or Xilinx BITstream.

# 3.2 Pin Configuration of GAL

It’s having a Large Number of Basic logic gates. It’s a erasable logic gate.

Here,

Pins 1-9 can only be used as inputs.

Pin 12-19 either can be used for inputs or outputs.

Here Inputs are,

A(Pin 2)

B(Pin 3)

C(Pin 4)

D(Pin 5)

Outputs are,

X(Pin 19) = A*B*C+A*C*D’

Y(Pin 18) = B*D

Z(Pin 17) = B’*D

U(Pin 16) = B’+D’

V(Pin 13) = C’

W(Pin 12) = C’

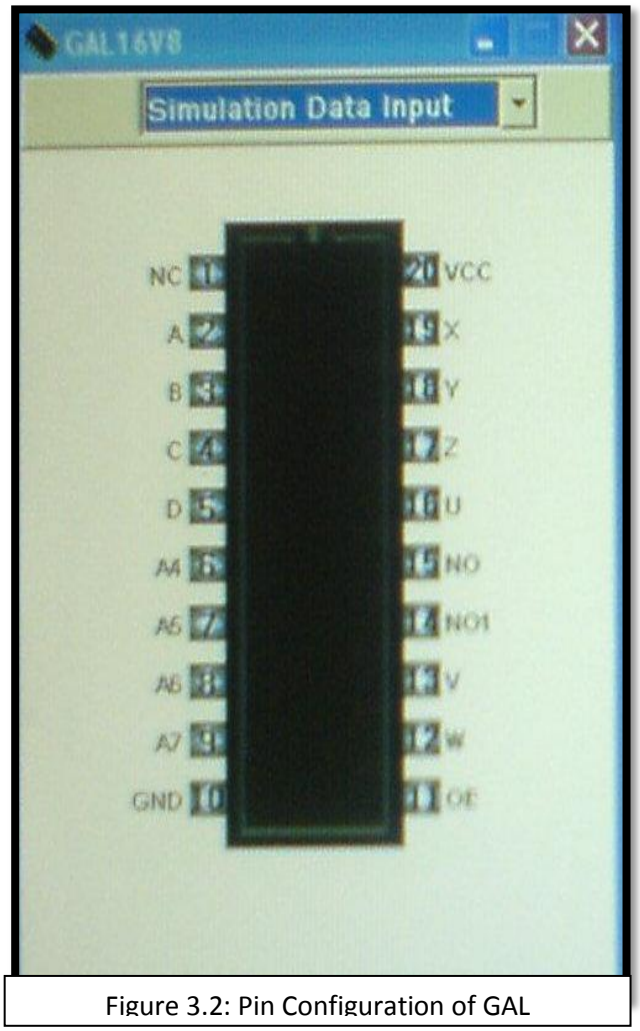



Figure 3.2: Pin Configuration of GAL

## 3.3 Truth Table of the GAL

| | A | B | C | D | X | Y | Z | U | V | W |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 2 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 4 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 6 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| 7 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 8 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 10 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| 11 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 12 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| 13 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| 14 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| 15 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

Figure 3.3: Truth Table of GAL Chip

## 3.4 Testing Outputs form the GAL

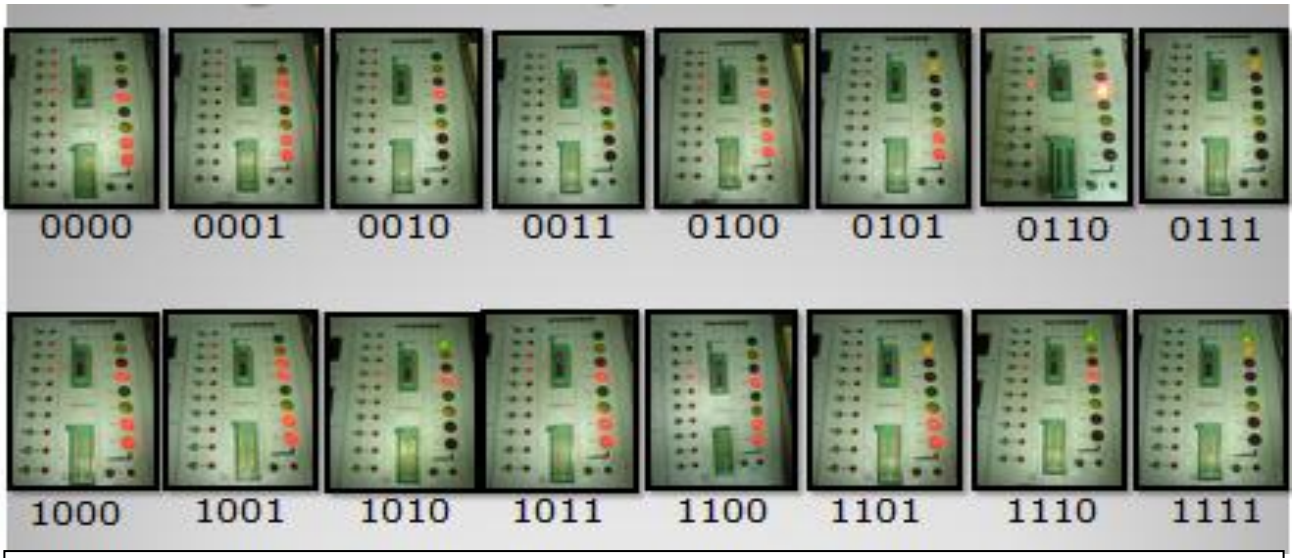



Figure 3.4: Outputs on PLD Board

# Chapter: IV

# Solidworks Design Process

## 4.1Overview

SolidWorks is a 3D mechanical CAD (computer-aided design) program. The Solidworks software is a mechanical design automation application that takes advantage of the Microsoft Windows graphical user interface. This software makes possible for designer to quickly sketch out ideas, experiment with features and dimensions and produce models and details drawings.

IntroducingSolidworks discusses some basic concepts and terminology used throughout the Solidworks application. It familiarizes you with the commonly used function of Solidworks.

### 4.1.1 Reason for using Solidworks 2012

- It can make faster product designs(more than 45% faster on average).
- Having automatic flattening of sheet metal parts (with bend allowance).
- Visualize more 'what-if' the actual scenarios during the design process.
- The ability to create renderings and animations for design proposals or reviews.
- More effective and detail internal design reviews.
- Generation of virtual prototypes allows non-CAD people to participate in the process of design.
- Easily incorporate late design changes or late design complete.
- Test and validate your designs to reduce production costs from the quality problems.

- Here data management to organize and manage your design data.
- It helps to standardize on detailing and drafting practices.
- Automate the total design process and increase speed and accuracy of output and directly response to customers.

# 4.2 Documentation Software

### 4.2.1 3DVIA Composer

3DVIA Composer allows non-CAD users to create associative 2D and 3D product documentation directly from 3D CAD data. 3DVIA Composer empowers users in documentation, sales, marketing, customer service, training, support and manufacturing with 3D data and tools.

### 4.2.2 Save time and money while improving product information

With 3DVIA Composer, companies realize substantial savings in time and rework costs by not having to recreate product documentation when there are changes happen to the product. In addition, 3DVIA Composer saves translation costs by enabling more graphics and less text in your documents and improves a wide range of product communication with 3D animations and with the ability to create interactive product documentation.

Because product documentation is a recurring process, 3DVIA Composer makes it possible to automatically regenerate documentation content when there are changes to the product. 3DVIA Composer also saves time and money by allowing the content creator to use whatever partial product information is currently available. As the latest product data is made

available, 3DVIA Composer – which is built on a light-weight, open XML-based architecture – can apply the new information seamlessly and create updated documentation.

# 4.3 Design Automation

### 4.3.1 DriveWorks

DriveWorks is proven technology that reduces the time and money consumed on custom product design and support.

Today customers and markets demand ever increasing variation and customization. Most manufacturers wish they could reap the benefits of mass production where an initial investment in design and engineering can be exploited over time.

DriveWorks lets you capture and re-use the rules needed to specify, design, manufacture and engineer to order. DriveWorks also lets you automate repetitive tasks and generates all the design and manufacturing output required.

DriveWorks is a SolidWorks Certified Gold Partner and is THE Easy-to-Use Design Automation Choice for SolidWorks Users.

# 4.4 Designing Process of Solar water heater by this Solidworks 2012

Solidworks is a high detail and high resolution designing software. That's why I have to design each and every single parts of that solar water heater. And then combine all together. So, at first I design the solar water heater part.

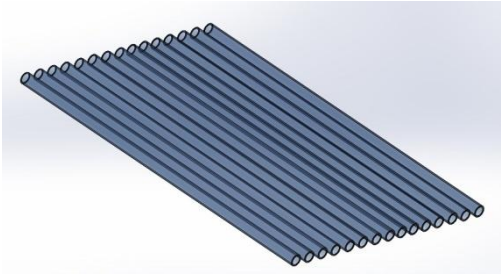


Figure 4.1: Solar Collector Tubes

From the sketch option of the Solidworks 2012, I sketched the solar tubes.The first step is to start a new sketch on the Top plane. I like to start with a circle centered at the origin. Immediately give this circle a dimension. Next step is to draw the inside edge (use the center point box option this will add some construction lines and relations that will help. The first thing I like to do is add a relation to the top edge and one of the side edges. This ensures that we have a circle (since the tube is round). Then I add a single dimension to the tube giving it a width of 76.6mm. Because we used a center point rectangle and we used the = relation 1qthings, these relations will be deleted but it is a good idea to keep this in mind when modeling. . Then make it 15 pieces of it, put then on parallel with the same distance. After this change its material into glass material.

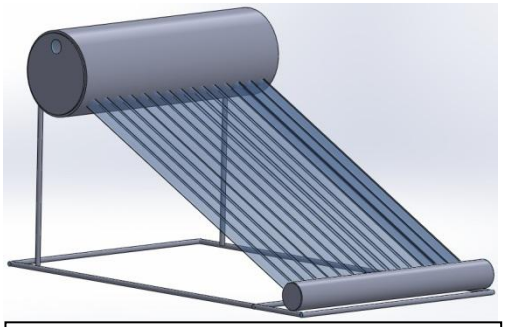


Figure 4.2: Solar Water Collector

After finishing this I made the body of this solar water heater. So I made a rough body stand of that solar heater. Next go ahead and trim away the unwanted sections. You will notice your nice fully defined sketch is now under defined. That's okay because we know nothing has moved and there is a simple solution. When a sketch is under defined you have the option to let Solidworks fully define the sketch. Since we know everything is where we want it, we use Fully Define Sketch and modify some of its options. You can specify to add relations, dimensions or both. You can also get really specific as to what types of relations and dimensions you wish to be added. In this case make sure Dimensions is not selected and only allow it to add relations, and then calculate. Also

note that reference lines do not need to be fully defined for a sketch to be considered fully defined.

If you want to add other things like a Brand logo, LED or power button you should be able to tackle those things. If you just want to render what you have you can apply a Cotton Cloth material to the solar collector face, and a high gloss glass to the rest of the body and you're done! Step1. Set Up Images

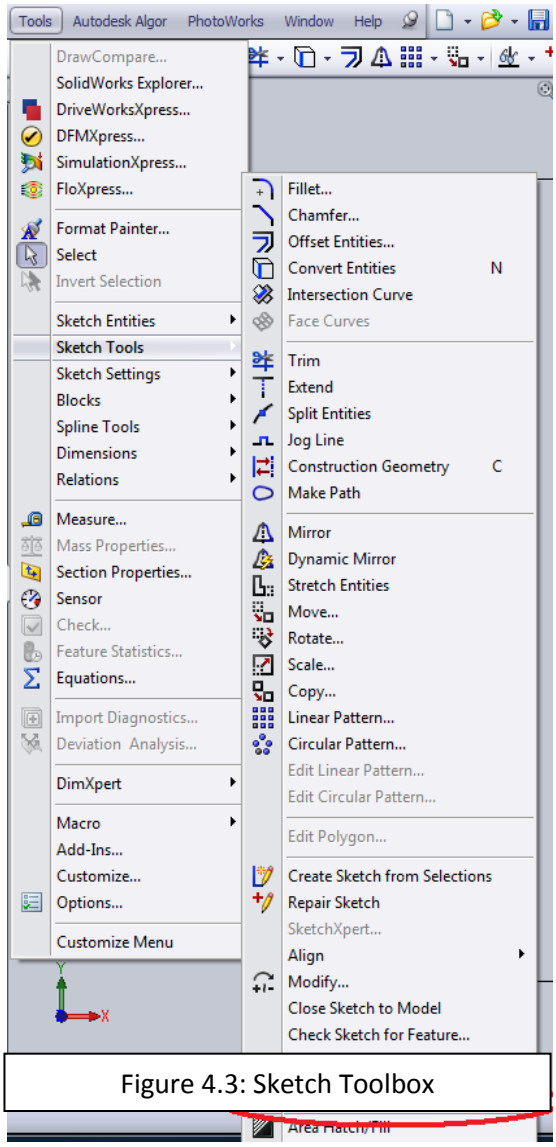


Figure 4.3: Sketch Toolbox

Start a new Metric Part. Start a sketch on the Front Plane.

To determine a scale start by drawing a vertical construction line from the origin. Dimension this line to 200mm. Insert a Sketch Picture: Tools>Sketch Tools>Sketch Picture

Normally I leave fillets to the very end of a model, but in this case we need to add some fillets now or the next step will not work out for us. This is also a good time to take a look at FilletXpert. When you select the fillet option on your feature tab you will have the option to create Manual fillets or use FilletXpert. One of the great benefits of filletXpert is that it allows you to select one edge, and then you are given options for other edges like it. So in this case we need to fillet 8 vertical edges inside the fan body. When you select one edge a

pop up next to the cursor will give you the available options which will highlight on the model. You can see them in pink. While 8 edges don't seem like a lot, this can be extremely helpful in many different ways. Add a 10mm fillet to the 8 vertical edges. The sketch picture properties box will give you options for scale, location and angle of the picture as well as a few other options such as transparency. You can also grab the control corners of the picture to scale it. Scale and move the picture until it's roughly centered on your vertical reference line like the image below.

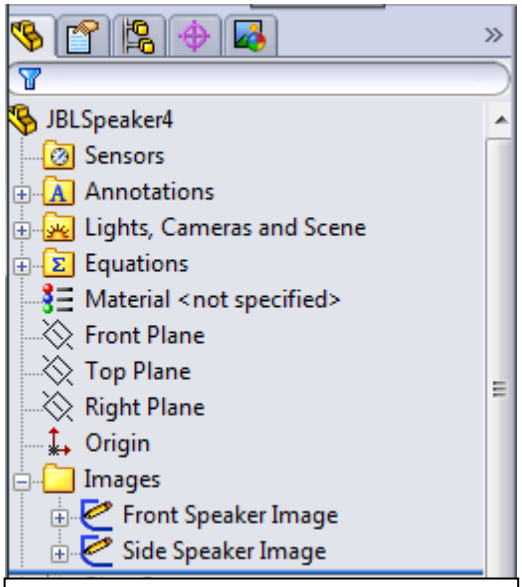


Figure 4.4: toolbox

Follow the same procedure and insert a Sketch Picture on the Right Plane. Scale it to be roughly the same size. Remember this isn't a true side picture so we are only using it as a loose reference, but in general you want to get these images/blueprints as close as possible.

Now that we have our images in place take this opportunity to organize your feature tree. It's a good idea to name your sketches as well as place them in a folder.

To place sketches or features into a folder simply select them (everything you want in one folder), right click and choose "Add to New Folder".

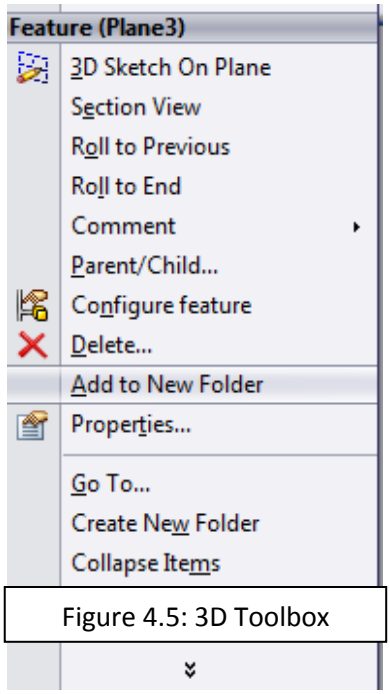


Figure 4.5: 3D Toolbox

I like to keep any work planes that are based off the Top, Rightor Front planes at the top of my feature tree. Since I know allof the planes already we can lay them out now, but during the

Modeling process you can drag the created planes back up the feature tree to better organize. It's also good to name them something meaningful. In this case I named them their offsetamount. Create 5 planes that are offset from the Top Plane in these amounts: 200, 150, 20, 6and 6.

Naming them in this manner not only helps when selecting a plane for sketching, but when looking at Parent/Child relationships. You might be wondering how I came about the Plane offsets. The 200mm plane came from the 200mm line we added to our front sketch.

The 150 plane really could have been a wide range. We needed a plane to add a contour for our boundary surface. For whatever surface you aredrawing you have to plan it out by looking at the shape of your part and planning a good location for guides. Same thing for the 20mm offset. The –6mm offset plane was a decision for the location of the "feet" for the solar collector.

When you plan this out you may move planes around as needed Create a sketch on the Front Plane.

We need to draw a spline similar to the one used to trim our other speakerface, but this one will need to be inset at the bottom. The reason for thisis based on the image of the solar collector. The area around the button and ledis inset a bit so we need to be aware of this when creating the geometry.

This spline has a control point as well as end points. Note the vertical andhorizontal relations for the end handles and that we have not touched the mid-point handle Knit the trimmed surface with the first Speaker Face boundary surface. Knit surface (unless you specify) will make appropriate changes to surfaces in order to knit them together. This change will help us and is why we knitted the face to the trimmed body when using Split you have a limitation. Split will not allow you to use a sketch with more than one open or closed profile. This means our last sketch used in the Trim operation could not be used to split a face. Be-cause of this we will need to start a new sketch on the Front Plane and use Convert Entities on just the bottom set of lines.

Splitting a face allows us to use these new edges for things like lofts or boundary surfaces.Start a sketch on the Right Plane and draw a spline as follows. Spline is coincident with the sketch just created. The top point also has a horizontal construction line so it can be dimensioned 30degrees below as well as having 187mm tangent length. Use Convert Entities on our loft front edge and give the spline a Tangent relation as well as 123.5 tangent length dimension. Make sure your sketches are fully defined! The 200 in this image should not be necessary if you are coincident to our 200 Plane. It's merely there for reference on the image and either method of defining the sketch is acceptable.Start a sketch on Plane200 and draw a spline as shown using only a start and end point. The spline is coincident with the endpoint of the previous spline drawn. Its handle has a horizontal relation as well as a 75mm dimension for its tangent length. The bottom right end of the spline is dimensioned as shown and its handle was never adjusted.Create a Boundary Surface using our sketch on the top plane and Plane200 as Direction1 and our sketch on the Right plane as Direction2. For Tangency Type, on the bottom sketch place a Tangency to Face. These will ensure our boundary surface is tangent to our lofted surface at the base. This is needed for our speaker to look right.One thing you will need to make use of in the display section of the Boundary properties box is Zebra Stripes and Curvature Combs. These are useful to show you (in the preview) any major problems with the geometry. You want your curvature combs to have a decent transition and not jump from long to short very quicklyStart a new sketch on the Front Plane and turn on the visibility of our Front

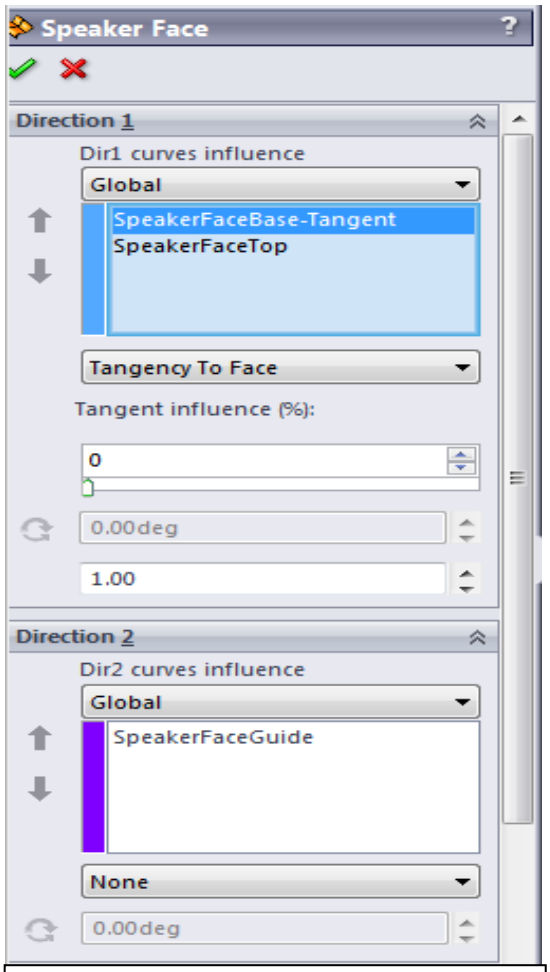



Figure 4.6: face Curve Toolbox

Solar collector Image. You will need to create a spline with a control point and its end points. As a note I like to Right Click on the spline and Dis-play Control Polygon.For the spline remember these images are only for reference and they have perspective so don't be afraid to deviate from the shape slightly to achieve a better end result. You will see the spline doesn't follow the solar collector exactly.

Make sure the top spline handle has a horizontal relation and is coincident with the vertical line end point on our image sketch and that the bottom spline handle has a vertical relation.Use this sketch to Trim Surface and remove the blue section from the image below.Start a sketch on the Right Plane.

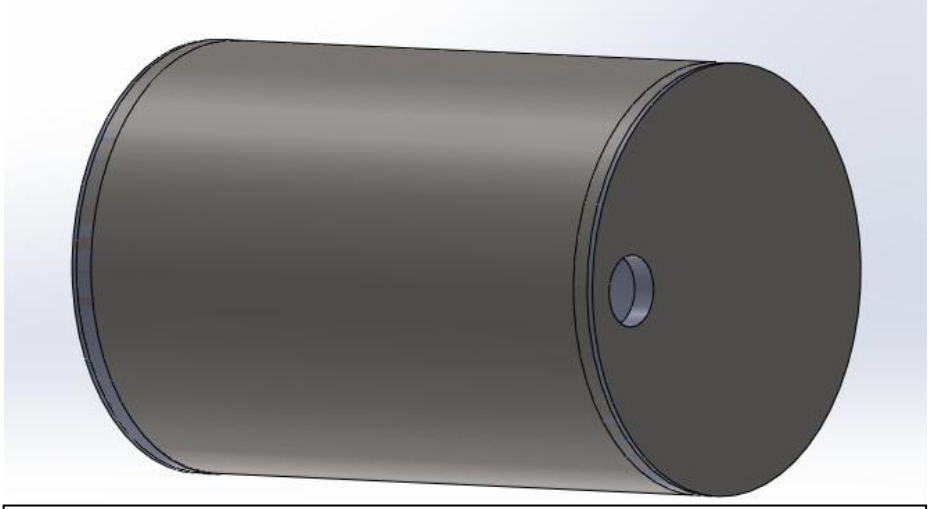


Figure 4.7: Storage Tank

Recreate this spline making note that the lower point has a horizontal relation with the origin and the upper point is coincident with the end point of the storage tank face surface we just created.Start a new sketch on Plane150.

Create a spline as shown. You can create a vertical construction line or simply add a vertical relation be-tween your spline endpoint and the origin. The spline has vertical and horizontal relations on the tangency handles.Start a sketch on the Top Plane.

Create a spline as shown. Spline handles have horizontal and vertical relations as well as dimensions. Again you can create a vertical construction line from the origin or use vertical relations for the spline endselect the boundary surface edge for your first curve. Depending on your trim and geometry this may have more than one section so be aware of this. If it does make sure you Right Click and use the selection man Select our Right Plane sketch for our second curve for Direction1. In the Tangent Type drop down select Direction Vector. Select the Right Plane as your reference and give it a 45% influence. For Direction 2 curves select our top plane sketch and our plane150 sketch.Some clarification.The reason we chose to add a direction vector influence is because even though we have guide curves that we ensured were horizontal, they will not control the entire boundary surface. Adding this direction influence to the surface will ensure that when we mirror our body we can avoid a visible Ridge at the back.Create a sketch on Right Plane.

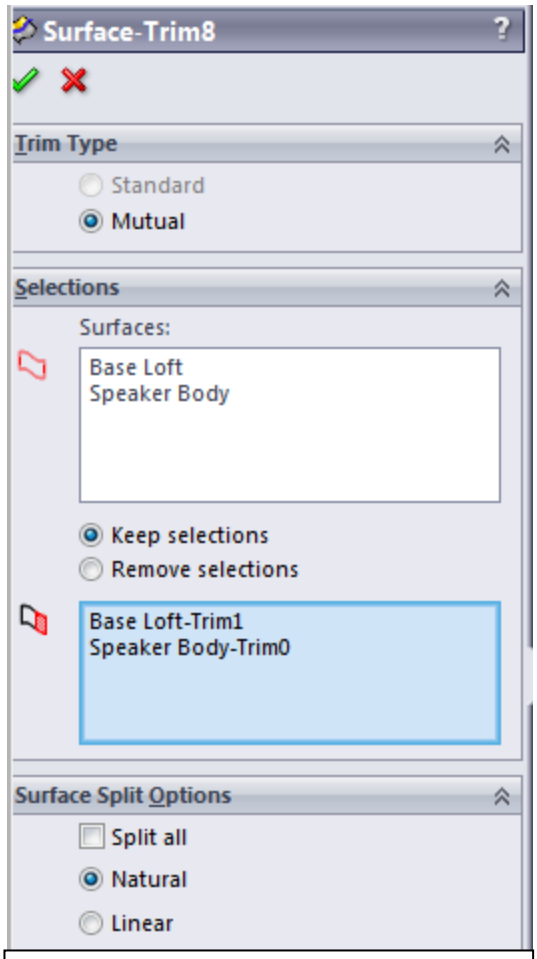
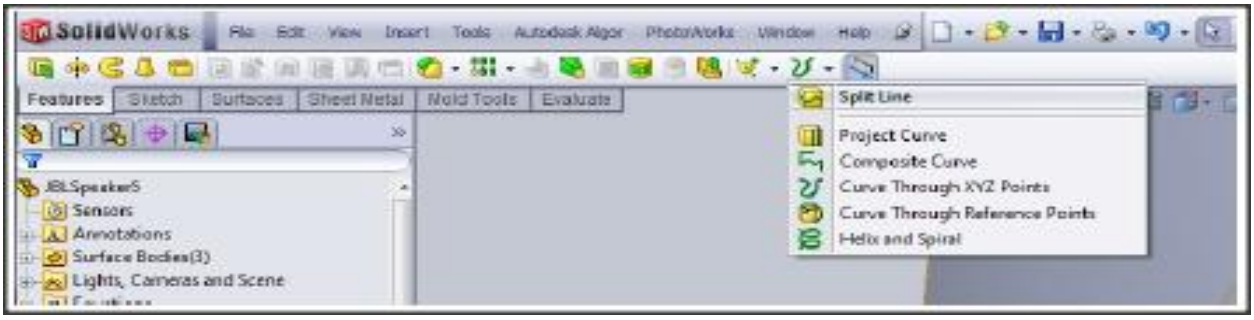


Figure 4.8: Surface- trim panel

Draw a spline that is coincident to the bottom of the speaker face and coincident at the top with Plane200. Add the dimensions shown.

You may be wondering where some of these numbers are coming from like 46.390. In cases where you are dealing with complex shapes it's often easier to draw a curve so it looks right and add the dimension after to locate it. That is the case with some of these.Create a sketch on Plane200.




Make the sketch used for the top edge of the speaker face boundary surface visible. What we are doing is creating a surface that will be offset to create the outer face of the speaker. Draw a spline similar to the one shown making it coincident to the previous sketchCreate a Boundary Surface using the bottom sketch from our first speaker face and our new top profile as the Direction1 curves. Use our Right Plane sketch spline as Direction2. Again pay attention to the curve combs in the preview.We need to draw a spline similar to the one used to trim our other electric water heater face, but this one will need to be inset at the bottom. The reason for this is based on the image of the speaker. The area around the button and led is inset a bit so we need to be aware of this when creating the geometry. This spline has a control point as well as end points. Note the vertical and horizontal relations for the end handles and that we have not touched the mid-point handle.Use this sketch to trim our boundary surface by removing the blue area as shown below.We should now have 4 different surfaces that are starting to resemble the electric water.Using Trim, we are going to make a Mutual Trim of the main loft and boundary surfaces. We want to keep the purple section below and remove the blue section so make your choices appropriate based on your settings. Also note that using mutual trim with knit these two surfaces together.The result will be a nice trimmed surface. Note that I have hidden the two electric water heater face

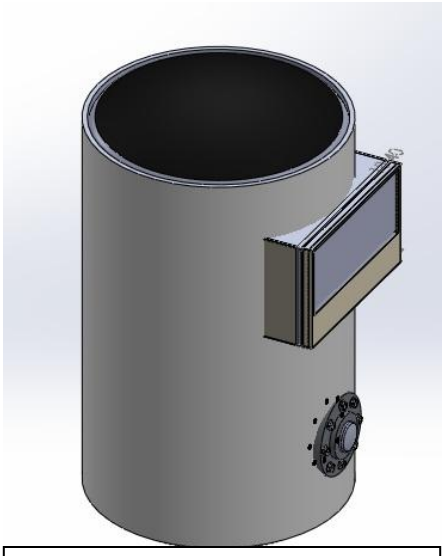


Figure 4.9: Electric Water Heater

surfaces; they were not part of the trim operation.Knit the trimmed surface with the first electric water heater Face boundary surface. Knit surface (unless you specify) will make appropriate changes to surfaces in order to knit them together. This change will help us and is why we knitted the face to the trimmed body.Trim the 3mm section away from the second electric water heater face boundary surface. Remove the purple section shown.You should now have 3 surfaces. The main body and two surfaces that make up the Electric water heater face.When using Split you have a limitation. Split will not allow you to use a sketch with more than one open or closed profile. This means our last sketch used in the Trim operation could not be used to split a face. Because of this we will need to start a new sketch on the Front Plane and use Convert Entities on just the bottom set of lines.

Splitting a face allows us to use these new edges for things like lofts or boundary surfaces.Using the new sketch and Split Line split the faces as shown.

The pink line is our split tool and the blue face is our selected face to split.You can now see our surface has a split on its face but is still one knitted surface. I have hidden the other two surfaces from view.We are going to make another split but this time we are going to reuse a sketch we have already created. Make the sketch we used to trim our secondary motor face visible. This sketch was slightly inset from our first motor face sketch at the bottom.

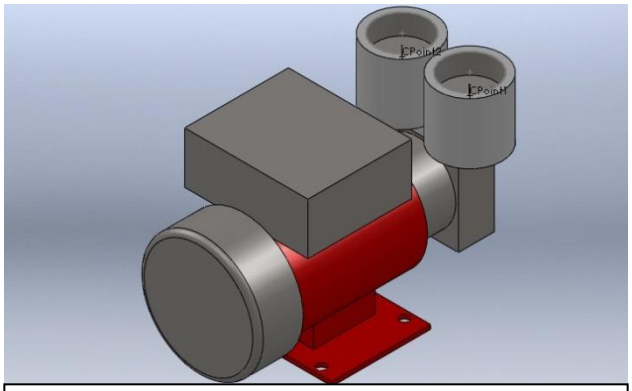


Figure 4.10: Water Pump or Motor

Split only the blue face shown here.Now that our face is split go ahead and create a boundary surface between this split edge and the matching surface in front of it. You will need to use the selection manager and select the 3 edges needed for each.You might be wondering why we needed to make the second split for this surface. Looking at the picture it appears as if

there is a small “step” in this area. It really comes down to a judgment call on the person making the drawing. I drew it the other way first and it didn't appear right to me so I made the call to do it this way.

One note that I feel is important. When dealing with complex surfaces it’s often a good idea to have a quick try at the general shape you are dealing with. This will let you know if a certain approach will or will not work for you. In the motor case my first approach was to use a boundary surface for the back first, then model the base using a boundary and split lines on the first face. This worked well enough but produced problems down the road with fillets and surface intersections. So I learned by taking a shot at it first that my original method was flawed.

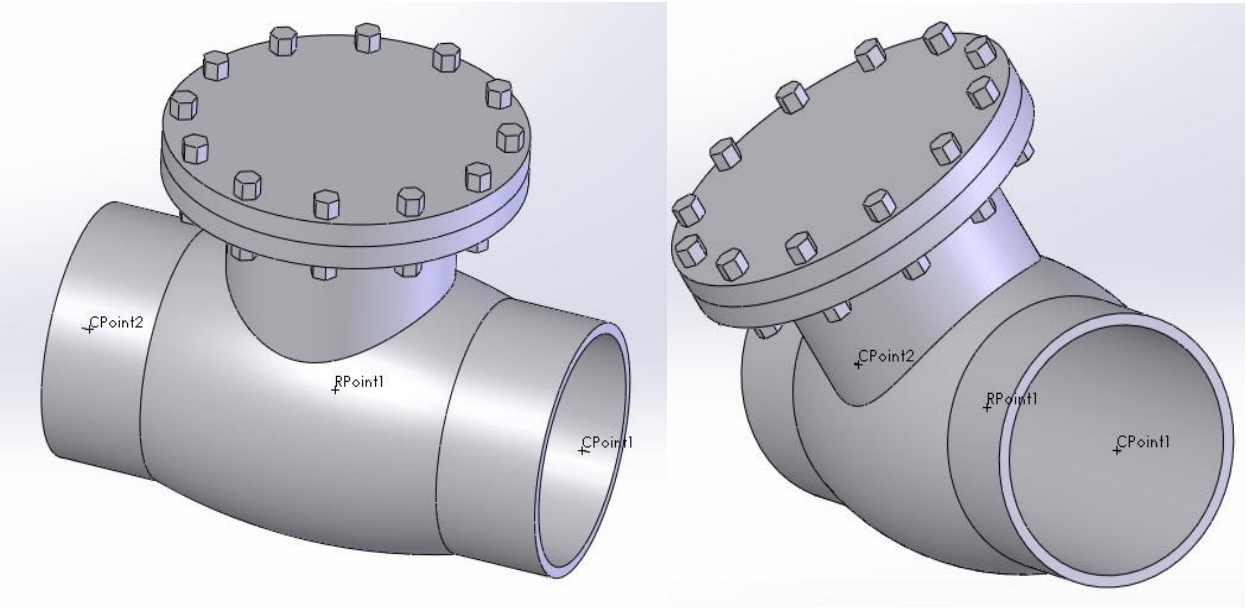



Figure 4.11: Electro- Magnetic Valve

Producing the base first with a loft then using a boundary and trimming both together gave me a much more stable set of surfaces to work with.Using the new boundary surface as a trim tool, trim away part of the face behind it shown in purple.

Just as a note, since we already split this face to use for our surface, we could have also used the Delete Face command and arrived at the same result.Start a new sketch on the Front Plane and Convert Entities on the edge shown below.

This edge comes from our sketch used to trim the second speaker face.Use this new sketch as the split tool and split the blue face shown below.Using the new bottom split line we can now make the boundary surface for the motor face. In the boundary surface selection box you will need to use the selection manager and select each edge needed. This will be 3 edges for each selection.Now we have our motor face edge filled in we have complete almost all of the major surfaces. Now the devil is in the detail work!Now we want to take our inside motor face surface (which is part of the main body) and make a 0mm off-set of that. So make a 0mm offset of the surface shown below.Now hide the main body and the two lower surfaces that go with it but leave the new offset surface visible and make our speaker face and its edge visible.

Knit the offset surface and the front and edge surfaces of the motor face together.Hide the newly knitted surface and then make the other 3 surfaces visible. Now knit these surfaces together. Take note of what happens to the face with our split line on it. Once you have knitted that face with another, the split line is no longer there.

This can be both valuable knowledge and annoying. Since you know this will happen make sure you use your split line edges on surfaces before knit operations.

Now we have two main bodies to work with. The motor faces the main body. Now we are going to make some holes for the button and led on the bottom portion of the motor body.

Start a new sketch on the Front Plane. If you remember when we made our sketch to trim the motor face away from this portion we started with a construction circle. Use Convert Entities to bring that circle into our new sketch. If you like you can create a vertical line to trim the circle or you can leave it complete.

Use this sketch to trim away the area for the power button.

Note on trimming. In this case we are dealing with a sketch that would intersect out surface body in two places. With cases like this you have to be very careful of your selection. I like to “Remove Selections” as op-posed to “Keep Selections” because of this. With Remove Selections only the surfaces you select will be removed. With Keep selections, depending on your view, you might not notice that this sketch would trim the surface in two places. This would leave a hole all the way through the surface. Of course this is an easy fix, just edit the trim operation, but I just want you to keep this in mind when you make your selections.

Notice I have Remove Selections option toggled on.

Start a new sketch on the Front Plane for the led hole trim. For this position you should make your front speaker image visible and choose its location. I chose 19mm up from the origin and drew a vertical reference line that was above the origin. I chose 5mm as my LED hole size. Again you can draw a full circle or a half circle like I did. Use this sketch to trim away for the led hole.

Rule Surfaces are very versatile. Whenever you are dealing with surfaces that are complex and you need to add edges or lips to them, rule surfaces are the way to go. The context in which they are used here is only a small fraction of what can be done so be sure to play around with them.

Choose Rule Surface from your surfaces tab on the ribbon. You will notice 5 different options for “type”. We are going to use “Normal to Surface”. Select the edge of our power button trim and enter a distance of 1mm. Ensure the direction is going into the body of the motor.

Follow the same procedure for the LED hole with the same 1mm Normal Rule Surface.

Looking at a side view you will notice a little bit of the power of Rule Surfaces. These 1mm surfaces stayed normal to the face where they intersect. Now I will make one note here about

“tapered to vector”. In reality this speaker body would be injection molded, meaning everything would need an appropriate draft angle. While the rule surface normal to our face works great for this visual representation, the real thing would probably use a tapered to vector surface where

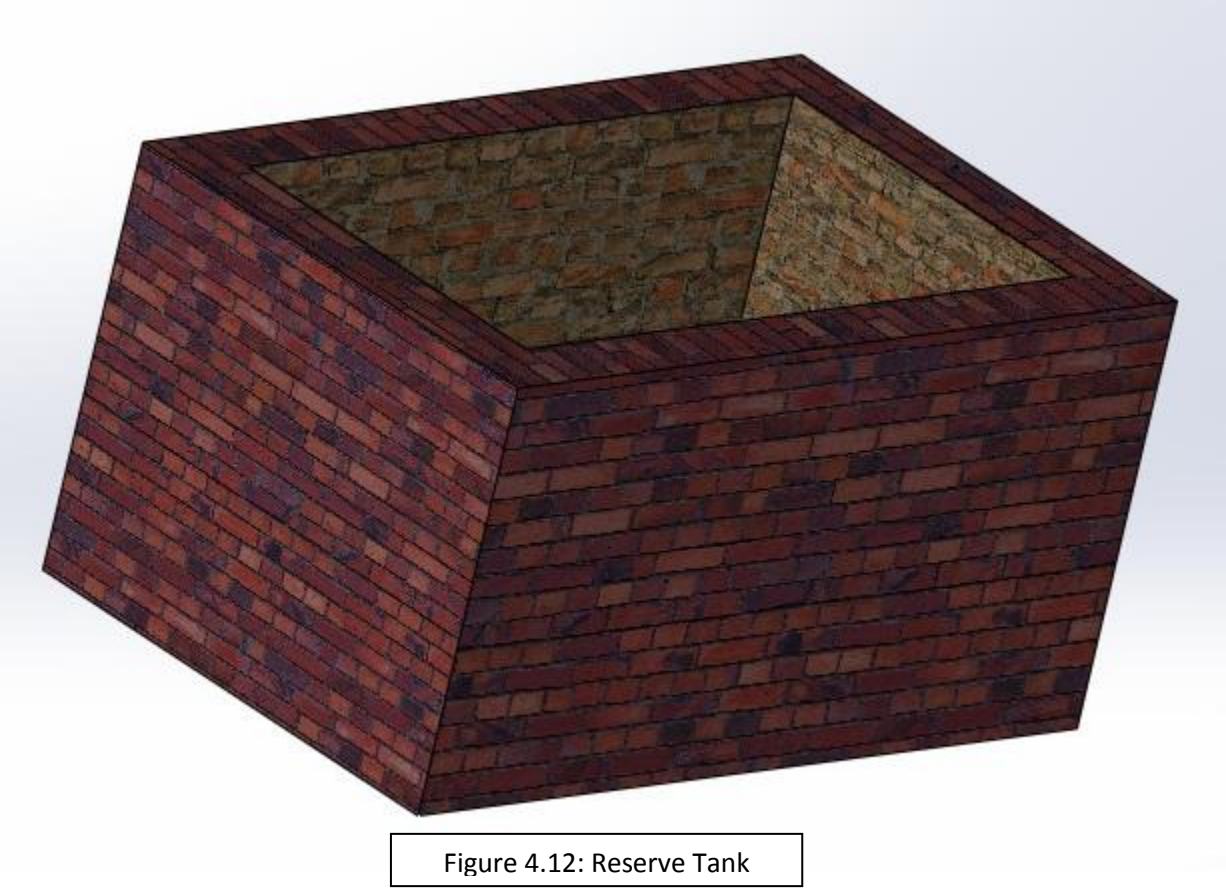


Figure 4.12: Reserve Tank

you would pick a reference plane that suits your direction of pull. This is a bit much to digest at the moment but just understand difference here between a visual model and production part.

You should now have a 1mm surface that is normal to the Power Button hole and LED hole. Go ahead and Knit both of those to the main body.

When you look at production brick parts they have what’s called a reveal. This is a gap left between parts for several reasons. One of which allows a margin for manufacture tolerances so you don't have pieces that can’t fit together. Sometimes these reveals are made very apparent by the designer and sometimes they are hidden. In the case of the reserve tank, the main body is split right up the middle. Also there is a gap between the reserve tank face and the main

body. The part we are drawing is less than accurate because it won't be wrapped in tank face. The real part would be undersized an appropriate amount to allow room for the cloth as well as an additional gap. We won't be going that far into it because we don't have enough information so our focus is "looks". We are going to leave a 1/2mm gap between the tank face and main body to start with and see how things look. Because the material between this part and the main body will be different, the space between the two parts will be very hard to distinguish anyways so that is why I chose such a small number.

Start by creating a 0.5mm offset surface of the inside face of our tank "cover". This needs to be offset into this part because we are going to use it to trim away part of it.

Hide everything except this offset surface. We are going to extend part of it near the bottom. The reason we have to do this is because it does not completely intersect these areas. If you try to use it as a trim surface you will get an error.

Use Extended Surface and select the two edges shown to extend them 0.5mm. This is enough to allow us to trim what we need.

Make the speaker face visible again and use this offset surface as a trim tool to remove the back portion (shown in blue).

Now use the speaker face body to trim our offset surface. Remove the purple section shown below.

Some of you who have played with the trim tool might be wondering why we didn't use the “mutual” option in the trim tool and take care of both trim operations at once. The reason we didn’t do that is because using mutual trim will knit both surfaces together. It’s very powerful, but unless you know you want these two surfaces knitted together, having the extra operation in there gives you more freedom. I have a plan for this surface which makes having it separate a benefit.

Figure 4.13: Solar collector with

Start a new sketch on the Front Plane. Offset the outer most edge of our newest face 0.5mm inward. You do not need to use Convert Entities in order to offset this; you can simply select the edge and then the offset but-ton in your sketch. When you offset an edge like this (or any) it is fully defined, but you can still grab its endpoints and drag them. They will stay tangent to the line, or follow the curvature of a spline. Go ahead and drag the lower endpoint of your offset edge to ensure it goes past the surfaces we are working with.

The reason we do this is because we are dealing with offset entities and surfaces that taper in space. This edge is going to split the back face and we don't want it to end short of the edge of the face.Use this sketch as a Split Line to split the back face shown in blue.

Now offset the larger portion of that face 0.5mm back towards the main body of the tank. This is hard to show in a screen shot but here is the bottom corner. Notice the split line on the face and the offset surface.

The reason we are doing this is because we want to end up with a step at the edge of our part. Sure with the curvature of this part we could have just left a gap between it and the main body, but this way is better. Some of you might wonder why we offset one surface, trimmed it, and then offset our new surface back after a split rather than just splitting the first. The main reason is because looking from the Front Plane we drew the shape of the outer surface to be slightly smaller than the inner one. This means when we offset that first surface 1/2mm we came up with a whole new edge. We could have offset the original edge and really it would have looked nearly the same. Because our inner and outer edges for these faces were two different splines, I wanted to use the actual trimmed edge for mine. Again these types of things are judgment calls. Sometimes there isn't a good reason to do one over the other. Sometimes you will try one, it won't work and you will have to go back and try another. Only practice will let you decide which is best but you should always be thinking of alternative options when modeling anything.

Now use the Delete Face command and remove the face shown in blue. Since our recently offset surface will be the "back" of our speaker face, there is no need for this inner surface.

Now we want to make a boundary surface to finish off this reveal. There is one small issue that may arise with this. We are dealing with several different surfaces now so edges may have some discontinuity. Knitting surfaces together fixes these so we are going to approach this boundary a little different. If you try to create a single boundary surface you may get a curvature error. I encourage you to first try that using the selection manager and selecting the proper edges. If it works that's great, if not this is a valid second option.

Start with a single selection boundary surface going from our split line to the offset surface.

Now knit that boundary surface, the offset surface and remaining bodies (4 surfaces total) together. This will heal some edges where curvature may cause a problem. I suspected that the large spline edges were the ones causing the issue which is why I chose those as my first boundary surface before the knit operation.

Now create a boundary surface using the selection manager and selecting the bottom edges.

Knit that boundary surface to the rest of the knitted surface. You should now have a single surface for the speaker face with a reveal lip all the way around it (except at the bottom). We didn't need one at the bot-tom because we already created a space between this part and the area around the button/led.Moving into the main body, Hide the tank face and make the main body visible. Start a new sketch on the Front Plane. We need to offset a few edges. First offset the main shape of the speaker 0.75mm.

Next offset the arc and line around the power button 1.5mm.We need to extend the straight line and trim everything so you are left with this.Use this sketch as a trim tool and remove the purple section pictured below. The reason we need to trim this away is because it will make creating a reveal very difficult. Or at least more difficult that it needs to be for this tutorial.

Start a new sketch on the Right Plane.

We are going to draw a rectangle that we will use to split our main body for a reveal. Start by drawing a vertical construction line. Make its end points coincident with the base edge and upper edge shown. Use a bi-direction offset with a dimension of 0.5mm. Draw a line to join the two offset lines together at the bottom. At the top we will need to add a few lines.

You can either add lines or “pull” the endpoints of the offset lines up. I added a 12mm dimension but the important thing here is that the lines go past the edge shown in orange. The reason is because we need our split to split the entire face.Use the sketch as a split tool and split only the

2 faces shown in blue. We are not splitting the small lip left by the previous trim operation with this sketch.

Start a new sketch on the Front Plane.

We are going to draw another rectangle this time using the edges of our split line for coincident relations with our rectangle. For simplicity sake I make my left vertical line above the origin even though we do not need this large of a rectangle. It allows me to use no dimensions. You can also see the top edge is made up of two lines. This could have been done with one that went through our reference point but this works as well. Since this sketch is fully defined with no dimensions, this extra line will not cause any undesirable results during updates.Use this sketch to split the face as shown.

The end result is a set of split faces that intersect properly. If we used our first sketch to split all 3 faces, the results would have been less than satisfactory be-cause of the curvature.Use Delete Face and delete all 3 faces that we have just created with our split.

This will turn the single solar tubes body into two separate bodies since these faces are the only thing keeping them together. We want to do this because we want to have a front and back of our solar tube body.

Create a 1mm Rule Surface using “Normal to Surface” type. Select the two edges shown on the back half of our speaker body.

Create another 1mm Rule Surface for the same edges on the front half of the speaker body.

Now we need to fill in the small gaps between the rule surfaces and the rest of the trimmed surfaces. At the top on the back half of the solar tube body there is a small triangular section. Create a Boundary Surface to fill this in. Do the same for the top edges on the front half of the speaker body.

Now create a boundary surface between the two ruled surfaces to fill in this reveal area. You will need to use the selection manager and select two edges for each selection.Here is a close up at the bottom of the bodies to show you what we have done.

But we need one more piece to finish off this reveal. At the top we will need one more boundary surface. This surface will have selections in both the Direction1 and Direction2 box.

Think of the Direction1 selections as to the curves. We will make a surface between those. Direc-tion2 selection will give the surface a path to follow between the two Direction1 selections.

This surface fills in the last gap we have at the top.

Earlier I mentioned we wanted to split the speaker body up into two pieces. Since we are only creating a visual representation we are going to knit both pieces and all these rule and boundary surfaces back together to make one body again. Again I want to note the difference between modeling for “looks” and modeling for production. The purpose of this is only to show you how to work with the surfaces to create these parts and not actually give you all the info to produce them in reality. Knowing how to work with and manipulate the surfaces is the first step.

At this point we have two surface bodies. The main body and the speaker face. We have a little bit more of the solar system to produce but at this point we can go ahead and mirror what we have in order to make the remaining surfaces a little easier.Mirror the main solar system body across the Right Plane and knit the two surface bodies together.

Note: you can use the Knit Surfaces option during the mirror or perform a knit after the mirror operation. I like to separate these during the tutorial to remind us what we are doing, but you can reduce the size of your feature tree by combining operations like that.

One of the reasons for the mirror was to more easily fill the power button and led hole. Using Filled Surface and make your selections to fill both holes. These will be two separate Filled

Surface operations. Knit these two filled surfaces to the rest of the body.Now mirror the speaker face surface and knit.

Start a new sketch on the Top Plane.

Use Convert Entities to convert all of the edges around the base of the solar system. There will be two small gaps where we created our reveal.To fix the gap you want to grab the lower curves end points and drag them up to merge the two.

Once the sketch is closed, use it with the Planar Sur-face operationStart a new sketch on the Top Plane. Create the sketch shown below. The 70mm wide holes are horizontal to the midpoint of the ellipse. The vertical holes have a vertical relation with the origin. Start a new sketch on Plane-6. Offset the four 14mm circles 3mm inside.

Create four different Lofted Surfaces between the 14mm circles and the 3mm offset circles. Add a direction Vector constraint to the 14mm circle with the Top Plane. Change the Tangency Length to 1.5. This will change the shape of our loft from a cone to a rounded surface because that tangency make the loft follow a certain direction for a certain length. The 1.5 doesn't mean 1.5mm. It’s a unit-less value.Here is a side by side shot of the loft with and without the tangency added. Using the tangency to control the shape allows us to create some nice shapes without the use of guide rails.Once you create the first loft, the sketches will automatically hide. You will have to make them visible in order to have the circles available for selection for your other three lofts.

Start a new sketch on the Top Plane. Draw an ellipse as shown.

Start a new sketch on Plane-6. Offset the ellipse 4mm to the inside.

Create a Lofted Surface between the ellipses. Add a Direction Tangency for the larger ellipse. Use the Top Plane as the references and make the Tangency Length 1.5.

Start a trim operation and select “mutual” for the trim type. Select all 5 lofted surfaces for the Trimming Surfaces selections. Remove the purple sections shown below.

This is the first time we have used Mutual Trim and I mentioned earlier that it knits the sections together. This will now be apparent when we use this new surface as a trim surface.

Use this new surface as a Standard Trim Tool (not mutual) and remove the purple section shown below.

There is no good reason to not use Mutual Trim here as well, but I may want to work with this surface a little more so I made the call to use Standard Trim here.Create a Filled Surface to fill in the bottom as shown.Knit these 3 surfaces to the main body of the full design.Start with a 1mm fillet to the 4 edges shown.

Add a variable fillet to the edges shown. It goes from 0mm to 0.5mm and back to zero. The reason we do this is because the curve starts and ends in a place where you cannot fillet. A conventional fillet would fail.

Now we want to make a boundary surface to finish off this reveal. There is one small issue that may arise with this. We are dealing with several different surfaces now so edges may have some discontinuity. Knitting surfaces together fixes these so we are going to approach this boundary a little different. If you try to create a single boundary surface you may get a curvature error. I encourage you to first try that using the selection manager and selecting the proper edges. If it works that’s great, if not this is a valid second option.

The end result is a set of split faces that intersect properly. If we used our first sketch to split all 3 faces, the results would have been less than satisfactory be-cause of the curvature. Use Delete Face and delete all 3 faces that we have just created with our split.

Add a variable fillet to the front edge using the same numbers.

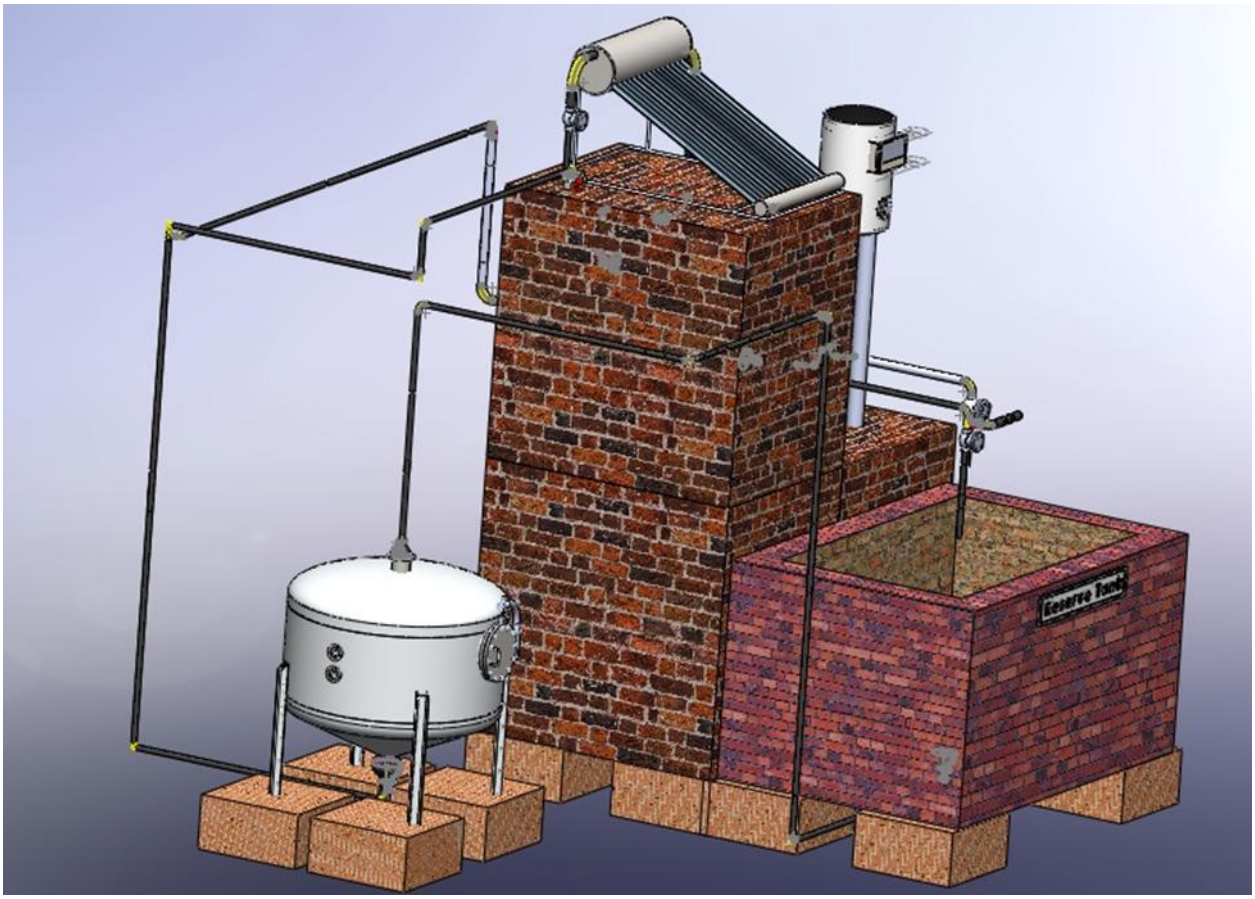



Figure 4.14: Final Design of Alternative Solar water system

Add a variable fillet to the edge shown going from 0mm to 2mm. Note that there is a small section of this edge near the bottom that was not selected. Repeat for the edge on the other side (its mirror).Add a 2mm constant radius fillet to the edge shown around the back of the final English body. Add a 1mm constant radius fillet to the two edges shown below.Add a 0.5mm constant radius fillet to the edges shown below. Add a 1mm constant radius fillet to the entire outer edge of the design face.Add a 1mm constant radius fillet to the edges shown below in two separate operations. And then I get the final design of the Automated Alternative Solar Hot Water System.

# Chapter: V

## Conclusion

In this thesis, I have made the 3D model of “Automated Alternative Hot Water System” using a CAD to called SolidWorks. After that I have designed the whole system using GAL chip. After thorough analysis, I came to believe that this project will work more efficiently using a GAL chip instead of a microcontroller because a system designed using gates and flip flops will work more efficiently  then a microcontroller. The main reason for this is that a microcontroller is like a small scale CPU, which performs the same operations such as instruction fetch, instruction decode, operand fetch etc. However, a GAL uses gates. That’s why GAL performs better than microcontroller.

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