THE PERFECT CHAI MAKER

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of
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Abstract

This senior thesis project presents The Perfect Chai Maker, a machine capable of making masala chai, a South Asian tea beverage, automatically. Chai is a method of making tea rather an a flavour itself. With an increasing demand for chai in the American and European market, products have failed to replicate the traditional recipe or to improve on the inconvenience currently associated with making chai – such as time taken for preparation of the ingredients and supervising the recipe when on the heat. This machine follows strict tolerances based on a modified version of a chai recipe to replicate a traditional cup of chai. The milk is inserted to the machine by the user though it self dispenses ingredients and hot water, taking a total of less than 5 minutes to operate. Most of the specifications were met for the machine.

It shall be noted that the concluding three weeks of this project were cut short due to complications related to the COVID-19 pandemic.

1 Introduction

1.1 Motivation

There are over 2 billion daily tea drinkers around the world; approximately 165 million cups are drunk daily in the UK, averaging to three cups per person. The Chai Latte has become an increasingly popular drink since its introduction around 2 decades ago; however, this mixture of concentrated "chai" syrup and milk is not a true form of chai. Making masala chai, a traditional South Asian tea beverage, is a lengthy process. Contrary to popular belief, chai is not a flavour, rather, it is a process of making tea with a range of spices and milk. This requires more time, both for preparation and clean up, as well as accounting for different needs for each person, for example spice or sugar ratio, or the type of preferred milk. At the typical workplace, coffee machines are a common sight allowing one to make coffee in a couple minutes; however, making a cup of English breakfast tea – the closest alternative to chai – requires much more time and effort. The customary aspect of chai closely aligns to reasons that employees at a workplace may want to drink it. In a study conducted by the Institute for Scientific Information on Coffee, as shown in Figure 1, three of the most prominent categories for drinking coffee at work were to: socialise with colleagues, feel less tired, and get some time to pause and rest, all of which are important concepts with the social tradition revolving chai.[1]

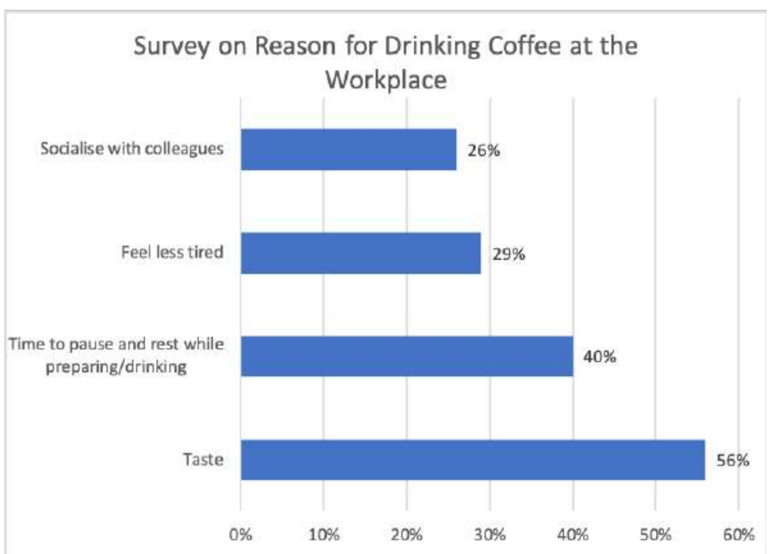


Figure 1: **Percentage of people who responded to study on reasons for drinking hot beverages at work.[1]** The customary aspect of drinking chai closely aligns to the top three selected options.

This project aims to bring together electrical engineering concepts with novel commercial product development. By using knowledge derived from control systems and analogue/digital circuitry design, this thesis will produce an optimised solution to the posed problem. The goal of the project is to produce a prototype machine that brings an authentic cup of chai to homes and offices at the touch of a button – a discussion of what is meant by 'authentic' is provided in Section 2.1. With its low maintenance and low user-involvement design, it would be a convenient, time efficient, and mess free solution to the traditional method of chai making.

1.2 Problem Statement

Making coffee at the workplace has become an integrated part of workflow, generally requiring just the touch of a button. However, making chai, a South Asian tea, or the closest alternative, has required more time, preparation, and handling of multiple components.

1.3 Background Research and Existing Work

There are many machines that make hot beverages and "chai flavoured" drinks. The four products, however, that were focused on allow a spectrum of approaches to making both coffee and tea be taken into account: *CRAFTEA*, *Keurig K-Café*, *BrewChime*, and *Nespresso Latisima Pro*. These products have varying levels of automation and involvement from the user to produce a beverage.

CRAFTEA is an induction heating kettle that requires all ingredients to be inserted by the user and a control screen allows a time to be set for making the tea. *CRAFTEA* does not come with a scoop or other measuring system for the ingredients, so one would have to manually measure those – adding to the preparation time; however, lines on the inside of the pot do indicate how much water or milk has been added. The main advantages of this machine are its form factor, strainer (see Figure 2) and custom brewing features. This allows users to not have to worry about having spare tea leaves or spices in the serving mug, as well as ensuring that only one thing – the kettle – needs to be cleaned. The cost of this machine is $199.[2]

(a) (b)

Figure 2: **Front (a) and top (b) view of the *CRAFTEA* machine.** This machine does not have an automation focus for making chai or other tea drinks.

Keurig K-Café is a pod based beverage maker with a reservoir to store and preheat water and an induction heater-operated milk frother, see Figure 3(a). To make a beverage, the user inserts a *K-Cup* (costings upwards of $0.50), see Figure 3(b), and selects the volume of the beverage from one of four options.[3] The brewing process happens as the water passes through the *K-Cup*, with a dedicated pump to add pressure, which replaces the requirement of time to brew the coffee/tea. Should the user require frothed milk, it can be inserted in the provided saucepan and a selection of three buttons allow the user to choose the heat of the milk. This would then be manually inserted to the mug that the water-based beverage is made in. For the *Keurig K-Café*, the saucepan would be the only item needed to be cleaned by the user. The machine costs $199.99 though there is a recurrent cost of replenishing the single-use *K-Cups*.[4]

(a) (b)

Figure 3: **Front view of the *Keurig K-Café* machine (a) and single-use *K-Cups* inserted into the Keurig to make a beverage (b).** [3, 4] The Keurig has two separate mechanisms to make the beverage and to froth milk.

The *BrewChime* machine is designed specifically for making chai, the goal of this thesis, by using two separate compartments for heating water/brewing tea, and heating milk. The main control is a jog wheel/button for selecting the drink size and tea strength. The screen instructs the user how much milk to insert into the carafe. This machine also uses pods, whereby the user inserts a pod to the top of the brewing compartment and manually inserts milk into the pot for the lower milk heating compartment. The brewed tea pours into the milk due to its position above the water before being ready for serving. The main advantage, alongside the fact that this machine is dedicated to make as close to an authentic cup of chai, is that the ingredients are integrated inside the water to brew, rather than the water passing through the pod.[7] However, some of the major disadvantages are the use of the limited number of pods, which cost just over a dollar per chai; using the limited number of flavoured pods is quite wasteful for the environment (though they are recyclable) and the machine cannot be used unless a pod, which are exclusively produced by *BrewChime*, is inserted into the machine; the user is quite involved in the process of making the chai as both the milk and the pod have to be manually inserted, and multiple parts of the machine (the brewing chamber and the carafe) have to be cleaned after every use – it is also recommended that a "clean cycle" is run after every "50-60 brews," adding additional hassle for the user.[6, 7]

Figure 4: **Front view of the BrewChime machine.** In the top left is the boiling water/brewing compartment, with a strainer to not allow the ingredients to pass through, below is the carafe for milk heating and final production of chai, and the top right has the touch screen display and water reservoir (not visible in figure).

Finally, the *Nespresso Latisima Pro* machine automates the entire process of making hot beverages, specifically, lattes, cappuccinos, and espressos.[8] There are two removable reservoirs in the machine, as seen in Figure 5, one for milk and the other for water. The removable milk reservoir allows it to be stored in a fridge, avoiding the milk from going bad while also ensuring that the machine has complete control over how much milk is inserted. With a touch screen interface, can control the size and type of drink. The advantage of a machine like the *Latisima* is that the user does not need to clean anything to make a drink – after each use, the milk container pipe released steam to clean the pipe. This container, however, does need to be rinsed after many uses, depending on how often and how old the milk in the carafe is. This device is priced at $749.99, making it significantly less accessible and affordable than the other three machines combined.[8, 9]

(a)

(b)

Figure 5: **Front view of the *Nespresso Latisima Pro* machine (a) and single-use *Nespresso* pods inserted into the *Nespresso Latisima Pro* to make a beverage (b).**[8] The *Nespresso* requires the least effort from a user to make espresso based beverages, comes with a removable milk carafe to ensure freshness but is the most expensive.

2 Problem Definition

2.1 Chai Recipe

There are many forms, recipes, and varieties of making masala chai.[10] The recipe of making chai chosen for this chai maker illustrated in Figure 9, is required to be specifically quantified in order to create technical specifications and set constrains. The following one has been chosen for its precision with the ingredients, ties to the traditional method, and its yield: one large mug. The time taken by this recipe is 10 minutes of cooking and 5 minutes for preparation.

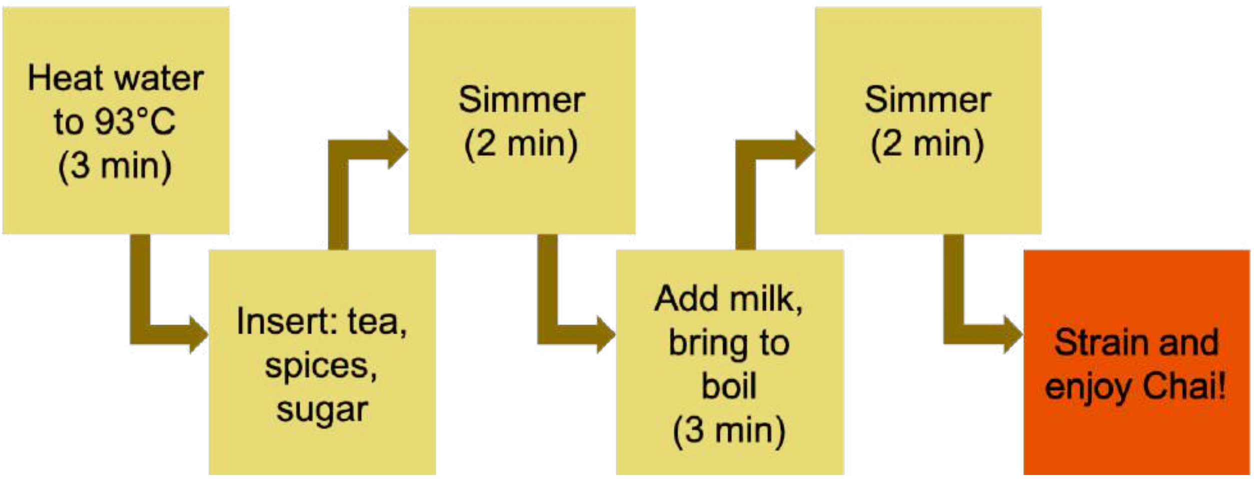


Figure 6: **Flowchart of a typical recipe of making chai.** Chai requires a step-by-step process of heating, inserting ingredients, boiling, and simmering.

The ingredients for such a recipe are [11, 12]:

- 180 ml water
- 90 ml whole milk
  - can be substituted with any vegan/lactose free option
- 10 grams sugar
- 2 grams black tea (1 tablespoon loose-leaf)
- Variety of spices (optional)
  - 2 pinches ground cardamom
  - 2 pinches fennel seeds
  - 2 slices fresh ginger
  - 1 cinnamon stick

The recipe is:

1. Heat water to 93°C

2. Insert sugar, spices, tea and bring to boil
3. Add milk and bring to boil
4. Lower the heat and simmer for 5 minutes
5. Strain into a glass

2.1.1 Adjustments and Additions to the Recipe

First of all, as fresh ginger is required in this recipe, the machine dod not include this spice. This is as the ginger would need to be (1) cut into pieces, which cannot be guaranteed to be standard and (2) if fresh ginger is kept cut in dispensers, it would eventually dry out. Cinnamon sticks were also not be used in this recipe as their freshness in powdered form would not equate a stick and cracked cinnamon sticks do not have a consistent granularity.

Secondly, 2 pinches of cardamom and fennel seeds are approximately 1 gram.

Finally, the milk and water will be heated separately before being added together, reducing the time taken to heat and boil the liquids, both in step 1 and 3 shown in Figure 9. According to the Royal Society of Chemistry, 65°C is the optimal temperature to drink tea [13], therefore the final product will be served to this temperature.

2.1.2 Time for Making

For users at the workplace, reducing the time required to have a ready drink is key. The preparation time for the user is effectively 0 as the user is not required to prepare any of the ingredients. The only exception for this is when the machine is running low on ingredients or water. Furthermore, the machine should make the drink in less than 5 minutes, reducing the time taken by half. The modified recipe is illustrated in Figure 7.

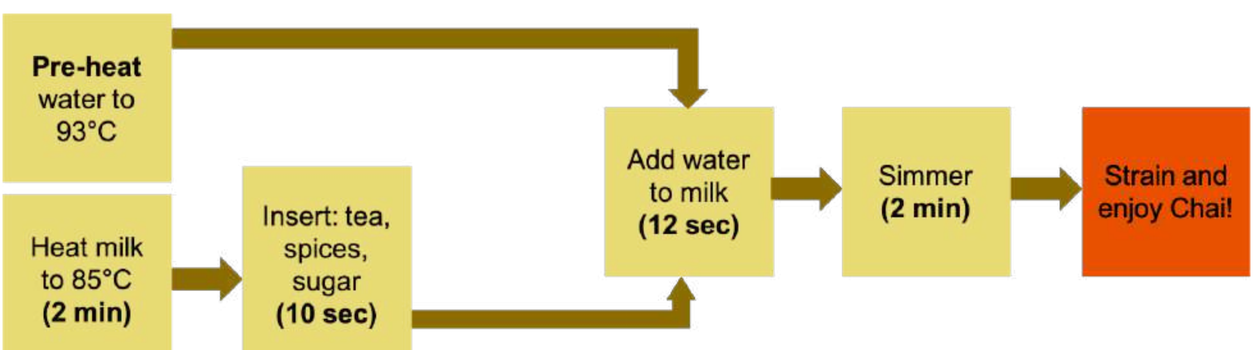


Figure 7: **Flowchart of the redefined chai recipe for this machine.** The modified recipe ensures that a traditional cup of chai is made while reducing time through conducting simultaneous processes.

2.1.3 Cleaning of Machine

Cleaning the machine is the key inconvenience and non-automated process of the machine, therefore it must be reduced. The final design should only have one container that requires cleaning: both the insoluble spices and tea, and the milk residue should end up in a single container that can be removed. Due to this, the machine will not store milk, reducing the automatic nature of the machine as storing the milk would require: refrigeration, regular cleaning of tubes, all of which significantly affect the purpose of the machine.

2.1.4 Tolerances

As with any recipe there is leeway with the inserted ingredients, and the tolerances will determine the precision of the components. The milk is inserted manually into the machine; however, the rest of the ingredients (water, sugar, spices) are dispensed by the machine. The machine will assume the user inserted milk is correct as verifying this adds complexity beyond the necessity of the goal of the thesis. An experiment of pouring the dry ingredients using a tea spoon 10 times revealed the tolerances listed in the technical specifications, see Appendix D.1, depicting the leeway in a typical human measuring ingredients.

As the modified recipe has an idle water temperature and a heated chai temperature, the tolerances for these differ. For the idle temperature, the tolerance can be larger as the controller maintains this fluctuating temperature during the time that chai is not being made. Therefore, this tolerance is $\pm 20\%$. When chai is made, the water is heated to the chai temperature, with a tighter tolerance of approximately $+1\%$, -5%, according to temperatures taken during experimentation by making chai.

For the milk temperature, reaching close to the boiling point while avoiding spill over is important. Should the boiling point be exceeded, milk would spill on the components and cause damage. However, this temperature also cannot be too cold since the ingredients need to adequately brew. Therefore, the tolerance was set for 80°C +5°C, -0°C.

2.1.5 Size

To accommodate office spaces, the machine must take into consideration the average counter top size. The machines discussed in Section 1.3 are sized: $28cm \times 23cm \times 33cm, 44cm \times 36cm \times 37cm, 34cm \times 28cm \times 28cm$, and $27 \times 20 \times 33cm$ respectfully. The size of The Perfect Chai Maker therefore should not exceed $50cm \times 50cm \times 50cm$.

2.2 Cost

The total cost of the machine should be less than the average cost of an office space coffee machine as well as the main competitors. Since the BrewChime is most closely aligned to this machine, the cost of the machine should not exceed \$200. This machine would not have the recurring cost for pods, making it cheaper in the long term. The cost of per chai using the ingredients in this machine is \$0.30, significantly lower than the cost of pods for the analysed machines – see Appendix A for cost breakdown.

2.3 Technical Specifications

The prior analysis and the refined chai recipe inform the development of quantitative functional requirements, outlined in Table 1.

Specification	**Target Value**	**Tolerance**	**Units**
Process			
Time to make chai	< 5		mins
Pump: Hot water is transferred from the water tank to the mixing container	180	± 15	mL
Controller: Maintenance of idle temperature when machine is not in use	50	$+5$	°C
Time taken to raise milk and water temperature	120	$^{+10}_{-0}$	secs
Ingredients			
Temperature of water when making chai	96	$^{+1}_{-4}$	°C
Temperature of milk when making chai	80	$^{+5}_{-0}$	°C
Dispense:			
Tea leaves	2	± 0.4	g
Sugar	8	± 2.0	g
Cardamom	1	± 0.2	g
Fennel seeds	1	± 0.2	g
Other			
Device Size	50x50x50		cm^3

Table 1: **Technical specifications for the implementation of The Perfect Chai Maker.** Using the conducted analyses and the developed recipe, the specifications for the build of the machine were formed.

3 Design Approach

3.1 Modifications to Recipe

The approach to the design of the machine was implemented by adjusting the recipe to optimise the process of making chai. Firstly, to ensure that the user only needs to clean one part of the machine and because milk cannot be stored in the machine (see Section 2.1.3) means that the ingredients would have to be inserted directly into the milk rather than letting them steep in the water first. Secondly, to decrease time, two separate heating devices are designed so that the heating process can be done simultaneously, rather than consecutively. See Figure 8.

The updated recipe therefore is:

1. Heat water to 93°C; heat milk to 85°C
2. Insert sugar, spices, tea to milk and simmer for 2 minute
3. Add water and bring to boil
4. Lower the heat and simmer for 2 minute
5. Strain into a glass

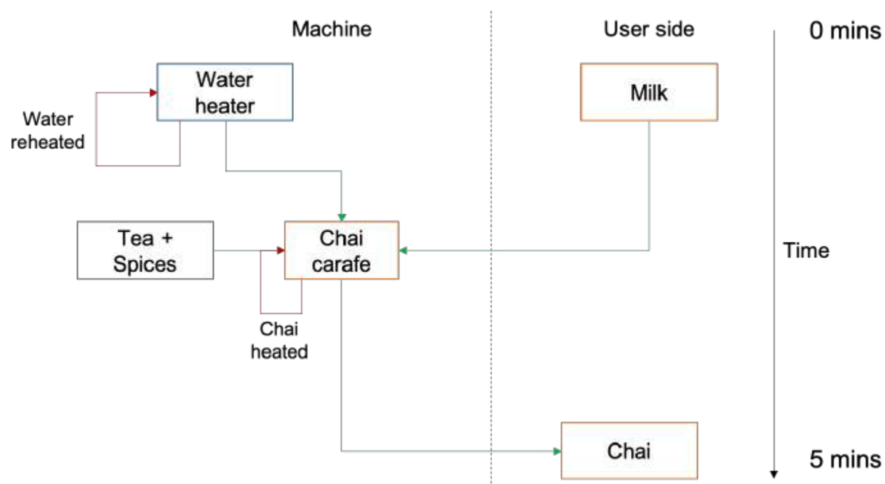


Figure 8: **Flowchart of the modified version of making chai.** The user has to insert milk into a carafe where all the ingredients combine together. This process allows the time taken to make chai to be reduced and ensures that all ingredients end up in one container, reducing cleaning time. The colour of the boxes indicate the container of storage, for example orange is for the user-inserted carafe. The green lines indicate transfer of ingredients, the red lines indicate the control systems.

3.2 System Diagram

The overall system is divided into four subsystems:

1. Micro-controller and power: This subsystem deals with supplying power to the different subcomponents in the machine and making sure that they interact in the correct way.

2. Water heater and control: This subsystem ensures that the machine has enough water to make chai; maintains water either at a resting (idle) temperature when the machine is not in use or heats it up to the chai temperature; and pumps the appropriate amount to the carafe when needed.

3. Ingredient dispenser: This subsystem dispenses the dry ingredients, each with specific required amounts, to the carafe while ensuring that steam from the milk/water does not penetrate, thus ruin, the ingredients.

4. Milk heater: This subsystem heats up the milk within the limited time frame before simmering all the ingredients to produce the final product.

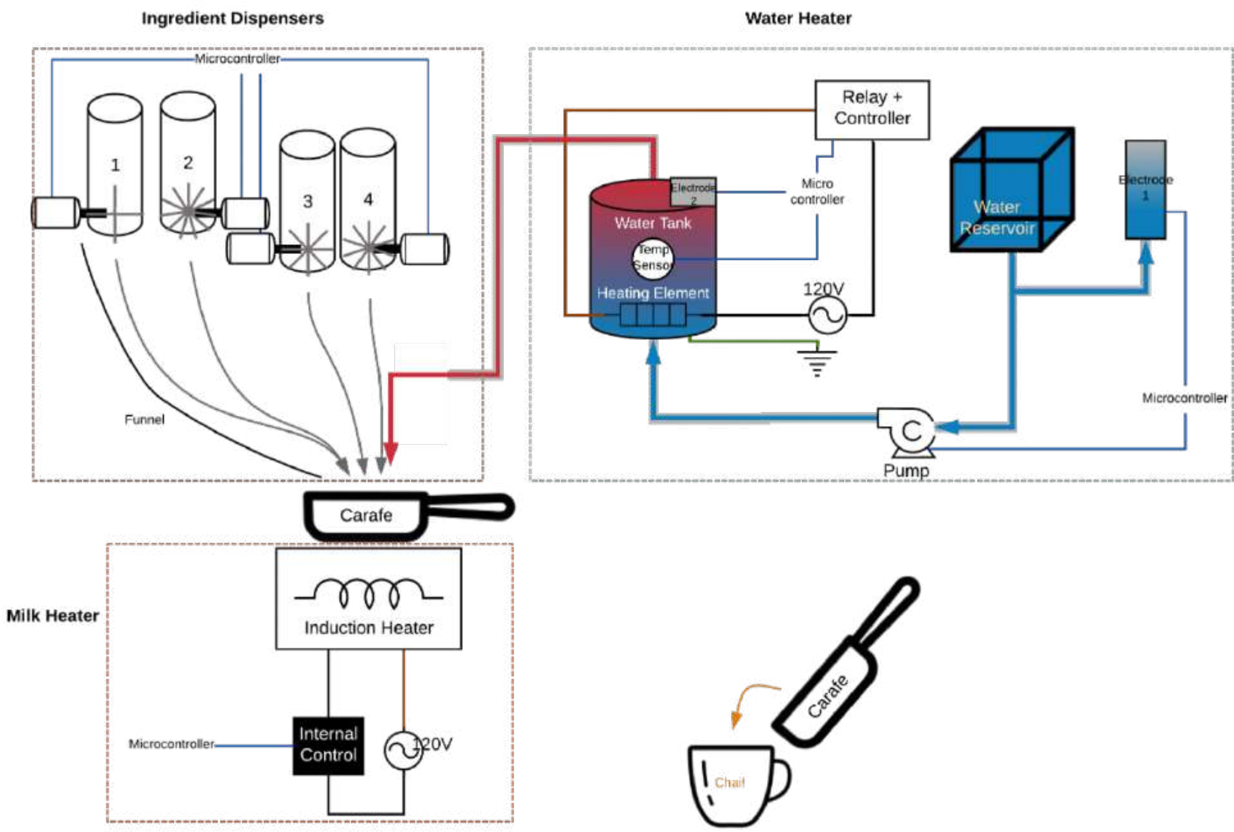


Figure 9: **System diagram of the final prototype model.** See Section 4 for hardware design choices.

The user can indicate making chai by pressing a button for a 3 seconds. This notifies the Arduino to start heating the milk and the water. Once the milk is sufficiently heated, the ingredients are dispensed into the milk carafe – the funnel ensure that they fall into the carafe as the dispensers do not sit directly above the carafe. Then, once the milk has reached the chai temperature, the hot water gets inserted into the milk and the concoction simmers until it is ready. The user can remove the carafe from the machine and pour it into a mug to enjoy the chai while ensuring that the ingredients get filtered by the mesh that covers the carafe.

4 Hardware Design

4.1 Micro-controller and Power

4.1.1 Arduino Controller

The micro-controller for this project is an Arduino Mega 2560 R3 due to its many component compatible libraries and abundance of analogue and digital pins. The micro-controller also did not need to source current. Initially, more pins were thought of as a requirement because of the use of multiple servos; however, only one pin is needed per servo and a 16-channel PWM/Servo shield is also able to solve that issue. Figure 10 shows the wired connections from the Arduino to the breadboard, which then branch to individual components, for example input to the relay switch.

4.2 Power Management

4.2.1 Voltage Divider

There are three current requirements for the machine: 120V AC for the water heater, 120V AC for the milk heater, and an AC to DC 12V–1A adapter to power the Arduino, pump, and servos. A breadboard is used to hold all the components, as shown in Figure 10.

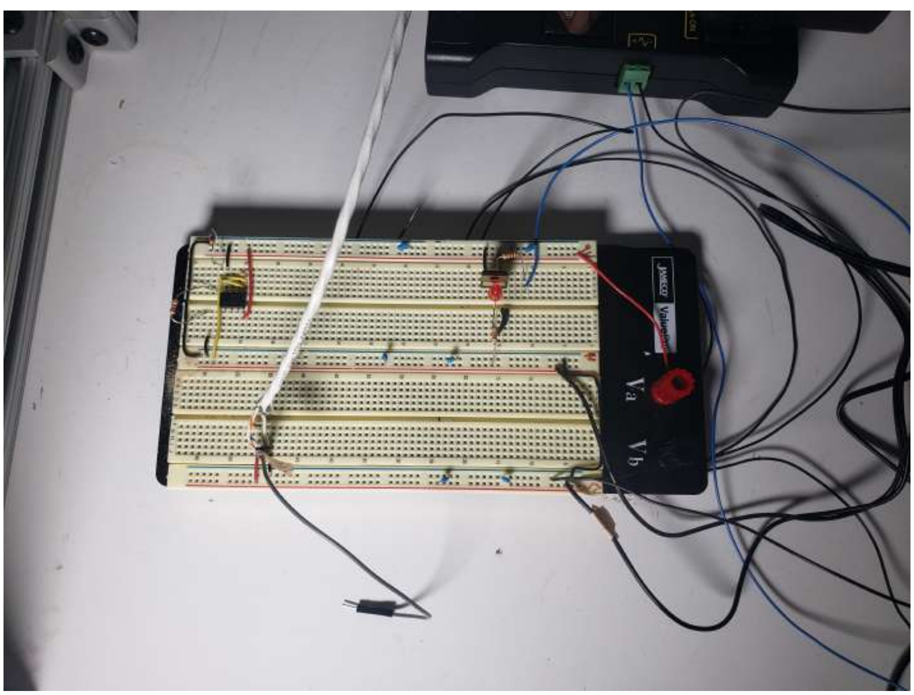


Figure 10: **Breadboard with components and connections from the Arduino to the machine.** Red represents 12V, yellow is 5V, blue for control signals from the Arduino, and black is common ground. The Arduino is not in this image as it was in an inaccessible lab and the servo motors also were not attached when this photo was taken.

To power components which would require 5V, rather than 12V, a voltage divider and a unity gain buffer amplifier is used to transfer the voltage from the first circuit, having a high output impedance level, to a second circuit with a low input impedance level, see circuit diagram in Figure 11. The interposed buffer prevents the second circuit from loading the first circuit unacceptably – with a sudden increase in current use – and interfering with the desired operation of the pump, whose flow rate depends on the input current.

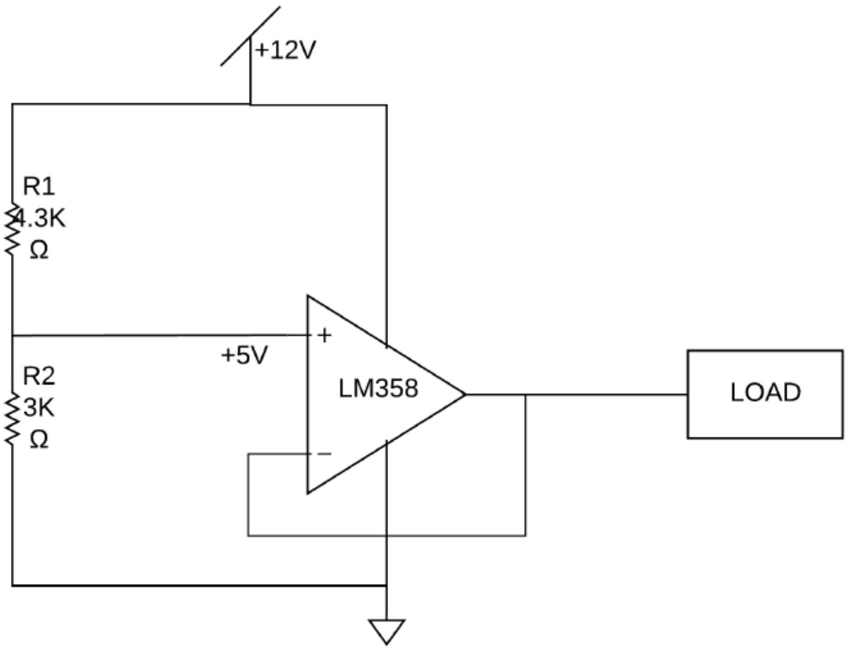


Figure 11: **Operational Amplifier LM358 is used to allow components such as the 12V water pump to not interfere with the operation of the servos.**

4.2.2 Relay Switch

The water heater converts AC electrical energy into heat through the process of Joule heating. Current through the element encounters resistance, resulting in heating of the element. Therefore, controlling the current input will change the amount of heat generated. This can be done either by changing the AC input to the heating element or by turning the heater on and off. The latter method can easily be done using a relay switch. The electromagnetic relay switch originally used required a significant current draw that the Arduino was not able to provide. An Arduino logic-operated BJT allowed the relay switch to be triggered by the flow of current, shown in Figure 12. One of the concerns with this set up was its lack of insulation, therefore it was replaced with an IOT Relay II, which does not require a driver and offers four outlets. This allows the IOT Relay to act as a hub for all three current source as well as provide safety for the user.

(a) (b)

Figure 12: **Image of (a) original JQX relay used that was replaced by (b) IOT Relay II.** The latter switch is insulated, allows multiple outlets to be plugged into one consolidated brick, and does not require the Arduino to have a separate current driver.

The relay switch, additionally, has the following benefits (see Appendix E): relay hysteresis, preventing relay chatter; LEDs to verify an input voltage and the switch state of the Arduino; a 12A thermal safety circuit breaker to prevent overloads and add supplemental protection; and a switch rate of 5.3 million mechanical operations, providing a long operational life.

4.3 Water Heater and Control

4.3.1 Water Heater

The water heater was reconfigured from a used Keurig machine. The sealed water tank is bolt-fastened, contains a heating element, has a volume of 800mL, and has holes for tubing on the top and bottom, making it ideal for the machine. A pump connects a water reservoir to the bottom hole of the tank only - as illustrated in Figure 13, because hot water rises, there is no necessity for a secondary pump to transfer the water out since pumping cold water in from the bottom would lead to the hot water leaving from the top hole.

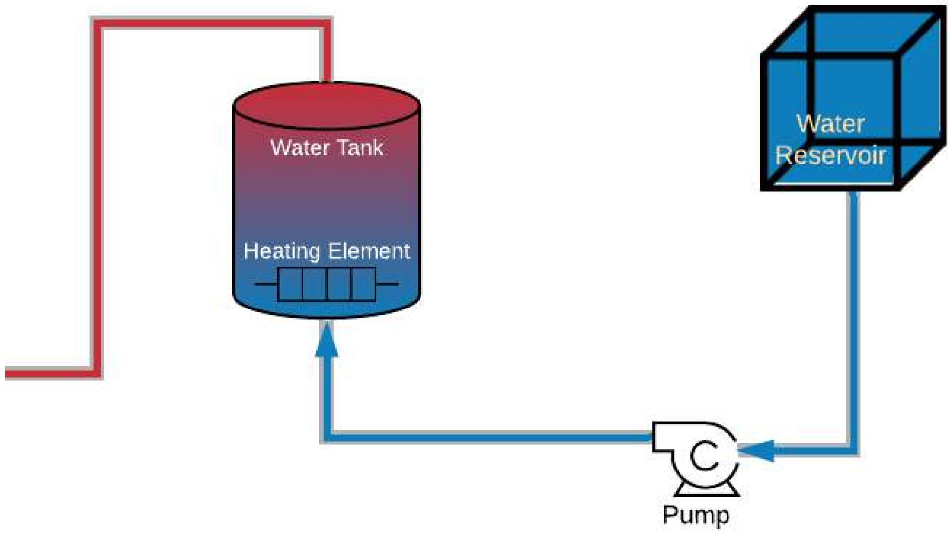


Figure 13: **Illustration of hot water transfer by pumping cold water from the reservoir.** The cold water inserted by the pump pushes the hot water upwards and into the tube that goes out to the carafe. The pump and water tank are reconfigured from a used Keurig machine.

When chai is not being made, the water temperature is maintained at 50°C, as written in Section 2.3. The controller used to heat the water up is hysteresis or 'bang-bang' control, whereby the heating element is controlled only by turning it on or off, shown in the control diagram in Figure 14.

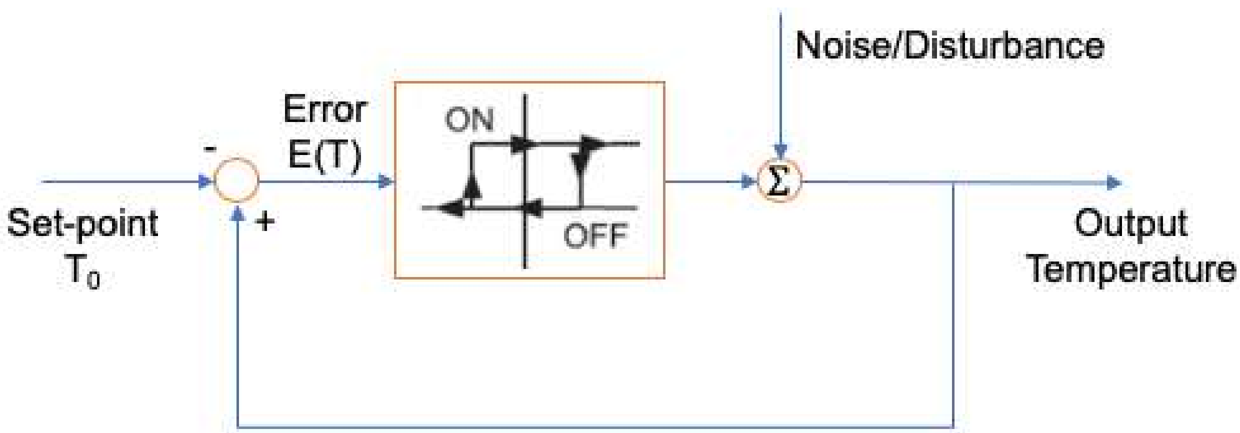


Figure 14: **Control diagram for water temperature.** The error, E(T), which is the difference between the temperature measured by the sensor (output temperature) and the set point temperature, is used to determine whether to turn the controller on or off.

The controller receives temperature feedback through a digital thermometer, DS18B20, which has been sealed inside the water tank using a food-safe, water and heat withstanding adhesive, and mechanically secured outside of the tank, as shown in Figure 15. The adhesive also has a yield tensile strength of 3000

PSI. The sensor is placed in the middle of the tank and protrudes as close to the centre of the tank to ensure an accurate average temperature of the water is taken.

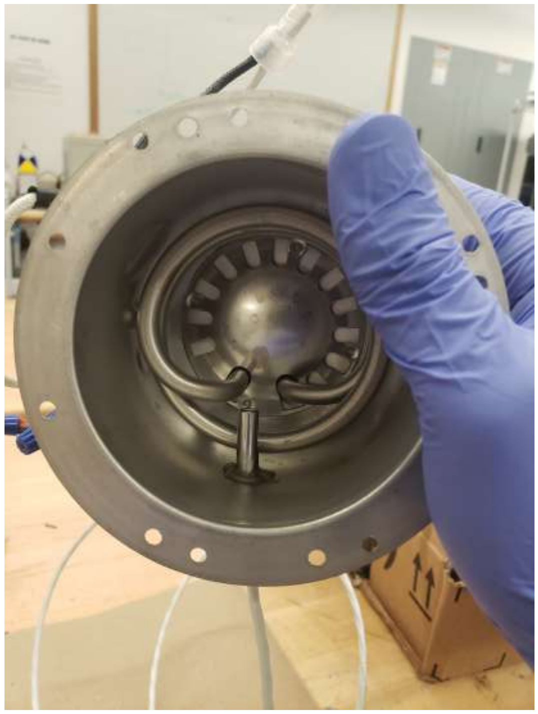


Figure 15: **Image of temperature sensor being glued into the water tank.** The adhesive is food-safe, can withstand temperatures above 100° and has mechanical strength.

4.3.2 Safety Features of Water Tank

Though the controller expects the water temperature to never exceed 100°C, the circuit has been modified to include a thermoswitch, thermal fuse, and the tank itself is connected to earth ground. The thermal switch is an electromechanical device which opens and closes contacts to control the flow of current in response to temperature change, with a threshold for 105°C whereas the thermal fuse would physically break the circuit. Finally, the earth ground helps carry unexpected electrical charges from other sources away safely, especially since the current intake to the circuit can exceed 10A. These components are attached using a Jubilee clip along the circumference of the tank, shown in Figure 16. The tank is securely bolted to the laser cut wooden frame board of the machine.

Figure 16: **Image of thermal switch secured to tank with a Jubilee clip.** The thermal switch, thermal fuse, and ground cable ensure that the user is kept safe in the case of excessive current or heat transfer. The tank is bolted to the machine's laser cut wooden frame board.

4.3.3 Controller

The controller focused on two parameters: temperature tolerance and time. Initially, with a tolerance of ±2% (pink in Figure 17), the issue was that a tight tolerance of 2% cannot be obtained due to the overshoot caused by the remnant heat of the heating element even once it's turned off – since this is the idle temperature, the tolerance was adjusted to take that into account. Furthermore, with just temperature as the variable, the peaks of the pink line asymptotically decrease implying that the frequency of the peaks increases as idle time increases; therefore, the relay switch (and heating element) would need to turn on and off at a very fast pace, damaging the components. With the tolerance increased to ±20% (green line), though the asymptotic behaviour is mitigated, there variation in the peaks would still need to be addressed. Longer testing times may have revealed more information with regards to the variation and decreasing values of the peaks. Finally, the frequency of the peaks also decreased – in Figure 17, the first trough of both lines are aligned showing that the larger tolerance stretches out the time between each heating cycle.

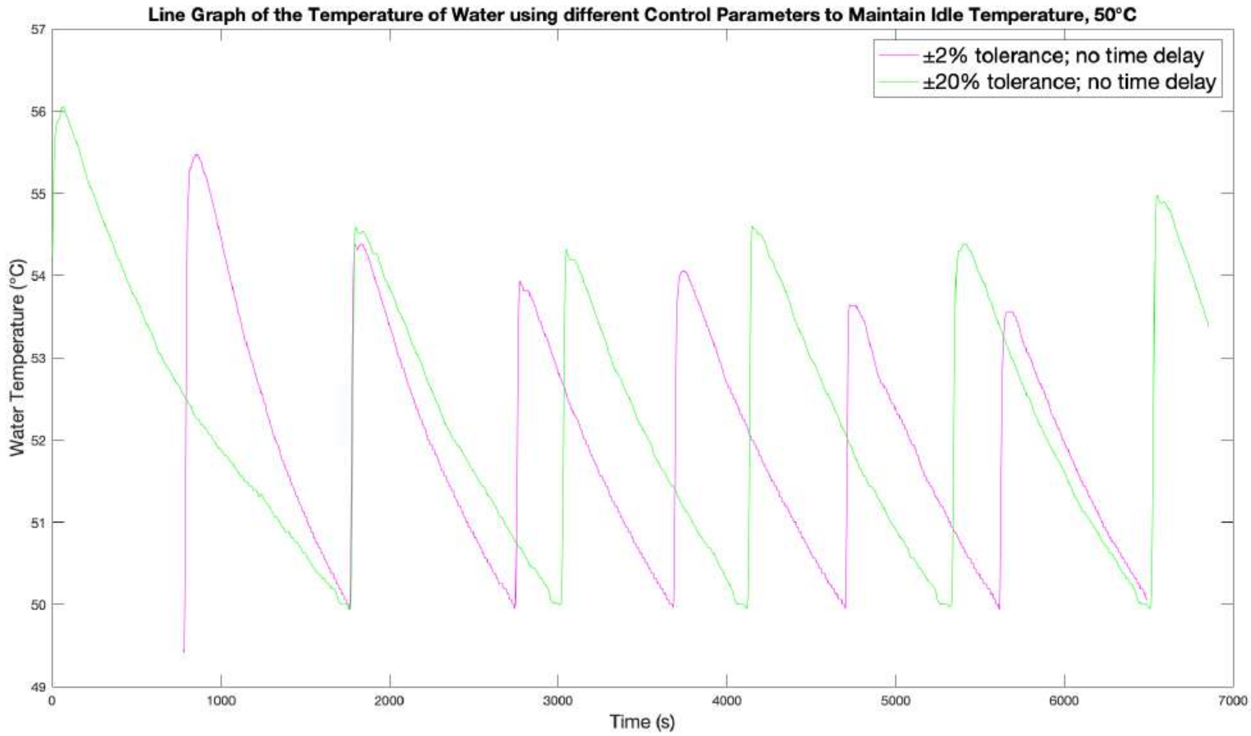


Figure 17: **Line graphs of water temperatures at idle temperature using only temperature as control parameter.** The two tolerances shown in the figure are for ±2% (pink) and ±20% (green). In the 2 hour experiment, the higher tolerance showed less asymptotic behaviour between its peaks and had a longer duration between each peak.

Therefore, by adding a time delay parameter, such that the temperature sensor remains on for two extra seconds after the threshold has been met, can decrease the disparity between these times – an updated control diagram is shown in Figure 18.

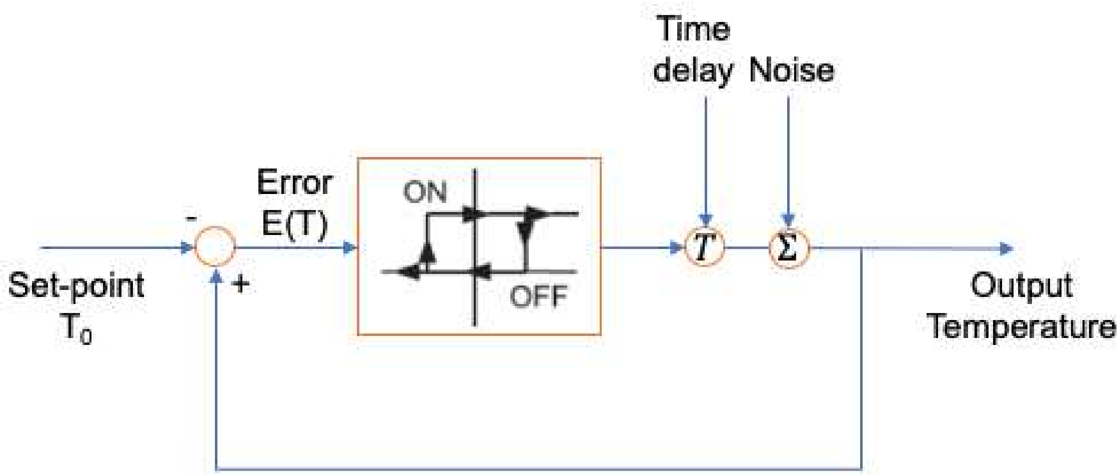


Figure 18: **Updated control diagram for water temperature.** When the conditions from the previous controller is met, the heater remains on for an additional 2 seconds to address the asymptotic behaviour.

In Figure 19, the additional red (±5%) and grey (20%) line highlight the improvement of using a time delay. The initial peaks of the lines vary due to differing start temperatures – a colder water tank would lead to a larger initial overshoot – therefore the lines on the graph have been aligned at their first troughs.

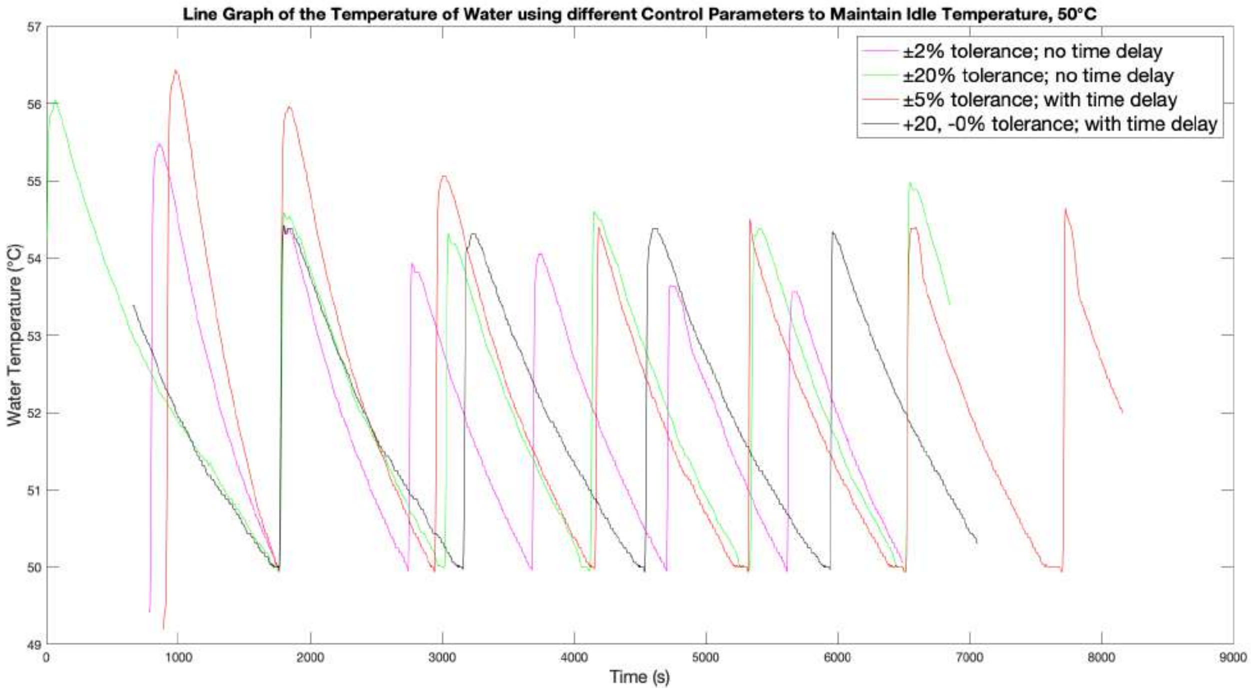


Figure 19: **Line graphs of water temperatures at idle temperature using both temperature and time as control parameters.** The four tolerances shown in the figure are for ±2% (pink), ±20% (green), ±5% (red), and +20%, −0% (grey). In the 2 hour experiments, the higher tolerance, time delayed parameters improved the performance of the controller. The lines have been offset so that the first troughs are aligned.

The line graph itself is difficult to analyse. In Table 2, information on the peaks of each line is written with the exception of the first two peaks of each graph (due to the offshoot explained above). By comparing the time difference between each peak (and taking an average), it is clear from the last row that adding a large tolerance and time parameter in the control allows for a longer duration between when the heating element is triggered. Furthermore, when comparing the difference between the max temperature of each peak (absolute value is used as sometimes the difference may be negative), the lowest difference and standard deviation is also seen by the high tolerance, time delayed controller.

Parameters		Difference of Peak Times		Difference of Peak Temps	
Tolerance	Time delay	**Mean**	**Standard Deviation**	**Absolute Mean**	**Standard Deviation**
$\pm$ 2%	none	972 sec	17.0 sec	0.523	0.310
$\pm$ 20%	none	1187 sec	81.2 sec	0.570	0.301
$\pm$ 5%	2 sec	1180 sec	45.1 sec	0.378	0.274
+20%, −0%	2 sec	1370 sec	23.2 sec	0.0600	0.0351

Table 2: **Table with information on the means and standard deviations of different water heating control parameters.** By comparing these values, a clear improvement can be seen from the +20%, −0%, time delayed controller, with least variance and stable peaks.

When the user requires chai to be made, the water is then heater from its idle temperature to 96°C, per the technical specifications. Figure 20 shows the temperature rising accordingly when a button is pressed at time, $t = 18s$, and takes approximately 90 seconds to heat up, meeting the specification. Though this initial test was conducted to ensure that the specification was met, it should have been repeated multiple times to make sure that they are reliable.

In this test, the heating element is switched off at 90°C as the remnant heat is able to make the temperature rise to 96°C. For the test, the Arduino was programmed to reheat the temperature of the water to 96°C, though this would normally not happen as the water only heats up to the chai temperature once when chai is being made. The Arduino was not able to both trigger the heating element and pump water at the same time, showing that the Arduino cannot conduct two operations, continuously, at once. This posed a problem for the milk heater, discussed in Section 4.5.

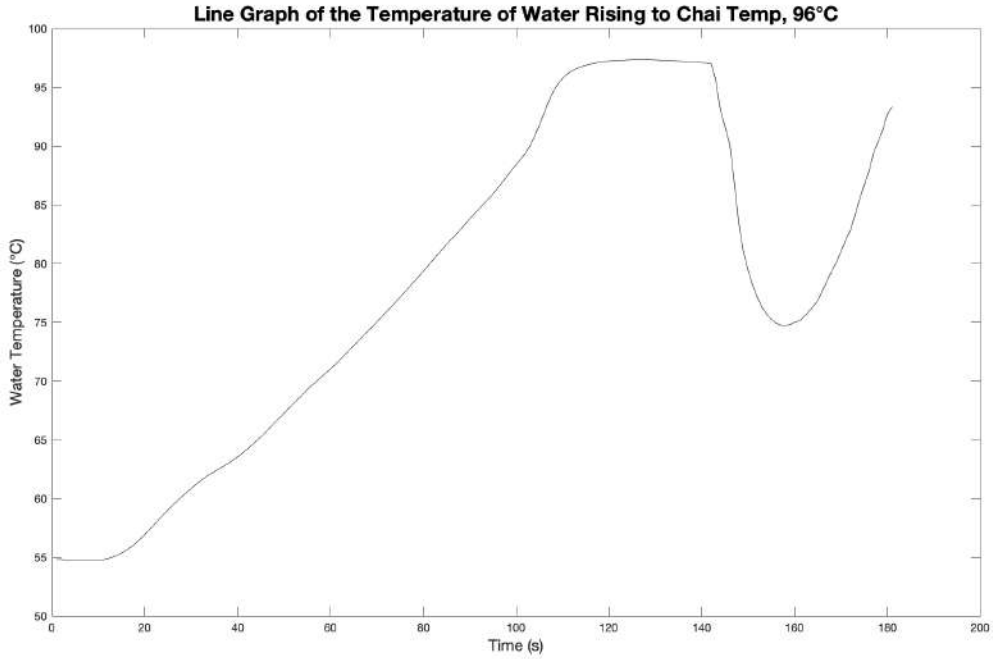


Figure 20: **Line graph of the temperature of water after heating to chai temperature and then pumping 180mL out.** The water is heated up in 90 seconds to the right temperature, meeting the technical specification. The Arduino was programmed in this experiment to reheat the water though normally the water would then return to its idle state.

4.3.4 Pump

The pump selected for this machine is also re-purposed from a Keurig. There are a number of reasons for this: the pump did not need to handle hot water, therefore eliminating that requirement; the compatibility of the size tubing from the reservoir and the water tank; and the flow rate, see Table 3, allowing for the timely transfer of the water, as per the specification.

The pump is voltage controlled, rated at 12V. As the Arduino cannot and does not need to drive this level of voltage, the IRLZ14 NPN MOSFET (see Appendix E) is used that has a gate to source trigger voltage of less than 5V, i.e. the maximum output of the Arduino. The circuit diagram for this is shown in Figure 21.

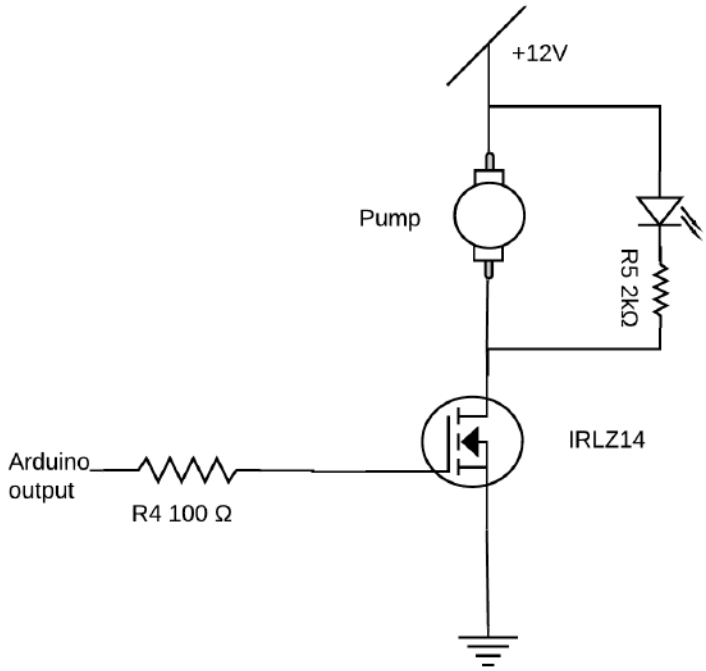


Figure 21: **Schematic of the pump control.** The pump is driven by an external voltage source that is controlled by the IRLZ14 using the Arduino. A red LED (YSL-R531R3D-D2) is also attached to the circuit as a visible verification method for the circuit.

The flow rate was determined by pumping cold water for 12 seconds into a jar on a scale 20 times since 1 gram of water equals 1 mL. The flow rate was determined to be 11.9 mL s^{-1}. Therefore, the time for pumping 180 mL is t = 15.1 s. However, the volume of water when testing with hot water did not correspond to 180mL, showing that the flow rate is affected by temperature..

The test was conducted again with hot water and the results are in Table 3. The hot water in the experiment is when the temperature is set to the chai temperature, 96°C, and the cold water is room temperature, approximately 16°C.

	Water Temp	**Mean** (mL)	**Standard Deviation** (mL)
1	room temp (16°C)	140	0.2
1	chai temp (93°C)	177	4.0
2		178	5.4

Table 3: **Data from water pumped out of the water tank.** In each experiment, the water was pumped for 12 seconds and its mass (ergo volume) was measured 20 times.

The flow rate is therefore 14.9mL s^{-1}. The results show that the amount of water pumped, in account to the standard deviation, fit within the tolerance of the amount of water required. There is a significantly larger standard deviation with the hot water than with the cold. From observation, when the water reached boiling temperatures, a few millilitres of water would drop into the container. A possible solution would be to add a pressure valve, ensuring that the water leaving the tube is only due to the pressure formed by the pump while also ensuring that the pressure can be maintained by the pump (possibly alterning the flow rate) and the water tank (causing it to explode), see Section 5.

Water Storage and Electrodes for Water Sensing

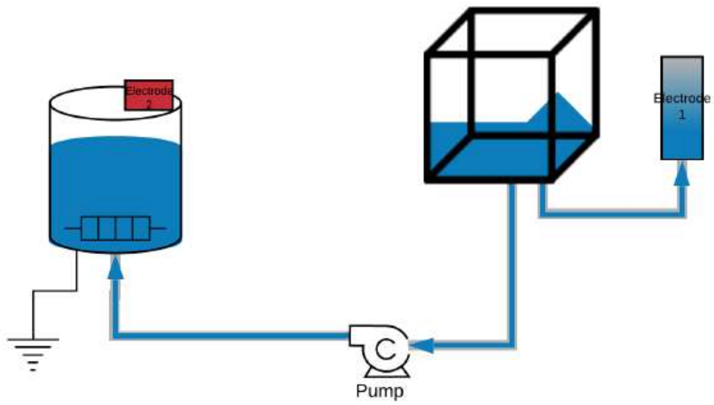
The machine stores water in a 2L removable reservoir, which was reconfigured from a used Keurig. This is as the reservoir comes with a stand and valve at the bottom, making sure that water does not leak. The valve attached to two tubes, one to the pump and the other to electrodes that sense the presence of water. Figure 22(a) show the reservoir on its stand and the water sensing electrodes taped upright to the side of the device.

(a) (b)

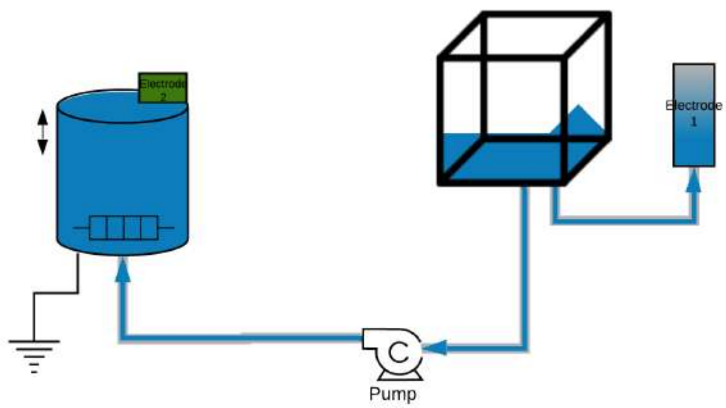
Figure 22: **Images of (a) the water reservoir and its volume-checking electrodes and (b) cable at the top of the tank soldered to the electrode inside the tank.** The electrode in (a) is aligned vertically so that the water can only reach them if the reservoir has 200mL in it, detecting a high signal, an error is presented otherwise (prompting the user to fill up the reservoir). The electrode in (b) detects if water has reached the top of the tank, detecting a low signal, otherwise the pump is triggered until the tank is full.

The machine needs to verify that there is water in two places: in the reservoir and the top of the tank. The former ensures that there is enough water to pump out the required amount of water to make chai, 180mL. The latter is to ensure that when 180mL of cold water is pumped in, 180mL of hot water is displaced out since if the tank is not full to the top, no water will be displaced until that point has been reached, see

Figure 23. If there is not enough water in the reservoir or the reservoir in not attached, the electrode will not detect a signal, thus prompting an error. If there is not enough water in the tank – which would typically only be when the machine is first set up (since the tank would be empty) or if the machine has not been used in a significantly long time for water to evaporate through the tube – the pump is triggered until the tank is full.



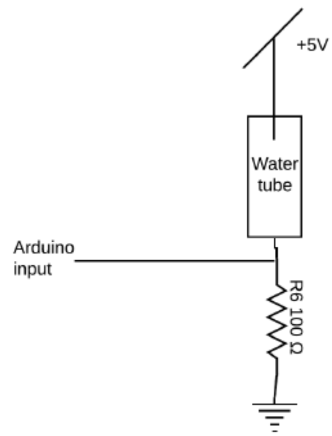
(a)



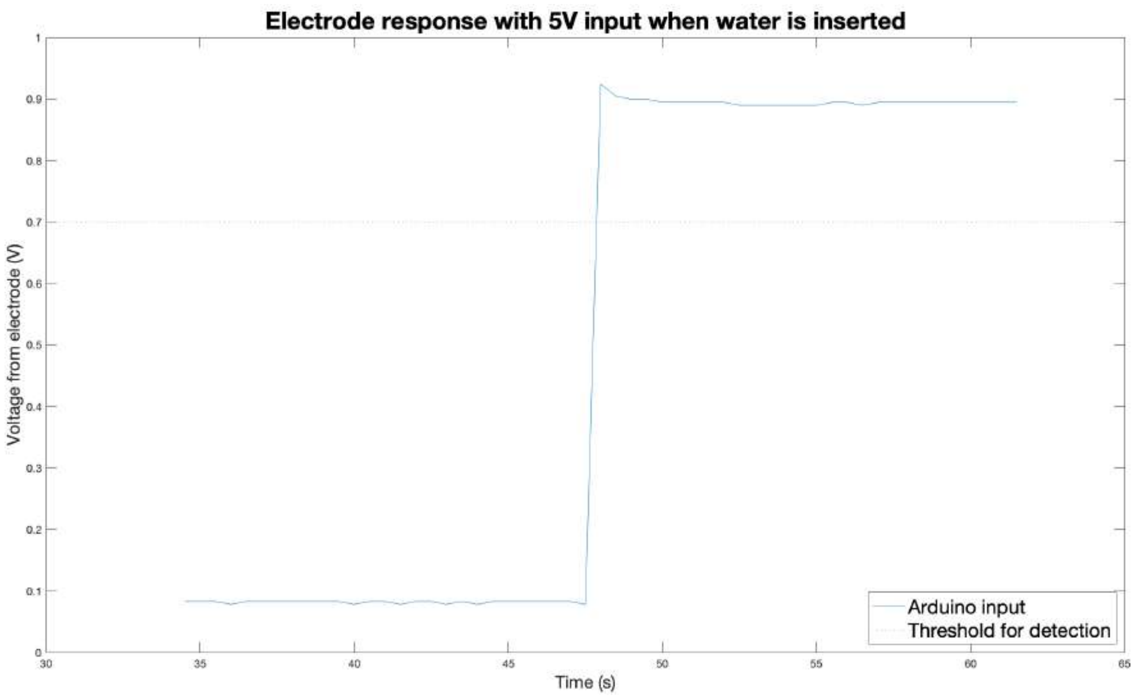
(b)

Figure 23: **Illustrations of (a) not enough water for electrode 2 to be triggered, therefore (b) the pump transfers more cold water until the tank has been filled.**

The reservoir electrode is active high. As shown in the schematic in Figure 24(a), the red cable in Figure 22(a) is attached to 5V and the blue cable is attached to the Arduino and ground. When water is present, the connection is shorted, allowing the Arduino to detect a signal, shown in Figure 24(b).



(a)



(b)

Figure 24: **(a) Schematic of the reservoir electrodes and (b) graph of the voltage output from the electrodes before and after water is in contact from the reservoir.** The dotted line represents the threshold that needs to be met in order to avoid false readings.

The water tank electrode is active low. The tank itself, as explained in Section 4.3.2, is connected to earth ground; when water fills the tank up, the Arduino would read 0V. Hence, the default reading into the Arduino is 5V. No data was attained for this due to lack of time. To test this, water would have been removed from the water tank to trigger the code that checks for this and a script to collect serial data would be run on MATLAB.

```
DEFINE ElectrodeReading A2
DEFINE PUMPDRIVER 47
while ElectrodeReading >= 4V:
   PUMPDRIVER output = HIGH
PUMPDRIVER output = LOW
```

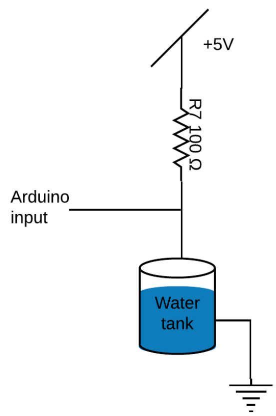


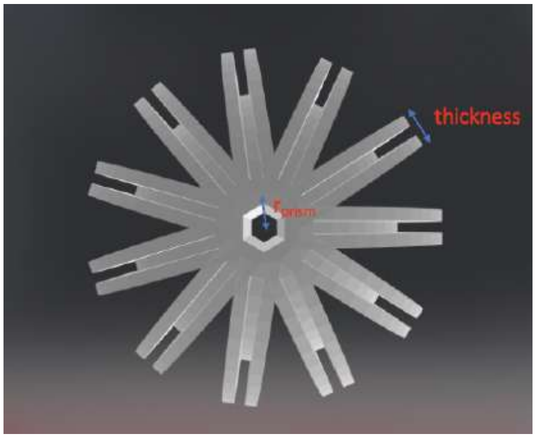
Figure 25: **Schematic of the electrode attached to the water tank.** This electrode is active low since the water tank is already earth grounder. The default input to the Arduino is 5V.

4.4 Ingredient Dispenser

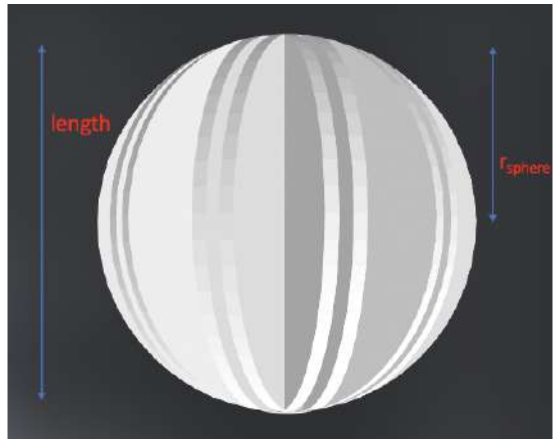
The design of the dispenser takes into account: dispensing ingredients with the tight tolerances, provided in Section 2.3; sealing the ingredients away from steam entering the dispenser; and the ability for the user to store a large quantity of the ingredients inside the machine avoiding the user from having to replenish them frequently.

4.4.1 Dispenser Design

The dispenser, as shown in Figure 26, is a sphere with segment that has the volume (ergo mass) required for each individual ingredient. This also allows the strength of the chai to be increased by allowing multiple rotations of the same ingredient – see Section 5. The following calculation generalises the approximate number of segments each sphere would need – both the mass and density of the ingredient are required for this calculation. Figure 26 provides the labels used in the calculations.



(a)



(b)

Figure 26: **A (a) top and (b) front view of the rotator.** The thickness of the edge of the spokes and the number of spokes determine the amount of each ingredient being dispensed. The gap in between each spoke is to fit silicone, which acts as a seal.

$$N = \frac{V_{sphere} - N(V_{segment} - V_{\text{double counted bottom}}) - V_{prism}}{V_{ingredient}}$$

$$N = \frac{V_{sphere} - V_{prism}}{V_{ingredient} + (V_{segment} - V_{\text{double counted bottom}})}$$

$$N = \frac{[\frac{4}{3}\pi r_{sphere}^3] - [length \pi r_{prism}^2]}{\frac{m_{ingredient}}{\rho_{ingredient}} + ([thickness \cdot \frac{1}{2}\pi r_{segment}] - [height \cdot thickness \cdot length])}$$

Some measurements in these calculations are kept constant, for example, the radius of the PVC pipe is 9.53mm (0.375 inch), therefore:

$$N = \frac{[\frac{4}{3} \cdot \pi \cdot (25.4mm)^3] - [(50.8mm \cdot \pi \cdot (4mm)^2]}{\frac{m_{ingredient}}{\rho_{ingredient}} + ([thickness \cdot \frac{1}{2}\pi(25.4mm)^2] - [25.4mm \cdot thickness \cdot 50.8mm])}$$

The density of each ingredient was then calculated (the method is listed in Appendix D.2) and the final size for each dispenser is listed in Table 4.

Ingredient	**Density** (g mm^{-3})	**Spoke Thickness** (mm)	$\mathbf{N}_{calculated}$	$\mathbf{N}_{final}$	**Actual Mass Dispensed** (g)
Sugar	1.59×10^{-3}	3.81	5.05	5	7.52
Tea Leaves	4.77×10^{-6}	6.10	0.14	4*	0.28
Cardamom	4.70×10^{-4}	5.08	10.58	10	1.18
Fennel Seeds	5.35×10^{-4}	4.83	11.44	11	1.07

Table 4: **Calculations for the number of spokes required for each ingredient.** The spoke number calculated is not an integer therefore by rounding N, the approximate actual mass dispensed is calculated. These masses remain within the tolerances specified in Section 2.3.

Table 4 lists N=0.14 for the tea leaves as the density of the leaves is two to three orders of magnitude smaller than the other ingredients. Therefore, a 4 spoked dispenser is designed as this is the minimum number of spokes required for the dispenser to form a seal within the PVC pipe.

The spokes were then fitted with semicircular silicone using the residual food-safe adhesive from the water heater (see Section 4.3.1).

4.4.2 Dispenser Design Changes

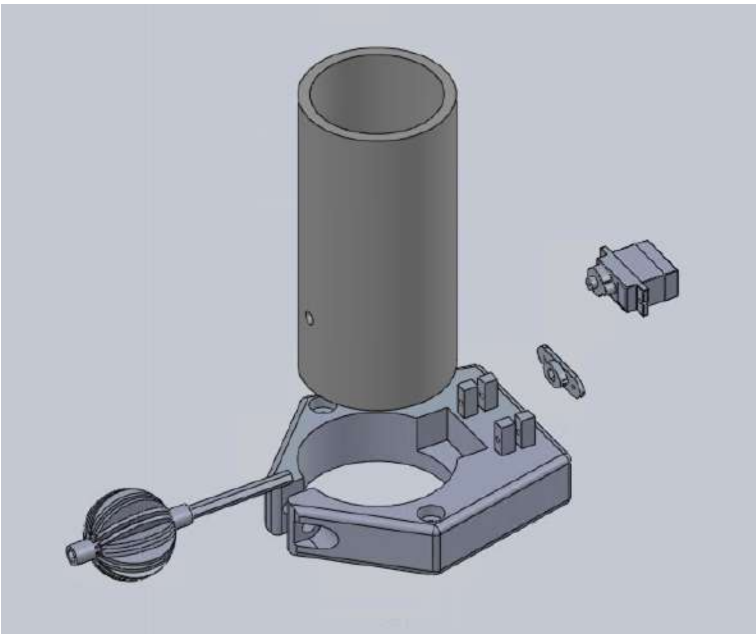
When initially designed, the dispenser's radius was as close to the radius of the pipe, as shown in Figure 28(a), accounting for residual differences due to the 3D printer. As the silicone, however, had little space to flex, it generated a lot of friction against the pipe and did not move. The radius of the spokes was reconsidered to be approximately two thirds their original length, giving more surface area to the silicone sheets while retaining a seal that does not allow steam in or ingredients out when the dispenser is not being rotated.

(a)

(b)

Figure 27: **An (a) inside view of the original dispenser (without the silicone attachments) and (b) the evolved final dispenser (far right).** The larger silicone flaps allow a seal to be maintained without causing friction with the pipe.

The spherical dispenser has an extruded cut for a hex rod to force fit through it (once it is placed inside the pipe) and connect to the servo with a 3D printed hex rod attachment. The servo is secured to the pipe using a 3D printed, CAD designed, clamp, as shown in Figure 28. The pipe and hex rod were bought cut to size.



(a)

(b)

Figure 28: **(a) Blown view of the SolidWorks designed ingredient dispensing subsystem, the bolts are not shown. (b) Image of the final fennel seed dispenser.** The dispenser, clamp, and servo attachment were 3D printed using food safe PLA.

4.4.3 Results

Tests were conducted to collect data on the accuracy of the dispensers in order to make sure that the specifications were met. Due to time constraints, the sugar dispenser was not tested. Each dispenser was placed above a digital weighing scale and was programmed to spin at a specific angle repeatedly, with a delay between each rotation to give time to record the mass, in order to take 20 readings. The continuous servo (SM-4303R – see Appendix E) provided enough torque to spin the dispenser however cannot be programmed to rotate at a specific angle, rather a specific time. The rotation speed is $\frac{60}{54} = 1.11$ rounds per second.

The angle of the rotation was originally predetermined as each dispenser would dispense exactly the amount in the segment. For example, as listed in Table 4, the cardamom dispenser has N= $10 spokes$, therefore its angle should be $\frac{360}{10} = 36°$; however, this was not the case.

The cardamom dispenser has 10 spokes, therefore a rotation angle of $\theta_c = \frac{360}{10} = 36°$ was applied. Figure 29 shows the results for the cardamom. A 36° rotation resulted in a range of masses, between 0g and 2g, to be dispensed. The mean for this test was 0g as the success rate, i.e. the percentage of times that a non-zero mass was dispensed, was 40%. Decreasing the angle to 30° decreased the range by half, increased the mean (though not within the tolerances in the technical specifications). Furthermore, the yield rate increased to 67%. Through observation it was discovered that since the dispenser rotates in one direction, the fine cardamom clumps together on one side of the pipe. This means that more force is required from the servo to rotate and that the density of the cardamom increases as it is being squashed together on one side. The solution to this is to have the servo jerk backwards, allowing the cardamom to redistribute in the pipe, shown in Figure 30. Though this increased the range again, the mean and the interquartile range fell within the tolerance listed in Section 2.3.

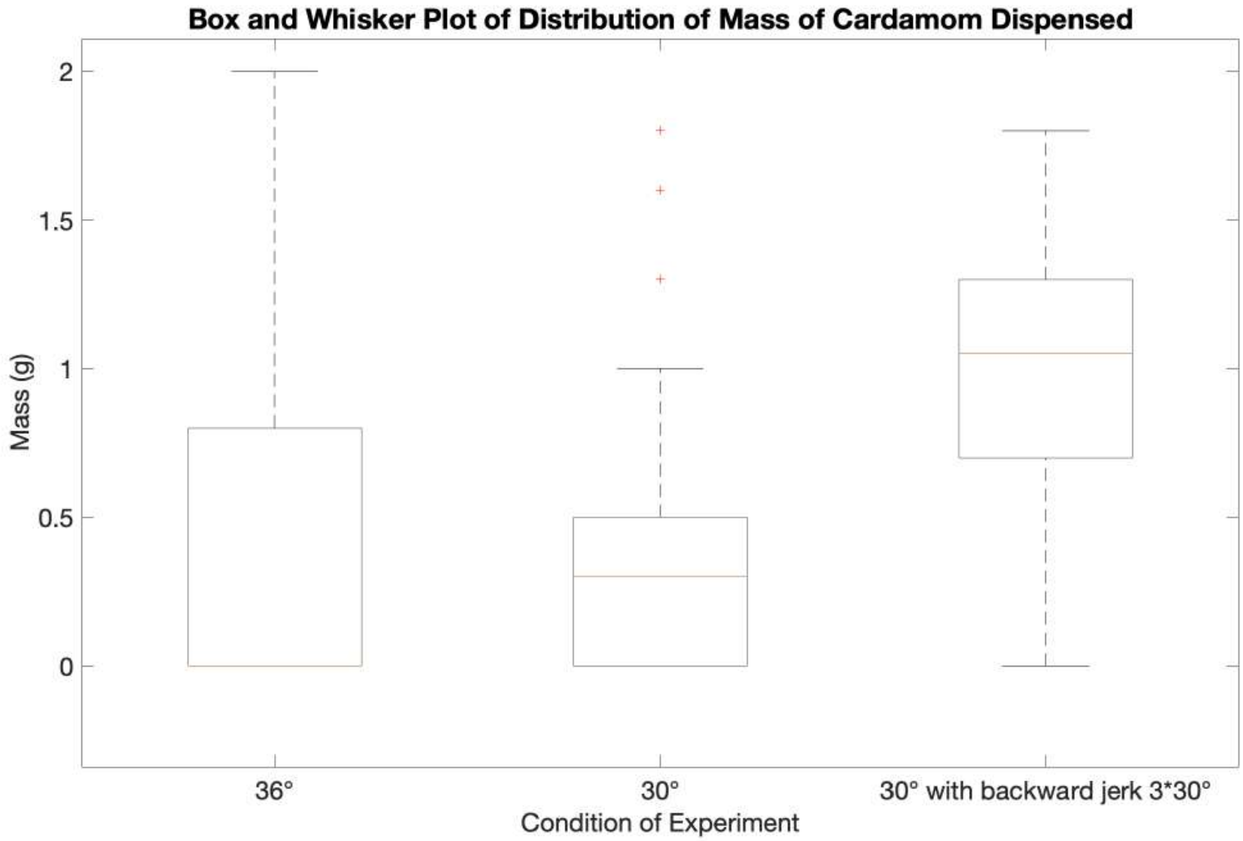


Figure 29: **Box plot of the mass distribution from the cardamom dispenser.** Decreasing the angle of rotation decreased the 0 yield rate of the dispenser and adding a jerk motion brought the mean and interquartile range within the tolerance for making chai.

Figure 30: **Screen capture of video during one of mass tests showing uneven distribution of cardamom.** The constant rotation of the dispenser in one direction leads the cardamom to become unevenly distributed, seen on the left side of the pipe.

The fennel seed dispenser has 11 spokes, therefore each spoke has an angular displacement of approximately $\theta_f = \frac{360}{11} \approx 33°$. Due to the experience with the cardamom dispenser, a larger angle, 60°, was tested first. The range was just above 2g and, though the mean was close to 0g, the success rate was 78%. Decreasing the angle to 45° increased the success rate to 88% and brought the range closer, though the mass yield from each rotation remain low. Finally, with a 36°, the range once again increased but the yield rate became 100%, with no rotation resulting in a 0 yield and the mean moved closer to the desired level of 1g. Unlike cardamom, which is finer and can 'clump' together, the fennel seeds (with its higher density) could not be jerked back to redistribute; however, adding a 30° tilt to the pipe itself allowed the seeds' weight to redistribute the fennel seeds. This test was done by holding the dispenser as shown in Figure 32 – a vertical sheet marked 30° is not shown in the image. The success rate remained 100% with the tilt and tightened the range of the mass dispensed but brought the mean to 1.3g, missing the specification by being above the upper tolerance of 1.2g. Reducing the rotation angle further to 33° would have improved this as 36° angle may have caused excess fennel seeds to dispense.

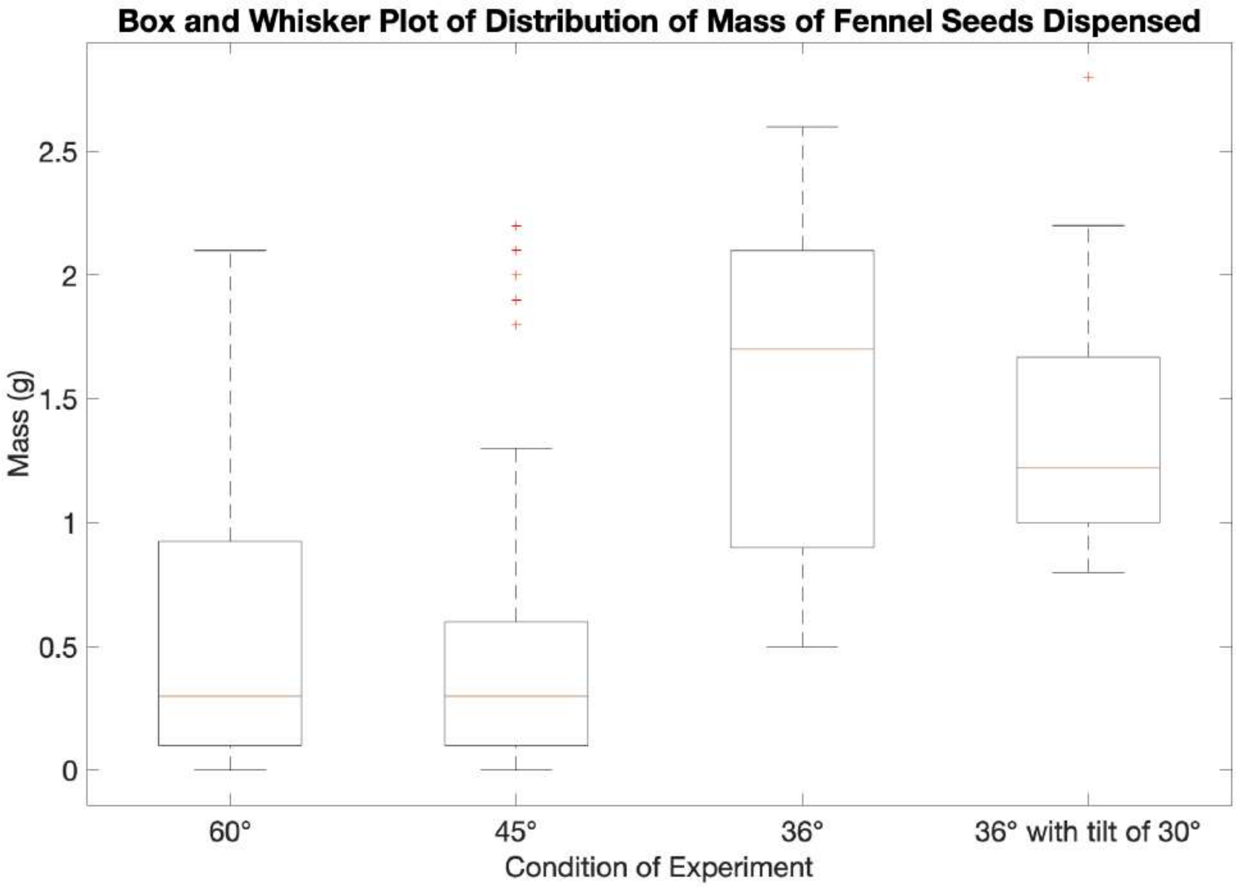


Figure 31: **Box plot of the mass distribution from the fennel seed dispenser.** The increased mean with changing the angle highlights a decrease in the number of 0 yields; adding a tilt to the dispenser itself allow the seeds to redistribute, therefore decreasing the variation in the results – both of which bring the mean dispensed ingredient to within the range for the technical specifications.

Figure 32: **Image reenacting how the fennel seed test with 30° tilt occurred.** In the actual test, a vertical sheet was placed behind the pipe marked with a 30° angle to ensure. Note: the dispenser shown in the image is filled with cardamom, the test did occur with fennel seeds.

A modified, angled clamp was designed for the fennel seed dispenser so that the pipe does not interfere with the rest of the dispensers, as shown in Figure 33. The hole for the hex rod would remain in the centre of the clamp so that the servo is attached in the same position. This was not 3D printed or implemented due to time restrictions.

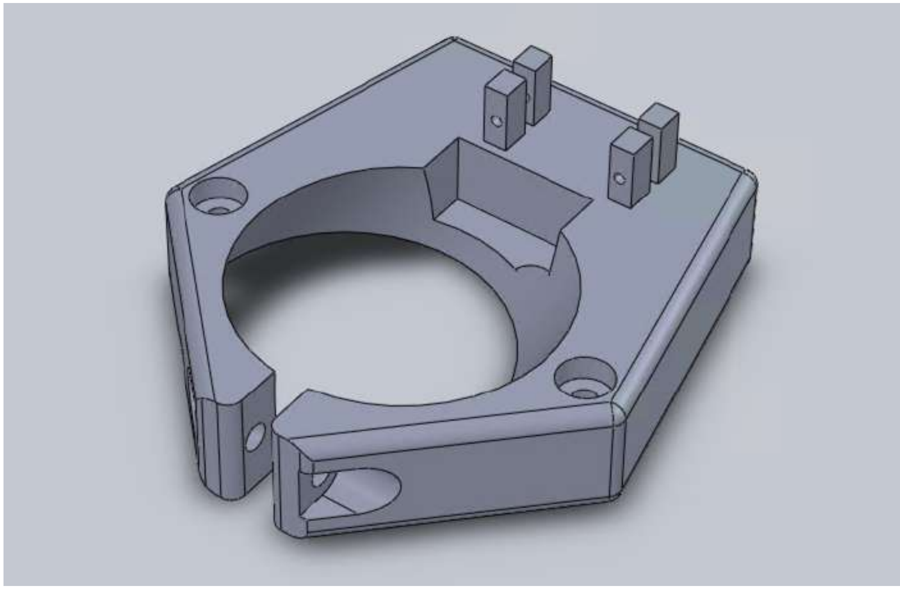


Figure 33: **SolidWorks model of the modified clamp.** The pipe would slide in at a 30° angle while still meeting its centre hole (for the hex rod and servo) at the centre of the clamp.

The tea dispenser, as listed in Table 4, has 4 spokes, giving a rotation angle of 90°. This angle corresponds to 0.28g of tea leaves being dispensed, therefore the dispenser is triggered $\frac{2}{0.28} \approx 7$ times, equivalent to 630° or 1.75 rotations. The results for different angles of the tea do not indicate success for the technical specification. Since the tea dispenser relies more on number of rotations rather than changing the angle of rotation, changing the angle did not greatly improve the results. The success rates were all 100% as the dispenser rotated multiple times for each test. The 90° test highlights the vast spread of the dispenser due to leakage of leaves in between each rotation, giving certain rotation up to 6 grams of tea and leaving others with nothing to dispense. Reducing the angle to 72° did not significantly alter the results. Increasing the angle to 100° did increase the mean, yet failed to address the spread of the results and meeting the technical specification of 2 ± 0.4g of tea leaves.

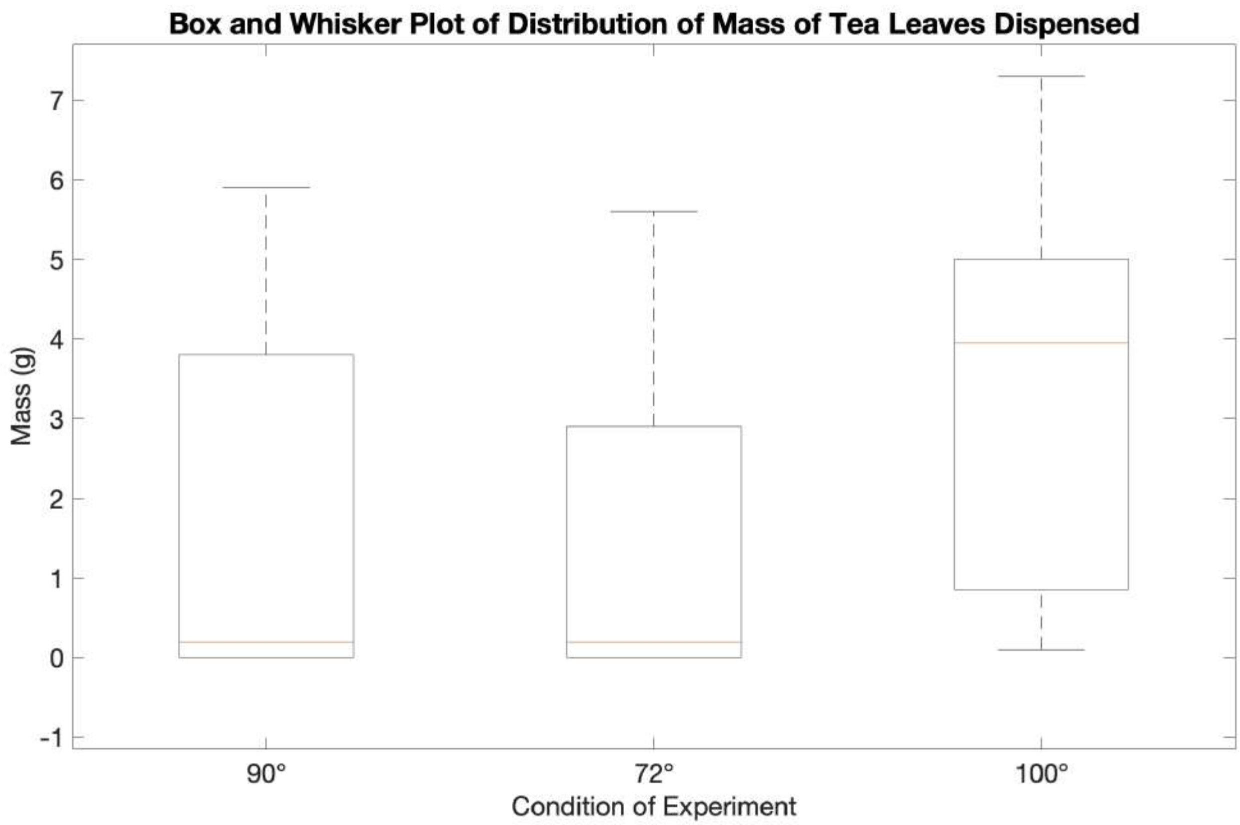
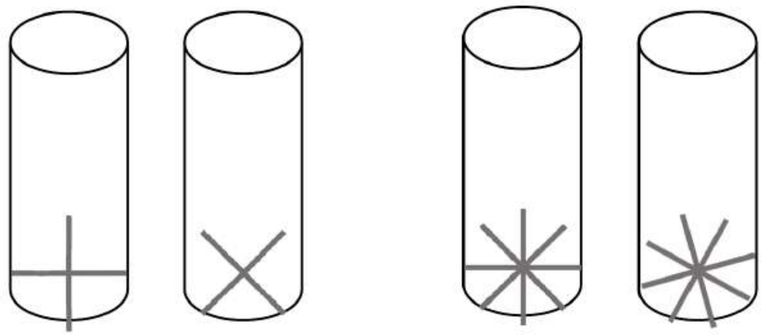


Figure 34: **Box plot of the mass distribution from the tea dispenser.** The angles should be multiplied by 7 to correspond to the total angle of rotation. The plot shows a significant variation in all three of the results due to the leakage problem as well as a large proportion of 0 yields, when nothing is dispensed on a rotation.

The problem, as observed from the initial test with 90°, is the leakage of ingredients due to the 4 spoke design. As illustrated in Figure35(a), between each rotation, leaves would be able to leak, altering the mass and increasing the variance of the results. In future iterations, by doubling the number of spokes, the dispenser still only need to rotate 1.75 revolutions, though without leakage.



(a) (b)

Figure 35: **(a) Illustration of tea leaves dispenser with 4 spokes and (b) a dispenser with 8 spokes at initial position and when rotated** $45°$**.** The 4 spoked dispenser leaves gaps on both sides between each rotation, whereas the 8 spoke dispenser always has a spoke sealing the edge.

The dispensers were then bolted onto the machine's laser cut frame board, shown in Figure 36. The funnel was not built for the prototype due to time constraints.

Figure 36: **The tea leaves, sugar, cardamom, and fennel seed dispensers attached to the frame of the machine.** The 3D printed clamps have bolt holes and counter sinks, which align with the laser cut board. The funnel was not built due to time constraints.

4.5 Milk Heater

4.5.1 Heater Selection

As the user inserts the milk in a carafe into the machine it needs to be safe for the user to handle. A traditional immersion heating element can reach hundreds of degrees, deeming unsafe for a user to be exposed to it and burning the milk. Milk is a complex mixture of water, fats, and proteins; with a heating element, the fats and proteins will separate out from the water when heated, and form a layer on top. This layer prevents the water from evaporating and the continued heat causes compounds to stick to the bottom. An induction heater, which only transfers heat to an inductive plate – in this case, a 4 inch stainless steel, 480mL saucepan – is used instead.[14] Typical induction heaters available on Amazon are equipped with fans to make sure that the base plate does not heat up significantly enough to burn the user and can recognise if the pan is removed from the heater, flagging an error.[15, 16]

Initially, AmazonBasics 1800W induction cook top was selected for its size (its length being 33cm – below the 50cm technical specification), power output, and compatibility with the 4 inch carafe. The cook top was tested to make sure that the milk heats up within the time specified by the technical specifications, which it does, graphed in Figure 37. Approximately 100mL is added to the carafe, placed on the cook top and the cook top is powered to its maximum "power" setting of 1200. The temperature data was collected using a infrared sensor at a rate of 1 per second. The variation in the data is attributed to the this, which would have been improved on by using an immersed thermocouple sensor, like the tests conducted for the water heater.

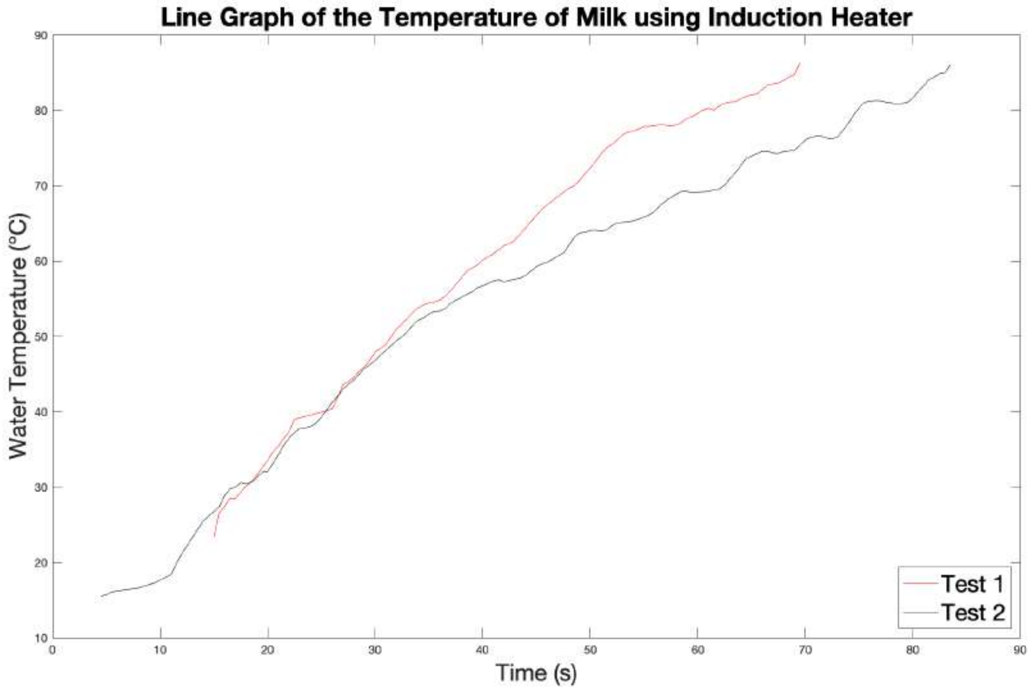
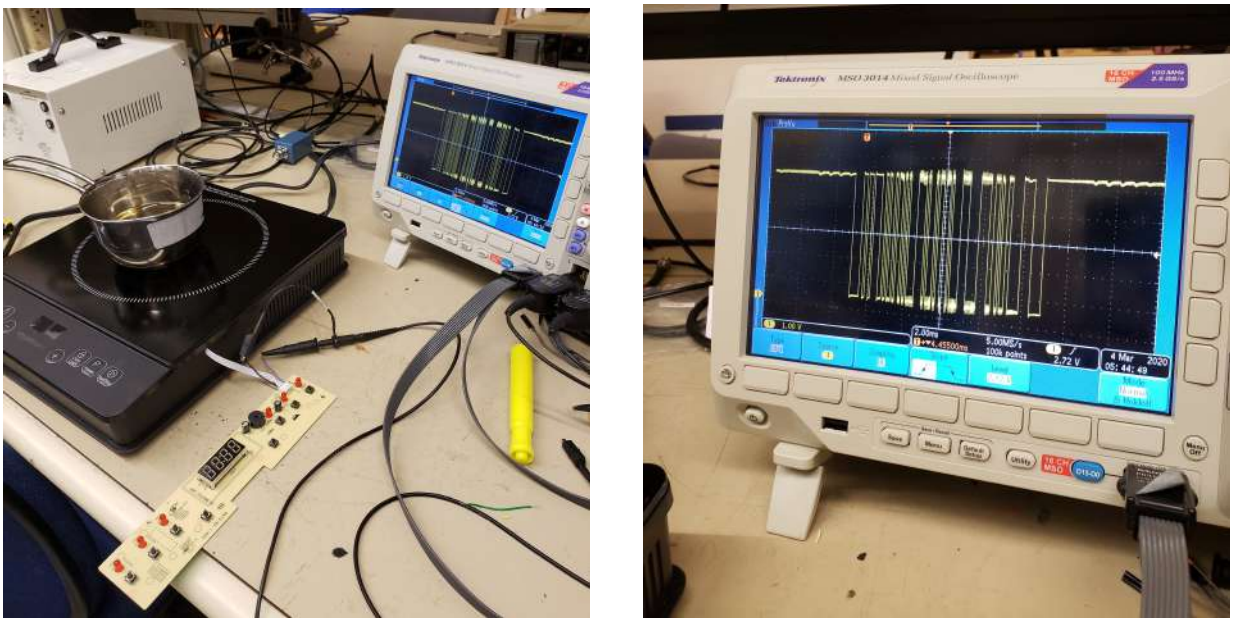


Figure 37: **Line graphs of the temperature of milk over time using the "1200 power" setting on the induction heater.** Test 1 is offset to align its initial temperature with Test 2. The noise in the data is attributed to the positioning of the infrared temperature sensor used to take recordings.

Both tests in Figure 37 do conclude that the milk can be heated to 80° within the time frame indicated in the recipe and technical specifications.

4.5.2 Controlling Induction Heater

The AmazonBasics cook top is fitted with two control circuits: the user interface with pushbuttons and a digital number display, and an internal controller. Since there are internal controls for sensing the presence of a saucepan on the cook top and for temperature, the Arduino was programmed to replicate the code sent to the internal controller using the interface's asynchronous transmit and receive protocol – this needs to be decoded first. The user interface controller, viewed in Figure 38(a), is connected to a 2000W power isolation transformer as the cook top is not earth grounded, which could cause a short due to the potential difference between the floating ground of the induction heater and the earth ground of the oscilloscope.



(a) (b)

Figure 38: **Images of (a) the user interface controller connected to the oscilloscope and (b) bits read from the TX pin of the controller.** The cook top does not have an earth ground cable hence it is plugged in through a 2000W power isolation transformer (grey box in top left) to avoid it from shorting. The bits are continuously sent in a loop at a baud rate of 9600 bits per second.

The oscilloscope, as shown in Figure 38(b), was set to trigger on the first rising edge of the signal, which is otherwise displayed to loop itself. Each bit is has a time width of 104μs and each signal is comprised of 100 bits, giving a time cycle of 10.4ms. The signal is comprised of 10 bytes, with each byte having a start bit, 0, and stop bit, 1, address. By pressing the following sequence of buttons, the induction heater enters its maximum power output capability and then it's minimum power output:

- 'Start/Stop'
- 'Temp.'
  - Max power output
- '−' five times
  - Min power output

The TX readings do not correspond each button press in the same sequence. For example, if the temperature setting is turned down by pressing '−,' from 400°F to 300°F, the signal transmitted will remain the same until the temperature of the carafe has reached 300°, at which point the induction heater would switch off or enter an intermediate heat state. This means that the induction heater is not continuously varying its temperature, rather following a 3 tier hysteresis control. The following states, relevant to the sequence above, are transmitted by the controller:

- Off
  - When the controller is plugged in
- Standby
  - When the 'Start/Stop' button is pressed

- Induction heater on
  - When the 'Temp.' button is initially pressed, entering the highest temperature setting
  - When the temperature of the base plate falls below the temperature displayed on the digital number display
- Induction heater off
  - When the temperature of the base plate exceeds the temperature displayed on the digital number display
- Induction heater intermediate on
  - Assumed to be when the temperature of the base plate is within a tolerance of the temperature displayed on the digital number

See Appendix D.4 for the signals for each state and their decoded hex values.

The Arduino is able to transmit asynchronous 8-bit signals, defaulting with a 0 start bit and 1 end bit; however, the Arduino does so by sending them right to left rather than left to right. For example, 0x0A corresponds to 00001010 but on an oscilloscope, the Arduino's output would be 01010000. Figure 39 represents the altered binary bytes in decimal.

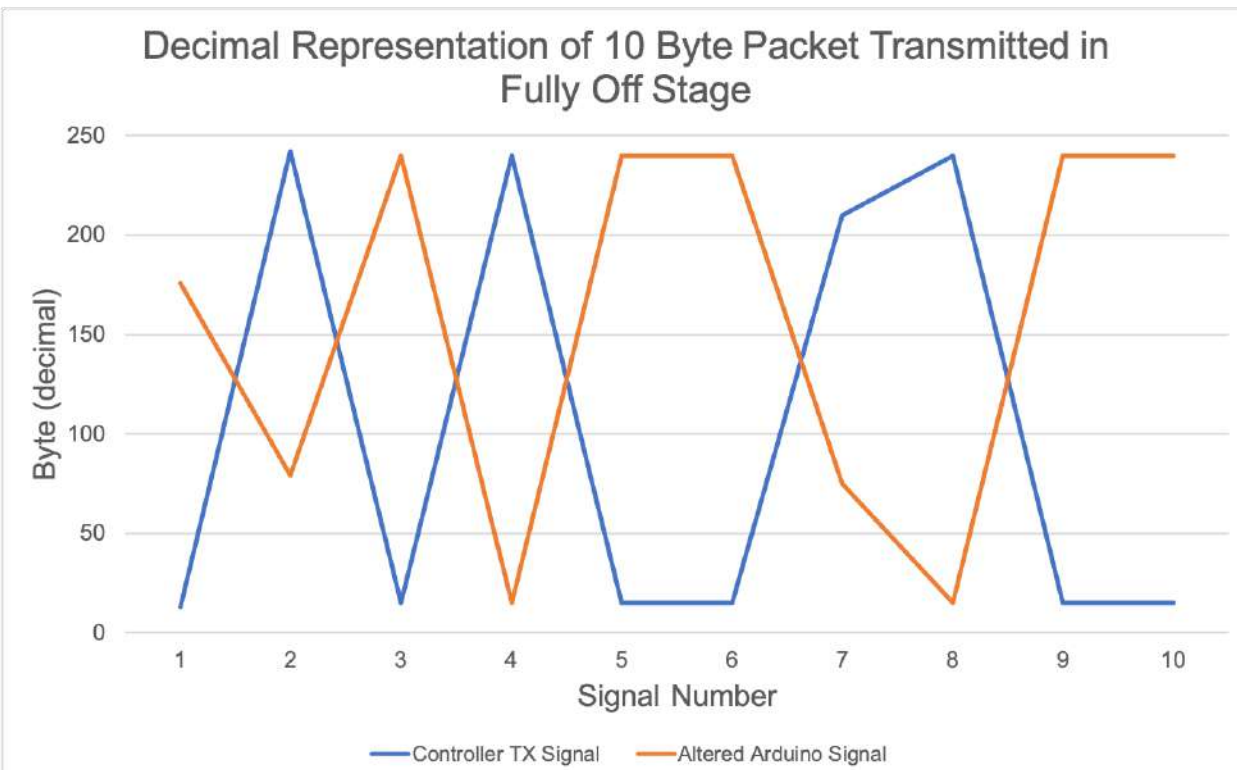


Figure 39: **Graph of the bytes (in decimal) transmitted by the original controller (blue) and by the altered code sent by the Arduino (orange).** The 10 bytes of code are sent in 10.4ms.

These signals would then be used in alignment with the times from the tests shown in Figure 37 to determine how much and how long the milk should be heated. Should time restrictions not have been an impedance, the following tests would have been carried out to conclude the milk heater subsystem: while timing the entire process, using the induction heater, the milk would have been brought to its boiling point, triggering the intermediate on state; the ingredients would have been inserted into the carafe, followed by the water. The concoction would be monitored to determine if the intermediate on state is able to provide sufficient heat or if the fully on/off state need to be triggered.

4.5.3 Determining Presence of Carafe

When the user presses the button to make chai, the machine has to verify if the carafe has been placed in the machine. Data was also collected from the RX pin of the user interface controller as when nothing is placed on the base plate an error, 'E1', is displayed. The bits fluctuated very rapidly, not allowing the oscilloscope to latch onto the signal, thus there is no data to determine the code that would be displayed when the saucepan is not placed onto the plate. Alternate methods for verifying this as well as checking if the carafe has milk inside it are discussed in Section 6.

5 Final Prototype and Conclusions

This senior design project presents The Perfect Chai Maker that was concluded three weeks early due to complications related to the COVID-19 pandemic. As a result, much of the verification stage for the final subsystem and the integration stage were not completed, seen in Figure 40.

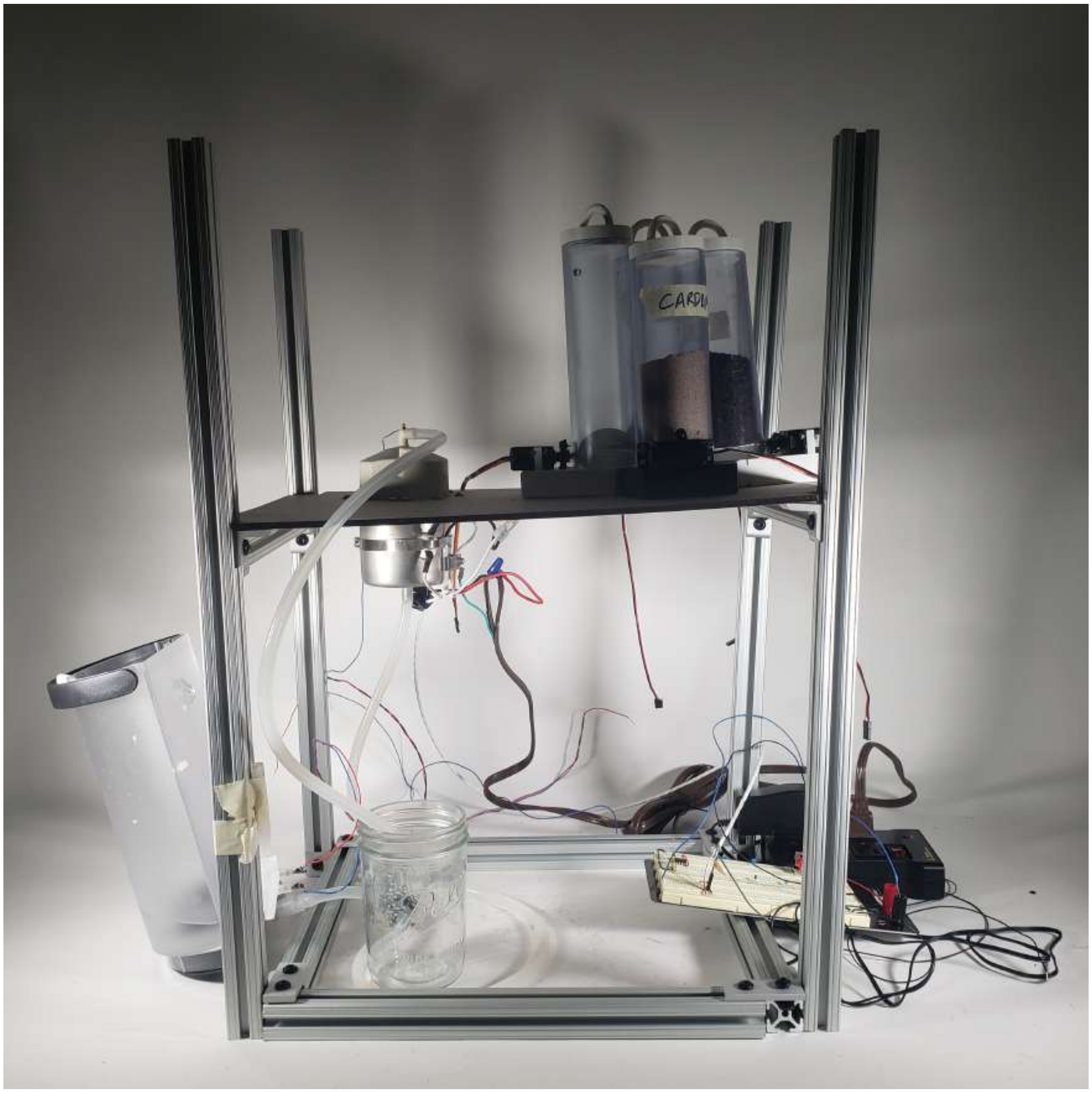


Figure 40: **Final prototype of The Perfect Chai Maker.** The image is missing the induction heater, Arduino, and carafe, and the servo wires are disconnected since the Arduino was removed.

To analyse the performance of each independently working subsystem, the technical specifications are revisited in Table 5. The attained (or average, if applicable) value and their tolerances (standard deviations) are listen. If the attained value is within the tolerance of the target value, it is marked green; if the value was not tested but predictably could have been attained, it is marked orange; if the test failed to achieve the target value, it is red.

Specification	Target Value	Tolerance	Attained Value	Attained Tolerance	Units
Process					
Time to make chai	< 5		**Inferred**		mins
Pump: Hot water is transferred from the water tank to the mixing container	180	± 15	178	± 5	mL
Controller: Maintenance of idle temperature when machine is not in use	50	$+5$	52	± 2	°C
Time taken to raise milk and water temperature	120	$^{+10}_{-0}$	water: 90, milk:75	water: n/a, milk: ± 5	secs
Ingredients					
Temperature of water when making chai	96	$^{+1}_{-4}$			°C
Temperature of milk when making chai	80	$^{+5}_{-0}$			°C
Dispense:					
Tea leaves	2	± 0.4	3.9	3.5	g
Sugar	8	± 2.0	**Inferred**		g
Cardamom	1	± 0.2	1.0	0.4	g
Fennel seeds	1	± 0.2	1.3	0.3	g
Other					
Device Size	50x50x50		47x33x50		cm^3

Table 5: **Technical specifications for the implementation of The Perfect Chai Maker.** Using the recipe and testing, the specifications for the build of the machine were formed. Green rows are specifications that were met, orange are inferred to have been met, and red were not met.

The sugar dispenser had not been tested but from the iterations on the cardamom and fennel seed dispenser, testing would have probably resulted successful. Moreover, there is greater leeway with the amount of sugar dispensed due to the larger tolerance, which from Figure 29 and 31, the dispenser is capable of dealing with.

The time to make chai was also not tested owing to the subsystems not being integrated. Each subsystem, though, was designed to operate independently and simultaneously, and showed to complete their tasks within their allocated times. Thus, it can be inferred that the machine would indeed have followed the chai recipe and made chai in under 5 minutes.

6 Future Development

There are many places improvements that can be made to the machine to ensure that it is a useful and versatile product for the user. This includes additional hardware design or software features, as well as testing the machine to debug errors and ensure reliability.

6.1 User Interface and Customizability

The machine is currently controlled by one button that triggers it to simply make one mug of chai. The machine was designed with the capability to alter the strength of the chai, which is controlled by the dispenser. The first solution to this is to add multiple buttons, each indicating a different strength, which corresponds to the number of rotations made to the dispensers. Furthermore, a screen and a jog wheel/button layout can allow the user to be specific about the strength. This would, in turn, require the dispensers to divided into even finer segments than they are currently at, as well as have a tighter tolerance in order to deal with the specificity, see Section 6.2

The machine's current form of design is capable of producing more than one mug of chai due to the large induction heater, which can fit a larger saucepan, and the volume of water that the machine can hold, approximately 2.8L. By having an interface, the user could also select the amount of chai they want to make. Similar problems that were posed in Section 4.5.3 would be present in this case, which are discussed in Section 6.3.

6.2 Ingredient Dispenser

First of all, the tea leaves dispenser requires to be redesigned and tested to ensure that the issue of leakage was dealt with and that the variance with the results shrunk. The sugar dispenser also needs to be tested to verify that technical specification is also met.

One of the issues with the continuous rotation servo is that there is no feedback to determine the angle that the servo has turned, adding to the error in the results. By adding a sensing device, such as a switch that is flicked by the servo arm or a hall effect sensor that detects the proximity of the bolt inside the servo arm, every half revolution can be taken into account for how much the dispenser is spinning (since the arm has two sides).

The ingredient dispensers were designed with specific ingredients in mind that have different densities and granularities. Because of this, the dispensers are not flexible and the user cannot replenish, for example, the cardamom dispenser with cinnamon instead. The user could, first, be shipped dispenser pipes – the modular setup would allow the user to replace the pipes for their desired ingredient. Alternatively, the dispensers can be filled with different combinations of spices, rather than individual spices, which are distributed (sold) by the "manufacturer." This allows a regular income similar to the business models of the pod-based machines described in Section 1.3.

An alternative method of dispensing ingredients could also be explored, for example an auger conveyor.

The ingredients would not need to be sealed as they would be dispensed from the top of a pipe rather than the bottom, therefore no steam can penetrate in and the ingredients won't be able to fall out. Furthermore, the auger would not need specific designs for each ingredient, allowing it to be universal. This would require the pipes to be placed closer to the bottom of the machine so that they do not protrude more than already, illustrated in Figure 41. Furthermore, a different servo mount would need to be designed since the servo would sit at the base of the pipe rather than along its side.

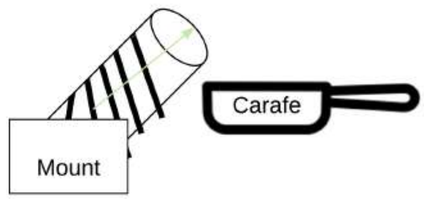


Figure 41: **Illustration of an auger/conveyor lift placed at a lower height.** This would ensure that the pipes are reliably dispensing into the carafe.

6.3 Milk Heater

The possibility of customising the volume of the drink, discussed in Section 6.1 poses the question of verifying the volume inserted by the user. The current carafe has labels marking the recommended volume of milk that should be inserted, but what if this level is not met or no milk is inserted at all? The current design would still heat an empty carafe for 90 seconds until the water is inserted. By adding a weighing scale underneath the base plate, which can accurately measure the weight being put on the base plate, this problem can be solved. If a larger saucepan is used, as suggested in Section 6.1, the machine would not recognise if the larger weight is due to the milk or the saucepan. The alternate solution is to store the milk inside the machine using a removable reservoir, allowing it to be stored in the fridge when not used as to avoid the milk from going bad. The milk would damage a normal water pump, instead, as illustrated in Figure 43, the pump can pump air into the reservoir, pushing the milk out from the bottom.

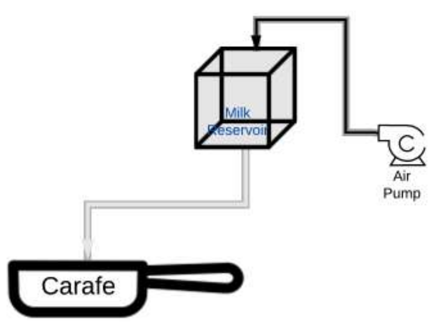


Figure 42: **Illustration of the air pump pushing milk (indicated in grey) out of the bottom of the reservoir by pushing in air.**

This setup causes the problem of cleaning products to arise. Since the milk is poured in cold, it decreases the chance and frequency of mold developing. This reservoir should have detachable tubes, similar to the *Nespresso Latisima*, see Section 1.3, so that they can be washed by the user.

6.4 Micro-controller

The Arduino was compatible with all the devices used in this machine. Further testing with the milk heater, however, would have revealed that that the Arduino would not be able to send a continuous string of bytes to the milk induction heater (which it requires) while also simultaneously communicating to the servos and water heating element. The concern is that once, for example, the servo is activated, the code transmitting the TX signal would no longer be run – making the TX signal go flat – causing the induction heater to reset to the off or standby state. A more complex finite state machine or, alternatively, a micro-controller that can continue running commands while focusing on a different task would solve this issue.

7 Acknowledgements

First and foremost, I'd like to thank my mentors. My thesis advisor, Dr Nathan Taylor, stepped in to provide help and advice even before officially signing up to be my advisor. Nathan's support, reminders, and critiques ensured that my project was being completed to the best of my ability. Without taking my first engineering class, ES51, with Nathan freshman spring semester, I would not have been as excited about engineering as I am today. My thesis section leader, Nishant Sule, has been the kindest, most patient, and dedicated not-engineer SEAS has. Nishant's attention to the details in everyone's project in our section and his ability to make us think critically as well as bounce ideas off each other was inspiring.

I'd also like to extend my thank yous to Evan Smith, Benjamin Brown, and Jim MacArthur, for making themselves available whenever I needed and answering my stupidest questions humbly and with patience. Without Evan and Ben, I would have electrocuted myself while working on the induction heater. Without Jim, I would have electrocuted myself assembling the water heater.

I'd like to thank my family and friends who have been a constant source of motivation for this project. I have been filled with love to see so many people interested in my project and hoping for its success. Thank you to Prasidh for reminding me everyday if it 'is making chai yet.' Needless to say, it is not. Lastly, I'd like to thank my parents for teaching me all I know about my culture – me drinking my father's chaa, made every morning, was integral to my routine most of my life.

To everyone, I promise to bring you a cup of chai produced by this machine.

Appendices

A Bill of Materials

Name	Vendor	Price	Quantity	Subtotal
Arduino Mega 2560 R3	Adafruit	28.50	1	28.50
Soft PVC Clear Tubing, 3/8" ID, 9/16" OD	McMaster	34.50	1	34.50
Waterproof temperature Sensor DS18B20	Adafruit	14.95	1	14.95
EP750 Adhesive	Ellsworth	30.30	1	30.30
AC Wall Adapter, 12V-1A	Digikey	8.95	1	8.95
480mL, 4 inch saucepan	Amazon	16.99	1	16.99
Standard-Wall Clear Rigid PVC Pipe for Water, Size 2, 2 Feet Long	McMaster	24.64	2	49.28
Food-Grade High-Temperature Silicone Rubber Sheets and Strips	McMaster	22.30	1	22.30
Davidson's English Breakfast Tea, 0.45g	Amazon	12.83	1	12.83
Simply Organic Cardamom, 80g	Amazon	4.59	1	4.59
Simply Organic Fennel Seeds, 54g pack of 2	Amazon	3.99	1	3.99
AmazonBasics 1800W Induction heater	Amazon	49.97	1	49.97
Unused Items			Total	$ 255.74
Servo TowerPro SG-5010	Adafruit	12	4	48
Contact-less Infrared Thermopile Sensor Breakout - TMP006	Adafruit	9.95	1	9.95
Relay Switch Kit - KIT-13815	Digikey	8.95	1	8.95
Adafruit 16-Channel Servo Driver - PCA9685	Adafruit	14.95	1	14.95
JQX-15F Relay Switch	Sparkfun	2.95	1	2.95
Isiler 1800W Induction Heater	Amazon	69.95	1	69.95
			Total	**$434.85**
Obtained from advisor				
Keurig K-Cafe: KPM27D air pump, water tank, reservoir				

B Schematic

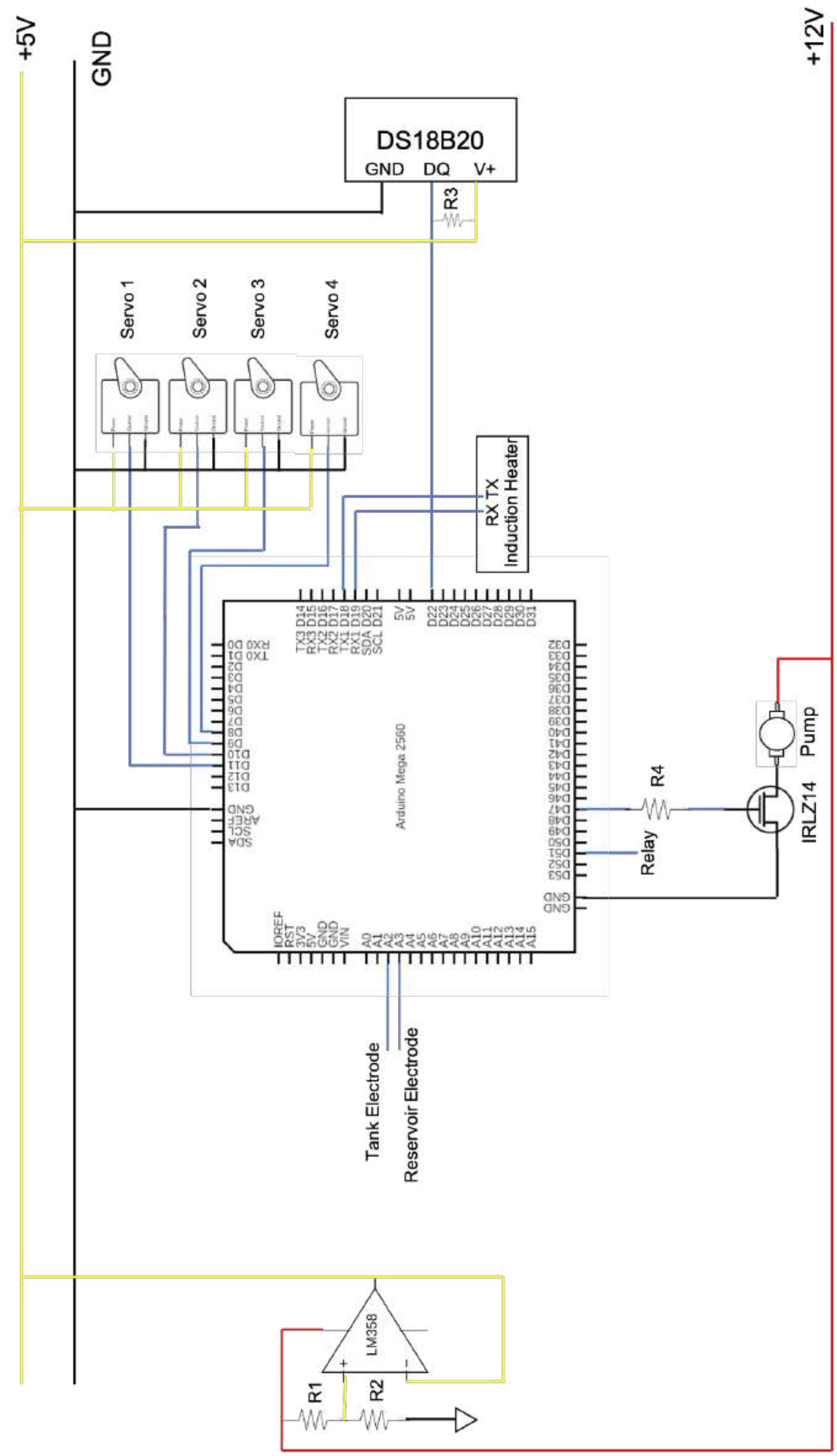


Figure 43: **Final schematic of electrical components.**

C Arduino Code

```
#include <OneWire.h>
#include <DallasTemperature.h>
#include <Servo.h>

//define pins for each component
#define MAKECHAI 22
//button for starting chai process, digital input
#define TEMPSENSE 30
//temp sensor, digital input
#define PUMPDRIVER 47
//pump switch, digital PWM
#define WATERHEATERCONTROL 51
//relay switch for heating element

#define WATERPRESENT_TANK A2
//electrodes detect voltage for presence in tank
//- **pump water if not enough
#define WATERPRESENT_RESERVOIR A3
//electrodes detect voltage for presence in reservoir
//- **ERROR if not enough

//dispenser
#define CARDAMOM 8
#define FENNEL 9
#define TEA 10
#define SUGAR 11

//Induction heater transmission buttons//
const byte idleoff[] = {176, 79, 240, 15, 240, 240, 75, 15, 240, 240};
//when first connected to power supply, completely off
const byte idleon[] = {176, 79, 240, 60, 240, 240, 240, 150, 240, 240};
//turn machine on
const byte fulltemp[] = {176, 79, 30, 120, 180, 225, 240, 150, 240, 240};
//turn induction heater on to max setting
const byte halftemp[] = {176, 79, 90, 120, 180, 225, 240, 150, 240, 240};
//turn induction heater to in between state
const byte zerotemp[] = {176, 79, 240, 60, 180, 225, 240, 150, 240, 240};
//turn induction heater off

const int arsize = sizeof(idleoff); //size of array for serial.write
```

```
//initiate temperature sensor
OneWire oneWire(TEMPSENSE);
DallasTemperature sensors(&oneWire);

// create servo object to control a servo
Servo cardamomServo;
Servo fennelServo;
Servo teaServo;
Servo sugarServo;

float Celcius = 0;
int amount = 14896; //pump on for 14.89455 secs to pump 187 ml

//bool isFirst = false;

void setup(void)
{
  Serial.begin(9600);
  sensors.begin();

  cardamomServo.attach(CARDAMOM);
  fennelServo.attach(FENNEL);
  teaServo.attach(TEA);
  sugarServo.attach(SUGAR);

  pinMode(PUMPDRIVER, OUTPUT);
  pinMode(WATERHEATERCONTROL, OUTPUT);

  pinMode(MAKECHAI, INPUT);   //Press button, active low
  pinMode(WATERPRESENT_TANK, INPUT);
  pinMode(WATERPRESENT_RESERVOIR, INPUT);

  Serial.write(idleoff);    //set up stage for heater should be off
}

void loop(void)
{
  tempSense();
  isWaterPresent();
  if(buttonPressed() == true)  //&& isWaterPresent()==true)
  {
    heatMilk();
    delay(300);
```

```
    dispenseIngred(1);
    delay(300);
    switchPump(2);
  }

//  else if(buttonPressed() == true && isWaterPresent()==true){
//    **SCREEN DISPLAYING LACK OF WATER
//  }

  delay(100);
}

bool isWaterPresent(){
  int tankValue = analogRead(WATERPRESENT_TANK);
  int reservoirValue = analogRead(WATERPRESENT_RESERVOIR);

//electrodeValue between 0-1023, input of 5V, therefore conversion required
  float resVoltage = reservoirValue * (5.0 / 1023.0);
  float tankVoltage = tankValue * (5.0 / 1023.0);

  if(resVoltage > 0.7)
  {
    return true;
  }
  //DISPLAY ADD WATER
  while(tankVoltage < 1)
  {
    switchPump(1);
  }
  switchPump(0);
}
bool buttonPressed(){
  int buttonState;

  buttonState = digitalRead(MAKECHAI);

  int programState = 0;
  long buttonMillis = 0;
  const long intervalButton = 3000;

  long ledMillis = 0;
  const long intervalLed = 5000;
```

```
  unsigned long currentMillis = millis();


  if (buttonState == LOW && programState == 0) {
    buttonMillis = currentMillis;
    programState = 1;
  }
  else if (programState == 1 && buttonState == HIGH) {
        programState = 0; //reset
  }
  if(currentMillis - buttonMillis > intervalButton && programState == 1) {
    programState = 2;
    ledMillis = currentMillis;

    return true;
  }

  if(currentMillis - ledMillis > intervalLed && programState == 2) {
    programState = 0;
    return false;
  }

  if(buttonState == LOW)
  {
    return true;
  }
  return false;
}

void waterHeat(bool on){
  if(on){
  digitalWrite(WATERHEATERCONTROL, HIGH);
  }
  else{
  digitalWrite(WATERHEATERCONTROL, LOW);
  }

}

// SENSOR FOR WATER TEMPERATURE
//*********CALIBRATE**********//
void tempSense()
{
```

```
  int idealTemp = 50;
  int tolerance = 0.2;
  sensors.requestTemperatures();
  Celcius = sensors.getTempCByIndex(0);

  if(Celcius < idealTemp - idealTemp*tolerance && Celcius > 0)
  {
    waterHeat(true);
    //TURN RELAY OFF = HEATER OFF
  }
  else if(Celcius > idealTemp){
    delay(2000);
    waterHeat(false);
  }
  //Serial.println(Celcius);
}

// HEAT MILK IN TANK //
void heatMilk()
{
 //need to tap into controller settings to mess with this.
}

// DISPENSE INGREDIENTS. STRENGTH DETERMINED ON SCALE FROM 1 TO 3. ASSUME 1 'TIL IMPLEMENTATION //
void dispenseIngred(int strength)
{
    float servoSpeed = 1.11;
    float cs = servoSpeed*(360/10);
    float fs = servoSpeed*(360/11);
    float ss = servoSpeed*(360/5);
    float ts = servoSpeed*360/90;
    cardamomServo.attach(CARDAMOM);
    cardamomServo.write(180);
    delay(cs);
    cardamomServo.write(0);
    delay(cs*3);
    cardamomServo.detach();

    fennelServo.attach(FENNEL);
    fennelServo.write(180);
    delay(fs);
    fennelServo.detach();
```

```
    sugarServo.attach(SUGAR);
    sugarServo.write(180);
    delay(fs);
    sugarServo.detach();

    teaServo.attach(TEA);
    teaServo.write(180);
    delay(fs);
    teaServo.detach();

}

// PUMP WATER TO POT //
void switchPump(WATERPRESENT)
{
   int amount = 11781*5;

  if(WATERPRESENT == 2)
  {
    digitalWrite(PUMPDRIVER, HIGH);
    delay(amount);
    digitalWrite(PUMPDRIVER, LOW);
  }
  else if(WATERPRESENT == 1)
  {
    digitalWrite(PUMPDRIVER, HIGH);
  }
  else
  {
    digitalWrite(PUMPDRIVER, LOW);
  }
}
```

D Data Collection

D.1 Ingredient Tolerance Test

	Mass (g)			
	Cardamom	Fennel Seeds	Sugar	Tea Leaves
	1	1.2	8.6	2.4
	1.1	1.1	10	2.2
	1.2	0.9	8.9	1.7
	1	0.9	6	2.3
	1.3	0.9	6	1.4
	0.8	0.8	6.7	1.4
	0.9	0.7	8	2
	0.8	1	9	2.6
	0.8	1.2	11	2.3
	1.2	1.1	7.4	2
Standard Deviation	**0.19**	**0.17**	**1.67**	**0.41**

Table 6: **Test of measuring masses of ingredients using tea and table spoons. The standard deviations determine the tolerances for the technical specifications.**

D.2 Calculating Ingredient Density

The ingredients' densities were worked out by measuring their mass (directly) and their volume (indirectly). The Active Learning Lab space was not able to provide containers that are listed as being food safe. Therefore, the ingredients were kept in zipper storage bags. The bag would be filled around a third of the way and the air would be removed as the bag is being closed. The ingredients were not pressed on tightly as to ensure that they hold their density that would be maintained when they're in any other normal container. After being weighed on a scale, the bag is submerged fully into a large jar of water and a line is drawn at the new water level. The bag is removed, water is filled up to the line and measured using a serological pipette. The advantages of using a serological pipette are that it is optically optimised, reducing the observer's error, there is increased volume accuracy, and the clear ascending and descending graduation avoids spillage of water or droplets on the side of the jar being unaccounted for. Since the densities of the ingredients are very small, it was vital to ensure that these values are accurately obtained.

D.3 Dispensing Ingredients

Mass (g) of Fennel Seeds Dispensed with each Parameter			
60 °	45 °	36 °	36 ° with 30° tilt
0	2.2	0.5	1.1
0.8	0.3	1.5	1.3
0	0	0.6	1
0.3	0.2	1.7	1.22
2.1	2	0.8	1.5
0.3	0.1	1.5	1.4
0.1	0.1	2	1.44
0.3	0.3	2.1	1.9
1.6	0.1	0.6	1.9
0.4	0.1	2.6	1.32
0.2	0.3	1.7	1
2	2.1	1.9	1.21
0.3	0.3	2.1	1.1
0.2	2.1	2.2	2
0.5	0	2.2	1.1
1.4	0.3	0.9	1.3
0.3	0.4	1.4	1.06
0.2	1.3	0.6	1.6
1.6	0.4	1.7	1.5
0.9	0.1	2.1	1
0.1	0	2.2	1.7
0.5	0.1	0.5	1.9
1.7	0	1.5	1.23
0	0	0.6	1.2
0.3	0.1	1.7	1
1.8	0.2	0.8	1.8
0.6	0.1	1.5	1.1
0.1	0	2	2
0.6	0.2	2.1	1.1
1.4	0.4	0.6	1.3
0.1	0.5	2.6	1
0.3	0.6	1.7	1.66
1.8	0.1	1.9	1.43
0.3	0.5	2.1	1.23

0.3	0.6	2.2	1
1.9	0.4	2.2	0.98
0.4	0.4	0.9	1.9
1	0	1.4	2.2
0.5	0.1	0.6	1
1.4	0.5	1.7	1.8
0.3	0.6	2.1	1.1
0.2	0.2	2.2	1.7
1.6	0.2	0.5	0.93
0.9	0.4	1.5	1
0.1	0.8	0.6	2.2
0.5	0.6	1.7	1.7
1.7	0.1	0.8	0.95
0	0.1	1.5	1.9
0.3	0	2	1
1.8	0	2.1	2.8
0.6	0.1	0.6	0.97
0.1	0.1	2.6	1.1
0.6	0.4	1.7	2
1.4	2	1.9	0.97
0.1	0.5	2.1	1.3
0.3	0.6	2.2	0.94
1.8	0.6	2.2	1.6
0.3	1.9	0.9	1.5
0.3	0.1	1.4	1
1.9	0.1	0.6	1.7
0.4	0.1	1.7	1
0	1.8	2.1	1
0	0.5	2.2	1.2
0	0.6	1.7	1.4
0	0.5	1.9	1.8
0	1.9	2.1	1.1
0	0.5	2.2	1
0	0.6	2.2	1
0	0.1	0.9	0.9
0	0.1	1.4	0.8
0	0.1	0.6	1
0	1.2	1.7	1.3
0	0.4	2.1	1

Table 7: **Data collected from repeating the fennel seed mass tests 70 times.**

Mass (g) of Cardamom Dispensed with each Parameter		
36 °	30°	30° + 3*30° jerk
0	1	0.9
0	0	0.5
1	1.6	1.1
0	1	0.7
2	0	1.1
0	0.6	1.8
0.5	0	0.3
0.8	1.8	0
0	0.3	1.6
0	0.5	0.7
0	0.5	1.4
0	1.6	0.8
0	0.3	1.1
0.8	0	0.7
0.6	0.1	1.1
0.8	0	1.5
0	0	1.5
0.1	0	1.2
0.1	0.1	1.1
1.1	0	0.8
0	0.3	0.9
1.3	1.3	0.4
0	0.5	0.6
0	0	1.3
0	0	1.3
0	0.5	0.1
0	0.3	1
0.3	0	1.3
0	0.5	0.8
1.7	0.5	1.2

Table 8: **Data collected from repeating the cardamom mass tests 20 times.**

Mass (g) of Tea Leaves Dispensed with each Parameter		
90°	72°	100°
0.3	0	4
4	1.5	1.5
0.2	4.2	4.2
0.2	0	7
0.2	0	4
0.7	0	3
4.5	5.1	5.1
0.5	0.2	0.2
0	0	5
0.5	0.1	0.1
4.9	3	3
0	5	5
0	0.2	0.2
5.9	5.6	5.6
0	0.2	0.2
0	0	4
0.6	0	7
4.7	1.7	1.7
0	4.8	4.8
0	0	5
4.3	0	6.3
0.2	0.4	0.2
0	3.5	6.9
4.8	0.3	7.3
0	0.1	3
0.1	0	5
1.5	1.4	0.2
3.6	3.7	6.8
0	0	0.2
0.2	0	3.3
4	0.2	0.2
0.2	3.7	3.7
0	0	7
4	0	2.5
0	0.2	4.3
0	4.3	4.3
3.1	0	3.9
0.2	0.1	0.1
4	0.2	0.2
0.2	2.8	2.8

Table 9: **Data collected from repeating the tea leaves mass tests 40 times.**

D.4 Induction Heater Signals

The induction heater's signals, transmitted via the UI's TX pin, have been listen below. The yellow highlights indicate changes between each set of data.

State: off									
Start bit	Data bits (one byte)								End bit
0	0	0	0	0	1	1	0	1	1
0	1	1	1	1	0	0	1	0	1
0	0	0	0	0	1	1	1	1	1
0	1	1	1	1	0	0	0	0	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	1	1	0	1	0	0	1	0	1
0	1	1	1	1	0	0	0	0	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1

Concat	Hex	Decimal	Concat opposite for Arduino	New hex	New dec
00001101	D	13	10110000	B0	176
11110010	F2	242	01001111	4F	79
00001111	F	15	11110000	F0	240
11110000	F0	240	00001111	F	15
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240
11010010	D2	210	01001011	4B	75
11110000	F0	240	00001111	F	15
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240

Table 10: **Table for the signals, their converted decimal and hexadecimal equivalents, and the desired Arduino code for Off State**

State: Standby									
Start bit	Data bits (one byte)								End bit
0	0	0	0	0	1	1	0	1	1
0	1	1	1	1	0	0	1	0	1
0	0	0	0	0	1	1	1	1	1
0	0	0	1	1	1	1	0	0	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	0	1	1	0	1	0	0	1	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1

Concat	Hex	Decimal	Concat opposite for Arduino	New hex	New dec
00001101	D	13	10110000	B0	176
11110010	F2	242	01001111	4F	79
00001111	F	15	11110000	F0	240
00111100	3C	60	00111100	3C	60
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240
01101001	69	105	10010110	96	150
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240

Table 11: **Table for the signals, their converted decimal and hexadecimal equivalents, and the desired Arduino code for Standby State**

State: Induction heater on									
Start bit	Data bits (one byte)								End bit
0	0	0	0	0	1	1	0	1	1
0	1	1	1	1	0	0	1	0	1
0	0	1	1	1	1	0	0	0	1
0	0	0	0	1	1	1	1	0	1
0	0	0	1	0	1	1	0	1	1
0	1	0	0	0	0	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	0	1	1	0	1	0	0	1	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1

Concat	Hex	Decimal	Concat opposite for Arduino	New hex	New dec
00001101	D	13	10110000	B0	176
11110010	F2	242	01001111	4F	79
01111000	78	120	00011110	1E	30
00011110	1E	30	01111000	78	120
00101101	2D	45	10110100	B4	180
10000111	87	135	11100001	E1	225
00001111	F	15	11110000	F0	240
01101001	69	105	10010110	96	150
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240

Table 12: **Table for the signals, their converted decimal and hexadecimal equivalents, and the desired Arduino code for Induction Heater On State**

State: Induction heater intermediate on									
Start bit	Data bits (one byte)								End bit
0	0	0	0	0	1	1	0	1	1
0	1	1	1	1	0	0	1	0	1
0	0	1	0	1	1	0	1	0	1
0	0	0	0	1	1	1	1	0	1
0	0	0	1	0	1	1	0	1	1
0	1	0	0	0	0	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	0	1	1	0	1	0	0	1	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1

Concat	Hex	Decimal	Concat opposite for Arduino	New hex	New dec
00001101	D	13	10110000	B0	176
11110010	F2	242	01001111	4F	79
01011010	5A	90	01011010	5A	90
00011110	1E	30	01111000	78	120
00101101	2D	45	10110100	B4	180
10000111	87	135	11100001	E1	225
00001111	F	15	11110000	F0	240
01101001	69	105	10010110	96	150
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240

Table 13: **Table for the signals, their converted decimal and hexadecimal equivalents, and the desired Arduino code for Induction Heater Intermediate On State**

State: Induction heater off									
Start bit	Data bits (one byte)								End bit
0	0	0	0	0	1	1	0	1	1
0	1	1	1	1	0	0	1	0	1
0	0	0	0	0	1	1	1	1	1
0	0	0	1	1	1	1	0	0	1
0	0	0	1	0	1	1	0	1	1
0	1	0	0	0	0	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	0	1	1	0	1	0	0	1	1
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1

Concat	Hex	Decimal	Concat opposite for Arduino	New hex	New dec
00001101	D	13	10110000	B0	176
11110010	F2	242	01001111	4F	79
00001111	F	15	11110000	F0	240
00111100	3C	60	00111100	3C	60
00101101	2D	45	10110100	B4	180
10000111	87	135	11100001	E1	225
00001111	F	15	11110000	F0	240
01101001	69	105	10010110	96	150
00001111	F	15	11110000	F0	240
00001111	F	15	11110000	F0	240

Table 14: **Table for the signals, their converted decimal and hexadecimal equivalents, and the desired Arduino code for Induction Heater Off State**

E Data Sheets

The data sheets for components used in this project are attached in the following order: water pump, temperature sensor, NPN MOSFET, JQX relay switch, IOT relay switch, Op Amp, and servo.

KPM27D(U)

Air Pressure Pump

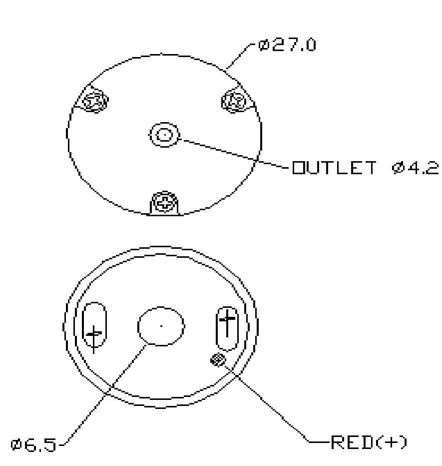
Applications

Blood Pressure M/C, Health Care, Bidet
Massager, Medical Equipment, etc

Specifications

1. Rated Voltage	DC6.0V (D-type)	DC6.0V (U-type)
2. Rated Current	<430mA	<410mA
3. Inflation Time	<10 S (From 0 to 300 mmHg in a 500CC tank.)	
4. Air Flow Without Load	>2.0LPM	
5. Max. Pressure	>350mmHg	
6. Leakage	Max. 3 mmHg/min from 300mmHg at 500CC tank.	
7. Noise Level	65dB (30cm away)	55dB (30cm away)
8. Apply For	Air	

Drawing



YUJIN ELECTRIC

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DS18B20

Programmable Resolution 1-Wire Digital Thermometer

General Description

The DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply.

Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus. Thus, it is simple to use one microprocessor to control many DS18B20s distributed over a large area. Applications that can benefit from this feature include HVAC environmental controls, temperature monitoring systems inside buildings, equipment, or machinery, and process monitoring and control systems.

Applications

- Thermostatic Controls
- Industrial Systems
- Consumer Products
- Thermometers
- Thermally Sensitive Systems

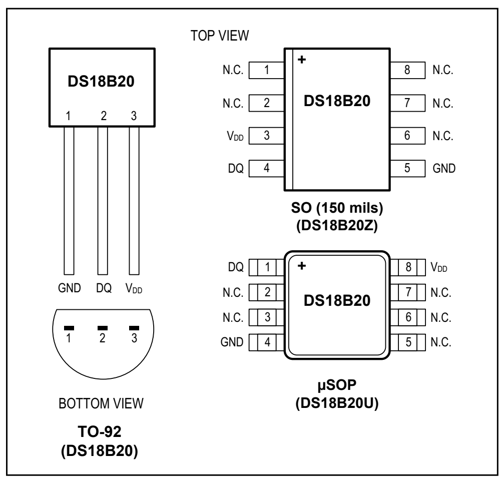
***Ordering Information* appears at end of data sheet.**

1-Wire is a registered trademark of Maxim Integrated Products, Inc.

Benefits and Features

- Unique 1-Wire® Interface Requires Only One Port Pin for Communication
- Reduce Component Count with Integrated Temperature Sensor and EEPROM
  - Measures Temperatures from -55°C to +125°C (-67°F to +257°F)
  - ±0.5°C Accuracy from -10°C to +85°C
  - Programmable Resolution from 9 Bits to 12 Bits
  - No External Components Required
- Parasitic Power Mode Requires Only 2 Pins for Operation (DQ and GND)
- Simplifies Distributed Temperature-Sensing Applications with Multidrop Capability
  - Each Device Has a Unique 64-Bit Serial Code Stored in On-Board ROM
- Flexible User-Definable Nonvolatile (NV) Alarm Settings with Alarm Search Command Identifies Devices with Temperatures Outside Programmed Limits
- Available in 8-Pin SO (150 mils), 8-Pin µSOP, and 3-Pin TO-92 Packages

Pin Configurations



19-7487; Rev 6; 7/19

Absolute Maximum Ratings

Voltage Range on Any Pin Relative to Ground ....-0.5V to +6.0V
Operating Temperature Range .... -55°C to +125°C
Storage Temperature Range .... -55°C to +125°C
Solder Temperature ....Refer to the IPC/JEDEC J-STD-020 Specification.

These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operation sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods of time may affect reliability.

DC Electrical Characteristics

(-55°C to +125°C; V_{DD} = 3.0V to 5.5V)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Supply Voltage	V_{DD}	Local power (Note 1)		+3.0		+5.5	V
Pullup Supply Voltage	V_{PU}	Parasite power	(Notes 1, 2)	+3.0		+5.5	V
		Local power		+3.0		V_{DD}	
Thermometer Error	t_{ERR}	-10°C to +85°C	(Note 3)			±0.5	°C
		-30°C to +100°C				±1	
		-55°C to +125°C				±2	
Input Logic-Low	V_{IL}	(Notes 1, 4, 5)		-0.3		+0.8	V
Input Logic-High	V_{IH}	Local power	(Notes 1,6)	+2.2		The lower of 5.5 or V_{DD} + 0.3	V
		Parasite power		+3.0			
Sink Current	I_L	$V_{I/O}$ = 0.4V		4.0			mA
Standby Current	I_{DDS}	(Notes 7, 8)			750	1000	nA
Active Current	I_{DD}	V_{DD} = 5V (Note 9)			1	1.5	mA
DQ Input Current	I_{DQ}	(Note 10)			5		µA
Drift		(Note 11)			±0.2		°C

Note 1: All voltages are referenced to ground.
Note 2: The Pullup Supply Voltage specification assumes that the pullup device is ideal, and therefore the high level of the pullup is equal to V_{PU}. In order to meet the V_{IH} spec of the DS18B20, the actual supply rail for the strong pullup transistor must include margin for the voltage drop across the transistor when it is turned on; thus: $V_{PU\_ACTUAL} = V_{PU\_IDEAL} + V_{TRANSISTOR}$.
Note 3: See typical performance curve in Figure 1. Thermometer Error limits are 3-sigma values.
Note 4: Logic-low voltages are specified at a sink current of 4mA.
Note 5: To guarantee a presence pulse under low voltage parasite power conditions, V_{ILMAX} may have to be reduced to as low as 0.5V.
Note 6: Logic-high voltages are specified at a source current of 1mA.
Note 7: Standby current specified up to +70°C. Standby current typically is 3µA at +125°C.
Note 8: To minimize I_{DDS}, DQ should be within the following ranges: GND ≤ DQ ≤ GND + 0.3V or V_{DD} – 0.3V ≤ DQ ≤ V_{DD}.
Note 9: Active current refers to supply current during active temperature conversions or EEPROM writes.
Note 10: DQ line is high ("high-Z" state).
Note 11: Drift data is based on a 1000-hour stress test at +125°C with V_{DD} = 5.5V.

AC Electrical Characteristics–NV Memory

(-55°C to +125°C; V_{DD} = 3.0V to 5.5V)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
NV Write Cycle Time	t_{WR}			2	10	ms
EEPROM Writes	N_{EEWR}	-55°C to +55°C	50k			writes
EEPROM Data Retention	t_{EEDR}	-55°C to +55°C	10			years

AC Electrical Characteristics

(-55°C to +125°C; V_{DD} = 3.0V to 5.5V)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Temperature Conversion Time	t_{CONV}	9-bit resolution	(Note 12)			93.75	ms
		10-bit resolution				187.5	
		11-bit resolution				375	
		12-bit resolution				750	
Time to Strong Pullup On	t_{SPON}	Start convert T command issued				10	µs
Time Slot	t_{SLOT}	(Note 12)		60		120	µs
Recovery Time	t_{REC}	(Note 12)		1			µs
Write 0 Low Time	t_{LOW0}	(Note 12)		60		120	µs
Write 1 Low Time	t_{LOW1}	(Note 12)		1		15	µs
Read Data Valid	t_{RDV}	(Note 12)				15	µs
Reset Time High	t_{RSTH}	(Note 12)		480			µs
Reset Time Low	t_{RSTL}	(Notes 12, 13)		480			µs
Presence-Detect High	t_{PDHIGH}	(Note 12)		15		60	µs
Presence-Detect Low	t_{PDLOW}	(Note 12)		60		240	µs
Capacitance	$C_{IN/OUT}$					25	pF

Note 12: See the timing diagrams in Figure 2.
Note 13: Under parasite power, if t_{RSTL} > 960µs, a power-on reset can occur.

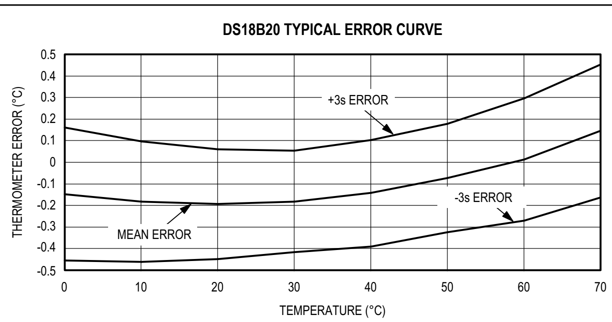


Figure 1. Typical Performance Curve

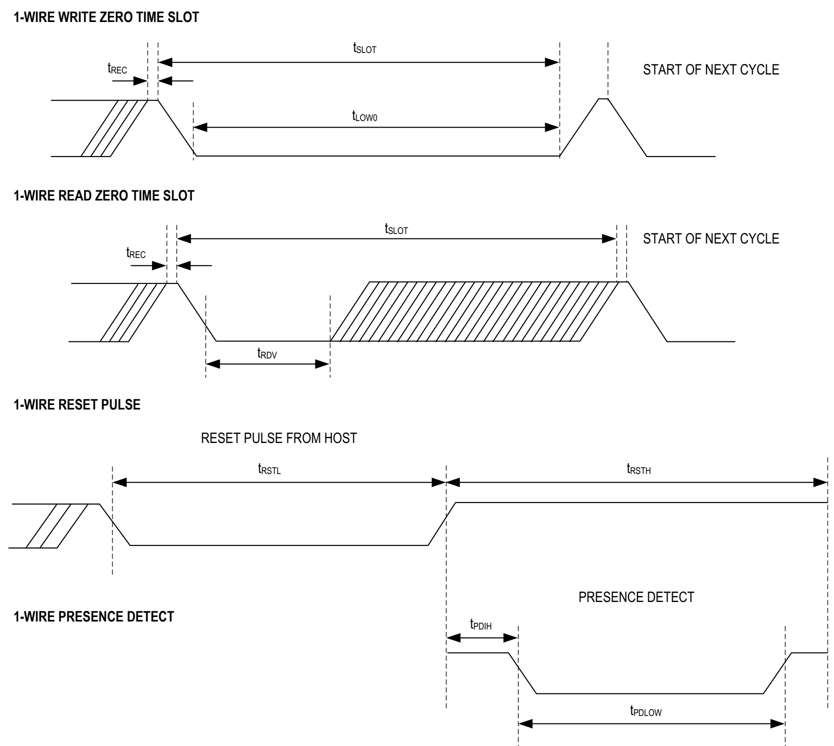


Figure 2. Timing Diagrams

Pin Description

PIN			NAME	FUNCTION
SO	µSOP	TO-92		
1, 2, 6, 7, 8	2, 3, 5, 6, 7	—	N.C.	No Connection
3	8	3	V_{DD}	Optional V_{DD}. V_{DD} must be grounded for operation in parasite power mode.
4	1	2	DQ	Data Input/Output. Open-drain 1-Wire interface pin. Also provides power to the device when used in parasite power mode (see the *Powering the DS18B20* section.)
5	4	1	GND	Ground

Overview

Figure 3 shows a block diagram of the DS18B20, and pin descriptions are given in the *Pin Description* table. The 64-bit ROM stores the device's unique serial code. The scratchpad memory contains the 2-byte temperature register that stores the digital output from the temperature sensor. In addition, the scratchpad provides access to the 1-byte upper and lower alarm trigger registers (T_H and T_L) and the 1-byte configuration register. The configuration register allows the user to set the resolution of the temperature-to-digital conversion to 9, 10, 11, or 12 bits. The T_H, T_L, and configuration registers are nonvolatile (EEPROM), so they will retain data when the device is powered down.

The DS18B20 uses Maxim's exclusive 1-Wire bus protocol that implements bus communication using one control signal. The control line requires a weak pullup resistor since all devices are linked to the bus via a 3-state or open-drain port (the DQ pin in the case of the DS18B20). In this bus system, the microprocessor (the master device) identifies and addresses devices on the bus using each device's unique 64-bit code. Because each device has a unique code, the number of devices that can be addressed on one bus is virtually unlimited. The 1-Wire bus protocol, including detailed explanations of the commands and "time slots," is covered in the *1-Wire Bus System* section.

Another feature of the DS18B20 is the ability to operate without an external power supply. Power is instead supplied through the 1-Wire pullup resistor through the DQ pin when the bus is high. The high bus signal also charges an internal capacitor (C_{PP}), which then supplies power to the device when the bus is low. This method of deriving power from the 1-Wire bus is referred to as "parasite power." As an alternative, the DS18B20 may also be powered by an external supply on V_{DD}.

Operation—Measuring Temperature

The core functionality of the DS18B20 is its direct-to-digital temperature sensor. The resolution of the temperature sensor is user-configurable to 9, 10, 11, or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.125°C, and 0.0625°C, respectively. The default resolution at power-up is 12-bit. The DS18B20 powers up in a low-power idle state. To initiate a temperature measurement and A-to-D conversion, the master must issue a Convert T [44h] command. Following the conversion, the resulting thermal data is stored in the 2-byte temperature register in the scratchpad memory and the DS18B20 returns to its idle state. If the DS18B20 is powered by an external supply, the master can issue "read time slots" (see the *1-Wire Bus System* section) after the Convert T command and the DS18B20 will respond by transmitting 0 while the temperature conversion is in progress and 1 when the conversion is done. If the DS18B20 is powered with parasite power, this notification technique cannot be used since the bus must be pulled high by a strong pullup during the entire temperature conversion. The bus requirements for parasite power are explained in detail in the *Powering the DS18B20* section.

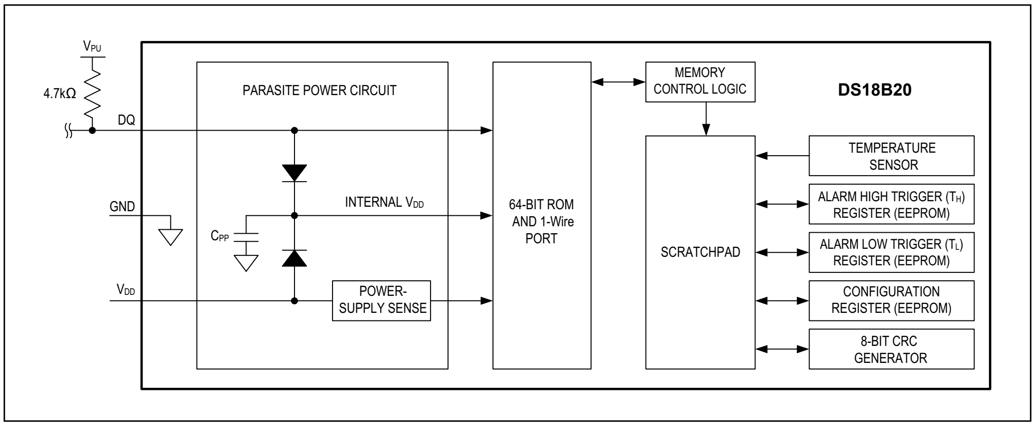


Figure 3. DS18B20 Block Diagram

The DS18B20 output temperature data is calibrated in degrees Celsius; for Fahrenheit applications, a lookup table or conversion routine must be used. The temperature data is stored as a 16-bit sign-extended two's complement number in the temperature register (see Figure 4). The sign bits (S) indicate if the temperature is positive or negative: for positive numbers S = 0 and for negative numbers S = 1. If the DS18B20 is configured for 12-bit resolution, all bits in the temperature register will contain valid data. For 11-bit resolution, bit 0 is undefined. For 10-bit resolution, bits 1 and 0 are undefined, and for 9-bit resolution bits 2, 1, and 0 are undefined. Table 1 gives examples of digital output data and the corresponding temperature reading for 12-bit resolution conversions.

Operation—Alarm Signaling

After the DS18B20 performs a temperature conversion, the temperature value is compared to the user-defined two's complement alarm trigger values stored in the 1-byte T_H and T_L registers (see Figure 5). The sign bit (S) indicates if the value is positive or negative: for positive numbers S = 0 and for negative numbers S = 1. The T_H and T_L registers are nonvolatile (EEPROM) so they will retain data when the device is powered down. T_H and T_L can be accessed through bytes 2 and 3 of the scratchpad as explained in the *Memory* section.

Only bits 11 through 4 of the temperature register are used in the T_H and T_L comparison since T_H and T_L are 8-bit registers. If the measured temperature is lower than

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
LS BYTE	2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}
	BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
MS BYTE	S	S	S	S	S	2^6	2^5	2^4

S = SIGN

Figure 4. Temperature Register Format

Table 1. Temperature/Data Relationship

TEMPERATURE (°C)	DIGITAL OUTPUT (BINARY)	DIGITAL OUTPUT (HEX)
+125	0000 0111 1101 0000	07D0h
+85*	0000 0101 0101 0000	0550h
+25.0625	0000 0001 1001 0001	0191h
+10.125	0000 0000 1010 0010	00A2h
+0.5	0000 0000 0000 1000	0008h
0	0000 0000 0000 0000	0000h
-0.5	1111 1111 1111 1000	FFF8h
-10.125	1111 1111 0101 1110	FF5Eh
-25.0625	1111 1110 0110 1111	FE6Fh
-55	1111 1100 1001 0000	FC90h

**The power-on reset value of the temperature register is +85°C.*

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
S	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Figure 5. T_H and T_L Register Format

or equal to T_L or higher than or equal to T_H, an alarm condition exists and an alarm flag is set inside the DS18B20. This flag is updated after every temperature measurement; therefore, if the alarm condition goes away, the flag will be turned off after the next temperature conversion.

The master device can check the alarm flag status of all DS18B20s on the bus by issuing an Alarm Search [ECh] command. Any DS18B20s with a set alarm flag will respond to the command, so the master can determine exactly which DS18B20s have experienced an alarm condition. If an alarm condition exists and the T_H or T_L settings have changed, another temperature conversion should be done to validate the alarm condition.

Powering the DS18B20

The DS18B20 can be powered by an external supply on the V_{DD} pin, or it can operate in "parasite power" mode, which allows the DS18B20 to function without a local external supply. Parasite power is very useful for applications that require remote temperature sensing or that are very space constrained. Figure 3 shows the DS18B20's parasite-power control circuitry, which "steals" power from the 1-Wire bus via the DQ pin when the bus is high. The stolen charge powers the DS18B20 while the bus is high, and some of the charge is stored on the parasite power capacitor (C_{PP}) to provide power when the bus is low. When the DS18B20 is used in parasite power mode, the V_{DD} pin must be connected to ground.

In parasite power mode, the 1-Wire bus and CPP can provide sufficient current to the DS18B20 for most operations as long as the specified timing and voltage requirements are met (see the *DC Electrical Characteristics* and *AC Electrical Characteristics*). However, when the DS18B20 is performing temperature conversions or copying data from the scratchpad memory to EEPROM, the operating current can be as high as 1.5mA. This current can cause an unacceptable voltage drop across the weak 1-Wire pullup resistor and is more current than can be supplied by C_{PP}. To assure that the DS18B20 has sufficient supply current, it is necessary to provide a strong pullup on the 1-Wire bus whenever temperature conversions are taking place or data is being copied from the scratchpad to EEPROM. This can be accomplished by using a MOSFET to pull the bus directly to the rail as shown in Figure 6. The 1-Wire bus must be switched to the strong pullup within 10µs (max) after a Convert T [44h] or Copy Scratchpad [48h] command is issued, and the bus must be held high by the pullup for the duration of the conversion (t_{CONV}) or data transfer (t_{WR} = 10ms). No other activity can take place on the 1-Wire bus while the pullup is enabled.

The DS18B20 can also be powered by the conventional method of connecting an external power supply to the V_{DD} pin, as shown in Figure 7. The advantage of this method is that the MOSFET pullup is not required, and the 1-Wire bus is free to carry other traffic during the temperature conversion time.

The use of parasite power is not recommended for temperatures above +100°C since the DS18B20 may not be able to sustain communications due to the higher leakage currents that can exist at these temperatures. For applications in which such temperatures are likely, it is strongly recommended that the DS18B20 be powered by an external power supply.

In some situations the bus master may not know whether the DS18B20s on the bus are parasite powered or powered by external supplies. The master needs this information to determine if the strong bus pullup should be used during temperature conversions. To get this information, the master can issue a Skip ROM [CCh] command followed by a Read Power Supply [B4h] command followed by a "read time slot". During the read time slot, parasite powered DS18B20s will pull the bus low, and externally powered DS18B20s will let the bus remain high. If the bus is pulled low, the master knows that it must supply the strong pullup on the 1-Wire bus during temperature conversions.

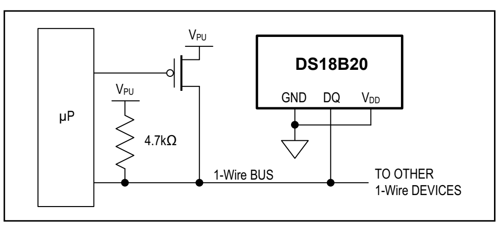


Figure 6. Supplying the Parasite-Powered DS18B20 During Temperature Conversions

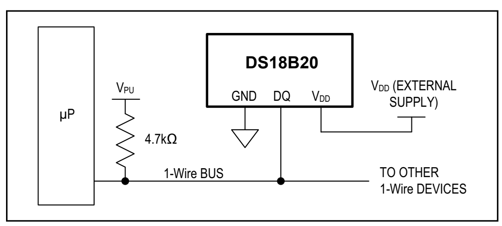


Figure 7. Powering the DS18B20 with an External Supply

64-BIT Lasered ROM code

Each DS18B20 contains a unique 64–bit code (see Figure 8) stored in ROM. The least significant 8 bits of the ROM code contain the DS18B20's 1-Wire family code: 28h. The next 48 bits contain a unique serial number. The most significant 8 bits contain a cyclic redundancy check (CRC) byte that is calculated from the first 56 bits of the ROM code. A detailed explanation of the CRC bits is provided in the *CRC Generation* section. The 64-bit ROM code and associated ROM function control logic allow the DS18B20 to operate as a 1-Wire device using the protocol detailed in the *1-Wire Bus System* section.

Memory

The DS18B20's memory is organized as shown in Figure 9. The memory consists of an SRAM scratchpad with nonvolatile EEPROM storage for the high and low alarm trigger registers (T_H and T_L) and configuration register. Note that if the DS18B20 alarm function is not used, the TH and TL registers can serve as general-purpose memory. All memory commands are described in detail in the *DS18B20 Function Commands* section.

Byte 0 and byte 1 of the scratchpad contain the LSB and the MSB of the temperature register, respectively. These bytes are read-only. Bytes 2 and 3 provide access to TH and TL registers. Byte 4 contains the configuration register data, which is explained in detail in the *Configuration Register* section. Bytes 5, 6, and 7 are reserved for internal use by the device and cannot be overwritten.

Byte 8 of the scratchpad is read-only and contains the CRC code for bytes 0 through 7 of the scratchpad. The DS18B20 generates this CRC using the method described in the *CRC Generation* section.

Data is written to bytes 2, 3, and 4 of the scratchpad using the Write Scratchpad [4Eh] command; the data must be transmitted to the DS18B20 starting with the least significant bit of byte 2. To verify data integrity, the scratchpad can be read (using the Read Scratchpad [BEh] command) after the data is written. When reading the scratchpad, data is transferred over the 1-Wire bus starting with the least significant bit of byte 0. To transfer the T_H, T_L and configuration data from the scratchpad to EEPROM, the master must issue the Copy Scratchpad [48h] command.

Data in the EEPROM registers is retained when the device is powered down; at power-up the EEPROM data is reloaded into the corresponding scratchpad locations. Data can also be reloaded from EEPROM to the scratchpad at any time using the Recall E^2 [B8h] command. The master can issue read time slots following the Recall E^2 command and the DS18B20 will indicate the status of the recall by transmitting 0 while the recall is in progress and 1 when the recall is done.

8-BIT CRC		48-BIT SERIAL NUMBER		8-BIT FAMILY CODE (28h)	
MSB	LSB	MSB	LSB	MSB	LSB

Figure 8. 64-Bit Lasered ROM Code

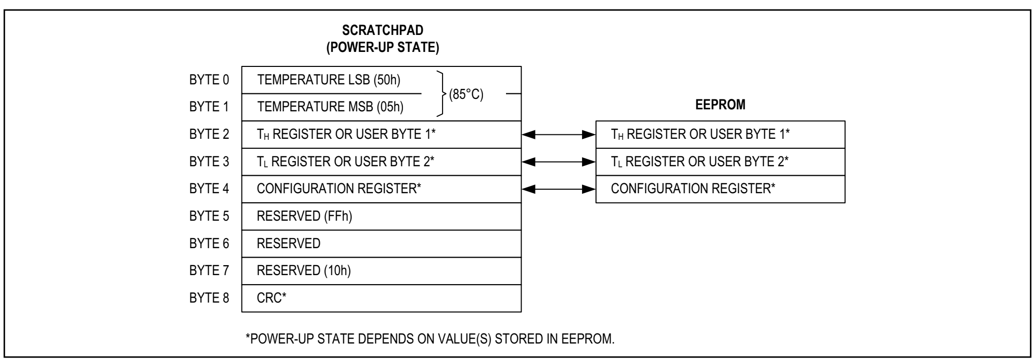


Figure 9. DS18B20 Memory Map

Configuration Register

Byte 4 of the scratchpad memory contains the configuration register, which is organized as illustrated in Figure 10. The user can set the conversion resolution of the DS18B20 using the R0 and R1 bits in this register as shown in Table 2. The power-up default of these bits is R0 = 1 and R1 = 1 (12-bit resolution). Note that there is a direct tradeoff between resolution and conversion time. Bit 7 and bits 0 to 4 in the configuration register are reserved for internal use by the device and cannot be overwritten.

CRC Generation

CRC bytes are provided as part of the DS18B20's 64-bit ROM code and in the 9^{th} byte of the scratchpad memory. The ROM code CRC is calculated from the first 56 bits of the ROM code and is contained in the most significant byte of the ROM. The scratchpad CRC is calculated from the data stored in the scratchpad, and therefore it changes when the data in the scratchpad changes. The CRCs provide the bus master with a method of data validation when data is read from the DS18B20. To verify that data has been read correctly, the bus master must re-calculate the CRC from the received data and then compare this value to either the ROM code CRC (for ROM reads) or to the scratchpad CRC (for scratchpad reads). If the calculated CRC matches the read CRC, the data has been received error free. The comparison of CRC values and the decision to continue with an operation are determined entirely by the bus master. There is no circuitry inside the DS18B20 that prevents a command sequence from proceeding if the DS18B20 CRC (ROM or scratchpad) does not match the value generated by the bus master.

The equivalent polynomial function of the CRC (ROM or scratchpad) is:

$$CRC = X^8 + X^5 + X^4 + 1$$

The bus master can re-calculate the CRC and compare it to the CRC values from the DS18B20 using the polynomial generator shown in Figure 11. This circuit consists of a shift register and XOR gates, and the shift register bits are initialized to 0. Starting with the least significant bit of the ROM code or the least significant bit of byte 0 in the scratchpad, one bit at a time should shifted into the shift register. After shifting in the 56th bit from the ROM or the most significant bit of byte 7 from the scratchpad, the polynomial generator will contain the recalculated CRC. Next, the 8-bit ROM code or scratchpad CRC from the DS18B20 must be shifted into the circuit. At this point, if the re-calculated CRC was correct, the shift register will contain all 0s. Additional information about the Maxim 1-Wire cyclic redundancy check is available in *Application Note 27: Understanding and Using Cyclic Redundancy Checks with Maxim iButton Products*.

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
0	R1	R0	1	1	1	1	1

Figure 10. Configuration Register

Table 2. Thermometer Resolution Configuration

R1	R0	RESOLUTION (BITS)	MAX CONVERSION TIME	
0	0	9	93.75ms	($t_{CONV}/8$)
0	1	10	187.5ms	($t_{CONV}/4$)
1	0	11	375ms	($t_{CONV}/2$)
1	1	12	750ms	(t_{CONV})

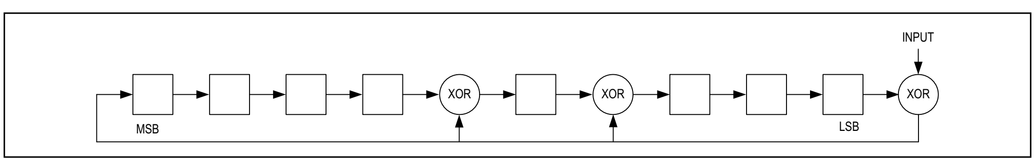


Figure 11. CRC Generator

1-Wire Bus System

The 1-Wire bus system uses a single bus master to control one or more slave devices. The DS18B20 is always a slave. When there is only one slave on the bus, the system is referred to as a "single-drop" system; the system is "multidrop" if there are multiple slaves on the bus.

All data and commands are transmitted least significant bit first over the 1-Wire bus.

The following discussion of the 1-Wire bus system is broken down into three topics: hardware configuration, transaction sequence, and 1-Wire signaling (signal types and timing).

Hardware Configuration

The 1-Wire bus has by definition only a single data line. Each device (master or slave) interfaces to the data line via an open-drain or 3-state port. This allows each device to "release" the data line when the device is not transmitting data so the bus is available for use by another device. The 1-Wire port of the DS18B20 (the DQ pin) is open drain with an internal circuit equivalent to that shown in Figure 12.

The 1-Wire bus requires an external pullup resistor of approximately 5kΩ; thus, the idle state for the 1-Wire bus is high. If for any reason a transaction needs to be suspended, the bus MUST be left in the idle state if the transaction is to resume. Infinite recovery time can occur between bits so long as the 1-Wire bus is in the inactive (high) state during the recovery period. If the bus is held low for more than 480µs, all components on the bus will be reset.

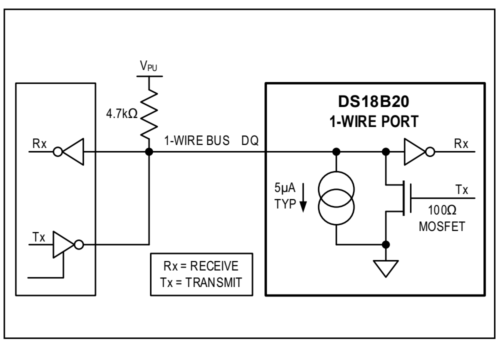


Figure 12. Hardware Configuration

Transaction Sequence

The transaction sequence for accessing the DS18B20 is as follows:

Step 1. Initialization

Step 2. ROM Command (followed by any required data exchange)

Step 3. DS18B20 Function Command (followed by any required data exchange)

It is very important to follow this sequence every time the DS18B20 is accessed, as the DS18B20 will not respond if any steps in the sequence are missing or out of order. Exceptions to this rule are the Search ROM [F0h] and Alarm Search [ECh] commands. After issuing either of these ROM commands, the master must return to Step 1 in the sequence.

Initialization

All transactions on the 1-Wire bus begin with an initialization sequence. The initialization sequence consists of a reset pulse transmitted by the bus master followed by presence pulse(s) transmitted by the slave(s). The presence pulse lets the bus master know that slave devices (such as the DS18B20) are on the bus and are ready to operate. Timing for the reset and presence pulses is detailed in the *1-Wire Signaling* section.

ROM Commands

After the bus master has detected a presence pulse, it can issue a ROM command. These commands operate on the unique 64-bit ROM codes of each slave device and allow the master to single out a specific device if many are present on the 1-Wire bus. These commands also allow the master to determine how many and what types of devices are present on the bus or if any device has experienced an alarm condition. There are five ROM commands, and each command is 8 bits long. The master device must issue an appropriate ROM command before issuing a DS18B20 function command. A flowchart for operation of the ROM commands is shown in Figure 13.

Search Rom [F0h]

When a system is initially powered up, the master must identify the ROM codes of all slave devices on the bus, which allows the master to determine the number of slaves and their device types. The master learns the ROM codes through a process of elimination that requires the master to perform a Search ROM cycle (i.e., Search ROM command followed by data exchange) as many times as necessary to identify all of the slave devices.

If there is only one slave on the bus, the simpler Read ROM [33h] command can be used in place of the Search ROM process. For a detailed explanation of the Search ROM procedure, refer to *Application Note 937: Book of iButton® Standards*. After every Search ROM cycle, the bus master must return to Step 1 (Initialization) in the transaction sequence.

Read Rom [33h]

This command can only be used when there is one slave on the bus. It allows the bus master to read the slave's 64-bit ROM code without using the Search ROM procedure. If this command is used when there is more than one slave present on the bus, a data collision will occur when all the slaves attempt to respond at the same time.

Match Rom [55H]

The match ROM command followed by a 64-bit ROM code sequence allows the bus master to address a specific slave device on a multidrop or single-drop bus. Only the slave that exactly matches the 64-bit ROM code sequence will respond to the function command issued by the master; all other slaves on the bus will wait for a reset pulse.

Skip Rom [CCh]

The master can use this command to address all devices on the bus simultaneously without sending out any ROM code information. For example, the master can make all DS18B20s on the bus perform simultaneous temperature conversions by issuing a Skip ROM command followed by a Convert T [44h] command.

Note that the Read Scratchpad [BEh] command can follow the Skip ROM command only if there is a single slave device on the bus. In this case, time is saved by allowing the master to read from the slave without sending the device's 64-bit ROM code. A Skip ROM command followed by a Read Scratchpad command will cause a data collision on the bus if there is more than one slave since multiple devices will attempt to transmit data simultaneously.

Alarm Search [ECh]

The operation of this command is identical to the operation of the Search ROM command except that only slaves with a set alarm flag will respond. This command allows the master device to determine if any DS18B20s experienced an alarm condition during the most recent temperature conversion. After every Alarm Search cycle (i.e., Alarm Search command followed by data exchange), the bus master must return to Step 1 (Initialization) in the transaction sequence. See the *Operation—Alarm Signaling* section for an explanation of alarm flag operation.

DS18B20 Function Commands

After the bus master has used a ROM command to address the DS18B20 with which it wishes to communicate, the master can issue one of the DS18B20 function commands. These commands allow the master to write to and read from the DS18B20's scratchpad memory, initiate temperature conversions and determine the power supply mode. The DS18B20 function commands, which are described below, are summarized in Table 3 and illustrated by the flowchart in Figure 14.

Convert T [44h]

This command initiates a single temperature conversion. Following the conversion, the resulting thermal data is stored in the 2-byte temperature register in the scratchpad memory and the DS18B20 returns to its low-power idle state. If the device is being used in parasite power mode, within 10µs (max) after this command is issued the master must enable a strong pullup on the 1-Wire bus for the duration of the conversion (t_{CONV}) as described in the *Powering the DS18B20* section. If the DS18B20 is powered by an external supply, the master can issue read time slots after the Convert T command and the DS18B20 will respond by transmitting a 0 while the temperature conversion is in progress and a 1 when the conversion is done. In parasite power mode this notification technique cannot be used since the bus is pulled high by the strong pullup during the conversion.

Write Scratchpad [4Eh]

This command allows the master to write 3 bytes of data to the DS18B20's scratchpad. The first data byte is written into the T_H register (byte 2 of the scratchpad), the second byte is written into the T_L register (byte 3), and the third byte is written into the configuration register (byte 4). Data must be transmitted least significant bit first. All three bytes MUST be written before the master issues a reset, or the data may be corrupted.

Read Scratchpad [BEh]

This command allows the master to read the contents of the scratchpad. The data transfer starts with the least significant bit of byte 0 and continues through the scratchpad until the 9th byte (byte 8 – CRC) is read. The master may issue a reset to terminate reading at any time if only part of the scratchpad data is needed.

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Copy Scratchpad [48h]

This command copies the contents of the scratchpad T_H, T_L and configuration registers (bytes 2, 3 and 4) to EEPROM. If the device is being used in parasite power mode, within 10µs (max) after this command is issued the master must enable a strong pullup on the 1-Wire bus for at least 10ms as described in the *Powering the DS18B20* section.

Recall E^2 [B8h]

This command recalls the alarm trigger values (T_H and T_L) and configuration data from EEPROM and places the data in bytes 2, 3, and 4, respectively, in the scratchpad memory. The master device can issue read time slots following the Recall E^2 command and the DS18B20 will indicate the status of the recall by transmitting 0 while the recall is in progress and 1 when the recall is done. The recall operation happens automatically at power-up, so valid data is available in the scratchpad as soon as power is applied to the device.

Read Power Supply [B4h]

The master device issues this command followed by a read time slot to determine if any DS18B20s on the bus are using parasite power. During the read time slot, parasite powered DS18B20s will pull the bus low, and externally powered DS18B20s will let the bus remain high. See the *Powering the DS18B20* section for usage information for this command.

Table 3. DS18B20 Function Command Set

COMMAND	DESCRIPTION	PROTOCOL	1-Wire BUS ACTIVITY AFTER COMMAND IS ISSUED	NOTES
TEMPERATURE CONVERSION COMMANDS				
Convert T	Initiates temperature conversion.	44h	DS18B20 transmits conversion status to master (not applicable for parasite-powered DS18B20s).	1
MEMORY COMMANDS				
Read Scratchpad	Reads the entire scratchpad including the CRC byte.	BEh	DS18B20 transmits up to 9 data bytes to master.	2
Write Scratchpad	Writes data into scratchpad bytes 2, 3, and 4 (T_H, T_L, and configuration registers).	4Eh	Master transmits 3 data bytes to DS18B20.	3
Copy Scratchpad	Copies T_H, T_L, and configuration register data from the scratchpad to EEPROM.	48h	None	1
Recall E^2	Recalls T_H, T_L, and configuration register data from EEPROM to the scratchpad.	B8h	DS18B20 transmits recall status to master.	
Read Power Supply	Signals DS18B20 power supply mode to the master.	B4h	DS18B20 transmits supply status to master.	

Note 1: For parasite-powered DS18B20s, the master must enable a strong pullup on the 1-Wire bus during temperature conversions and copies from the scratchpad to EEPROM. No other bus activity may take place during this time.
Note 2: The master can interrupt the transmission of data at any time by issuing a reset.
Note 3: All three bytes must be written before a reset is issued.

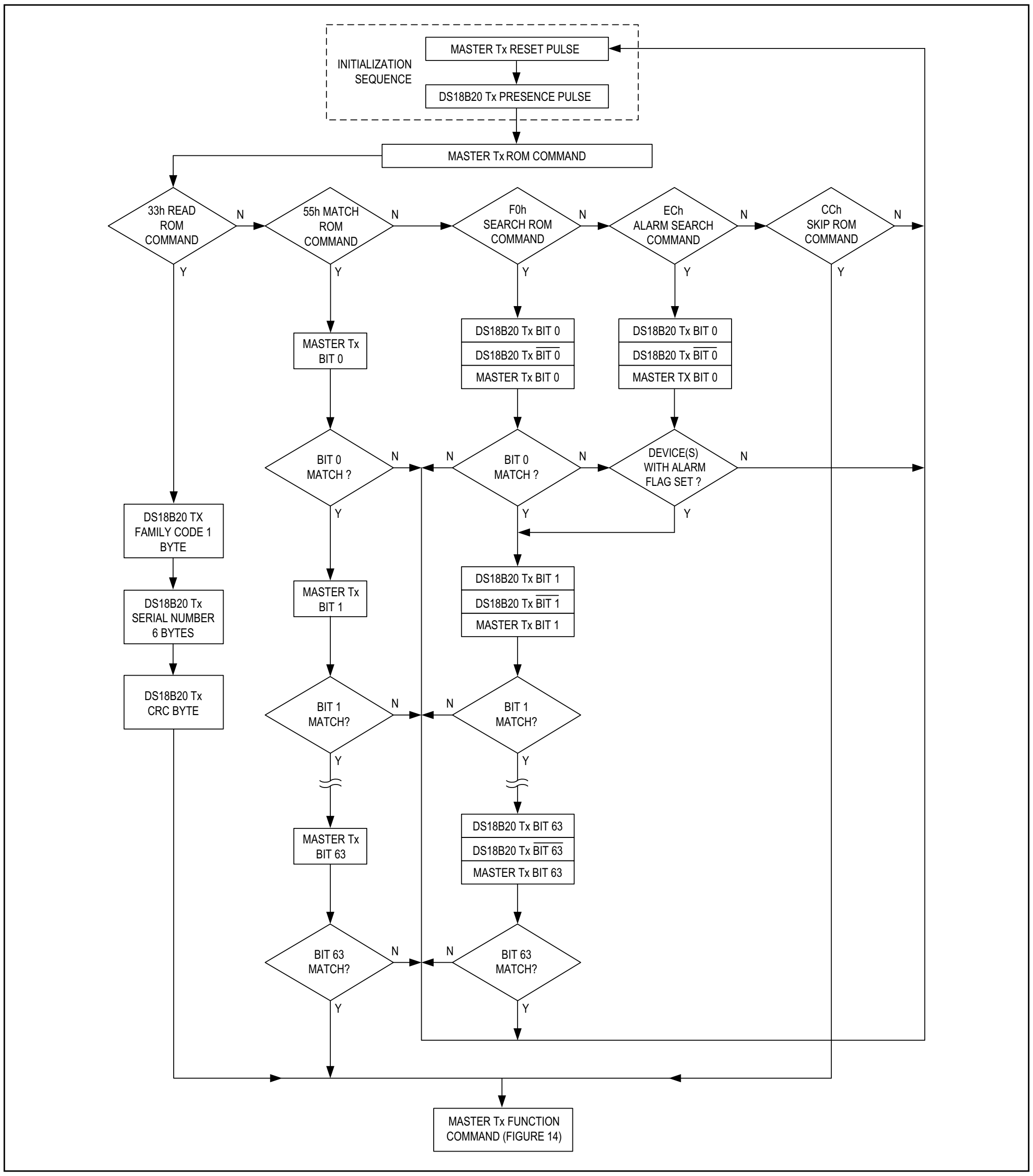


Figure 13. ROM Commands Flowchart

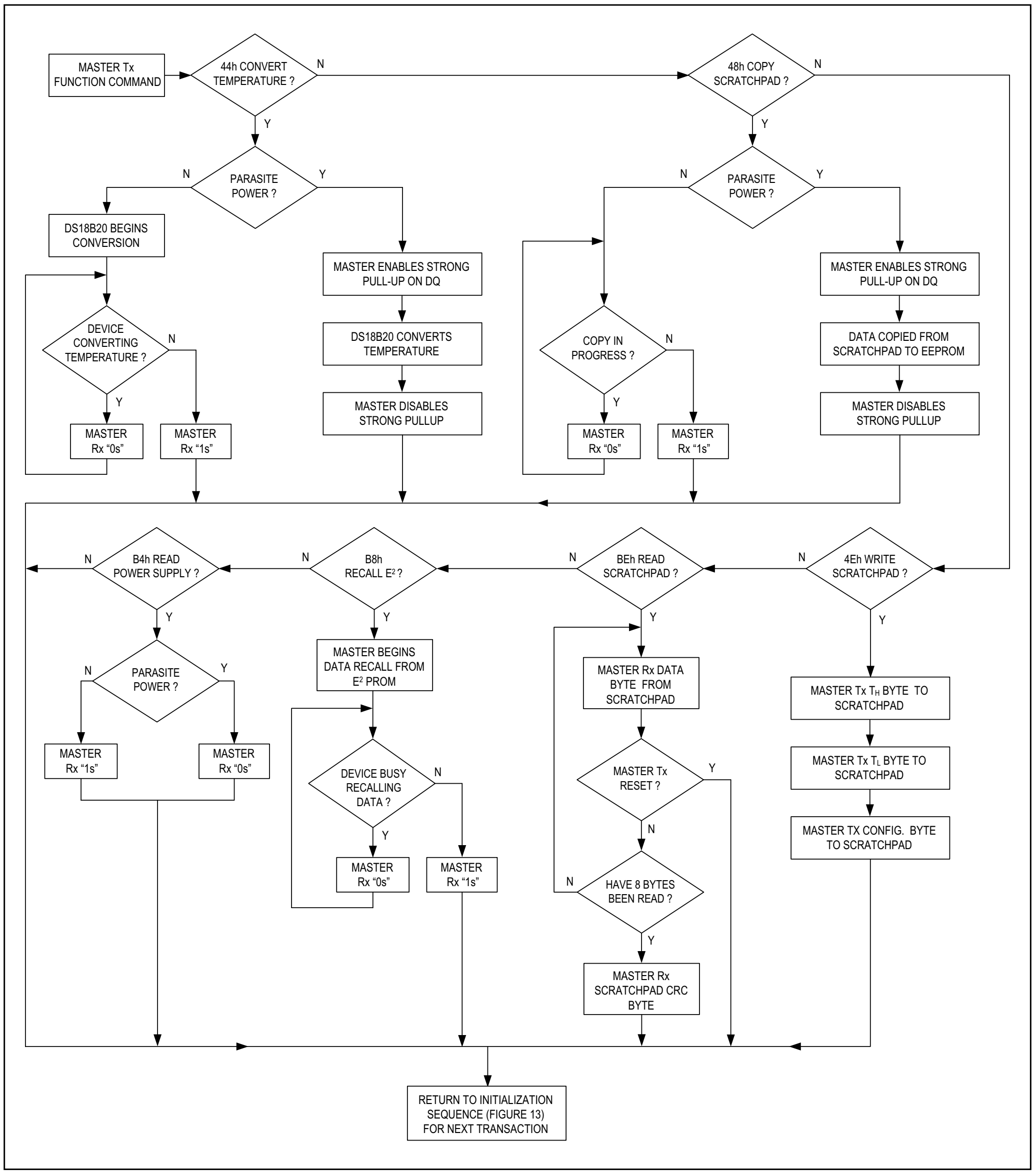


Figure 14. DS18B20 Function Commands Flowchart

1-Wire Signaling

The DS18B20 uses a strict 1-Wire communication protocol to ensure data integrity. Several signal types are defined by this protocol: reset pulse, presence pulse, write 0, write 1, read 0, and read 1. The bus master initiates all these signals, with the exception of the presence pulse.

Initialization Procedure—Reset And Presence Pulses

All communication with the DS18B20 begins with an initialization sequence that consists of a reset pulse from the master followed by a presence pulse from the DS18B20. This is illustrated in Figure 15. When the DS18B20 sends the presence pulse in response to the reset, it is indicating to the master that it is on the bus and ready to operate.

During the initialization sequence the bus master transmits (T_X) the reset pulse by pulling the 1-Wire bus low for a minimum of 480µs. The bus master then releases the bus and goes into receive mode (R_X). When the bus is released, the 5kΩ pullup resistor pulls the 1-Wire bus high. When the DS18B20 detects this rising edge, it waits 15µs to 60µs and then transmits a presence pulse by pulling the 1-Wire bus low for 60µs to 240µs.

Read/Write Time Slots

The bus master writes data to the DS18B20 during write time slots and reads data from the DS18B20 during read time slots. One bit of data is transmitted over the 1-Wire bus per time slot.

Write Time Slots

There are two types of write time slots: “Write 1” time slots and “Write 0” time slots. The bus master uses a Write 1 time slot to write a logic 1 to the DS18B20 and a Write 0 time slot to write a logic 0 to the DS18B20. All write time slots must be a minimum of 60µs in duration with a minimum of a 1µs recovery time between individual write slots. Both types of write time slots are initiated by the master pulling the 1-Wire bus low (see Figure 14).

To generate a Write 1 time slot, after pulling the 1-Wire bus low, the bus master must release the 1-Wire bus within 15µs. When the bus is released, the 5kΩ pullup resistor will pull the bus high. To generate a Write 0 time slot, after pulling the 1-Wire bus low, the bus master must continue to hold the bus low for the duration of the time slot (at least 60µs).

The DS18B20 samples the 1-Wire bus during a window that lasts from 15µs to 60µs after the master initiates the write time slot. If the bus is high during the sampling window, a 1 is written to the DS18B20. If the line is low, a 0 is written to the DS18B20.

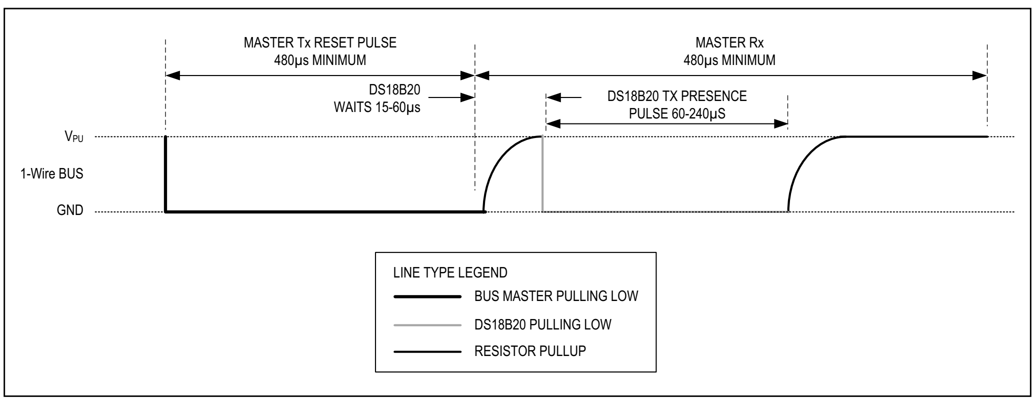


Figure 15. Initialization Timing

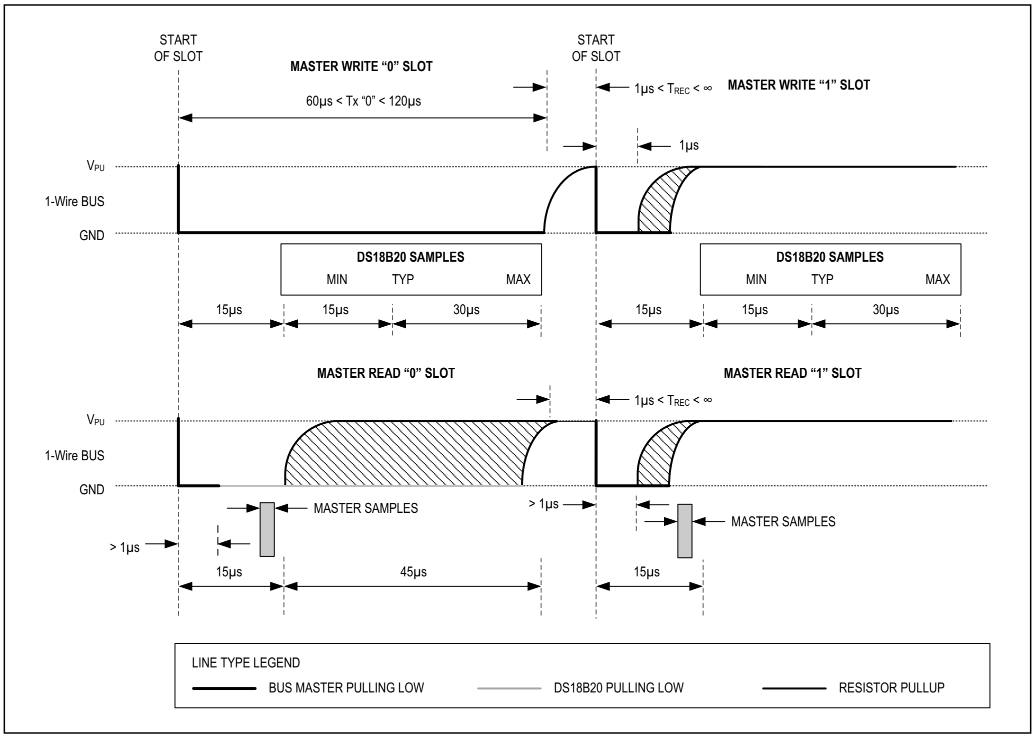


Figure 16. Read/Write Time Slot Timing Diagram

Read Time Slots

The DS18B20 can only transmit data to the master when the master issues read time slots. Therefore, the master must generate read time slots immediately after issuing a Read Scratchpad [BEh] or Read Power Supply [B4h] command, so that the DS18B20 can provide the requested data. In addition, the master can generate read time slots after issuing Convert T [44h] or Recall E^2 [B8h] commands to find out the status of the operation as explained in the *DS18B20 Function Commands* section.

All read time slots must be a minimum of 60µs in duration with a minimum of a 1µs recovery time between slots. A read time slot is initiated by the master device pulling the 1-Wire bus low for a minimum of 1µs and then releasing the bus (see Figure 16). After the master initiates the read time slot, the DS18B20 will begin transmitting a 1 or 0 on bus. The DS18B20 transmits a 1 by leaving the bus high and transmits a 0 by pulling the bus low. When transmitting a 0, the DS18B20 will release the bus by the end of the time slot, and the bus will be pulled back to its high idle state by the pullup resister. Output data from the DS18B20 is valid for 15µs after the falling edge that initiated the read time slot. Therefore, the master must release the bus and then sample the bus state within 15µs from the start of the slot.

Figure 17 illustrates that the sum of T_{INIT}, T_{RC}, and T_{SAMPLE} must be less than 15µs for a read time slot. Figure 18 shows that system timing margin is maximized by keeping T_{INIT} and T_{RC} as short as possible and by locating the master sample time during read time slots towards the end of the 15µs period.

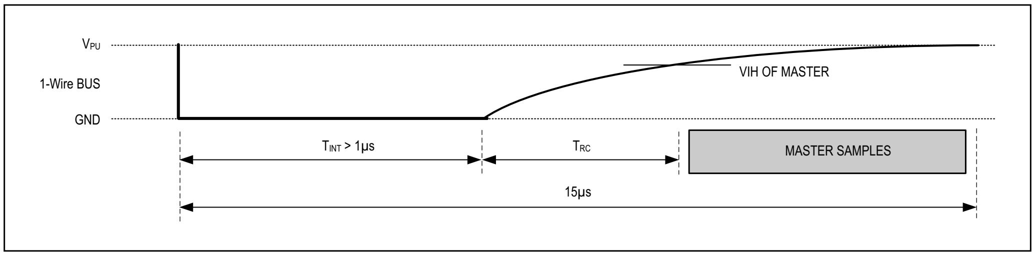


Figure 17. Detailed Master Read 1 Timing

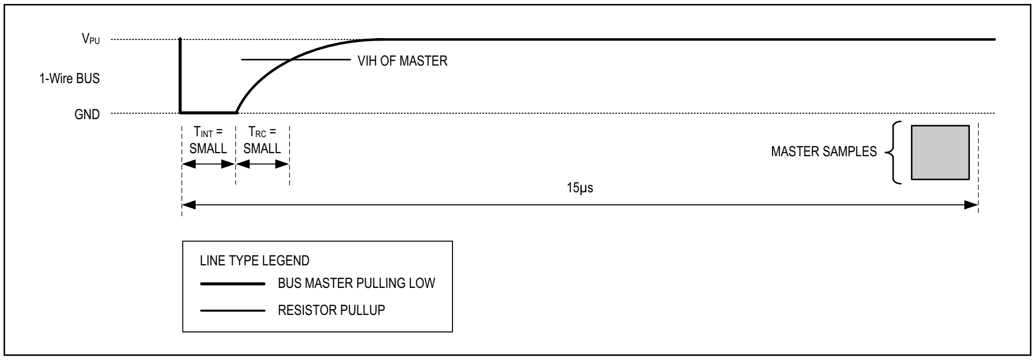


Figure 18. Recommended Master Read 1 Timing

Related Application Notes

The following application notes can be applied to the DS18B20 and are available at www.maximintegrated.com.

Application Note 27: Understanding and Using Cyclic Redundancy Checks with Maxim iButton Products

Application Note 122: Using Dallas' 1-Wire ICs in 1-Cell Li-Ion Battery Packs with Low-Side N-Channel Safety FETs Master

Application Note 126: 1-Wire Communication Through Software

Application Note 162: Interfacing the DS18x20/DS1822 1-Wire Temperature Sensor in a Microcontroller Environment

Application Note 208: Curve Fitting the Error of a Bandgap-Based Digital Temperature Sensor

Application Note 2420: 1-Wire Communication with a Microchip PICmicro Microcontroller

Application Note 3754: Single-Wire Serial Bus Carries Isolated Power and Data

Sample 1-Wire subroutines that can be used in conjunction with *Application Note 74: Reading and Writing iButtons via Serial Interfaces* can be downloaded from the Maxim website.

DS18B20 Operation Example 1

In this example there are multiple DS18B20s on the bus and they are using parasite power. The bus master initiates a temperature conversion in a specific DS18B20 and then reads its scratchpad and recalculates the CRC to verify the data.

MASTER MODE	DATA (LSB FIRST)	COMMENTS
Tx	Reset	Master issues reset pulse.
Rx	Presence	DS18B20s respond with presence pulse.
Tx	55h	Master issues Match ROM command.
Tx	64-bit ROM code	Master sends DS18B20 ROM code.
Tx	44h	Master issues Convert T command.
Tx	DQ line held high by strong pullup	Master applies strong pullup to DQ for the duration of the conversion (t_{CONV}).
Tx	Reset	Master issues reset pulse.
Rx	Presence	DS18B20s respond with presence pulse.
Tx	55h	Master issues Match ROM command.
Tx	64-bit ROM code	Master sends DS18B20 ROM code.
Tx	BEh	Master issues Read Scratchpad command.
Rx	9 data bytes	Master reads entire scratchpad including CRC. The master then recalculates the CRC of the first eight data bytes from the scratchpad and compares the calculated CRC with the read CRC (byte 9). If they match, the master continues; if not, the read operation is repeated.

DS18B20 Operation Example 2

In this example there is only one DS18B20 on the bus and it is using parasite power. The master writes to the TH, TL, and configuration registers in the DS18B20 scratchpad and then reads the scratchpad and recalculates the CRC to verify the data. The master then copies the scratchpad contents to EEPROM.

MASTER MODE	DATA (LSB FIRST)	COMMENTS
Tx	Reset	Master issues reset pulse.
Rx	Presence	DS18B20 responds with presence pulse.
Tx	CCh	Master issues Skip ROM command.
Tx	4Eh	Master issues Write Scratchpad command.
Tx	3 data bytes	Master sends three data bytes to scratchpad (T_H, T_L, and config).
Tx	Reset	Master issues reset pulse.
Rx	Presence	DS18B20 responds with presence pulse.
Tx	CCh	Master issues Skip ROM command.
Tx	BEh	Master issues Read Scratchpad command.
Rx	9 data bytes	Master reads entire scratchpad including CRC. The master then recalculates the CRC of the first eight data bytes from the scratchpad and compares the calculated CRC with the read CRC (byte 9). If they match, the master continues; if not, the read operation is repeated.
Tx	Reset	Master issues reset pulse.
Rx	Presence	DS18B20 responds with presence pulse.
Tx	CCh	Master issues Skip ROM command.
Tx	48h	Master issues Copy Scratchpad command.
Tx	DQ line held high by strong pullup	Master applies strong pullup to DQ for at least 10ms while copy operation is in progress.

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE	TOP MARK
DS18B20	-55°C to +125°C	3 TO-92	18B20
DS18B20+	-55°C to +125°C	3 TO-92	18B20
DS18B20/T&R	-55°C to +125°C	3 TO-92 (2000 Piece)	18B20
DS18B20+T&R	-55°C to +125°C	3 TO-92 (2000 Piece)	18B20
DS18B20-SL/T&R	-55°C to +125°C	3 TO-92 (2000 Piece)*	18B20
DS18B20-SL+T&R	-55°C to +125°C	3 TO-92 (2000 Piece)*	18B20
DS18B20U	-55°C to +125°C	8 FSOP	18B20
DS18B20U+	-55°C to +125°C	8 FSOP	18B20
DS18B20U/T&R	-55°C to +125°C	8 FSOP (3000 Piece)	18B20
DS18B20U+T&R	-55°C to +125°C	8 FSOP (3000 Piece)	18B20
DS18B20Z	-55°C to +125°C	8 SO	DS18B20
DS18B20Z+	-55°C to +125°C	8 SO	DS18B20
DS18B20Z/T&R	-55°C to +125°C	8 SO (2500 Piece)	DS18B20
DS18B20Z+T&R	-55°C to +125°C	8 SO (2500 Piece)	DS18B20

+Denotes a lead-free package. A "+" will appear on the top mark of lead-free packages.

T&R = Tape and reel.

**TO-92 packages in tape and reel can be ordered with straight or formed leads. Choose "SL" for straight leads. Bulk TO-92 orders are straight leads only.*

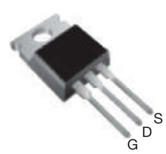
Revision History

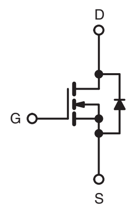
REVISION DATE	DESCRIPTION	PAGES CHANGED
3/1/07	In the Absolute Maximum Ratings section, removed the reflow oven temperature value of +220°C. Reference to JEDEC specification for reflow remains.	19
10/12/07	In the *Operation—Alarm Signaling* section, added “or equal to” in the description for a TH alarm condition	5
	In the *Memory* section, removed incorrect text describing memory.	7
	In the *Configuration Register* section, removed incorrect text describing configuration register.	8
4/22/08	In the *Ordering Information* table, added TO-92 straight-lead packages and included a note that the TO-92 package in tape and reel can be ordered with either formed or straight leads.	2
1/15	Updated *Benefits and Features* section	1
09/18	Updated *DC Electrical Characteristics* table	2
7/19	Updated Figure 12	10

Power MOSFET

PRODUCT SUMMARY		
V_{DS} (V)	60	
$R_{DS(on)}$ (Ω)	V_{GS} = 5.0 V	0.20
Q_g (Max.) (nC)	8.4	
Q_{gs} (nC)	3.5	
Q_{gd} (nC)	6.0	
Configuration	Single	

TO-220AB





N-Channel MOSFET

FEATURES

- Dynamic dV/dt Rating
- Logic-Level Gate Drive
- $R_{DS(on)}$ Specified at V_{GS} = 4 V and 5 V
- 175 °C Operating Temperature
- Fast Switching
- Ease of Paralleling
- Simple Drive Requirements
- Compliant to RoHS Directive 2002/95/EC

Pb Available
RoHS*
COMPLIANT

DESCRIPTION

Third generation Power MOSFETs from Vishay provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness.

The TO-220AB package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 W. The low thermal resistance and low package cost of the TO-220AB contribute to its wide acceptance throughout the industry.

ORDERING INFORMATION	
Package	TO-220AB
Lead (Pb)-free	IRLZ14PbF
	SiHLZ14-E3
SnPb	IRLZ14
	SiHLZ14

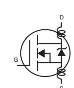
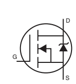
ABSOLUTE MAXIMUM RATINGS (T_C = 25 °C, unless otherwise noted)

PARAMETER			SYMBOL	LIMIT	UNIT
Drain-Source Voltage			V_{DS}	60	V
Gate-Source Voltage			V_{GS}	± 10	
Continuous Drain Current	V_{GS} at 5.0 V	T_C = 25 °C	I_D	10	A
		T_C = 100 °C		7.2	
Pulsed Drain Current[a]			I_{DM}	40	
Linear Derating Factor				0.29	W/°C
Single Pulse Avalanche Energy[b]			E_{AS}	39.5	mJ
Maximum Power Dissipation	T_C = 25 °C		P_D	43	W
Peak Diode Recovery dV/dt[c]			dV/dt	4.5	V/ns
Operating Junction and Storage Temperature Range			T_J, T_{stg}	- 55 to + 175	°C
Soldering Recommendations (Peak Temperature)	for 10 s			300[d]	
Mounting Torque	6-32 or M3 screw			10	lbf · in
				1.1	N · m

Notes
a. Repetitive rating; pulse width limited by maximum junction temperature (see fig. 11).
b. V_{DD} = 25 V, starting T_J = 25 °C, L = 0.79 mH, R_g = 25 Ω, I_{AS} = 10 A (see fig. 12).
c. $I_{SD} \leq$ 10 A, dI/dt ≤ 90 A/μs, $V_{DD} \leq V_{DS}$, $T_J \leq$ 175 °C.
d. 1.6 mm from case.

* Pb containing terminations are not RoHS compliant, exemptions may apply

THERMAL RESISTANCE					
PARAMETER	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Maximum Junction-to-Ambient	R_{thJA}	-	-	62	°C/W
Case-to-Sink, Flat, Greased Surface	R_{thCS}	-	0.50	-	
Maximum Junction-to-Case (Drain)	R_{thJC}	-	-	3.5	

SPECIFICATIONS (T_J = 25 °C, unless otherwise noted)						
PARAMETER	**SYMBOL**	**TEST CONDITIONS**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Static						
Drain-Source Breakdown Voltage	V_{DS}	V_{GS} = 0 V, I_D = 250 µA	60	-	-	V
V_{DS} Temperature Coefficient	$\Delta V_{DS}/T_J$	Reference to 25 °C, I_D = 1 mA	-	0.070	-	V/°C
Gate-Source Threshold Voltage	$V_{GS(th)}$	V_{DS} = V_{GS}, I_D = 250 µA	1.0	-	2.0	V
Gate-Source Leakage	I_{GSS}	V_{GS} = ± 10 V	-	-	± 100	nA
Zero Gate Voltage Drain Current	I_{DSS}	V_{DS} = 60 V, V_{GS} = 0 V	-	-	25	µA
		V_{DS} = 48 V, V_{GS} = 0 V, T_J = 150 °C	-	-	250	
Drain-Source On-State Resistance	$R_{DS(on)}$	V_{GS} = 5.0 V, I_D = 6.0 A[b]	-	-	0.20	Ω
		V_{GS} = 4.0 V, I_D = 5.0 A[b]	-	-	0.28	
Forward Transconductance	g_{fs}	V_{DS} = 25 V, I_D = 6.0 A[b]	3.5	-	-	S
Dynamic						
Input Capacitance	C_{iss}	V_{GS} = 0 V, V_{DS} = 25 V, f = 1.0 MHz, see fig. 5	-	400	-	pF
Output Capacitance	C_{oss}		-	170	-	
Reverse Transfer Capacitance	C_{rss}		-	42	-	
Total Gate Charge	Q_g	V_{GS} = 5.0 V, I_D = 10 A, V_{DS} = 48 V see fig. 6 and 13[b]	-	-	8.4	nC
Gate-Source Charge	Q_{gs}		-	-	3.5	
Gate-Drain Charge	Q_{gd}		-	-	6.0	
Turn-On Delay Time	$t_{d(on)}$	V_{DD} = 30 V, I_D = 10 A, R_g = 12 Ω, R_D= 2.8 Ω see fig. 10[b]	-	9.3	-	ns
Rise Time	t_r		-	110	-	
Turn-Off Delay Time	$t_{d(off)}$		-	17	-	
Fall Time	t_f		-	26	-	
Internal Drain Inductance	L_D	Between lead, 6 mm (0.25") from package and center of die contact 	-	4.5	-	nH
Internal Source Inductance	L_S		-	7.5	-	
Drain-Source Body Diode Characteristics						
Continuous Source-Drain Diode Current	I_S	MOSFET symbol showing the integral reverse p - n junction diode 	-	-	10	A
Pulsed Diode Forward Current[a]	I_{SM}		-	-	40	
Body Diode Voltage	V_{SD}	T_J = 25 °C, I_S = 10 A, V_{GS} = 0 V[b]	-	-	1.6	V
Body Diode Reverse Recovery Time	t_{rr}	T_J = 25 °C, I_F = 10 A, dI/dt = 100 A/µs[b]	-	93	130	ns
Body Diode Reverse Recovery Charge	Q_{rr}		-	0.34	0.65	µC
Forward Turn-On Time	t_{on}	Intrinsic turn-on time is negligible (turn-on is dominated by L_S and L_D)				

Notes
a. Repetitive rating; pulse width limited by maximum junction temperature (see fig. 11).
b. Pulse width ≤ 300 µs; duty cycle ≤ 2 %.

TYPICAL CHARACTERISTICS (25 °C, unless otherwise noted)

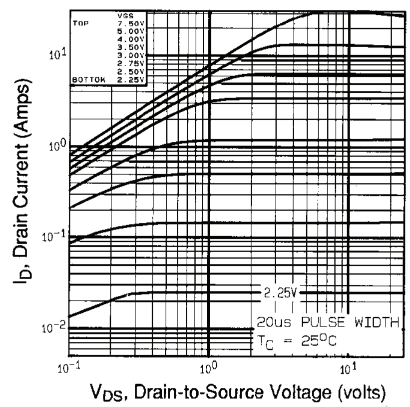


Fig. 1 - Typical Output Characteristics, T_C = 25 °C

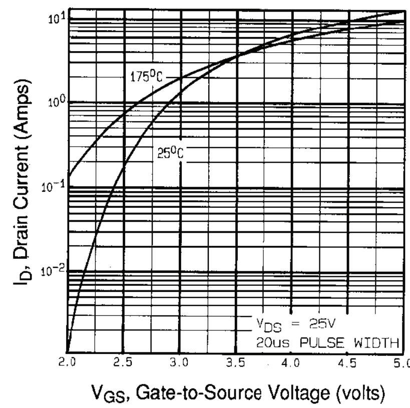


Fig. 3 - Typical Transfer Characteristics

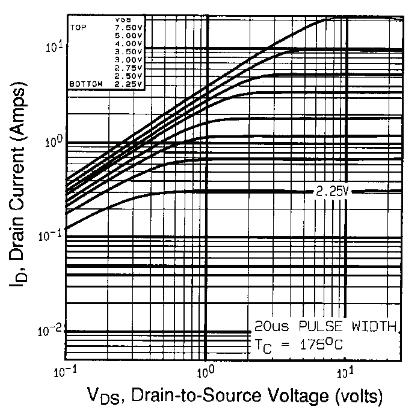


Fig. 2 - Typical Output Characteristics, T_C = 175 °C

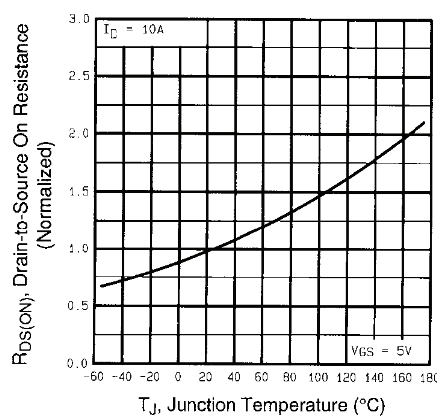


Fig. 4 - Normalized On-Resistance vs. Temperature

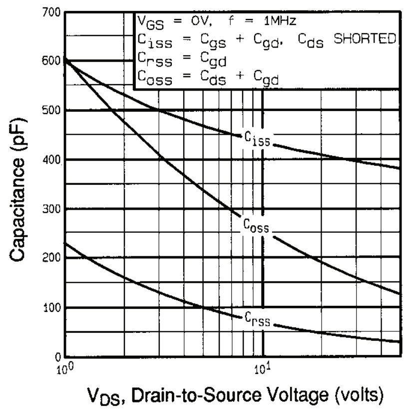


Fig. 5 - Typical Capacitance vs. Drain-to-Source Voltage

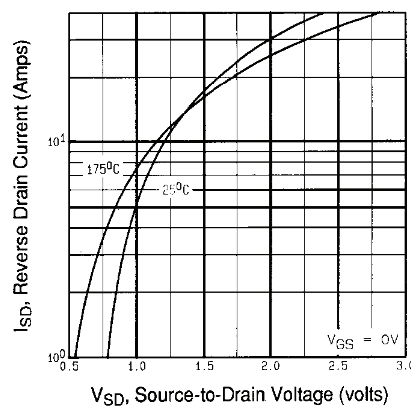


Fig. 7 - Typical Source-Drain Diode Forward Voltage

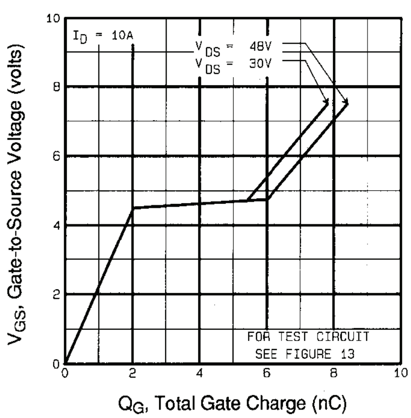


Fig. 6 - Typical Gate Charge vs. Gate-to-Source Voltage

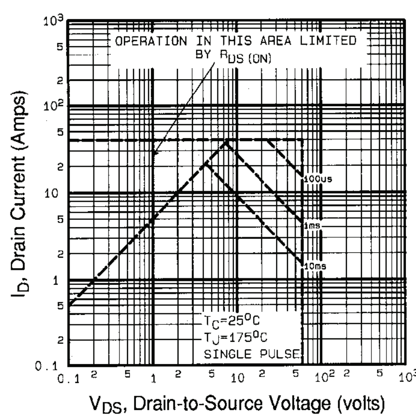


Fig. 8 - Maximum Safe Operating Area

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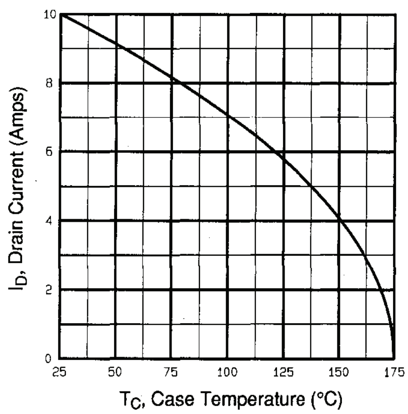


Fig. 9 - Maximum Drain Current vs. Case Temperature

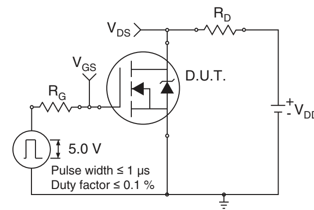


Fig. 10a - Switching Time Test Circuit

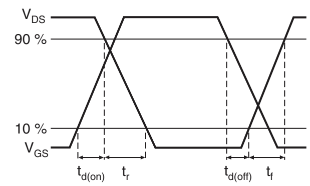


Fig. 10b - Switching Time Waveforms

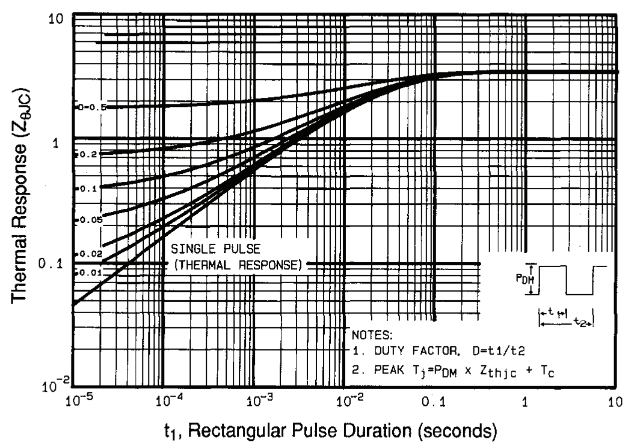


Fig. 11 - Maximum Effective Transient Thermal Impedance, Junction-to-Case

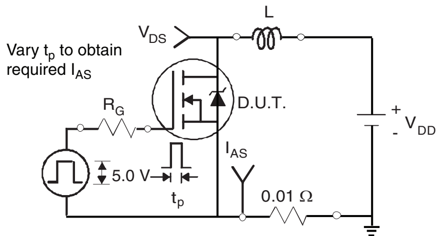


Fig. 12a - Unclamped Inductive Test Circuit

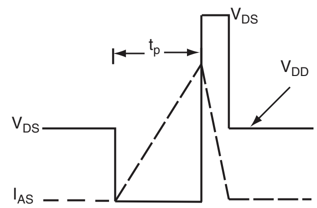


Fig. 12b - Unclamped Inductive Waveforms

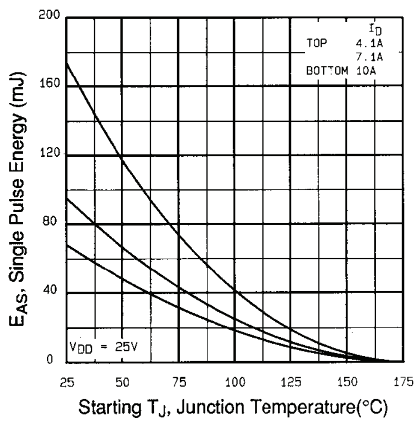


Fig. 12c - Maximum Avalanche Energy vs. Drain Current

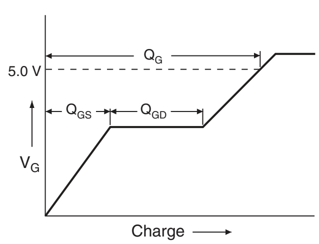


Fig. 13a - Basic Gate Charge Waveform

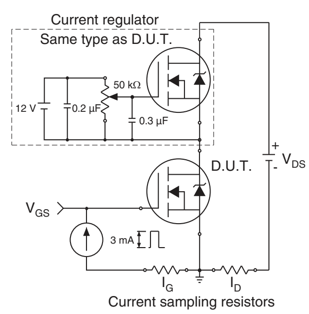
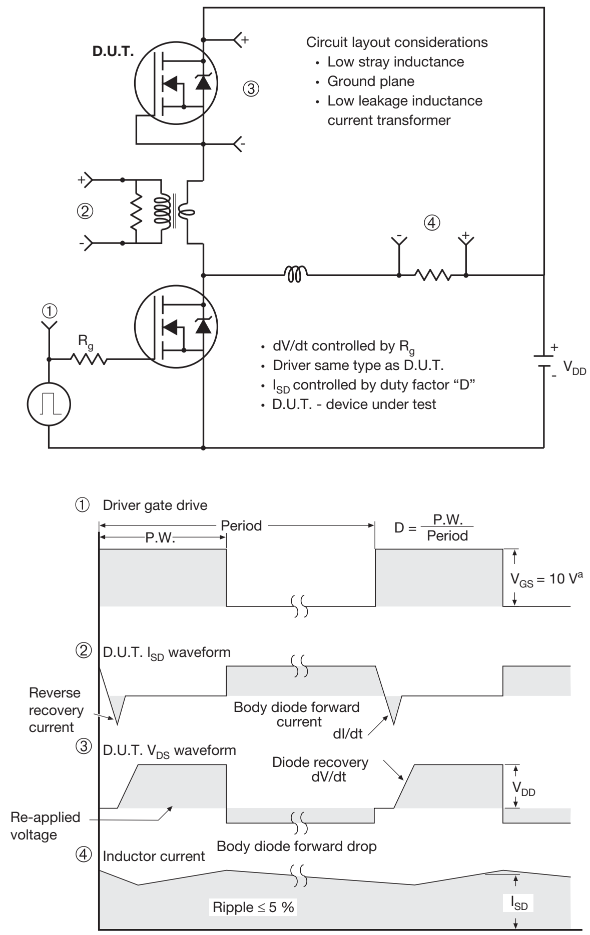


Fig. 13b - Gate Charge Test Circuit

Peak Diode Recovery dV/dt Test Circuit



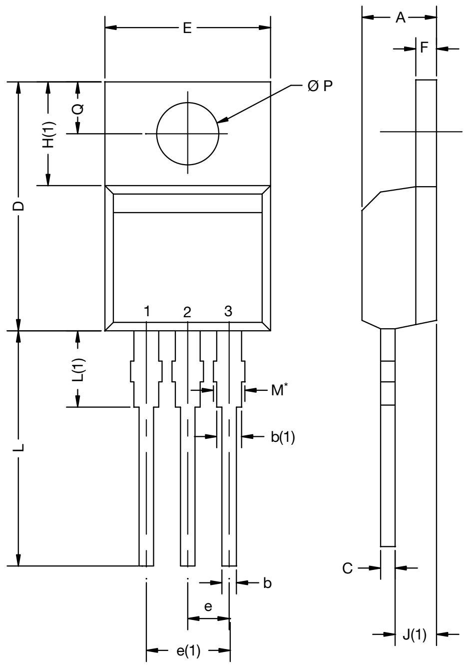
Note

a. V_{GS} = 5 V for logic level devices

Fig. 14 - For N-Channel

Vishay Siliconix maintains worldwide manufacturing capability. Products may be manufactured at one of several qualified locations. Reliability data for Silicon Technology and Package Reliability represent a composite of all qualified locations. For related documents such as package/tape drawings, part marking, and reliability data, see www.vishay.com/ppg?91325.

TO-220-1

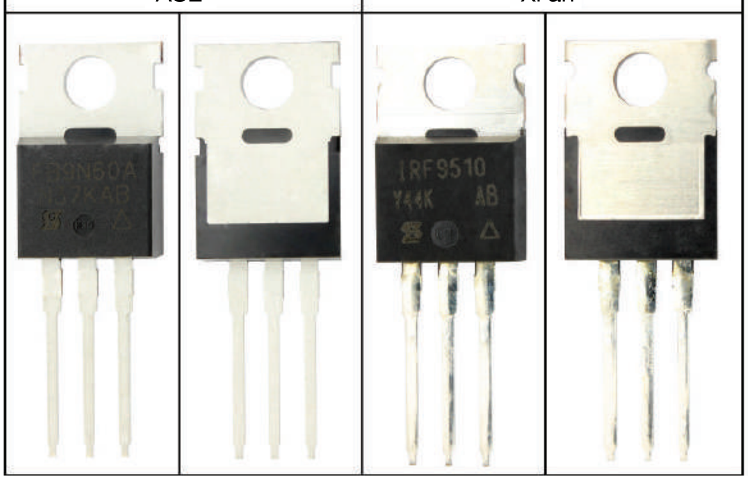


DIM.	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	4.24	4.65	0.167	0.183
b	0.69	1.02	0.027	0.040
b(1)	1.14	1.78	0.045	0.070
c	0.36	0.61	0.014	0.024
D	14.33	15.85	0.564	0.624
E	9.96	10.52	0.392	0.414
e	2.41	2.67	0.095	0.105
e(1)	4.88	5.28	0.192	0.208
F	1.14	1.40	0.045	0.055
H(1)	6.10	6.71	0.240	0.264
J(1)	2.41	2.92	0.095	0.115
L	13.36	14.40	0.526	0.567
L(1)	3.33	4.04	0.131	0.159
Ø P	3.53	3.94	0.139	0.155
Q	2.54	3.00	0.100	0.118
ECN: X15-0364-Rev. C, 14-Dec-15 DWG: 6031				

Note

- M* = 0.052 inches to 0.064 inches (dimension including protrusion), heatsink hole for HVM

Package Picture	
ASE	Xi'an



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JQX-15F(787)

MINIATURE HEAVY DUTY DC ELECTROMAGNETIC RELAY

FEATURES:

1.UL,CUL(E151736),TUV,CQC safety approval.
2. 1 Form A ,1 Form B,1 Form C.
3. Rated Load: 30A240VAC/28VDC,20A240VAC/28VDC.
4. Temperature Range: -55~+85 °C.

ORDERING INFORMATION:

JQX-15F / 012 -- 1H 1
1 2 3 4

1. Model;
2. Part No.(Rated Voltage);
3. Contact Form: 1H=1A;1D=1B;1Z=1C;
4. Terminal: 1: PCB; 6: Plug-in.

SPECIFICATIONS:

Part No.	Rated Voltage (V)	Coil Resistance ±10% (Ω)	Pick-up Voltage (V)	Drop-out Voltage (V)	Norminal Current (mA) (±10%)
005	5	27	3.75	0.5	185
006	6	40	4.5	0.6	150
009	9	97	6.75	0.9	92.8
012	12	155	9.00	1.2	77.4
015	15	256	11.25	1.5	58.6
018	18	380	13.50	1.8	47.3
024	24	660	18	2.4	36.7
048	48	2560	36	4.8	18.75
110	110	13450	82.50	11.0	10.6

CONTACT RATINGS:

Contact Arrangement	1 Form A (SPST-NO)	1 Form C (SPDT)
Max. Switching Power	7200VA/ 840W	4800VA/560W
Max. Switching Voltage	240VAC/28VDC	240VAC/28VDC
Max. Switching Current	30A	20A
Contact Resistance	50m Ω	50mΩ
Initial Contact Resistance	100m Ω	100m Ω
Rating Load	30A/240VAC 28VDC	20A240VAC 28VDC
Contact Material	Ag-CdO	

ENVIRONMENTAL CONDITIONS:

Temperature Range	-55~+85 °C
Relative Humidity	Up to 98% at +40 °C
Atmospheric Pressure	86~106kPa
Vibration	10~55Hz Dual Amplitude 1.65mm
Shock	98m/s^2
Operating Position	Optional

TECHNICAL REQUIREMENTS:

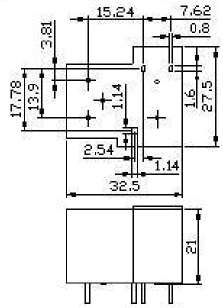
Coil Source	DC
Coil Dissipation	0.9W
Insulation Resistance	1000MΩ
Dieletric Withstanding Voltage (RMS/50Hz)	1500VAC(between contacts) 2500VAC(between coil and contacts)
Electrical Life	1x10^5 Operations
Mechanical Life	1x10^7 Operations
Contact Form	1H(SPST-NO);1D(SPSY-NC);1Z(SPDT).
Operate Time	15ms
Release Time	10ms
Outline and dimension	32.6mm x 27.7mm x 21mm
Weight	34g
Approved standard	UL,CUL(E151736),TUV,CQC

Contact: Jandy Lei Tel./Fax:0086-917-6293906 sxqlljd@hotmail.com

TERMINAL TYPE 1 (T90):

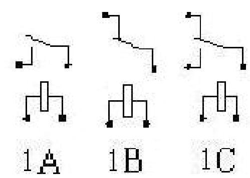
OUTLINE DIMENSIONS:

Tolerance: ±0.20mm.



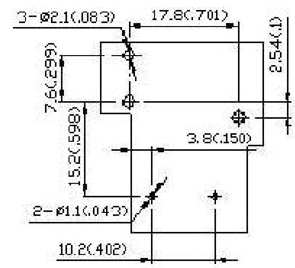
INTERNAL CONNECTIONS:

(Bottom View)



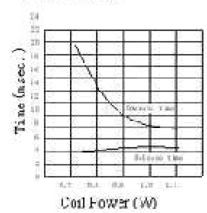
DRILLING PLAN:

(Bottom View)

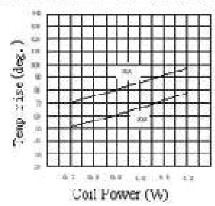


REFERENCIAL DATA:

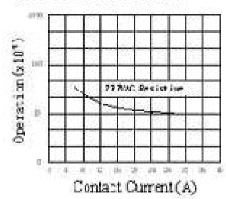
TIMING:



COIL TEMPERATURE RISE:

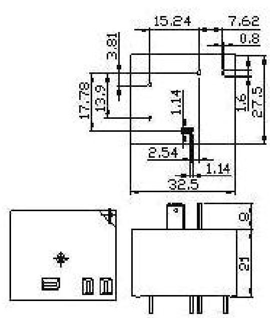


LIFE CURVES:

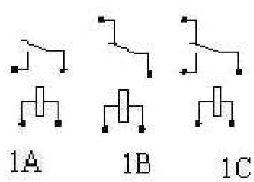


TERMINAL TYPE 6(T91)

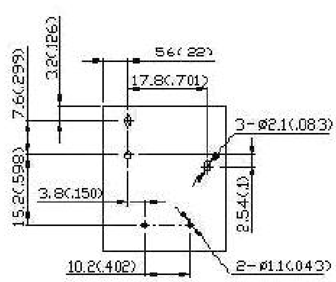
OUTLINE DIMENSIONS:



INTERNAL CONNECTIONS:

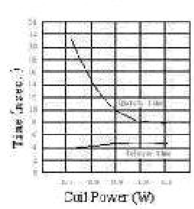


DRILLING PLAN:

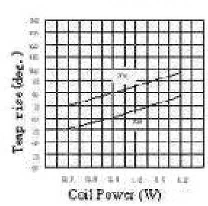


REFERENCIAL DATA:

TIMING:



COIL TEMPERATURE RISE:



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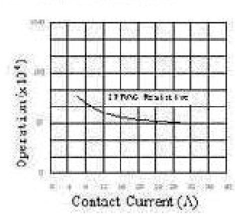


32

IoT RELAY II

Safely control AC power from logic.

Build the IoT. Connect easily and safely. Control power from an Arduino, Raspberry Pi, Galileo or other micro-controller. The universal input connects to any circuit including 3.3V and 5 volt logic. No driver is requried.

Simply connect two wires. One to ground and one to your control signal, such as an output bit on a micro-controller.

The relay can also be controlled by an AC input voltage of 12 to 120VAC. No changes or jumpers are required.

The internal circuitry is very power efficient, using approximately 1/5W unswitched and 1.1W activated.

Applications include:

- IoT products, DIY gadgets, OEM test equipment
- Industrial control and building automation
- Green power / energy conservation
- Kiosks, vending machines and signage controls
- Theater and Pro-Audio power control

Multiple AC loads of up to 12 Amps total may be controlled. Your imagination is the limit.

The IoT control relay is rugged and reliable, with US design and QC. It ships fully assembled and tested with a 1 year warranty. Now in it's second design revision, over 40,000 have been built. Available on Amazon.

0 705020 645490

Digital Loggers, Inc.
2695 Walsh, Santa Clara, CA 95051
Tel: (408) 330-5599 IoTrelay.com

- A single logic input signal controls one high-current SPDT AC relay. This one relay trigger signal switches three AC outlets simultaneously using a single-pole double-throw relay. One outlet normally is on. Two are normally off. A fourth outlet is unswitched. All outlets are proteced against surges and overloads..
- The universal control voltage 3-48VDC or 12-120VAC allows control from virtually any micro or AC source.
- Self-contained design eliminates dangerous high voltage wiring and safety hazards.
- Safety features include:

  3kV optical isolation -- eliminates shock hazard.
  Relay hysteresis -- prevents relay chatter.
  De-bounce protection -- extends contact life.
  LEDs -- verify input voltage and switch state.

- A large 3600W MOV clamps surges for clean power.
- The durable SPDT control relay is rated at 30/40A, 400,000 operations at 12A resistive. At no load, the estimated lifetime is 5.3 million mechanical operations.
- A 12A thermal safety circuit breaker switch prevents overloads and adds supplemental protection.
- Recommended operating range: AC input 90-120VAC. Current 0-8A with 18AWG power cords, 0-12A with 16AWG cord. Use 14AWG for 12A spans over 10 feet.
- Input connector: C-13/C14. Output: 4x NEMA 5-15.
- Included cord: 12" C-13 to 5-15 16AWG. Cords up to 50' length are in-stock.
- Indoor use only: -35F to 145F, 5-95% noncondensing. Not for use on 220V.

LM158/LM258/LM358/LM2904 Low Power Dual Operational Amplifiers

Check for Samples: LM158-N, LM258-N, LM2904-N, LM358-N

FEATURES

- **Available in 8-Bump DSBGA Chip-Sized Package, (See AN-1112 (SNVA009))**
- **Internally Frequency Compensated for Unity Gain**
- **Large DC Voltage Gain: 100 dB**
- **Wide Bandwidth (Unity Gain): 1 MHz (Temperature Compensated)**
- **Wide Power Supply Range:**
  - **Single Supply: 3V to 32V**
  - **Or Dual Supplies: ±1.5V to ±16V**
- **Very Low Supply Current Drain (500 μA)—Essentially Independent of Supply Voltage**
- **Low Input Offset Voltage: 2 mV**
- **Input Common-Mode Voltage Range Includes Ground**
- **Differential Input Voltage Range Equal to the Power Supply Voltage**
- **Large Output Voltage Swing**

UNIQUE CHARACTERISTICS

- **In the Llinear Mode the Input Common-Mode Voltage Range Includes Ground and the Output Voltage Can Also Swing to Ground, even though Operated from Only a Single Power Supply Voltage.**
- **The Unity Gain Cross Frequency is Temperature Compensated.**
- **The Input Bias Current is also Temperature Compensated.**

ADVANTAGES

- **Two Internally Compensated Op Amps**
- **Eliminates Need for Dual Supplies**
- **Allows Direct Sensing Near GND and V_{OUT} Also Goes to GND**
- **Compatible with All Forms of Logic**
- **Power Drain Suitable for Battery Operation**

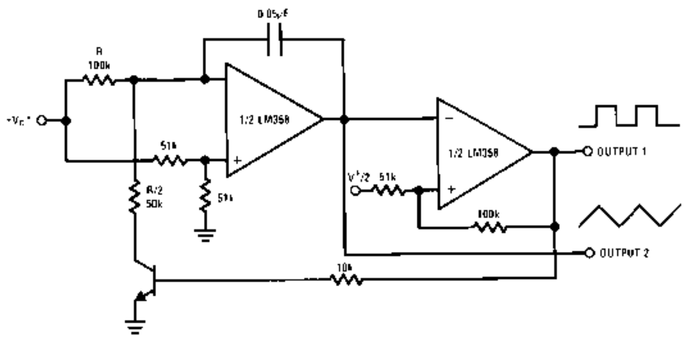
DESCRIPTION

The LM158 series consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

The LM358 and LM2904 are available in a chip sized package (8-Bump DSBGA) using TI's DSBGA package technology.

Voltage Controlled Oscillator (VCO)



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ABSOLUTE MAXIMUM RATINGS(1)(2)

		LM158/LM258/LM358 LM158A/LM258A/LM358A	LM2904
Supply Voltage, V^+		32V	26V
Differential Input Voltage		32V	26V
Input Voltage		−0.3V to +32V	−0.3V to +26V
Power Dissipation(3)			
PDIP (P)		830 mW	830 mW
TO-99 (LMC)		550 mW	
SOIC (D)		530 mW	530 mW
DSBGA (YPB)		435mW	
Output Short-Circuit to GND (One Amplifier)(4)	$V^+ \leq 15V$ and $T_A = 25°C$	Continuous	Continuous
Input Current ($V_{IN} < -0.3V$)(5)		50 mA	50 mA
Operating Temperature Range			
LM358		0°C to +70°C	−40°C to +85°C
LM258		−25°C to +85°C	
LM158		−55°C to +125°C	
Storage Temperature Range		−65°C to +150°C	−65°C to +150°C
Lead Temperature, PDIP (P)			
(Soldering, 10 seconds)		260°C	260°C
Lead Temperature, TO-99 (LMC)			
(Soldering, 10 seconds)		300°C	300°C
Soldering Information			
PDIP Package (P)			
Soldering (10 seconds)		260°C	260°C
SOIC Package (D)			
Vapor Phase (60 seconds)		215°C	215°C
Infrared (15 seconds)		220°C	220°C
ESD Tolerance(6)		250V	250V

(1) Refer to RETS158AX for LM158A military specifications and to RETS158X for LM158 military specifications.
(2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(3) For operating at high temperatures, the LM358/LM358A, LM2904 must be derated based on a +125°C maximum junction temperature and a thermal resistance of 120°C/W for PDIP, 182°C/W for TO-99, 189°C/W for SOIC package, and 230°C/W for DSBGA, which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM258/LM258A and LM158/LM158A can be derated based on a +150°C maximum junction temperature. The dissipation is the total of both amplifiers—use external resistors, where possible, to allow the amplifier to saturate or to reduce the power which is dissipated in the integrated circuit.
(4) Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.
(5) This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V^+voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than −0.3V (at 25°C).
(6) Human body model, 1.5 kΩ in series with 100 pF.

ELECTRICAL CHARACTERISTICS

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(1), $T_A = 25°C$		1	2		2	3		2	5	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25°C$,		20	50		45	100		45	150	nA
	$V_{CM} = 0V$, (2)										
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		2	10		5	30		3	30	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (3) (LM2904, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range										
	$R_L = \infty$ on All Op Amps										
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2		0.5	1.2	mA

(1) $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ −1.5V) at 25°C. For LM2904, V^+ from 5V to 26V.
(2) The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.
(3) The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25°C). The upper end of the common-mode voltage range is V^+ −1.5V (at 25°C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+.

ELECTRICAL CHARACTERISTICS

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	See (1), $T_A = 25°C$		2	7		2	7	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25°C$, $V_{CM} = 0V$, See (2)		45	250		45	250	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		5	50		5	50	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, See (3) (LM2904, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range							
	$R_L = \infty$ on All Op Amps							
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2	mA

(1) $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ −1.5V) at 25°C. For LM2904, V^+ from 5V to 26V.
(2) The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.
(3) The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25°C). The upper end of the common-mode voltage range is V^+ −1.5V (at 25°C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+.

ELECTRICAL CHARACTERISTICS

$V^+ = +5.0V$, See (1), unless otherwise stated

Parameter		Conditions	LM158A Min	LM158A Typ	LM158A Max	LM358A Min	LM358A Typ	LM358A Max	LM158/LM258 Min	LM158/LM258 Typ	LM158/LM258 Max	Units
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25°C$, $R_L \geq 2\ k\Omega$, (For $V_O = 1V$ to $11V$)	50	100		25	100		50	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25°C$, $V_{CM} = 0V$ to $V^+ - 1.5V$	70	85		65	85		70	85		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to $30V$ (LM2904, $V^+ = 5V$ to $26V$), $T_A = 25°C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred), See (2)		−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $T_A = 25°C$, $V_O = 2V$	10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$, $T_A = 25°C$, $V_O = 200\ mV$, $V^+ = 15V$	12	50		12	50		12	50		μA
Short Circuit to Ground		$T_A = 25°C$, See (3), $V^+ = 15V$		40	60		40	60		40	60	mA
Input Offset Voltage		See (4)			4			5			7	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7	15		7	20		7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			30			75			100	nA
Input Offset Current Drift		$R_S = 0\Omega$		10	200		10	300		10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	100		40	200		40	300	nA
Input Common-Mode Voltage Range		$V^+ = 30\ V$, See (5) (LM2904, $V^+ = 26V$)	0		V^+-2	0		V^+-2	0		V^+-2	V
Large Signal Voltage Gain		$V^+ = +15V$ ($V_O = 1V$ to $11V$) $R_L \geq 2\ k\Omega$	25			15			25			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$), $R_L = 2\ k\Omega$	26			26			26			V
		$V^+ = +30V$ (LM2904, $V^+ = 26V$), $R_L = 10\ k\Omega$	27	28		27	28		27	28		V
	V_{OL}	$V^+ = 5V$, $R_L = 10\ k\Omega$		5	20		5	20		5	20	mV

(1) These specifications are limited to $-55°C \leq T_A \leq +125°C$ for the LM158/LM158A. With the LM258/LM258A, all temperature specifications are limited to $-25°C \leq T_A \leq +85°C$, the LM358/LM358A temperature specifications are limited to $0°C \leq T_A \leq +70°C$, and the LM2904 specifications are limited to $-40°C \leq T_A \leq +85°C$.
(2) Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.
(3) Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.
(4) $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ −1.5V) at 25°C. For LM2904, V^+ from 5V to 26V.
(5) The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25°C). The upper end of the common-mode voltage range is V^+ −1.5V (at 25°C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+.

ELECTRICAL CHARACTERISTICS (continued)

$V^+ = +5.0V$, See(1), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$	10	20		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$	10	15		5	8		5	8		mA

ELECTRICAL CHARACTERISTICS

$V^+ = +5.0V$, See(1), unless otherwise stated

Parameter		Conditions	LM358			LM2904			Units
			Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25°C$, $R_L \geq 2\ k\Omega$, (For V_O = 1V to 11V)	25	100		25	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25°C$, V_{CM} = 0V to $V^+-1.5V$	65	85		50	70		dB
Power Supply Rejection Ratio		V^+ = 5V to 30V (LM2904, V^+ = 5V to 26V), $T_A = 25°C$	65	100		50	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred), See(2)		−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25°C$, $V_O = 2V$	10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25°C$, V_O = 200 mV, $V^+ = 15V$	12	50		12	50		μA
Short Circuit to Ground		$T_A = 25°C$, See(3), $V^+ = 15V$		40	60		40	60	mA
Input Offset Voltage		See(4)			9			10	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7			7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			150		45	200	nA
Input Offset Current Drift		$R_S = 0\Omega$		10			10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	500		40	500	nA
Input Common-Mode Voltage Range		V^+ = 30 V, See(5) (LM2904, V^+ = 26V)	0		V^+-2	0		V^+-2	V

(1) These specifications are limited to $-55°C \leq T_A \leq +125°C$ for the LM158/LM158A. With the LM258/LM258A, all temperature specifications are limited to $-25°C \leq T_A \leq +85°C$, the LM358/LM358A temperature specifications are limited to $0°C \leq T_A \leq +70°C$, and the LM2904 specifications are limited to $-40°C \leq T_A \leq +85°C$.
(2) Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.
(3) Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.
(4) $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ −1.5V) at 25°C. For LM2904, V^+ from 5V to 26V.
(5) The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25°C). The upper end of the common-mode voltage range is V^+ −1.5V (at 25°C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+.

ELECTRICAL CHARACTERISTICS (continued)

$V^+ = +5.0V$, See(1), unless otherwise stated

Parameter		Conditions		LM358			LM2904			Units
				Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = +15V$ (V_O = 1V to 11V) $R_L \geq 2$ kΩ		15			15			V/mV
Output	V_{OH}	$V^+ = +30V$	R_L = 2 kΩ	26			22			V
Voltage		(LM2904, V^+ = 26V)	R_L = 10 kΩ	27	28		23	24		V
Swing	V_{OL}	V^+ = 5V, R_L = 10 kΩ			5	20		5	100	mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$		5	8		5	8		mA

TYPICAL PERFORMANCE CHARACTERISTICS

Input Voltage Range

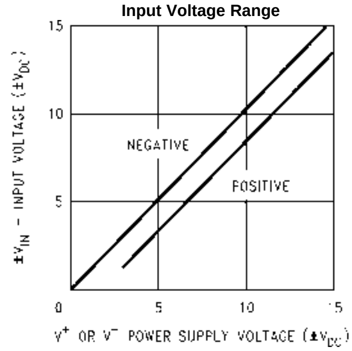


Figure 1.

Input Current

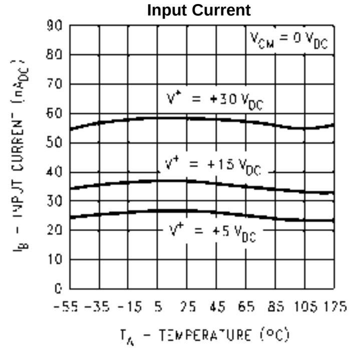


Figure 2.

Supply Current

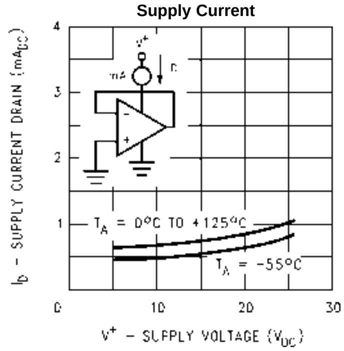


Figure 3.

Voltage Gain

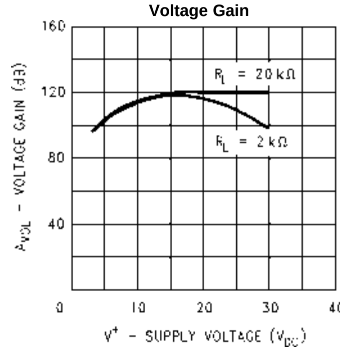


Figure 4.

Open Loop Frequency Response

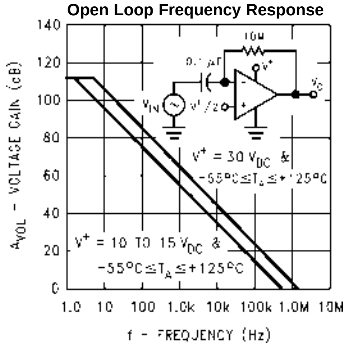


Figure 5.

Common-Mode Rejection Ratio

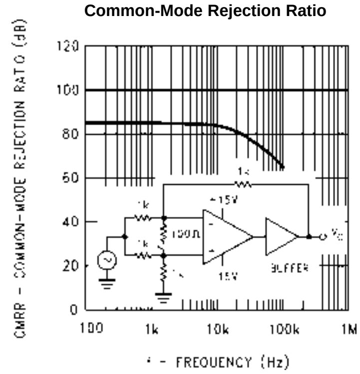


Figure 6.

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

Voltage Follower Pulse Response

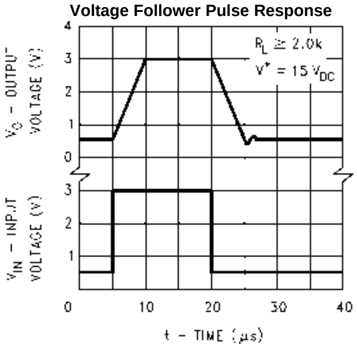


Figure 7.

Voltage Follower Pulse Response (Small Signal)

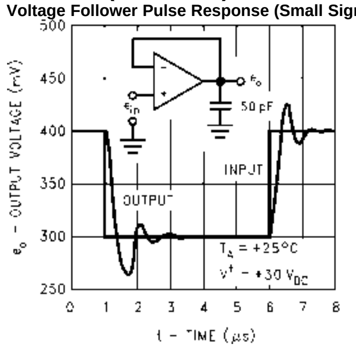


Figure 8.

Large Signal Frequency Response

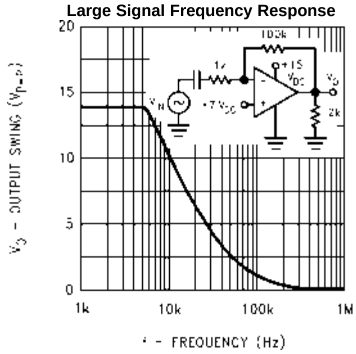


Figure 9.

Output Characteristics Current Sourcing

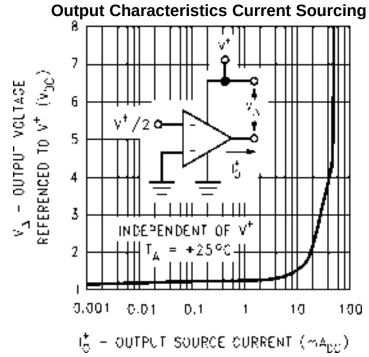


Figure 10.

Output Characteristics Current Sinking

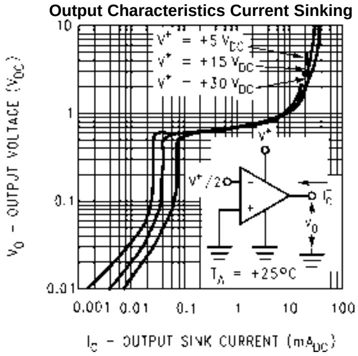


Figure 11.

Current Limiting

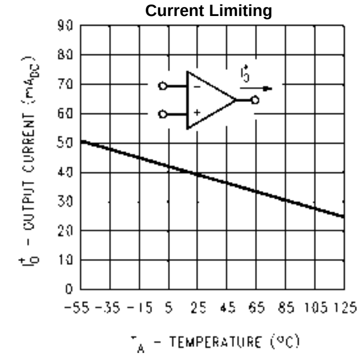


Figure 12.

TYPICAL PERFORMANCE CHARACTERISTICS (continued)

Input Current (LM2902 only)

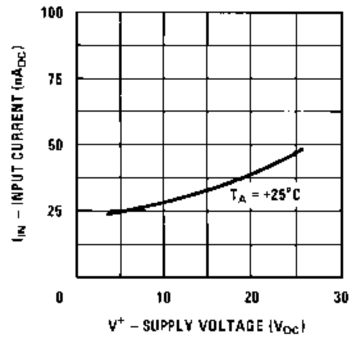


Figure 13.

Voltage Gain (LM2902 only)

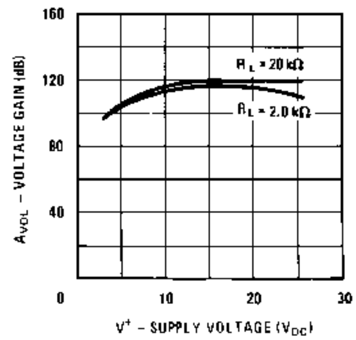


Figure 14.

APPLICATION HINTS

The LM158 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25°C amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC}.

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than −0.3 V_{DC} (at 25°C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply current drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion. Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

The bias network of the LM158 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of 3 V_{DC} to 30 V_{DC}.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive function temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25°C provides a larger output current capability at elevated temperatures (see TYPICAL PERFORMANCE CHARACTERISTICS) than a standard IC op amp.

The circuits presented in the TYPICAL SINGLE-SUPPLY APPLICATIONS emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

CONNECTION DIAGRAM

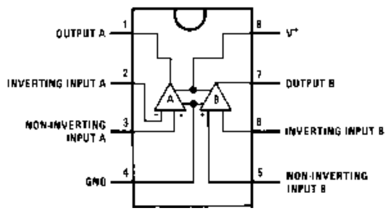


Figure 15. PDIP/CDIP/SOIC Package – Top View (See Package Number P, NAB0008A, or D)

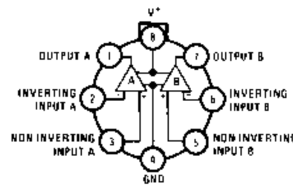


Figure 16. TO-99 Package – Top View (See Package Number LMC)

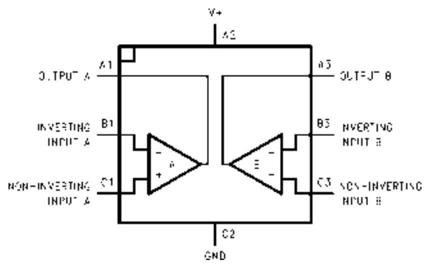
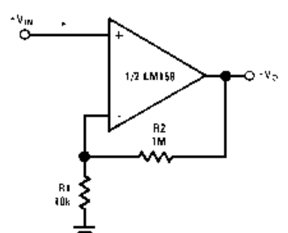


Figure 17. 8-Bump DSBGA - Top View, Bump Side Down (See Package Number YPB0008AAA)

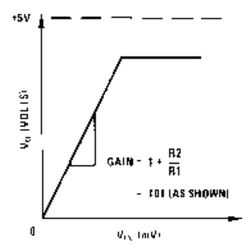
TYPICAL SINGLE-SUPPLY APPLICATIONS

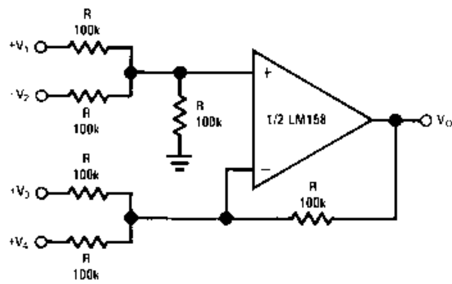
($V^+ = 5.0\ V_{DC}$)

Figure 18. Non-Inverting DC Gain (0V Output)



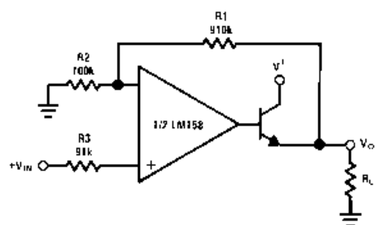
*R not needed due to temperature independent I_{IN}





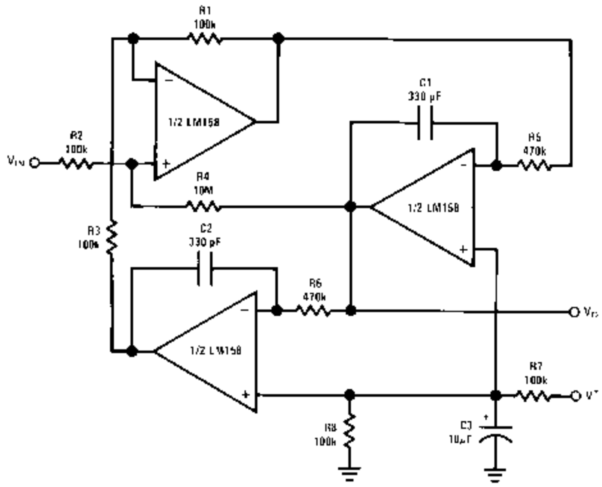
Where: $V_O = V_1 + V_2 - V_3 - V_4$
$(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_O > 0\ V_{DC}$

Figure 19. DC Summing Amplifier ($V_{IN'S} \geq 0\ V_{DC}$ and $V_O \geq 0\ V_{DC}$)



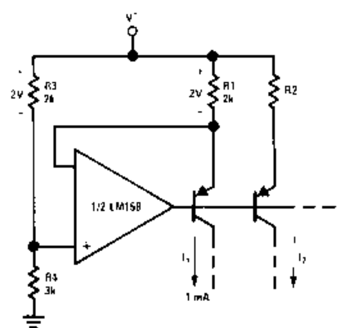
$V_O = 0\ V_{DC}$ for $V_{IN} = 0\ V_{DC}$
$A_V = 10$

Figure 20. Power Amplifier



f_o = 1 kHz
Q = 50
A_v = 100 (40 dB)

Figure 21. “BI-QUAD” RC Active Bandpass Filter



$$I_2 = \left(\frac{R1}{R2}\right) I_1$$

Figure 22. Fixed Current Sources

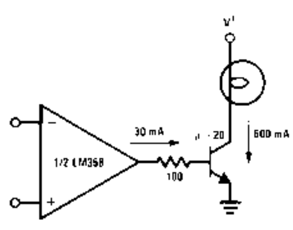


Figure 23. Lamp Driver

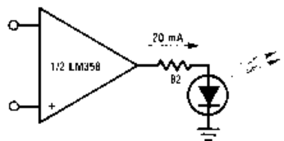
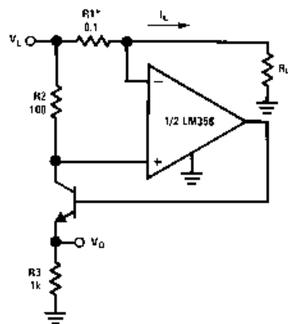


Figure 24. LED Driver



$$V_O = \frac{1V\,(I_L)}{1A}$$

*(Increase R1 for I_L small)
$V_L \leq V^+ - 2V$

Figure 25. Current Monitor

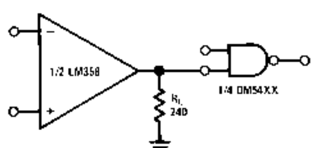
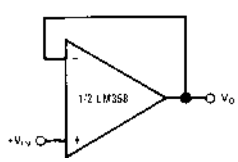


Figure 26. Driving TTL



$V_O = V_{IN}$

Figure 27. Voltage Follower

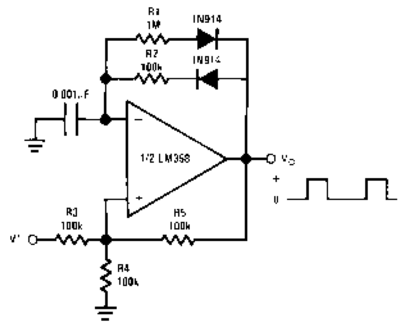


Figure 28. Pulse Generator

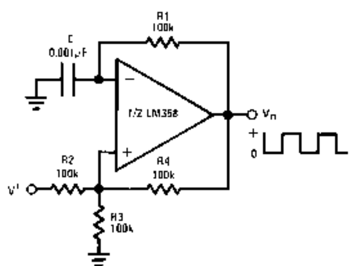


Figure 29. Squarewave Oscillator

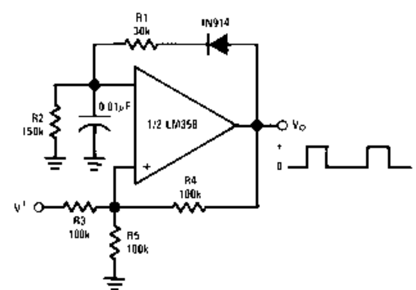
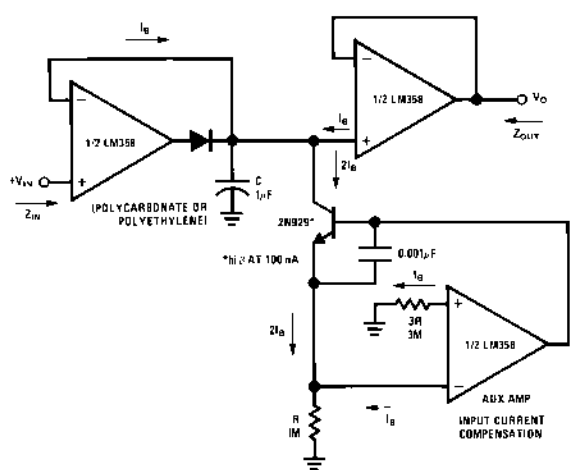
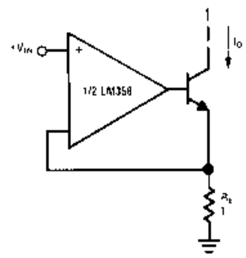


Figure 30. Pulse Generator



HIGH Z_{IN}
LOW Z_{OUT}

Figure 31. Low Drift Peak Detector



I_O = 1 amp/volt V_{IN}
(Increase R_E for I_O small)

Figure 32. High Compliance Current Sink

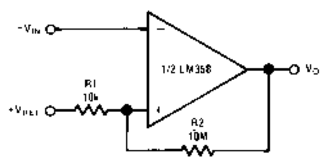
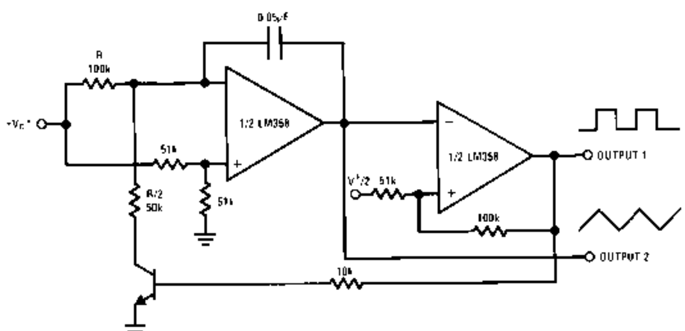
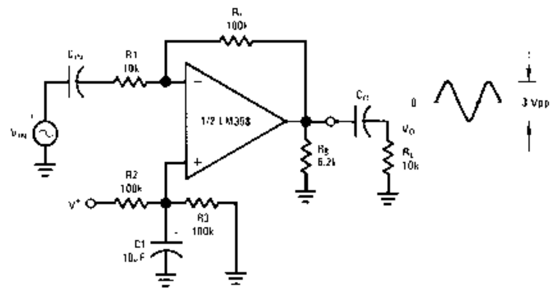


Figure 33. Comparator with Hysteresis



*WIDE CONTROL VOLTAGE RANGE: 0 V_{DC} ≤ V_C ≤ 2 (V^+ −1.5V $_{DC}$)

Figure 34. Voltage Controlled Oscillator (VCO)



$A_V = \frac{R_f}{R1}$ (As shown, $A_V = 10$)

Figure 35. AC Coupled Inverting Amplifier

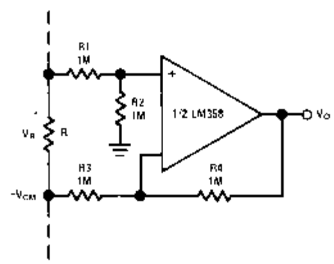
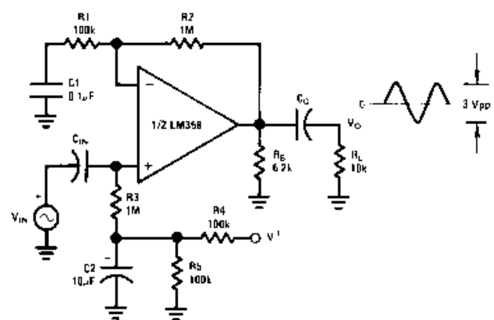


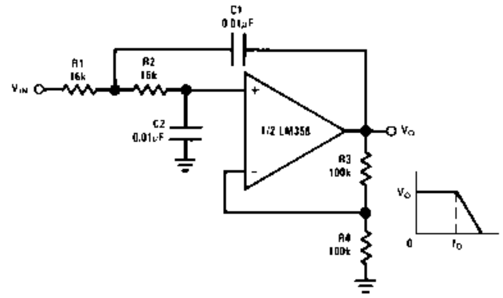
Figure 36. Ground Referencing a Differential Input Signal



$A_V = 1 + \frac{R2}{R1}$

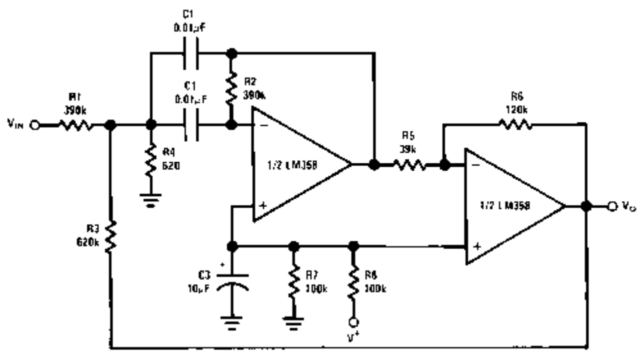
A_V = 11 (As Shown)

Figure 37. AC Coupled Non-Inverting Amplifier



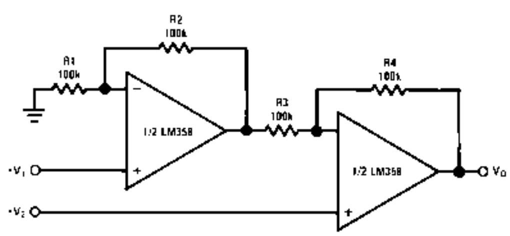
f_o = 1 kHz
Q = 1
A_V = 2

Figure 38. DC Coupled Low-Pass RC Active Filter



f_o = 1 kHz
Q = 25

Figure 39. Bandpass Active Filter



For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$V_O = 1 + \frac{R4}{R3} (V_2 - V_1)$

As Shown: $V_O = 2 (V_2 - V_1)$

Figure 40. High Input Z, DC Differential Amplifier

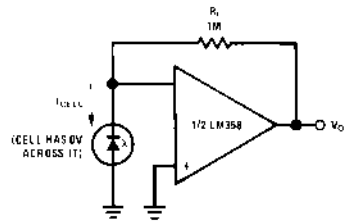
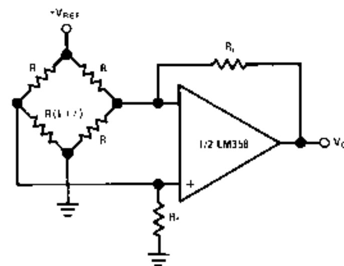


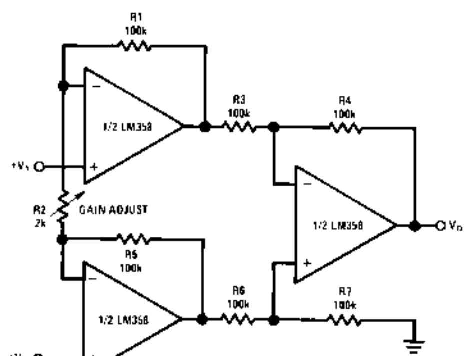
Figure 41. Photo Voltaic-Cell Amplifier



For $\delta << 1$ and $R_f >> R$

$$V_O = V_{REF}\left(\frac{\delta}{2}\right)\frac{R_f}{R}$$

Figure 42. Bridge Current Amplifier



If R1 = R5 & R3 = R4 = R6 = R7 (CMRR depends on match)

$$V_O = 1 + \frac{2R1}{R2}(V_2 - V_1)$$

As shown $V_O = 101 (V_2 - V_1)$

Figure 43. High Input Z Adjustable-Gain DC Instrumentation Amplifier

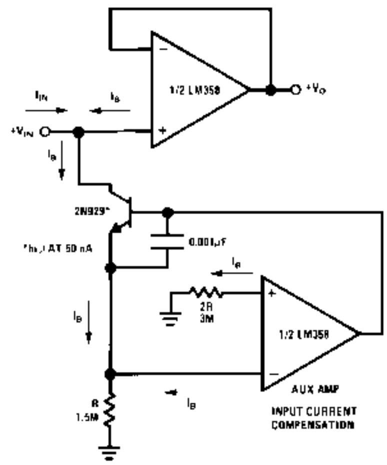
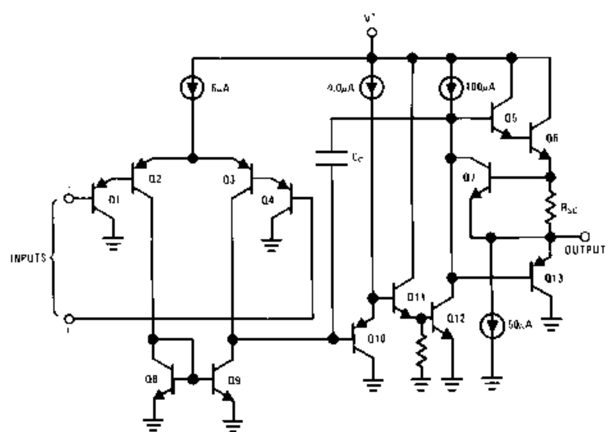


Figure 44. Using Symmetrical Amplifiers to Reduce Input Current (General Concept)

SCHEMATIC DIAGRAM

(Each Amplifier)



REVISION HISTORY

Changes from Revision G (March 2013) to Revision H	Page
• Changed layout of National Data Sheet to TI format	21

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM158AH	ACTIVE	TO-99	LMC	8	500	TBD	Call TI	Call TI	-55 to 125	LM158AH	Samples
LM158AH/NOPB	ACTIVE	TO-99	LMC	8	500	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-55 to 125	LM158AH	Samples
LM158H	ACTIVE	TO-99	LMC	8	500	TBD	Call TI	Call TI	-55 to 125	LM158H	Samples
LM158H/NOPB	ACTIVE	TO-99	LMC	8	500	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-55 to 125	LM158H	Samples
LM158J	ACTIVE	CDIP	NAB	8	40	TBD	Call TI	Call TI	-55 to 125	LM158J	Samples
LM258H	ACTIVE	TO-99	LMC	8	500	TBD	Call TI	Call TI	-25 to 85	LM258H	Samples
LM258H/NOPB	ACTIVE	TO-99	LMC	8	500	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	-25 to 85	LM258H	Samples
LM2904ITP/NOPB	ACTIVE	DSBGA	YPB	8	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	A 09	Samples
LM2904ITPX/NOPB	ACTIVE	DSBGA	YPB	8	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	A 09	Samples
LM2904M	ACTIVE	SOIC	D	8	95	TBD	Call TI	Call TI	-40 to 85	LM 2904M	Samples
LM2904M/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LM 2904M	Samples
LM2904MX	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	-40 to 85	LM 2904M	Samples
LM2904MX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	-40 to 85	LM 2904M	Samples
LM2904N	ACTIVE	PDIP	P	8	40	TBD	Call TI	Call TI	-40 to 85	LM 2904N	Samples
LM2904N/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	-40 to 85	LM 2904N	Samples
LM358AM	ACTIVE	SOIC	D	8	95	TBD	Call TI	Call TI	0 to 70	LM 358AM	Samples
LM358AM/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM 358AM	Samples
LM358AMX	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	0 to 70	LM 358AM	Samples

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM358AMX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM 358AM	Samples
LM358AN	ACTIVE	PDIP	P	8	40	TBD	Call TI	Call TI	0 to 70	LM 358AN	Samples
LM358AN/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	0 to 70	LM 358AN	Samples
LM358H	ACTIVE	TO-99	LMC	8	500	TBD	Call TI	Call TI	0 to 70	LM358H	Samples
LM358H/NOPB	ACTIVE	TO-99	LMC	8	500	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	0 to 70	LM358H	Samples
LM358M	ACTIVE	SOIC	D	8	95	TBD	Call TI	Call TI	0 to 70	LM 358M	Samples
LM358M/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM 358M	Samples
LM358MX	ACTIVE	SOIC	D	8	2500	TBD	Call TI	Call TI	0 to 70	LM 358M	Samples
LM358MX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM 358M	Samples
LM358N	ACTIVE	PDIP	P	8	40	TBD	Call TI	Call TI	0 to 70	LM 358N	Samples
LM358N/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	0 to 70	LM 358N	Samples
LM358TP/NOPB	ACTIVE	DSBGA	YPB	8	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	0 to 70	A 07	Samples
LM358TPX/NOPB	ACTIVE	DSBGA	YPB	8	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	0 to 70	A 07	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

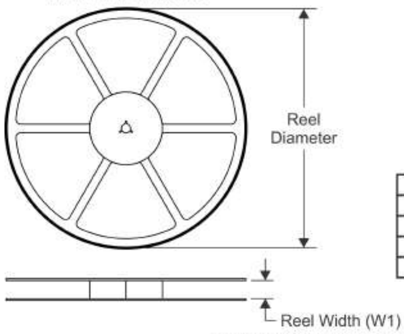
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

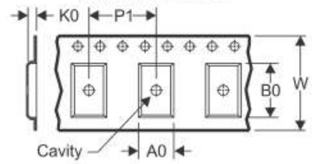
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

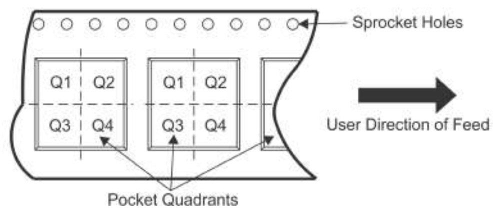


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

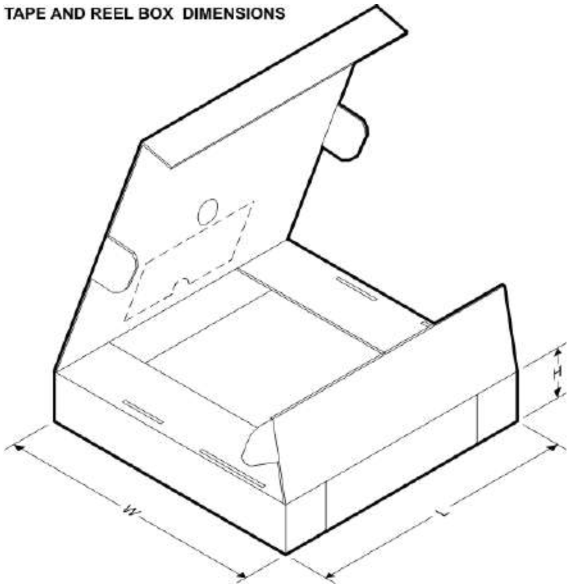
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM2904ITP/NOPB	DSBGA	YPB	8	250	178.0	8.4	1.5	1.5	0.66	4.0	8.0	Q1
LM2904ITPX/NOPB	DSBGA	YPB	8	3000	178.0	8.4	1.5	1.5	0.66	4.0	8.0	Q1
LM2904MX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM2904MX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM358AMX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM358AMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM358MX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM358MX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM358TP/NOPB	DSBGA	YPB	8	250	178.0	8.4	1.5	1.5	0.66	4.0	8.0	Q1
LM358TPX/NOPB	DSBGA	YPB	8	3000	178.0	8.4	1.5	1.5	0.66	4.0	8.0	Q1

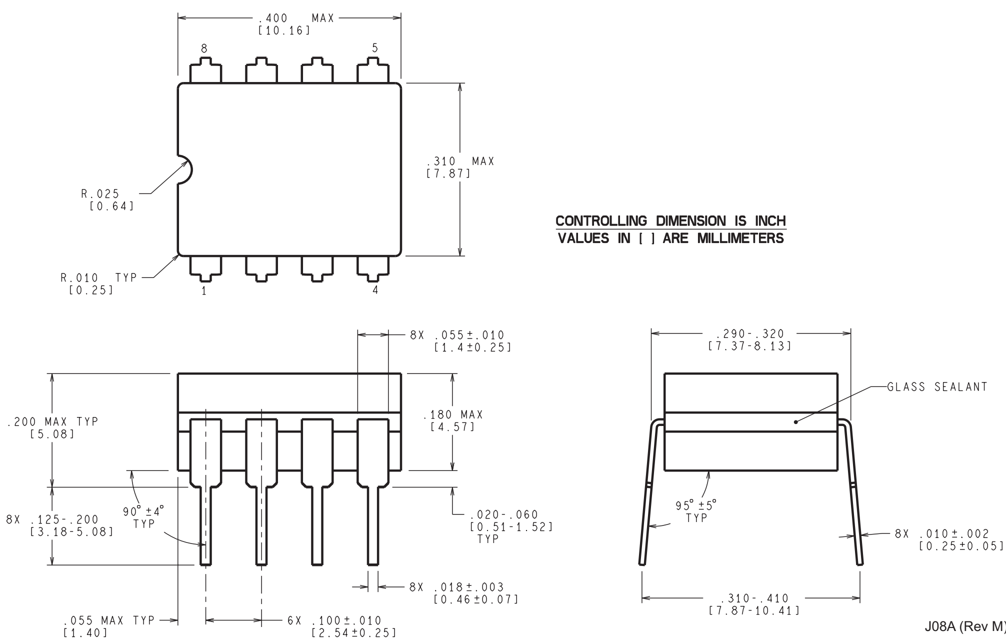
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

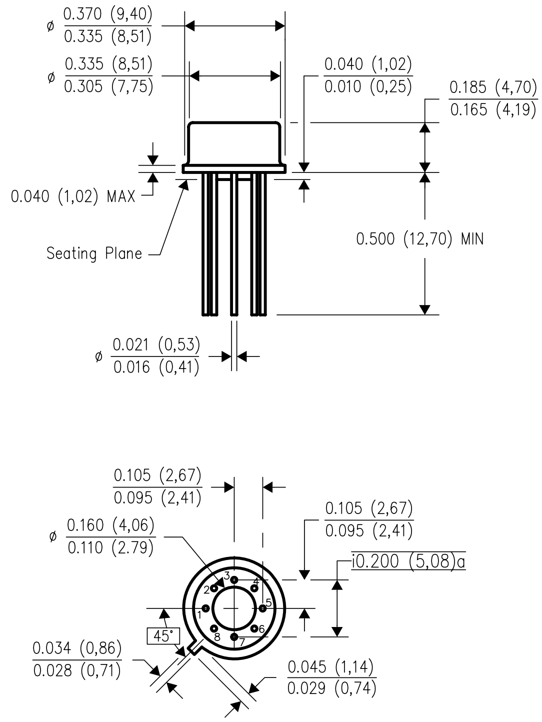
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM2904ITP/NOPB	DSBGA	YPB	8	250	210.0	185.0	35.0
LM2904ITPX/NOPB	DSBGA	YPB	8	3000	210.0	185.0	35.0
LM2904MX	SOIC	D	8	2500	367.0	367.0	35.0
LM2904MX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM358AMX	SOIC	D	8	2500	367.0	367.0	35.0
LM358AMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM358MX	SOIC	D	8	2500	367.0	367.0	35.0
LM358MX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0
LM358TP/NOPB	DSBGA	YPB	8	250	210.0	185.0	35.0
LM358TPX/NOPB	DSBGA	YPB	8	3000	210.0	185.0	35.0

NAB0008A



J08A (Rev M)

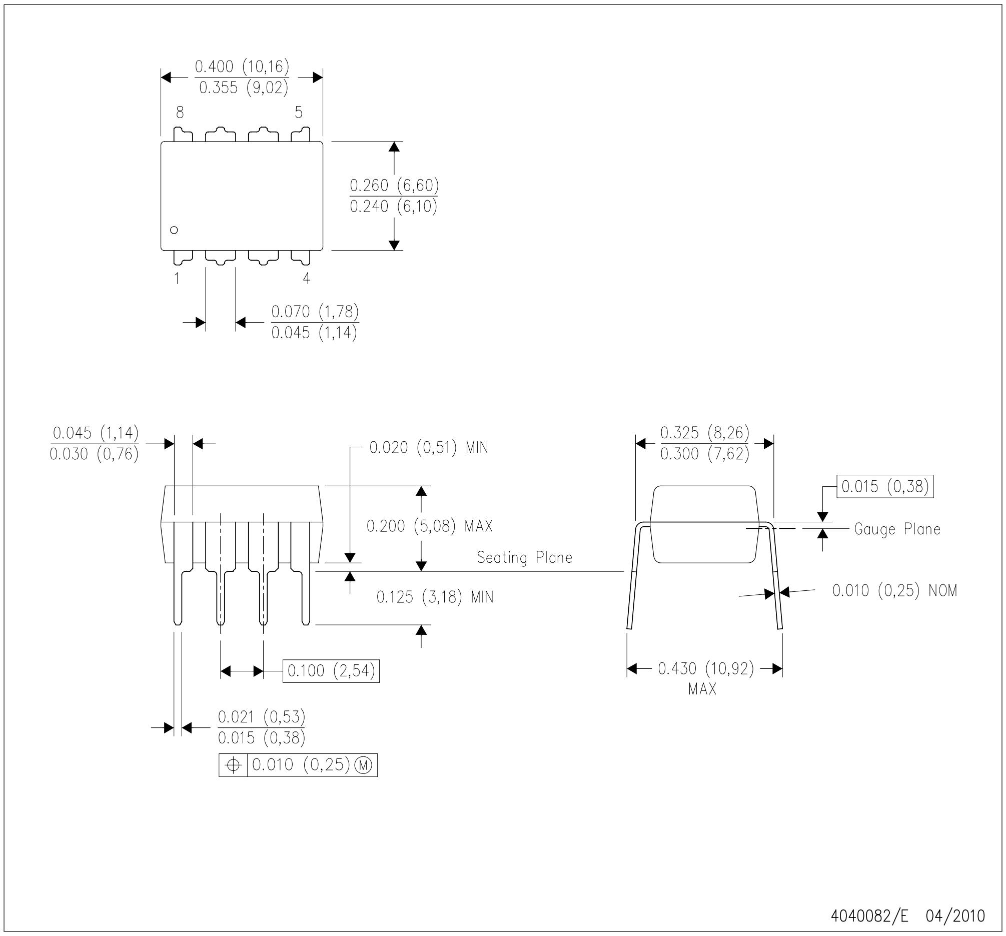
LMC (O–MBCY–W8) METAL CYLINDRICAL PACKAGE



4202483/B 09/07

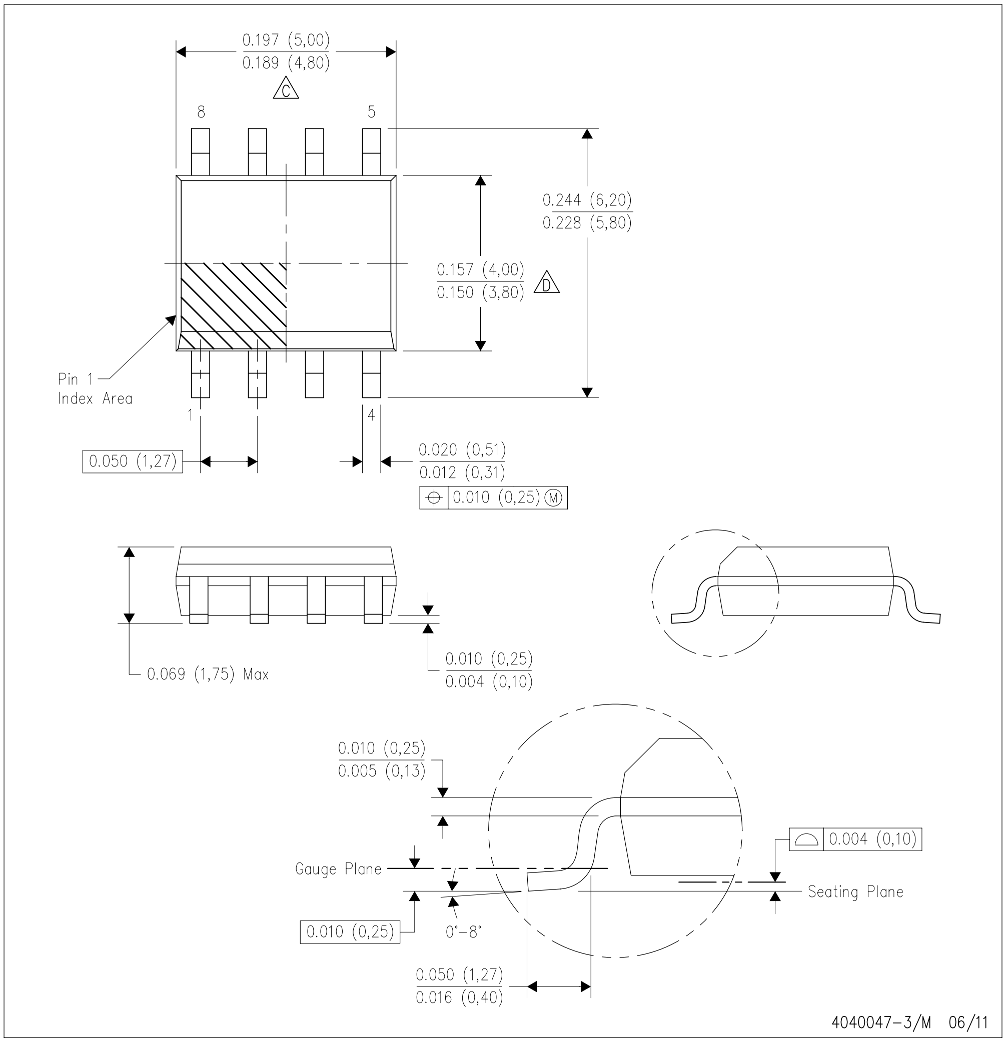
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Leads in true position within 0.010 (0,25) R @ MMC at seating plane.
D. Pin numbers shown for reference only. Numbers may not be marked on package.
E. Falls within JEDEC MO–002/TO–99.

P (R-PDIP-T8) PLASTIC DUAL-IN-LINE PACKAGE



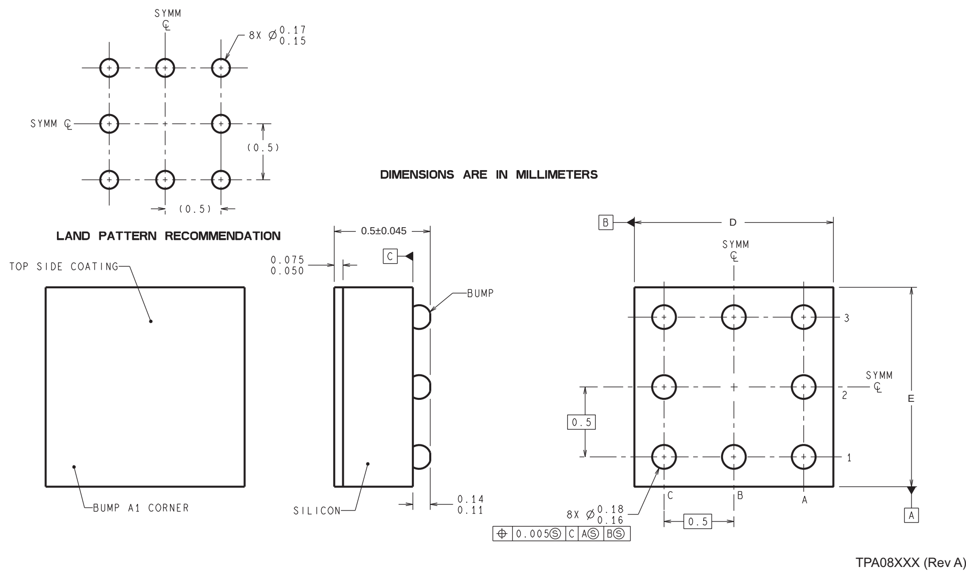
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001 variation BA.

D (R-PDSO-G8) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS-012 variation AA.

YPB0008



D: Max = 1.337 mm, Min =1.276 mm
E: Max = 1.337 mm, Min =1.276 mm

4215100/A 12/12

NOTES: A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
B. This drawing is subject to change without notice.

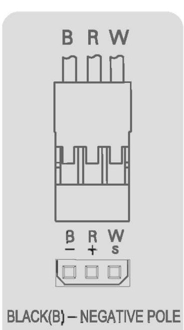
SPRINGRC
www.springrc.com

43R Servo(360^{o} Rotation) Specification

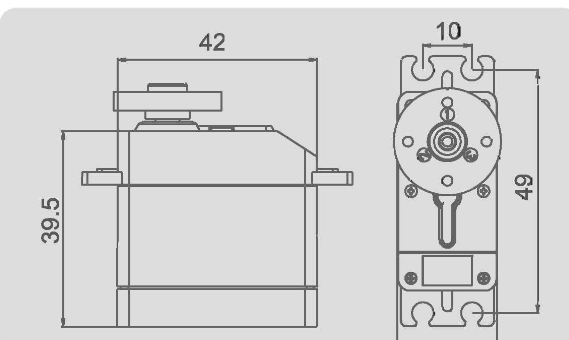
Thank you for choosing Spring Model's product

MODEL	TYPE	WEIGHT		4.8V			6V			DESCRIPTION	
		g	oz	SPEED	TORQUE		SPEED	TORQUE		GEAR	BEARING
				r/min	kg.cm	oz.in	r/min	kg.cm	oz.in		
SM-S4303R	Analog	44	1.55	60	3.3	45.8	70	4.8	66.7	1Metal Gear+ 4Plastic Gear	2
SM-S4306R		44	1.55	60	5.0	69.4	50	6.2	86.1	1Metal Gear+ 4Plastic Gear	2
SM-S4309R		60	2.12	58	7.9	109.7	49	8.7	120.8	Metal Gear	2
SM-S4315R		60	2.12	62	14.5	201.4	53	15.4	213.9	Metal Gear	2

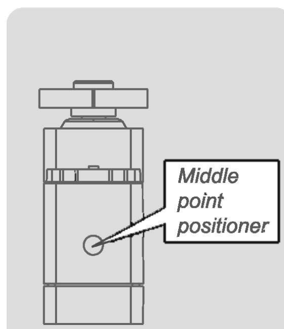
▲ 43R Robot series servo controled via analog signal(PWM),stopped via middle point positiner.
▲ Standard interface(like JR)with 30cm wire.
▲ Rotation and Rest Point Adjustment:when analog signal inputs,servo chooses orientation according to impulse width.when intermediatevalue of impluse width is above 1.5ms, servo is clockwise rotation,conversely,anticlockwise.Rest point need use slotted screwdriver to adjust the positioner carefully.Servo stopped rotation when the input signal is equivalent to impluse width.
▲ Please choose correct model for your application.
Caution: Torque over-loaded will damage the servo's mechanism.
▲ Keep the servo clean and away from dust, corrosive gas and humid air.
▲ Without further notification when some parameters slightly amend for improving quality.



BLACK(B) – NEGATIVE POLE
RED(R) – POSITIVE POLE
WHITE(W) – SIGNAL



Dimension（Unit：mm）



Rest Point Adjustment

SPRING MODEL ELECTRONICS Co.,LTD. MADE IN CHINA XBBS4306R119 V1.0

RoHS CE

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