Helmet Temperature Sensor Project

BME 401 Senior Design Final Report

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Contents

1 Introduction

According to the Center for Disease Control and Prevention, between 1979 and 1997, there were 7,000 deaths related to excessive heat in the U.S.[34]. Heatstroke is a serious concern for athletes, specifically football players, as they exercise in the heat, have a greater risk of dehydration, and wear helmets that block the ventilation of the head. Among U.S. high school athletes, heat illness is the third leading cause of death and disability. Since 2005, 39 football players have died from heatstroke, with 29 of those being high school athletes[2]. Mortality rate and organ damage from heatstroke are directly related to length of time between core temperature elevation and initiation of cooling therapy[2]. Heat illness and heatstroke are preventable if an athlete is warned and seeks appropriate treatment prior to core temperature rising above a certain temperature. In order to prevent further death or injury, a monitoring device needs to be created to detect a football player's core temperature during physical activity and alert them when their temperature is reaching dangerous levels. This monitoring system could prevent death and injury to many players every year.

1.1 Design Requirements

The ultimate goal of the proposed device is to use a thermometry system that is integrated into current football equipment so that the subject can be observed for early indications of heat illness. The design must be able to take a temperature reading and relate it to the core body temperature of the subject. The temperature sensor will need to account for environmental factors in the location of thermometry. The system must be able to relate these temperature readings back to the core temperature of the subject. Should the temperature increase beyond a set threshold, an alarm will warn the athlete that he or she needs to seek medical attention. This threshold will be adjustable, but a general value will be set at 38°C, which has been shown to be related to the onset of heat exhaustion. Any temperature recorded higher than 40.5°C indicates heatstroke, and the subject should be immediately taken to see a medical physician[3].

Special considerations that must be made related to the power lifetime of this system. The power supply needs to be able to run the device for a complete season. The National Football League (NFL) and the National Collegiate Athletic Association (NCAA) - Division I have the two longest football seasons at 26 and 23 weeks, respectively. These lengths represent weeks of team-run preseason, regular season, and postseason activities. NCAA rules do not allow athletes to practice for more than 20 hours per week[4]. Assuming that all players are in full equipment for all 20 hours, the device would need to operate for 460-520 hours. To prevent early failures, a 15% excess should be built in so the device can run for about 600 hours.

The important design requirement is that the system is accurate enough to detect temperature to within 0.1°C[3]. The system must fit inside current football equipment. The weight of the components should not cause a noticeable difference in the equipment's weight distribution and position of the equipment on the athlete. According to the client, the system should weigh no more than 2-3 ounces[5]. The warning signal should be able to easily alert the subject that he or she needs to seek medical attention. This could be a sound in the range of 70-75 decibels (dB)[6], a light visible from 100 yards away[5], or a vibrating component that generates at least 1.2 g[7]. The final product should be easy to use by subjects with limited knowledge of the product and should not be invasive. More specifically, the subject should not be at risk of accidental injury from the system. Reliability and durability are important as well, since accidental alarms would be both disruptive to the game and annoying. Given the impacts the system may experience, it should still be able to operate after impacts up to 300G[5]. At this point in time, the cost of the product is not a concern since a proof of concept is more important.

1.2 Analysis and Design Overview

The Pugh Chart shown in Table 1 summarizes the analysis performed to select the components for the mouthguard temperature and alert system. It was determined that a thermistor would be used to measure oral temperature, and the player would be alerted by means of a vibration motor. The variables are listed by weight of importance, and the criteria used to determine the scoring values are as follows:

10:

- The client's preference represents the primary focus of the project.
- The time constraint is absolute in producing a feasible design for the project, and thus must be considered when weighing options that might require additional amounts of time.
- For a product in close contact with the user, safety is paramount to ensure that that the design minimizes risk of harming the user. Additionally, a product without sufficient safety would not pass regulations.

9:

- Size was the next important variable, as the product could not exist if all components did not fit in the allotted space.

8:

- One of the main functionalities of the system is to measure the temperature of the player, so the accuracy of this measurement is next in terms of importance.
- The other functionality of the system is to alert the player, so the effectiveness of the alert method is equally important.

7:

- As described in the design requirements, the weight of the additional components to the mouth guard should not cause the usage of the product to differ from a standard mouth guard.

6:

- Mouth guards can be and are replaced, so the susceptibility of the product to damage is not paramount. However, it is still relatively important that the mouth guard be sufficiently rugged.

4:

- The client has indicated that since this design is a proof-of-concept, the cost is not of significant concern[5].

		Location: Mouth Guard								
		Infrared Thermometer			Thermistor			Thermocouple		
Variables	**Weight**	Sound Alert	Vibration Alert	Light Alert	Sound Alert	Vibration Alert	Light Alert	Sound Alert	Vibration Alert	Light Alert
Client Preference	10	9	9	9	9	9	9	9	9	9
Time	10	7	7	8	7	7	8	7	7	8
Safety	10	7	7	6	7	7	6	7	7	6
Size	9	6	5	6	7	6	7	7	6	7
Accuracy	8	7	7	7	8	8	8	6	6	6
Alert Efficacy	8	5	9	5	5	9	5	5	9	5
Weight	7	6	5	6	7	6	7	7	6	7
Susceptibility to damage	6	6	6	4	7	7	5	7	7	5
Cost	4	7	7	7	8	8	8	8	8	8
Total		**486**	**502**	**474**	**520**	**536**	**508**	**504**	**520**	**492**

Table 1: Abbreviated Pugh chart, with variables ordered by weight. Note that the thermistor with vibration alert option in the mouth guard scored the highest.

1.2.1 Thermometry Location: Oral Temperature

Oral temperature was found to be the most practical method of measuring a football player's core body temperature. Oral temperature is currently the most popular method used for finding a person's core body temperature. The advantages of oral temperature include the location's easy accessibility and its ability to change quickly with a change in body temperature. Oral temperature tends to be influenced by consumption of cold or hot fluids, as well as irregular breathing patterns. Especially for athletes, rapid breathing through the mouth can prevent accurate measurements form being taken. However, oral thermometry is less volatile than other locations. The preferred location for measurement is under the tongue[3]. For the case of a football player, oral temperature is a potential idea because a mouth guard could be used to integrate the proper technology needed to obtain an oral temperature.

1.2.2 Thermometry Method: Thermistor

It was decided that a thermistor (Figure 1) would be used in the mouth guard to measure the core body temperature. Thermistors are temperature sensors that determine an object's temperature by direct contact. Thermistors are made out of semiconductor material, and their resistance varies with temperature, hence their name. When a temperature change occurs, the resistance changes by an expected amount[8]. Thermistors exist as either negative or positive temperature coefficient types, with the negative temperature coefficient type being the most common. Thermistors can be accurate to within $\pm 0.1°C$ and can measure over a wide range of temperatures, depending on the chosen thermistor resistance[9].

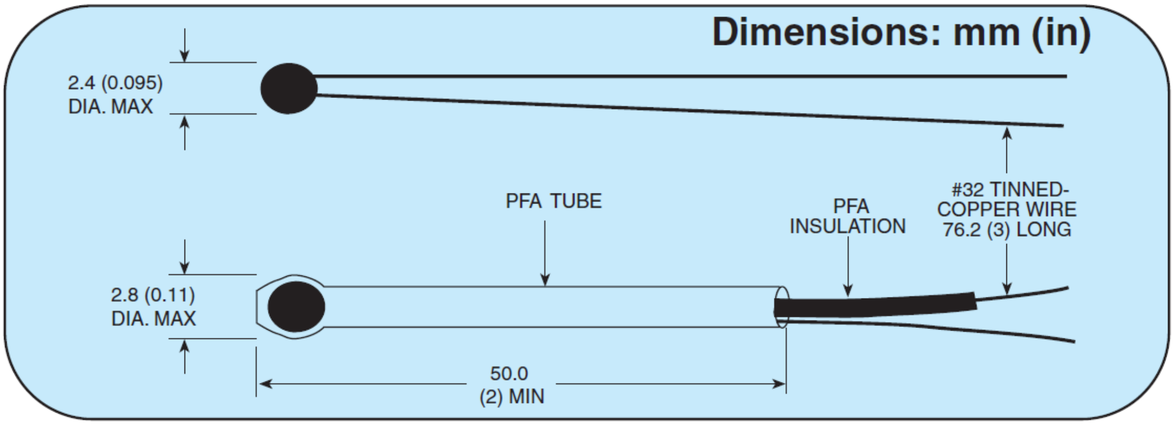
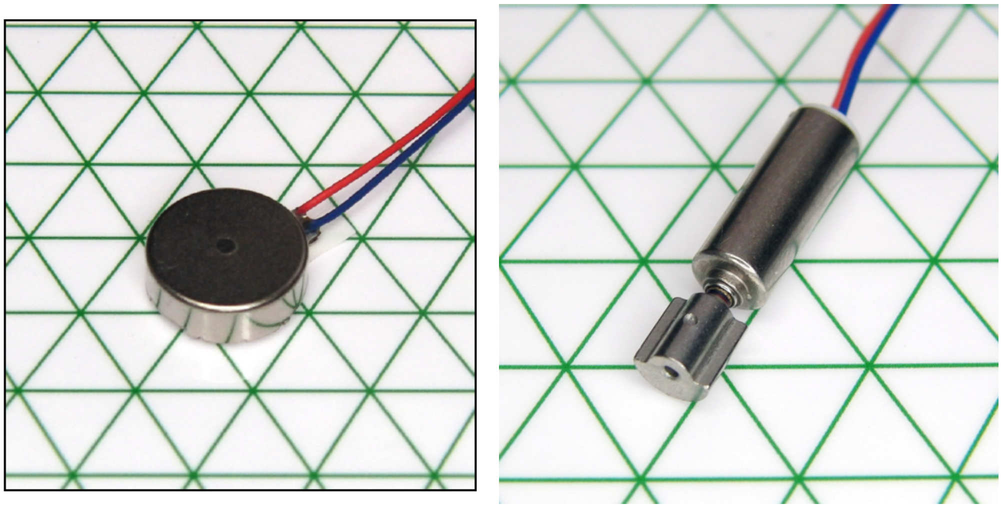


Figure 1: Typical thermistor components, with size specifications, of an Omega thermistor. The thermistors are small but provide good accuracy. Source: Omega Engineering

1.2.3 Alert Method: Vibration Motor

A coin vibration motor, also known as a shaftless or pancake vibration motor, has been chosen as a player-targeted alert system for informing the athlete that the core body temperature is above the set threshold. In comparison to other methods, such as sound stimuli, visual stimuli, or alerting other people, vibration offers the most effective, direct, and safe method of alerting the player.

A coin vibration motor was chosen over rod-shaped motors for several reasons. The coin shape offers a relatively flat profile, in comparison to the rod-shaped motor. Additionally, the complete encapsulation of the eccentric mass in the coin motor means that the motor can be placed directly into an injection mold for mouth guard manufacturing, while the rod-shaped motor would require additional encapsulation to protect the eccentric mass during injection molding, further increasing the profile, as well as increasing the engineering cost. Figure 2 shows an example of each type of motor.



(a) (b)

Figure 2: Two types of vibration motors are pictured on 6mm isometric backgrounds, a coin (a) and a rod-shaped vibration motor (b). Note the exposed eccentric mass on the rod-shaped motor. Source: Precision Microdrives

1.2.4 Power Requirement: Battery

A button cell, lithium battery has been chosen to power the mouth guard temperature sensor and alert system. The three considerations for the optimal power supply for the device are the voltage and current levels of the battery, the battery size, and the safety of the battery materials. Each type of battery has its own set of advantages and drawbacks based on the chemical reactions in the battery. Chemical battery cells are small enough to fit into current equipment and deliver enough energy to run the sensor and alert system. Small batteries such as the button cell type, whose chemical reaction is specifically formulated to power low drain devices for an extended period of time, are an appropriate option for the system[10].

1.2.5 Type of Mouth Guard

For this project, the stock mouth guard from Shock Doctor™ was used for design measurements and integration of the sensor and alert system components. When the parts of the system are being integrated into the mouth guard, the dimensions of the mouth guard can affect the the ability of different components to be used. There are three main types of mouth guards – stock, boil-and-bite, and custom-fit mouth guards. The stock model is the most viable option because it does not need to be custom made for each person and does not risk being crushed when fitted to an individual's mouth. Although stock mouth guards provide less protection than the other two types, it is inexpensive and provides the most space for incorporation of the system components[11].

2 Analysis and Design of Components

Because space is a major constraint for this design, the selection of parts used for the circuitry is largely driven by the parts capabilities and their size. Based on general dimensions of comercially available mouth guards and their straps, rough dimensional requirements were identified. The next step was to identify parts that had the capabilities to implement the device. When multiple parts fulfilled the system requirements and were small enough, the part with the lower power consumption was selected. Table 2 shows the individual parts needed for the device.

Parts	Model Number
Thermistor	ON-909-44034 OMEGA surface sensing
Battery	CR1225 3V Lithium Cell Battery
Battery Cell Holder	HU1225-LF Through-hole battery holder
Microprocessor	MSP430F2003IPW Mixed Signal Microcontroller
Vibrating Motor	310-013 Pico Vibe 10mm Vibration Motor
Operational Amplifier	LM321MF Low Power Single Op Amp
Resistor	CH0402-20RJPT, Thin Film Microwave Resistor
Additional Wires	Primary Wire 1120103

Table 2: Parts and the specific models used int he device were selected based on the design specifications as well as size.

2.1 Thermistor

There are many different types of thermistors that are used for various purposes. Omega provides a good guide to choosing a proper thermistor. There are three pieces of information necessary to choose a thermistor. First, the proper base resistance needs to be found for the application of the thermistor. Second, a resistance versus temperature needs to be specified. Finally, the proper thermistor size and sensor package style needs to be chosen[9].

2.1.1 Base Resistance

When the target temperature of the thermistor is between -55°C and 70°C, a lower base resistance thermistor is ideal. The cody bore temperature should never go beyond the range of 30°C to 45°C, so a thermistor with a lower base resistance will work well this application[9].

2.1.2 Resistance vs. Temperature Relationship

Thermistors do not have standards that are associated with their resistance vs. temperature characteristics. Each type of metal creates a different resistance vs. temperature relationship. Companies will often label a constant β between two specified temperatures on a thermistor so that the relationship can be determined. Table 3 displays some of the thermistors with smaller base resistances and their resistance change per degree Celsius. It would be ideal to have a larger resistance change per degree Celsius to provide for more accuracy in the temperature readings[9].

Thermistor Model Number	Resistance at 25°C	Resistance Change per °C
44004	2252 Ω	30.7 Ω
44005	3000 Ω	42 Ω
44007	5000 Ω	70 Ω

Table 3: Various thermistors with low base resistance values and the resistance vs. temperature relationships. Source: Omega Engineering

Typically, the Steinhart-Hart Equation is used to indicate the resistance vs. temperature characteristics for thermistors. Equation (1) shows temperature as a function of resistance,

$$\frac{1}{T} = a + b\ln(R) + c\ln^3(R) \tag{1}$$

where a, b, and c are constants that are derived from three temperature test points, R is the thermistor resistance in Ohms, and T is the temperature in degrees Kelvin[9]. The values used in the Steinhart-Hart equation for the thermistor that has been chosen are shown in Table 4.

Model No.	Resistance at 25°C	A	B	C
ON-909-44034	5000 Ω	1.285 x 10^{-3}	2.362 x 10^{-4}	9.285 x 10^{-8}

Table 4: The Steinhart-Hart equation constants for the chosen thermistor. These values help to define the resistance vs. temperature curve for this thermistor. Source: Omega Engineering

2.1.3 Size and Sensor Package Type

Omega provides various options and additions that allow a thermistor to be customized for different purposes. For example, Omega provides general use, waterproof, and surface sensing thermistors. To fulfill the requirements of this system, the size of the thermistor has to allow it to fit within a mouth guard. In addition, the thermistor is exposed to the wet environment of the mouth and therefore ideally would be waterproof. Omega creates waterproof thermistors by using closed-ended tubes and specially designed housings. In order for a thermistor of this type to work properly, a sufficient thermal path must be created to the thermistor, and the thermal mass needs to be as small as possible[9].

Omega also creates surface sensing thermistors. In the application being considered, the thermistor would be in direct contact with a surface of the mouth. Omega creates a particular series of surface sensing thermistors. The design includes a thin, round metal stamping into which the thermistor is attached by epoxy resin. The metal stamping can then be attached to the desired surface to be monitored[9]. The ON-909 series would be the most ideal for the mouth guard application. The thermistors in this series are are epoxy-encapsulated and are contained within stamped, 300-Series, stainless steel housing. These thermistors are surface sensing models and are constructed to have maximum surface contact. The tip of the thermistor is flat and round so the thermistor can be attached to a flat surface. This series of thermistors is non-linear and can have base resistances between 2.252 and 30 kΩ. Other options that can be changed with this series of thermistors are the cable length and the tolerance level. Omega claims that the thermistors in this series are suited for applications such as determining heat loss, compressor efficiency, and measuring manifold temperature. Based on past research, the most practical resistor for this application is the ON-909-44034 thermistor, shown in Figure 3. The specifications for this thermistor are in Table 5.

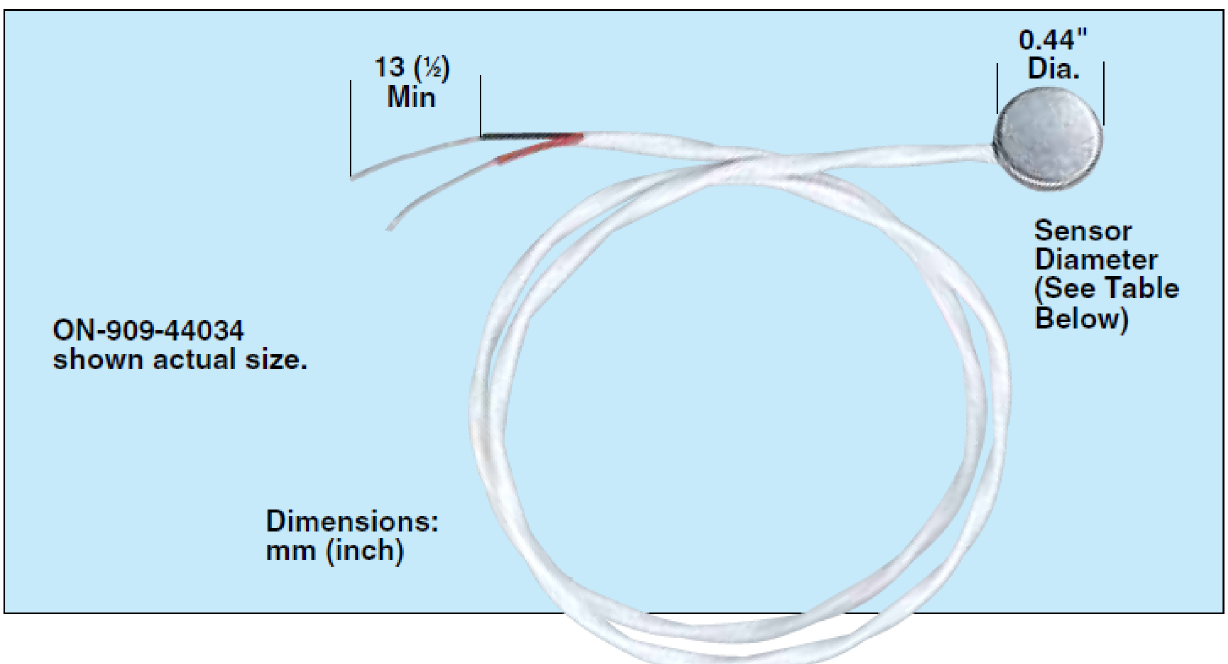


Figure 3: The pictured thermistor, the ON-909-44034 by Omega, best fits the desired specifications for this application. Source: Omega Engineering

Model No.	Resistance at 25°C	Interchangeability at 0 - 70°C	Max. Temp.	Tip Diameter
ON-909-44034	5000 Ω	±0.1°C	75°C	0.38

Table 5: The specifications for the ON-909-44034 thermistor. Source: Omega Engineering

2.1.4 Price and Availability

Part Number: ON-909-44034	
1 to 9	$55.00
10 to 24	$49.50
25 to 49	$44.00
50 to 99	$38.50
100 and over	$33.00
Availability	Now
Lead Time	None

Table 6: The thermistor is the most expensive component of the design and should be considered when thinking about large scale production of product profitability. Source: Omega Engineering

2.2 Motor

Out of several manufacturers considered, Precision Microdrives offers the widest variety of vibration motors applicable to the mouth guard design in their Pico Vibe™ range. In selecting the optimal motor for the design, several factors are considered. In addition to the physical constraints of the mouth guard, the motor has to offer sufficient amplitude of vibration while minimizing power requirements.

2.2.1 Physical constraints

The vibration motors made by Precision Microdrives fall generally into two categories – coin and rod-shaped vibration motors. Rod-shaped motors generally range from 4 to 7 mm in diameter and come in a variety of lengths[12]. An example of one of these types of motors is shown in Figure 4. Although rod-shaped motors could fit in the mouth guard, the primary concern is the exposed eccentric mass. As shown later in this report, the manufacture of the mouth guard is to be performed using injection molding. Since the motor operates by spinning the eccentric mass, whose unbalanced rotation causes the motor to displace and thus vibrate at high frequency, the mass must be free to rotate. As such, injection molding would require encapsulation or some other protection of the mass to maintain the free space.

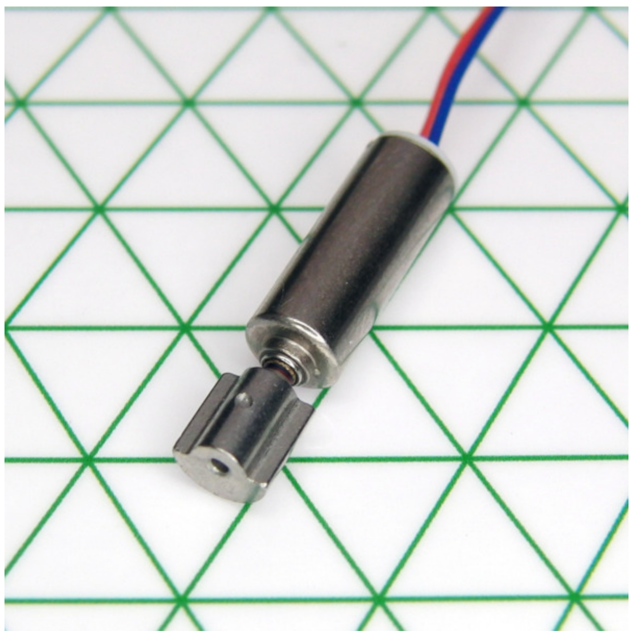


Figure 4: The 304-001 vibration motor pictured is a rod-shaped motor. Note the exposed eccentric mass. Source: Precision Microdrives

Coin vibration motors, also called pancake vibration motors, are flatter than their rod-shaped counterparts, with thicknesses ranging from 3 to 4 mm, but have diameters ranging from 8 to 10 mm[13]. The main benefit of the coin motors is their complete encapsulation as produced, so that no additional time and cost goes into protecting the mass from injection molding. For this primary reason, the coin vibration motor is the one chosen for the design.

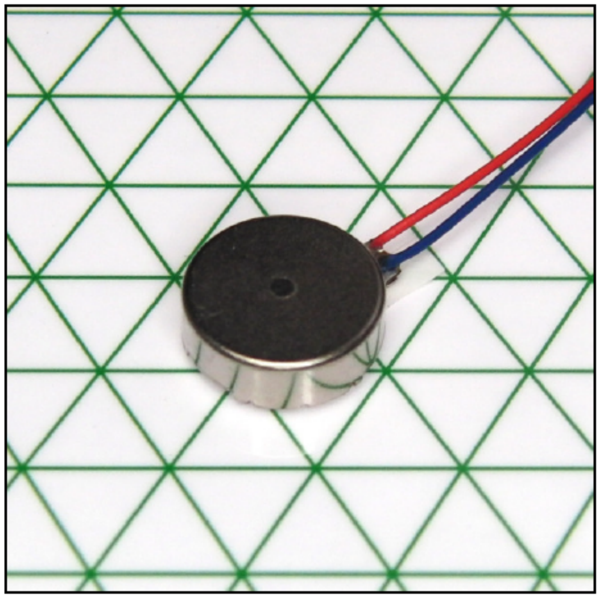


Figure 5: The pictured motor, the 310-113 coin vibration motor from Precision Microdrives, best fits the desired specifications for this application and is shown on a 6mm isometric background. Source: Precision Microdrives

2.2.2 Operational Characteristics

The coin vibration motors produced by Precision Microdrives are all rated for either 1.5 or 3V. Although the lower voltage requirement is preferable, the more important requirement for the motor is that it generates sufficient amplitude of vibration, 1.2G, to alert the player[7]. Given these requirements, the motor chosen is the 310-113 coin vibration motor shown in Figure 5, which is rated for 3V and generates 1.4G of vibration amplitude. The dimensions of the 310-113 motor are shown in Figure 6.

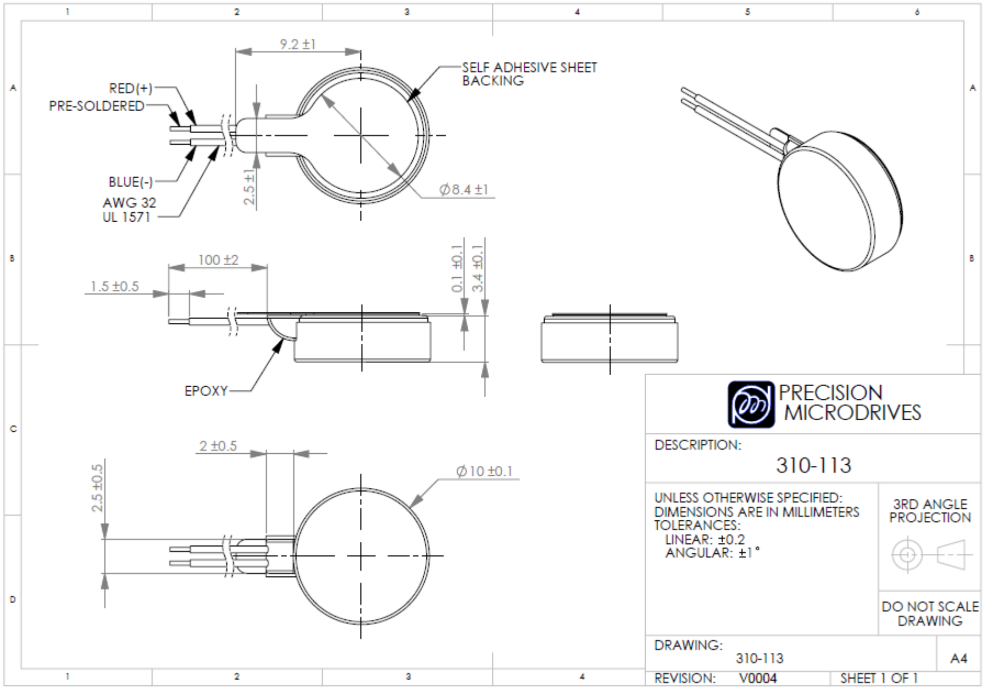


Figure 6: Technical drawings of the 310-113 vibration motor. Source: Precision Microdrives

2.2.3 Price and Availability

Part Number: 310-013	
100	$5.77
1000	$1.80
10000	$1.62
Availability	Now
Lead Time	3 weeks

Table 7: The motor is available but requires extra time for delivers since Presicion Microdrives is not a domestic company. Source: Presicion Microdrives

2.3 Battery

For a self-contained system in the mouth guard, size is an important factor. To mitigate risk, a safer option than placing the battery within the mouthguard is to have the battery embedded in the strap of the mouth guard, which is outside of the athlete's mouth. The idea is that the athlete will not be able to accidentally bite down into the battery if it is encased in the strap outside of the mouth. However, this greatly limits the amount of space for the battery. Cylindrical batteries would easily have a high enough capacity to power a system that draws 15 μA while recording the temperature[17]. However, both the disposable and rechargeable batteries of the variety would be too large for the mouth guard.

The size requirement means that only the button and coin cell types of battery could fit; these batteries exist in disposable and rechargeable forms. These batteries have significantly lower capacities, but are able to power an average thermistor for enough time to ensure that the system is working throughout the season.

Based on measurements of the strap used for mouth guards, the diameter of the button cell battery should not exceed 13 mm. The possible chemistries of the battery are the silver-oxide, alkaline, zinc-air, or lithium types of button cells. While the zinc-air variety has the highest capacity, it discharges quickly because the battery continues to run until it can no longer reduce oxygen from the environment. Alkaline and lithium batteries have similar capacities, have size varieties that meet the requirement for the mouth guard, and have enough power to power the system for the entire season[17]. However, based on the safety of the material used in the chemical reactions, the lithium button cell is less harmful. Additionally, the silver-oxide cell, though also safe, lacks sufficient capacity to power the system for the season. As such, the lithium battery has the capacity to deliver the needed voltage and current for the system, meets the size criteria, and has the safest materials for batteries of its size.

For the battery, it was found that the CR1225 3V Lithium battery was the best battery to use for this design. The battery is 12.5mm in diameter, making it small enough to fit in the optimal design[20]. The battery will be placed outside of the mouth guard itself in the strap. Due to the chemicals contained in the battery, it does have some safety hazards. Placing the battery outside of the mouth improves the safety of the product.

2.3.1 Price and Availability

Part Number: CR 1225 3V Lithium Cell Battery	
1	$1.41
10	$1.33
50	$1.26
100	$1.20
200	$1.12
500	$1.01
1000	$0.93
Availability	Now
Lead Time	None

Table 8: The CR1225 3V lithium battery is readily available with no lead time. The price per unit decreases when more units are ordered. Source: Renata Batteries

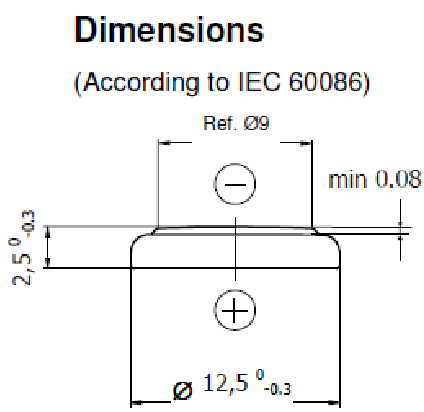


Figure 7: The dimensions of the CR 1225 style battery that is used in the device. Source: Renata Batteries

2.4 Battery Cell Holder

The battery will be placed in a coin cell battery holder within the mouth guard strap. A battery holder will allow for the battery to be replaced quickly and easily. The battery holder provides the necessary conduction leads to provide power from the battery to the rest of the system. In addition, the battery holder also provides extra safety from shorts and inverse polarity[24]. The Through-Hole battery holder is 12.7mm in diameter and 4.6mm thick. This battery holder is the smallest size holder for the CR 1225 battery which was chosen to power the system.

2.4.1 Price and Availability

Part Number: HU1225-LF	
1	$0.85
10	$0.77
50	$0.73
100	$0.69
200	$0.64
500	$0.61
1000	$0.57
2000	$0.54
Availability	Now
Lead Time	None

Table 9: The battery holder that accomodates the CR 1225 style battery is quickly available at a low price. Source: Renata Batteries

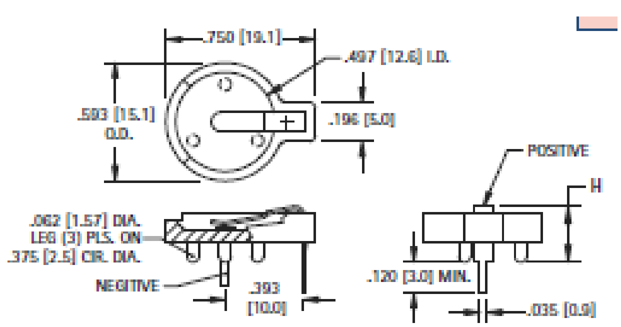


Figure 8: The dimensions of the selected battery holder for the device. Source: Keystone

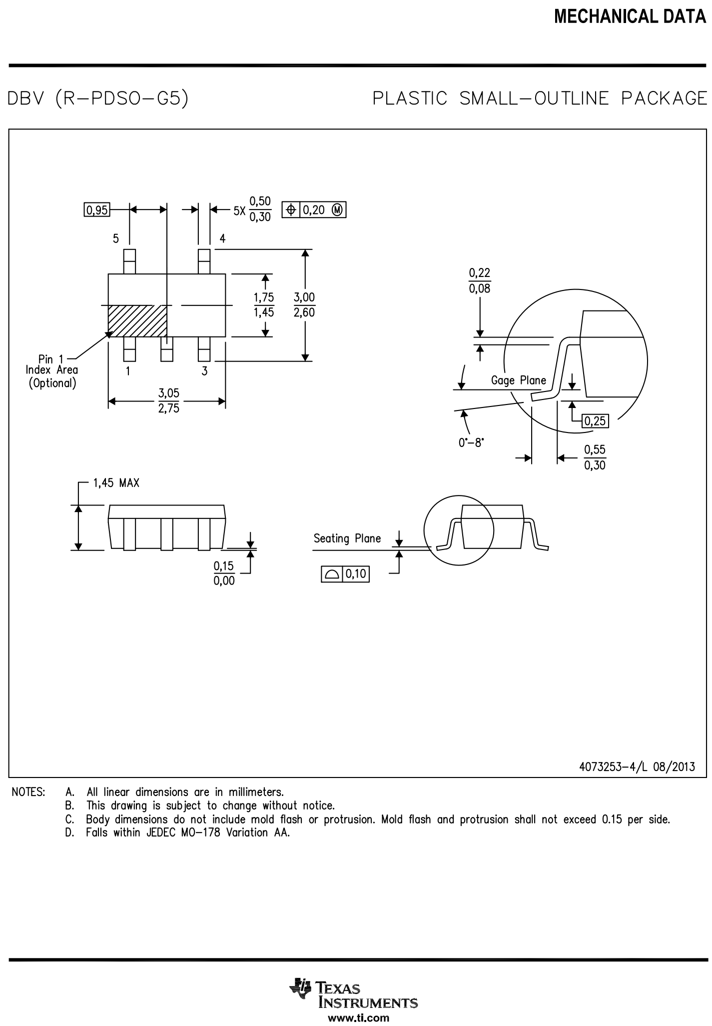
2.5 Operational Amplifier

An operational amplifier is needed for the circuit to ensure that the voltage induced in the microprocessor is within the input range. The LM321 Low Power Single Op Amp suits the needs for this project. The SOT23 5-pin packaging of the op amp offers a small size. The dimensions of this packaging are shown in Figure 9. The op amp also has a low operating current of 430 μA, which helps to preserve battery power[21].

2.5.1 Price and Availability

Part Number: LM321MF	
1	\$0.70
10	\$0.53
100	\$0.28
1000	\$0.25
Availability	Now
Lead Time	2 weeks

Table 10: The operational amplifier selected can be purchased very cheap depending on the order size but does require 2 weeks lead time. Source: Texas Instruments



MECHANICAL DATA

DBV (R–PDSO–G5) PLASTIC SMALL–OUTLINE PACKAGE

NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Falls within JEDEC MO–178 Variation AA.

TEXAS INSTRUMENTS
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Figure 9: The dimensions of the selected operational amplifier for the design. Source: Texas Instruments

2.6 Resistor

It was recommended that a resistor be used with the operational amplifier that was found to best fit the design. This resistor was chosen due to its small size and because it fits the specifications for the op amp. The resistor is 0.02 inches by 0.04 inches and it is also wire bondable[22].

2.6.1 Price and Availability

Part Number: CH0402-20RJPT	
1	$4.33
25	$3.66
50	$2.99
100	$2.66
200	$2.40
500	$2.13
1000	$2.06
2000	$2.00
5000	$1.93
Availability	Stock Low
Lead Time	None

Table 11: The thin film resistors have a limited availablility but can be shipped immediately after ordering. Source: Vishay

2.7 Microprocessor

The microcontroller used by the temperature sensing circuit is the MSP430F2003IPW produced by Texas Instruments. This mixed signal microprocessor has a low supply voltage and current. The optimal package uses the RSA packaging which, as seen in Figure 11, has 16 pins. The part also has the ability to cycle between an active state and one of four low power modes. This ability greatly reduces the average supply current for the microprocessor. In the active state, the microprocessor operates at 730 μA, while in the low power mode of this device, it only uses 0.9 μA. In order for the microprocessor to interpret the analog signal from the circuit, the input at the number 10 pin is a 16-bit analog-to-digital converter (ADC). This is especially important because as shown in Section 3.1.2, the 16 bit convert allows for resolution to detect small enough temperature changes to meet the design requirements. The input frequency of the ADC is 100 Hz, which helps define the criteria for the motor activation[26].

2.7.1 Price and Availability

Part Number: MSP430F2003IPW	
1	\$2.41
10	\$2.00
25	\$1.78
50	\$1.68
100	\$1.20
250	\$1.18
500	\$1.16
750	\$1.14
1000	\$1.11
Availability	Available now
Lead Time	6 weeks

Table 12: The selected microprocessor has the longest lead time of any parts which should be considered when placing part orders. Source: Texas Instruments

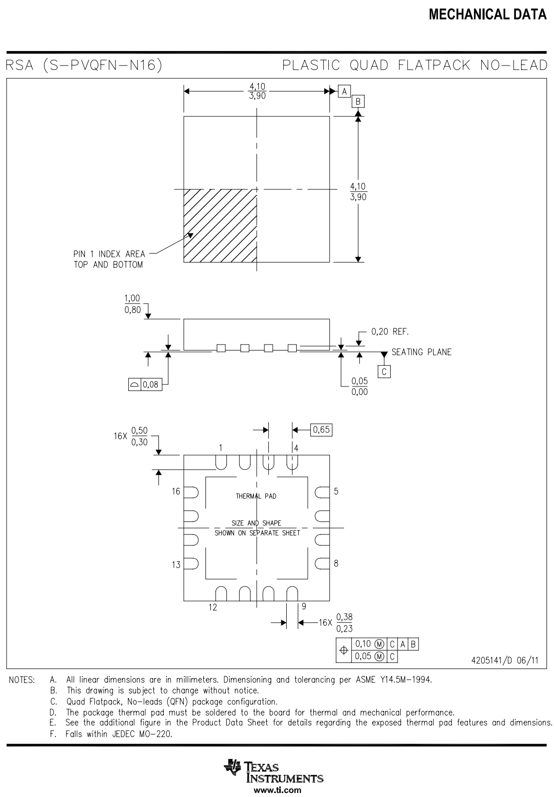


Figure 10: The dimensions of the selected microprocessor for the device. Source: Texas Instruments

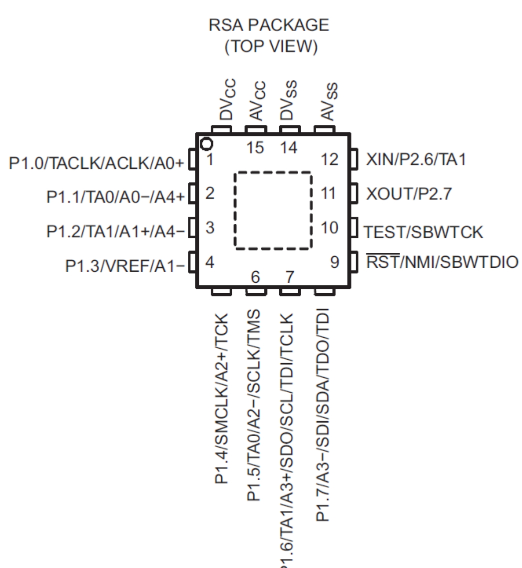


Figure 11: The pin setup for the RSA package of the microprocessor. Source: Texas Instruments

2.8 Mouth Guard

Although the mouth guard will be manufactured differently when the sensing and alert system is put in place, the mouth guard should be similar in shape and size to the Shock Doctor™ Double Braces mouth guard. This mouth guard sells for $22.99 and does not have a specific part number[29]. To remove some of the circuitry components from the mouth guard, there will also be a strap that connects the mouth guard to the facemask of the helmet. This strap is a standard design feature in some models of mouth guards. This mouth guard extension has an expansion that holds electronic components. These parts can be produced by injection molding using Protomold®. Orders of 25-100 molds cost $4.78 per unit[50]. The resin that is used for the molds is the Elvax ®265 and can be purchased from Du Pont™ for $2.50 per kilogram for a 25 kilogram bag.

2.9 Additional Wires

Additional wires are needed to connect all the components. Since the additional wiring connects short sections between electronic parts, the resistance of the wires is negligible. Primary wire was chosen because it is good for general purpose electrical use. The 20 gauge, 0.8mm diameter wire[30] will be used to connect the parts located in the strap to the parts located within the mouth guard.

2.9.1 Price and Availability

Part Number: 1120103 100 ft. spool of Primary Wire	
1ft. +	$0.0654
15000 ft. +	$0.0576
Availability	Now
Lead Time	None

Table 13: Primary 20 gauge wire is available in orders of at least 100 feet. Source: Del City

3 Details of Chosen Design

3.1 Circuit Design

A circuit is used to drive current through the thermistor and to power the operational amplifier and the microprocessor. The important concepts of the circuit include the use of the inverting amplifier, the data conversion from an analog to digital signal, and the decision making process for whether the motor is activated.

3.1.1 Circuit Diagram

The circuit diagram in Figure 12 shows how the circuit in the device is wired and run. On the high level overview, the battery provides a voltage difference over 3 different branches. Two of the branches are the power supply for the operational amplifier and the microprocessor. The third branch applies a voltage across the thermistor. The circuit then goes through the inverting amplifier where the signal is conditioned so that the output is in the range of the microprocessor. The output of the microprocessor runs to the motor. All other leads are grounded.

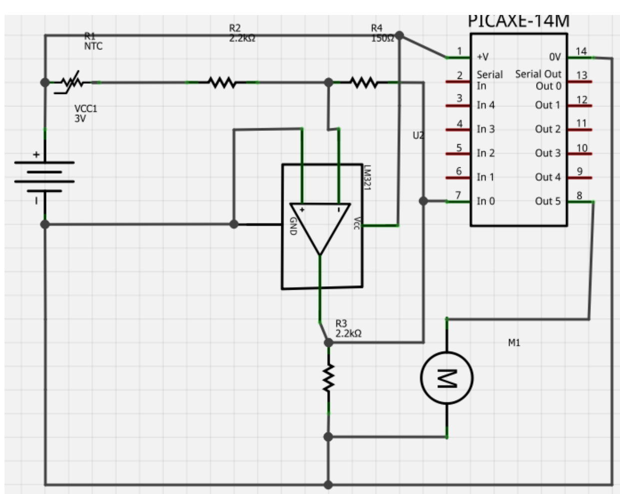


Figure 12: The circuit diagram shows the connections of the circuit used in the mouth guard temperature sensor.

Going into more detail, the positive lead of the battery holder branches off into three separate wires. The first wire connects to pin 5 of the operational amplifier. The second branch connects to pin 16 of the microprocessor. The third lead applies a voltage over the thermistor in the mouth guard. The resulting signal is then amplified using an operational amplifier by connecting the thermistor in series with a 20,000 Ω resistor, which is in turn connected to pin 1 of the operational amplifier. The output at pin 4 of the amplifier is split into 2 parallel branches. One branch has a 200 Ω resistor and connects back to pin 3 of the operational amplifier. The second branch from the output of the operational amplifier connects to pin 10 of the microprocessor. Parallel to this connection is a pull-out resistor with a resistance of 20,000 Ω. This resistor is used to preserve the signal to the microprocessor. Depending on which pin is programmed as the output of the microprocessor, that pin is connected to the motor. The output of the microprocessor can produce a voltage as high as the supply voltage. In this case, the voltage produced by the microprocessor is 3V, which is in the operating range of the selected vibrating motor. All other leads, including pins 1 and 2 of the operational amplifier and pin 14 of the microprocessor, are grounded and connect to the negative lead of the battery holder.

3.1.2 Circuit Calculations

Two assumptions were made in performing circuit calculations. The first is that the resistance in the wires is negligible The 20 gauge wire for 75 mm, which is longer than the expected length for the circuit, has a resistance of 0.0026 Ω[30]. Since this value is so much smaller than other resistance values, it has not been included in calculations. The second note is that the input bias of the operational amplifier is several magnitudes smaller than the values for an ideal operational amplifier, so it has not been considered.

Several calculations were done in order to ensure that the input into the microprocessor over the operating range of temperatures would be within the ADCs range. By having a more complete range filled, the microprocessor has enough resolution to detect small changes in the resistance of the thermistor. By having higher resolution to resistance changes, the system is more sensitive to the temperature changes in the mouth[33].

First, the appropriate gain in the inverting amplifying circuit was calculated. The upper temperature for the circuit was set at 323 K (50°C). This temperature is higher than any expected reasonable body temperature so the measurements of the actual circuit will easily be in the range. The gain was set so that the induced voltage in the microprocessor ADC will be at the maximum of its range when the thermistor is at 323 K. The math is shown in the equations starting with Equation (2).

Operational amplifier gain (analysis performed with 323 K (50°C) as upper limit)

$$I_{in} = \frac{V_{battery}}{R_T} = \frac{3\text{V}}{1.801k\Omega} = 1665\mu\text{A} \tag{2}$$

$$I_{out} = \frac{V_{max}}{R_{mp}} = \frac{3\text{V}}{200k\Omega} = 15\mu\text{A} \tag{3}$$

$$Gain = 0.01 \tag{4}$$

The temperature resolution of the microprocessor is based on the number of bits and the voltage range of the ADC[32]. Begining with Equation (5) the calculation of the temperature resolution is shown.

$$LSB = \frac{V_{FSR}}{2^n} = \frac{3}{2^{16}} = 4.58\text{x}10^{-5}\text{V} \tag{5}$$

Solving for the LSB for current entering the microprocessor

$$LSB_{current} = \frac{\Delta V}{R} = \frac{4.58\text{x}10^{-5}}{200,000} = 2.29\text{x}10^{-10}\text{A} \tag{6}$$

Divide by the operational amplifier gain to find the least significant bit of current before the amplification

$$LSB_{current} = 2.5\text{x}10^{-8}\text{A} \tag{7}$$

Solving for the change of resistance for the thermistor when at 310 K

$$\Delta LSB_{current} = \frac{V_{battery}}{R_1} - \frac{V_{battery}}{R_0} = \frac{3\text{V}}{3008} - \frac{3\text{V}}{R_0} \tag{8}$$

$$R_0 = 3008.076\Omega \tag{9}$$

$$\Delta R_T = 0.076\Omega \tag{10}$$

Using a linear approximation for the thermistor resistance vs. temperature:

$$\Delta R_T = -253.86 * T_1 + 253.86 * T_0 = -253.86 * 310 + 253.86 * T_0 \tag{11}$$

$$T_0 = 310.003°\text{C} \tag{12}$$

$$\Delta T = 0.003°\text{C} \tag{13}$$

The three branches that the battery supplies voltages to have different operating currents depending on configuration. The operational amplifier has the largest operating current at 430 μA[21]. The thermistor is also rated as operating at 15 μA but is dependent on temperature[15]. The supply current for the microprocessor is more complicated. The microprocessor for the device is configured to alternate between an active and low power mode. When in the low power mode, which is 98.3% of the time, the operating current is 0.9 μA. In comparison, the active mode requires 300 μA[26]. Based on the time-weighted averages, the microprocessor usually requires 5.89 μA. This required current gives a total operating current from the battery to be about 450 μA. The battery, with 48 mA-h of capacity, can operate the device for almost 107 hours' worth of practice and game time[20].

Part		Current Requirements
Thermistor		15μA
Operational amplifier		430 μA
Microprocessor Active	300 μA	5.89 μA
Microprocessor Low Power Mode	0.9 μA	
Total		**450.89**

Table 14: Each of the three branches that the battery applies a voltage to has a different operating current.

3.1.3 Microprocessor Design

As mentioned in Section 3.1.1, the microprocessor is important in determining if the motor activates to warn the user that their body temperature is dangerously high. This activation process occurs by having the ADC associated with pin 10 convert the analog signal at 100 Hz. The signal is read out in 16 bits of data in binary twos format. A threshold is preset that correlates to a high temperature detected by the thermistor[26]. According to previous research the temperature that indicates the onset of heat exhaustion is 38°C[3]. Since the temperature in the mouth is slightly lower than the true core temperature, the threshold will be set as 37.5°C.

The first criteria that must be met in order to activate the motor is that during a sampling period, 75% of the data points must be above the threshold. The second criteria relates to the time scale. As mentioned above, the microprocessor cylces from an active mode to a low power mode. The actual time in each mode is 1 second active and 59 seconds in the low power mode. If two active states in a row both meet criteria 1, then criteria 2 is met and the microprocessor applies a current through its output pin to the motor. The motor is then turned on for 10 seconds.

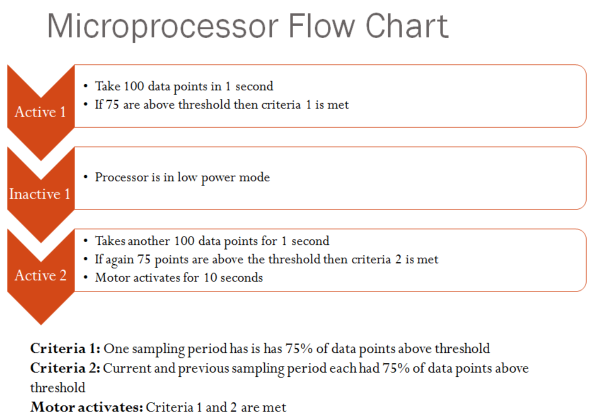


Figure 13: The processes that the microprocessor uses to make decisions on whether or not the motor activates have 2 criteria that must be met.

3.2 Component placements

For the chosen design, the required parts are the battery, battery holder, 3 resistors, microprocessor, operational amplifier, thermistor, vibrating motor, wires and mouth guard. Table 2 lists the part numbers and the specific information about the parts is in Section 2.

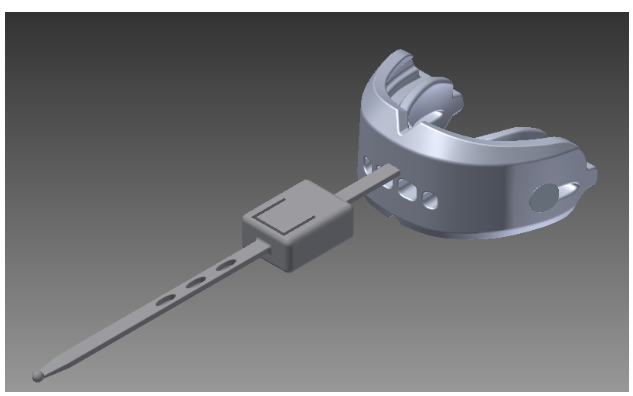


Figure 14: The complete mouth guard and strap encapsulates all of the components of the device except for the surface of the thermistor.

The basic framework of the design is based on the double brace mouth guard from Shock Doctor. The only components that are located in the mouth guard that is in the mouth are the thermistor and the vibrating motor. For this description, the right side of the mouth guard is the right side when looking at the mouth guard from the front of the mouth. The two components within the mouth guard are on opposite sides of the mouth. The thermistor will be on the right side of the mouth guard. The face of the thermistoris exposed outside of the mouth guard with the rest of the body and wires encapsulated inside the mouth guard. Figure 15 shows how the thermistor is in the back of the mouth guard so that it makes contact with the back of the mouth. The wires from the thermistor run inside the mouth guard up to the front and then go into the strap that comes out of the mouth.

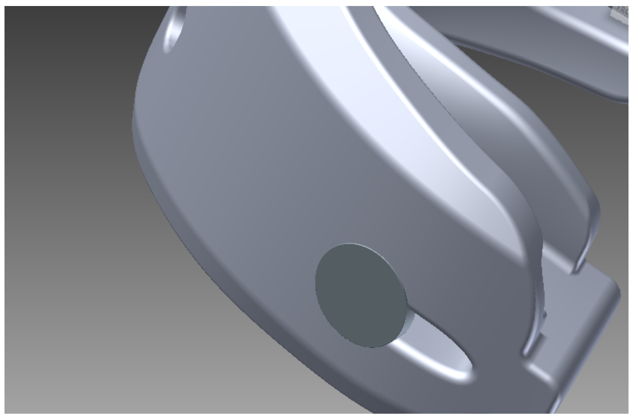


Figure 15: The thermistor is located in the back side of the mouth guard with only the surface exposed.

The vibrating motor is located on the left side of the mouth guard. The motor is completely encapsulated in the mouth guard half way between the front and the back of the mouth. The wires again are inside the mouth guard and leave through the strap of the mouth guard.

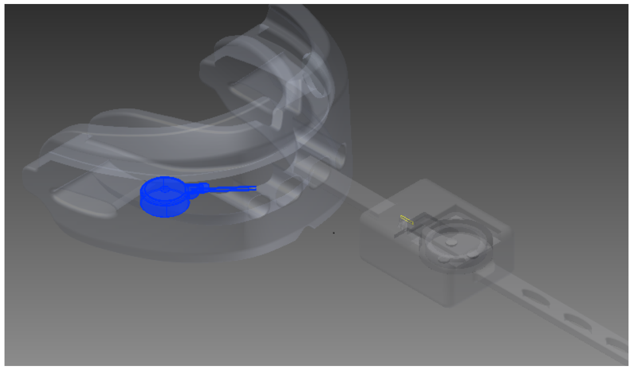


Figure 16: The motor is completely encapsulated in the mouth guard, opposite of the side with the thermistor.

The rest of the circuit is mostly encapsulated in the strap of the mouth guard. This includes the battery holder, battery, operational amplifier, microprocessor, and the resistors. The strap of the mouth guard comes out of the front of the mouth guard and allows the mouth guard to be attached to the face mask of the helmet. The strap, for most of the length, is a rectangular shape with rounded edges and dimensions of 2 mm x 5 mm. However, 25 mm from the interface of the strap and the mouth guard, the dimensions change to be 12 mm x 20 mm. This is the area that holds the rest of the electrical components. In this expanded area of the mouth guard strap, the battery holder is located under a peel-away strip of the material in the strap. The battery holder is at the top of the expanded area of the mouth guard strap and farther back from mouth guard itself. The rest of the electrical components are in the expanded region but are closer to the mouth guard. All these parts, which include the microprocessor, operational amplifier, and resistors are entirely encapsulated in the material.

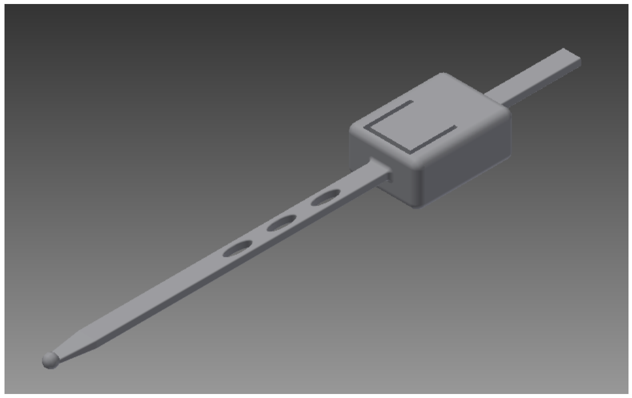


Figure 17: The mouth guard extension was designed to connect to the front of the mouth guard and have an expansion that holds the other electronic components.

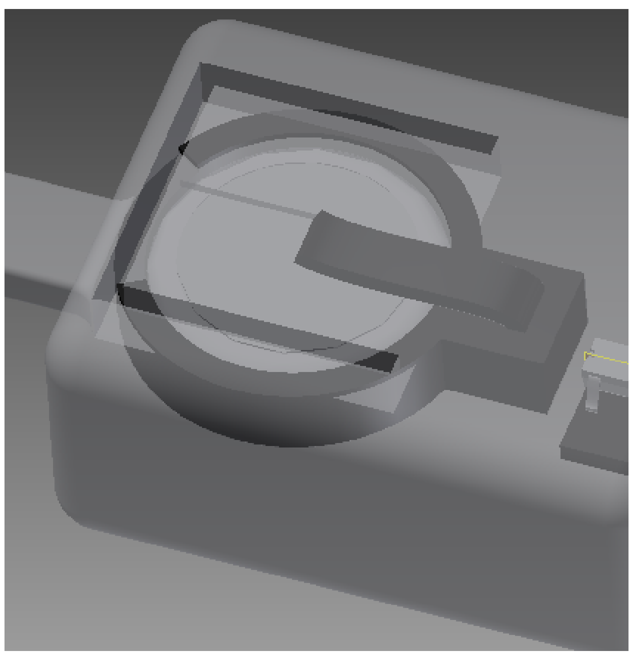


Figure 18: The battery and the battery holder are located close to the surface of the strap expansion. There is a piece of the strap that can be peeled back so the battery can be taken out or replaced.

An important thing to note is that this design is suppose to be a proof of concept for the client so the design does not need to use a printed circuit board. The motivation for this decision is because the material in which the electronics are encapsulated is flexible and if the material is deformed, the printed circuit board risks being damaged. There is a printed circuit board design in Figure 19 that shows how the circuit board could be configured. The prices for the boards are shown in Table 15[49]. The dimensions are also a concern since the board is 28.9 mm x 35.6 mm, which would require a much larger expansion in the mouth guard strap. For this report, the location of the electrical components will be described in terms of not being on a printed circuit board.

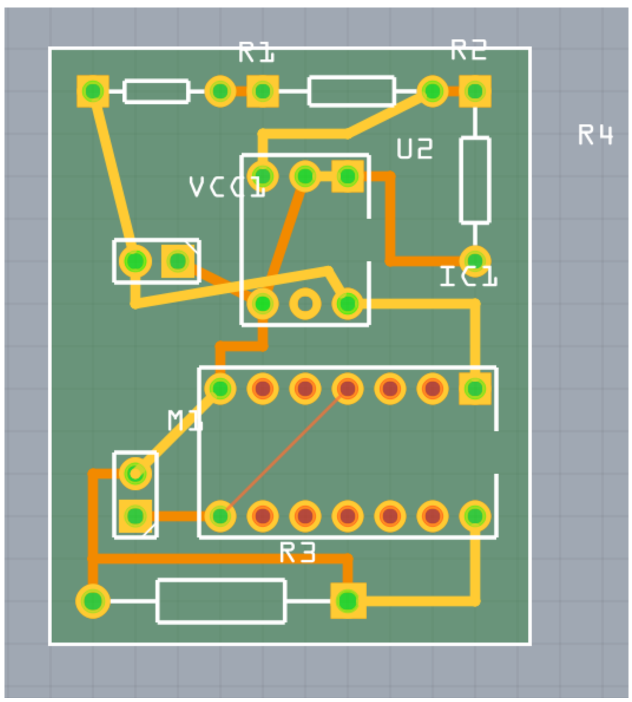


Figure 19: The printed circuit board is a two layer board that allows for wires or components to be soldered to the leads.

Part: Printed Circuit Board	
1	$9.86
5	$8.46
10	$7.05
Availability	Now
Lead Time	3 weeks

Table 15: Fritzing produces circuit boards that are order each week so their timeline must be considered when ordering parts. Source: Fritzing, Inc.

The electrical components in the expansion of the mouth guard strap are located closer to the front of the mouth guard than the battery. The operational amplifier is located above the microprocessor and resistors. Each of the components will be connected as described in Section 3.1.1.

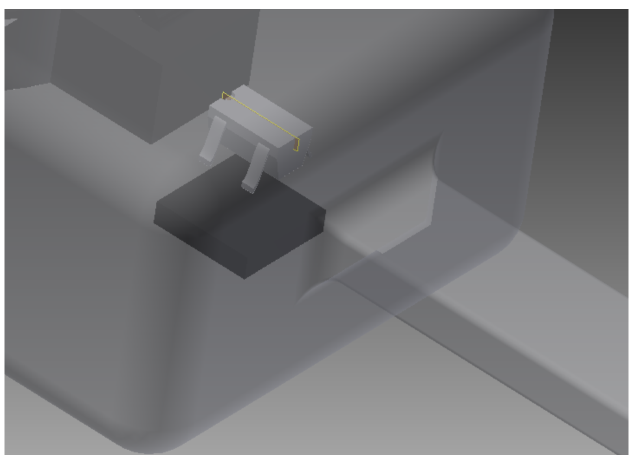


Figure 20: The eletrical componens in the mouth guard expansion include the microprocessor (black chip), operational amplfier (5 pin package) and the resistor.

3.3 Safety Analysis

Based on the safety analysis, there are several safety hazards that users should be aware of. First, there will be electronic parts contained within the mouth guard which users will place in their mouth. The combination of electronic components in the wet environment of the mouth creates a risk of shock. However, the current that is running through the circuit is very low and therefore does not represent a significant safety risk. The second big concern is that the mouth guard needs to be properly cared for in order to prevent the growth of mold or bacteria. The mouth guard should be cleaned and dried after each use to prevent any health hazards. There is a slight risk involved with using a lithium battery because of the chemistry used by the battery. However, the battery is placed in the strap of the mouth guard so the battery does not have to be in the users mouth. Warning labels and an instruction manual will be included with the product so that users know the risks and know how to properly handle the mouth guard. Overall, the product does not pose any huge safety concerns and should ultimately be safe for all users.

designsafe Report

Application:	Helmet Temperature Sensor	Analyst Name(s):	Grace Murray, Tyler Perez, Norman Luc
Description:	A system designed to monitor a football player's core temperature	Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Probability	Risk Level	Status / Responsible /Reference
1-1-1	Football Player normal operation	electrical / electronic : energized equipment / live parts	Serious Likely	High	warning label(s), instruction manuals	Serious Unlikely	Medium	
1-1-2	Football Player normal operation	electrical / electronic : lack of grounding (earthing or neutral)	Moderate Unlikely	Low	Other design change - battery holder provides a ground, warning label(s)	Moderate Remote	Negligible	
1-1-3	Football Player normal operation	electrical / electronic : shorts / arcing / sparking	Moderate Likely	Medium	other design change - Battery holder prevents shorts	Moderate Unlikely	Low	
1-1-4	Football Player normal operation	electrical / electronic : improper wiring	Moderate Unlikely	Low	warning label(s)	Moderate Remote	Negligible	
1-1-5	Football Player normal operation	electrical / electronic : water / wet locations	Serious Unlikely	Medium	warning label(s)	Serious Remote	Low	
1-1-6	Football Player normal operation	electrical / electronic : overvoltage /overcurrent	Moderate Unlikely	Low	warning label(s)	Moderate Remote	Negligible	
1-1-7	Football Player normal operation	electrical / electronic : power supply interruption	Moderate Unlikely	Low	warning label(s)	Moderate Remote	Negligible	
1-1-8	Football Player normal operation	noise / vibration : noise / sound levels > 80 dBA	Moderate Unlikely	Low	warning label(s)	Moderate Remote	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Probability	Risk Level	Status / Responsible /Reference
1-1-9	Football Player normal operation	noise / vibration : equipment damage	Minor Likely	Low	warning label(s), instruction manuals	Minor Unlikely	Negligible	
1-1-10	Football Player normal operation	Other : Mold/Bacteria	Serious Likely	High	warning label(s), instruction manuals	Serious Unlikely	Medium	

4 Manufacturing Definitions

Based on the prices shown in Section 3, the price to produce 100 units of is approximately \$5000. This price does not include non-recurring engineering or other fees.

4.1 Circuit Assembly

All of the electrical components are placed as described in Section 3.2, then soldered together to form the circuit, with the exception of the battery. The battery will be shipped separately, to be placed into the holder in the extension strap before use. For purposes of injection molding, the battery is replaced by a placeholder, which in turn is removed after ejection from the mold.

4.2 Injection Molding

After the components are assembled, the circuit is placed in an injection mold so a melted soft plastic resin can be injected to form the mouth guard itself around the circuit. The resin of choice is Elvax® 265, an ethylene-vinyl acetate copolymer produced by DuPont, with the specifications shown in Table 16. The molding process is performed per the instructions supplied in the DuPont guide for molding of the Elvax® line of resins[51].

Resin No.	Melt Index (dg/min)	Vinyl Acetate (wt%)	Density (kg/m^3)	Melting Point (°C)	Stiffness (MPa)
Elvax® 265	3.0	28.0	951	73	19

Table 16: Some specifications for the Elvax® 265 resin. Source: DuPont

5 Conclusion

5.1 Specification Fulfillment and Client Need

There has been an increase in deaths due to heat related illness as football players continue to try and push their bodies farther and farther[34]. This is especially concerning considering that heat exhaustion is preventable as long as it is properly monitored. Also, quick treatment of elevated core temperature can prevent the continuation to heat stroke. The goal of this project is to deliver a system that can measure a players core temperature and alert them when their temperature has reached a dangerous level so they can seek medical treatment immediately. The concept of a mouth guard temperature sensor was researched and a design was created in order to properly monitor football players core temperatures. The chosen design has the capabilities to use a thermistor powered by a battery cell to measure the core temperature from within the mouth. The system will set off a vibrating motor when a players core temperature reaches a dangerous level. The parts of the system were chosen so that they would be small enough to fit within the plastic of the mouth guard. The strap of the mouth guard was thickened so that some of the larger and more hazardous components could be kept outside of the mouth guard itself. Therefore, the deliverables were achieved in this product and the health and safety of football players was improved through this design.

There were also many specifications that were outlined to be met in this project. First, all the components needed to fit within existing equipment. This was achieved by making the strap portion of the mouth guard thicker in order to fit the larger components of the system. The next specification was to make the system between 2 and 3 ounces so that it did not throw off the balance of the equipment[5]. The motor has the largest weight of 1.1g[13] while the battery had the second largest weight of 0.9g[20]. The total weight of 2 grams of these two parts is equivalent to about 0.07 ounces. Therefore, the other parts used in the system which did not list their weights in their specifications sheets, need to weigh less than about 80 grams to fit within the weight requirement. Based on knowledge of the microprocessor, operational amplifier, battery holder, thermistor, resistor, and additional wires, the weight of these combined parts should be significantly less than 80 grams. The next specification was that the alert needed to generate 1.2 to 26.2G of force in order to be felt within the mouth guard[7]. The motor generates 1.4G of force, fitting within the required range[13]. The thermistor has an interchangeability of 0.1 degrees Celsius making for accurate temperature measurements[15]. This fulfills the specification for accuracy. The final specifications of reliability and durability depend on testing of the actual physical mouth guard creation which cannot be done until a prototype is built.

5.2 Project Takeaways and Future Direction

In the future, it would be interesting to continue researching a temperature monitoring design that would be placed within a football helmet. This option was considered early on in the design process before the client requested a mouth guard design. In the helmet design, the temperature could be monitored using infrared technology and scanning the heat emitted from the temporal artery. The initial analysis of this design seemed very interesting and looked like it would be a unique and plausible design. The infrared technology used to scan the temporal artery was found to more accurate than many other current methods used to monitor core temperature[3]. This could be another viable option to monitor football players and make sure that they are avoiding heat illness. Exploring a device in the helmet could also be useful because there is still a debate over how useful the mouth guard is as a safety device[7].

Another aspect of the design that could be considered in the future is wirelessly communicating the data being collected by the system to the sidelines so that coaches or athletic trainers can monitor the players. The data would be collected by the mouth guard and then communicate in real-time with a device on the sideline. A big concern is making sure that athletes are actually listening to the warning signal when it is activated and taking action to lower their core temperature. Including wireless communication would allow for additional parties to monitor players and make sure they are listening to the warning signals of the vibrating motor when necessary. Wireless monitoring would also allow for data to be collected over time to be further analyzed. Patterns can then be observed for players over time during training and games. If a player has a pattern of especially high risk of heat exhaustion, they can even begin the cooling process before the vibrating motor goes off.

Eventually, it would be beneficial to integrate the circuit into boil and bite or custom mouth guards. The boil and bite and custom fit variations of mouth guards provide a higher level of protection because they are fitted directly to the athletes mouth. While these two types do provide a better fit, there is a concern that when a player bites into a mouth guard to set its form there could be damage to some of the internal components. In the future, it would be ideal to get the temperature sensing system integrated into the boil and bite and the custom mouth guards in order to provide football players with the greatest amount of safety as possible. Research would need to be done to see where the ideal placement of components would be so that the player would not damage the components when setting the form of the mouth guard.

The strap that is used to connect the mouth guard to the helmet was used in order to store any parts that did not need to be in the physical mouth guard itself. In the current design, the strap was made thicker in order to fit the additional parts inside of the strap. In future designs, it would be a good idea to try and make the design of the strap more ergonomic. This would be safer and likely more comfortable for the players. In addition, it would also be beneficial to specially design the thermistor so that it would be ideal for the use in the mouth guard temperature sensor. Likely this would mean making the head of the thermistor as small but accurate as possible to allow for maximum contact with the surface of the mouth.

The client is looking into integrating other sensors into the mouth guard in the future. They have discussed adding accelerometers into the mouth guard in order to collect data and look at whether a football player is experiencing accelerations that could cause a concussion. This system would also work well with wireless transmission so that both temperatures and accelerations could be monitored from the sideline. This could allow the players to immediately get help for potential concussions and for heat illness. Overall, the mouth guard system could increase the safety of football players in multiple ways.

Another possible change to make would be to include pressure sensors within the mouth guard. When a player bites down on the mouth guard, the system would be activated and the clock of the microprocessor would begin running. As stated earlier, in order for the motor to be activated, there must be two consecutive readings that reach a certain criteria. If a player removes their mouth guard in between these readings, then the clock would stop and would begin again once the pressure sensors were activated.

One important thing that was discovered during the research of this project is that there is really no perfect way to non-invasively measure the core temperature of a person. Of all the methods that were researched, the most accurate location to measure the core temperature is the blood at the center of the heart. It is difficult to find the right balance of a method that is not too invasive for a football player and finding a method that will give an accurate enough reading of the core temperature.

If a similar research project was to be done again, it would be beneficial to talk to professionals in the field of football. This would include talking to players, coaches, and any equipment managers who might have a good idea about the maintenance of equipment. These people would have a good idea about what equipment works best in certain situations and what players are most likely to tolerate. For instance, some players may be more comfortable having a mouth guard that changes color rather than being alerted by a vibrating motor. On the other hand, coaches may be able to provide more information about how likely it is that athletes will listen to the warning signal and go to the sidelines for help. Talking to people who are around the sport of football would likely provide a lot of information that would be valuable to the design of the mouth guard temperature sensor.

There are not many ethical considerations that need to be looked at for this design. Although there are not any ethical issues pertaining to the design of the mouth guard, there could be ethical issues involving the use of the mouth guard by football players. The biggest issue is making sure that football players actually listen to the warning when the vibrating motor goes off. The fear is that football players will choose to keep on playing rather than going to the sidelines to get assistance. This is where the wireless communication system would come in handy. If there was wireless communication, there would be multiple parties monitoring players and making sure they are staying at healthy core temperature levels.

The intellectual property in this project would be applied to the combination of all of these parts into one device. Each individual part has already been patented but the combination of them altogether is a new idea that is not obvious and is unique. However, a Confidential and Proprietary Information Agreement was filled out giving the rights of the product to the company owning Jarden Team Sports. Under the agreement they have rights to, all inventions of significant technical or business innovations developed or conceived by the participants in this research project. The company was also given the right to any information regarding any Patent Application to be filed so that this project can be recorded in the appropriate Patent Office[28].

6 Appendix

6.1 Company Contact Information

Omega Engineering

Thermistor

Address: One Omega Drive, P.O. Box 4047, Stamford, CT 06906

Customer Service: 1-800-622-2378

Fax: 203-359-700

Email: cservice@omega.com

Website: www.omega.com

Renata Batteries

Coin Cell Battery and Battery Holder

Address: 10455 Olympic Dr., Dallas, TX 75220

Phone: 1-972-234-8091

Email: SRossi@sykessler.com

Website: www.renata.com

Texas Instruments

Microprocessor and Operational Amplifier

Address: 12500 TI Boulevard, Dallas TX 75243

Phone: 1-972-995-2011

Website: www.ti.com

Vishay Intertechnology, Inc.

Resistor

Address: One Greenwich Place, Shelton, CT 06484

Phone: 1-402-563-6866

Email: business-americas@vishay.com

Website: www.vishay.com

Precision Microdrives Limited

Vibration Motor

Address: 1 Brixton Road, London, SW9 6DE, United Kingdom

Phone: +44(0) 1932 252 482

Email: enquiries@precisionmicrodrives.com

Website: www.precisionmicrodrives.com

Del City

Additional wiring

Address: N85 W12545 Westbrook Crossing, Menomonee Falls, WI 53051

Phone: 1-800-654-4757

Email: info@delcity.net

Website: www.delcity.net

6.2 Data and Specification Sheets

6.2.1 Thermistor

Model No.	Resistance at 25°C	Interchangeability at 0 - 70°C	Max. Temp.	Tip Diameter	Storage and working temp. for best stability
ON-909-44034	5000 Ω	±0.1°C	75°C	0.38	-80 to 75°C

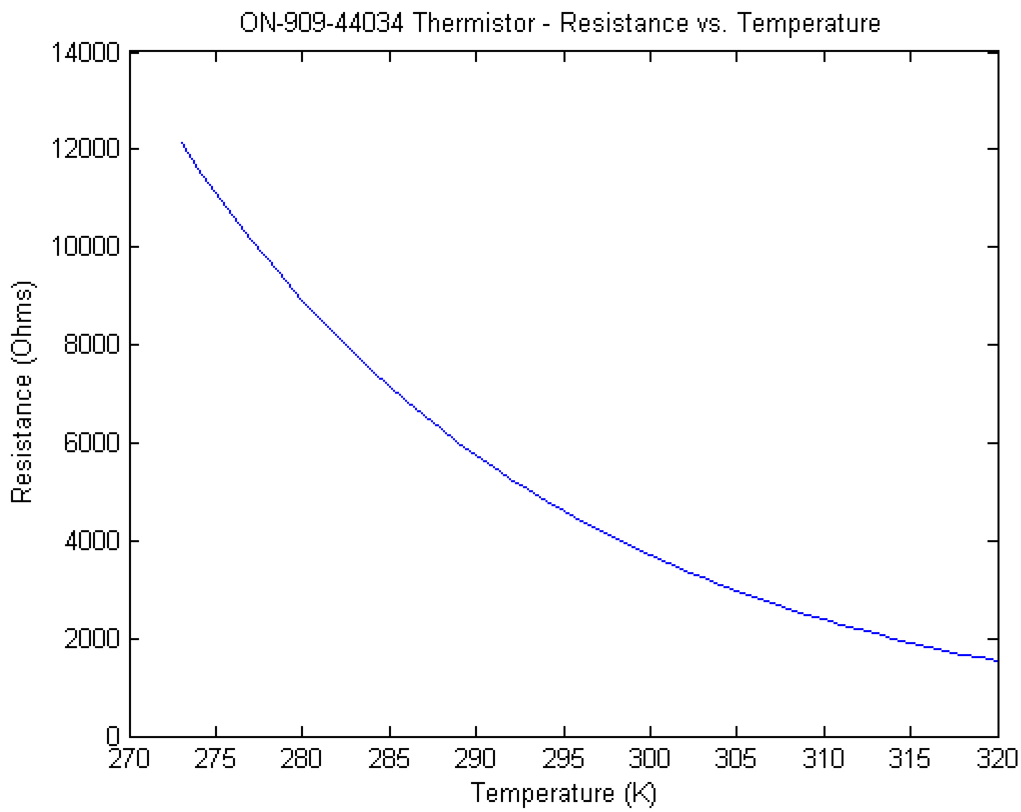
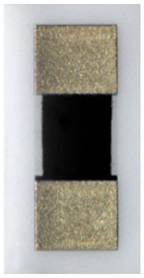


Figure 21: The temperature vs. resistance curve for the ON-909-44034 thermistor within the possible range that the thermistor could be measuring in the mouth guard sensor.

Thin Film Microwave Resistor



Product may not be to scale

The MIC resistor chips on alumina are designed with low shunt capacitance. Most lower value resistor geometrics are compatible with strip lines, making them ideally suited for microwave circuits.

These chips are manufactured using Vishay Electro-Films (EFI) sophisticated Thin Film equipment and manufacturing technology. The MICs are 100 % electrically tested and visually inspected to MIL-STD-883.

FEATURES

- Wire bondable
- High frequency
- Small single chip size: 0.020" x 0.040"
- Case: 0402
- Microwave resistance range: 20 Ω to 1 kΩ
- Overall resistance range: 20 Ω to 20 kΩ
- Alumina substrate
- Low stray capacitance: < 0.2 pF
- Resistor material: Tantalum nitride, self passivating
- Moisture resistant
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

Pb-free
RoHS COMPLIANT
HALOGEN FREE
GREEN (5-2008)

APPLICATIONS

Vishay EFI MIC chip resistors provide excellent high-frequency response and are ideally suited for prototyping.

Typical application areas are:

- Amplifiers
- Oscillators
- Attenuators
- Couplers
- Filters

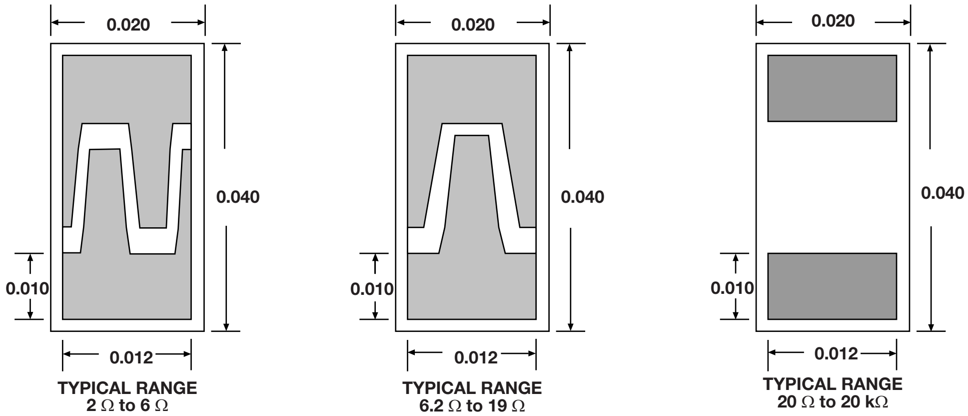
TEMPERATURE COEFFICIENT OF RESISTANCE, VALUES, AND TOLERANCES		
PARAMETER	**VALUE**	**UNIT**
Resistance Range	2 to 20K	Ω
Tolerances	± 1	%
TCR	± 25, ± 50, ± 100, ± 200	ppm/°C

Note

- Only 20 Ω to 1 kΩ are standard strip line designs for microwave applications

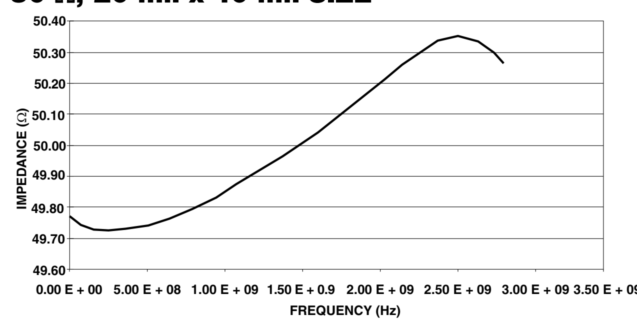
STANDARD ELECTRICAL SPECIFICATIONS		
PARAMETER	**VALUE**	**UNIT**
Noise, MIL-STD-202, Method 308	- 20 typ.	dB
Moisture Resistance, MIL-STD-202, Method 106	± 0.1 max. Δ*R*/*R*	%
Stability, 1000 h, + 125 °C, 62 mW	± 0.2 max. Δ*R*/*R*	%
Operating Temperature Range	- 55 to + 125	°C
Thermal Shock, MIL-STD-202, Method 107, Test Condition F	± 0.1 max. Δ*R*/*R*	%
High Temperature Exposure + 150 °C, 1000 h	± 0.2 max. Δ*R*/*R*	%
Dielectric Voltage Breakdown	400	V
Insulation Resistance	10^{12} min.	Ω
Operating Voltage	100 max.	V
DC Power Rating at + 70 °C (Derated to Zero at 150 °C)	0.125 max.	W
5 x Rated Power Short-Time Overload, + 25 °C, 5 s	± 0.1 max. Δ*R*/*R*	%

DIMENSIONS in inches



SCHEMATIC

IMPEDANCE VS. FREQUENCY
50 Ω, 20 mil x 40 mil SIZE



MECHANICAL SPECIFICATIONS	
PARAMETER	
Chip Size	0.020" x 0.040" ± 0.003" (0.5 mm x 1.0 mm ± 0.076 mm)
Chip Thickness	0.010" ± 0.002" (0.254 mm ± 0.05 mm)
Chip Substrate Material	99.6 % alumina, 2 µ" to 4 µ" finish
Resistor Material	Tantalum nitride, self-passivating
Bonding Pad Size	0.010" x 0.012" (0.254 mm x 0.30 mm) min.
Number of Pads	2
Pad Material	25 kÅ minimum gold standard
Backing	None

GLOBAL PART NUMBER INFORMATION

Global Part Number: MIC5000BKKMSNHWS

Global Part Number Description: MIC 50 10 %, 100 ppm/°C, MIC trim, SnPb termination, no back metal, class H, WS

M	I	C	5	0	0	0	B	K	K	M	S	N	H	W	S

MODEL	RESISTANCE	RESISTANCE MULTIPLIER CODE	TOL. CODE (%)	TCR (ppm/°C)	TRIM STYLE	TERMINATION	BACK METAL	VISUAL CLASS	PACKAGING CODE
MIC 20 x 40 size microwave resistor TaN on alumina	First 4 digits are significant figures of resistance	**C** = 0.001 **B** = 0.01 **A** = 0.1 **0** = 1 **1** = 10	**F** = 1.0 **G** = 2.0 **H** = 2.5 **J** = 5.0 **K** = 10 **M** = 20	**E** = ± 25 **C** = ± 50 **K** = ± 100 **L** = ± 200 **R** = 0/- 250	**M** = Microwave **S** = Standard	**G** = Au **S** = SnPb **A** = Al **T** = Lead (Pb)-free (e1)	**G** = Au **N** = None	**H** = Class H **K** = Class K	**WS** = Waffle pack 100 min, 1 mult

LM321 Low Power Single Op Amp

Check for Samples: LM321

FEATURES

- (V_{CC} = 5V, T_A = 25°C. Typical values unless specified.)
- Gain-Bandwidth Product 1MHz
- Low Supply Current 430µA
- Low Input Bias Current 45nA
- Wide Supply Voltage Range +3V to +32V
- Stable With High Capacitive Loads
- Single Version of LM324

APPLICATIONS

- Chargers
- Power Supplies
- Industrial: Controls, Instruments
- Desktops
- Communications Infrastructure

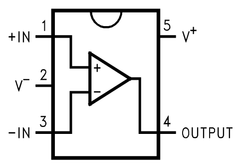
DESCRIPTION

The LM321 brings performance and economy to low power systems. With a high unity gain frequency and a specified 0.4V/µs slew rate, the quiescent current is only 430µA/amplifier (5V). The input common mode range includes ground and therefore the device is able to operate in single supply applications as well as in dual supply applications. It is also capable of comfortably driving large capacitive loads.

The LM321 is available in the SOT-23 package. Overall the LM321 is a low power, wide supply range performance op amp that can be designed into a wide range of applications at an economical price without sacrificing valuable board space.

Connection Diagram

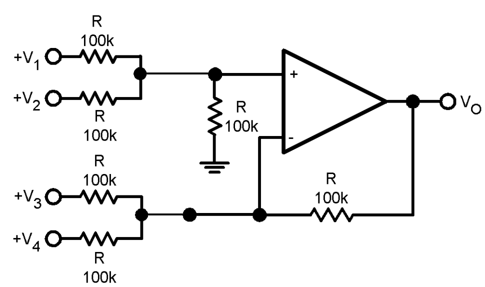
SOT-23



Top View

Application Circuit

DC Summing Amplifier
($V_{IN's}$ ≥ 0 V_{DC} and V_O ≥ V_{DC})



Where: $V_0 = V_1 + V_2 - V_3 - V_4$, $(V_1+V_2) \geq (V_3 + V_4)$ to keep $V_O > 0\ V_{DC}$

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)

Differential Input Voltage	±Supply Voltage
Input Current ($V_{IN} < -0.3V$) (2)	50mA
Supply Voltage ($V^+ - V^-$)	32V
Input Voltage	−0.3V to +32V
Output Short Circuit to GND, $V^+ \leq 15V$ and $T_A = 25°C$ (3)	Continuous
Storage Temperature Range	−65°C to 150°C
Junction Temperature (4)	150°C
Mounting Temperature	
Lead Temp (Soldering, 10 sec)	260°C
Infrared (10 sec)	215°C
Thermal Resistance to Ambient (θ_{JA})	265°C/W
ESD Tolerance (5)	300V

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not ensured. For ensured specifications and the test conditions, see the Electrical Characteristics.
(2) 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 −0.36V (at 25°C).
(3) Short circuits from the output V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground the maximum output current is approximately 40mA 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.
(4) The maximum power dissipation is a function of $T_{J(MAX)}$, θ_{JA} , and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A)/ \theta_{JA}$. All numbers apply for packages soldered directly onto a PC board.
(5) Human Body Model, 1.5kΩ in series with 100pF.

Operating Ratings (1)

Temperature Range	−40°C to 85°C
Supply Voltage	3V to 30V

(1) Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not ensured. For ensured specifications and the test conditions, see the Electrical Characteristics.

Electrical Characteristics

Unless otherwise specified, all limits specified for at T_A = 25°C; V^+ = 5V, V^- = 0V, V_O = 1.4V. **Boldface** limits apply at temperature extremes.

Symbol	Parameter		Conditions	Min (1)	Typ (2)	Max (1)	Units
V_{OS}	Input Offset Voltage		(3)		2	7 **9**	mV
I_{OS}	Input Offset Current				5	50 **150**	nA
I_B	Input Bias Current (4)				45	250 **500**	nA
V_{CM}	Input Common-Mode Voltage Range		V^+ = 30V (5) For CMRR > = 50dB	0		V^+ - 1.5 **V^+ -2**	V
A_V	Large Signal Voltage Gain		(V^+ = 15V, R_L = 2kΩ V_O = 1.4V to 11.4V)	25 **15**	100		V/mV
PSRR	Power Supply Rejection Ratio		R_S ≤ 10kΩ, V^+ ≤ 5V to 30V	65	100		dB
CMRR	Common Mode Rejection Ratio		R_S ≤ 10kΩ	65	85		dB
V_O	Output Swing	V_{OH}	V^+ = 30V, R_L = 2kΩ	**26**			V
			V^+ = 30V, R_L = 10kΩ	**27**	**28**		
		V_{OL}	V^+ = 5V, R_L = 10kΩ		**5**	**20**	mV
I_S	Supply Current, No Load		V^+ = 5V		0.430 **0.7**	1.15 **1.2**	mA
			V^+ = 30V		0.660 **1.5**	2.85 **3**	
I_{SOURCE}	Output Current Sourcing		V_{ID} = +1V, V^+ = 15V, V_O = 2V	20 **10**	40 **20**		mA
I_{SINK}	Output Current Sinking		V_{ID} = −1V V^+ = 15V, V_O = 2V	10 **5**	20 **8**		mA
			V_{ID} = −1V V^+ = 15V, V_O = 0.2V	12	100		µA
I_O	Output Short Circuit to Ground (6)		V^+ = 15V		40	85	mA
SR	Slew Rate		V^+ = 15V, R_L = 2kΩ, V_{IN} = 0.5 to 3V C_L = 100pF, Unity Gain		0.4		V/µs
GBW	Gain Bandwidth Product		V^+ = 30V, f = 100kHz, V_{IN} = 10mV, R_L =2kΩ, C_L = 100pF		1		MHz
φm	Phase Margin				60		deg
THD	Total Harmonic Distortion		f = 1kHz, A_V = 20dB R_L = 2kΩ, V_O = $2V_{PP}$, C_L = 100pF, V^+ = 30V		0.015		%
e_n	Equivalent Input Noise Voltage		f = 1kHz, R_S = 100Ω V^+ = 30V		40		$nV/\sqrt{Hz}$

(1) All limits are specified by testing or statistical analysis.
(2) Typical values represent the most likely parametric norm.
(3) V_O ≅ 1.4V, R_S = 0Ω with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ - 1.5V) at 25°C.
(4) 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.
(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, independent of the magnitude of V^+.
(6) Short circuits from the output V^+ can cause excessive heating and eventual destruction. When considering short circuits to ground the maximum output current is approximately 40mA 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.

APPLICATION HINTS

The LM321 op amp can operate with a single or dual power supply voltage, has true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. This amplifier operates over a wide range of power supply voltages, with little change in performance characteristics. At 25°C amplifier operation is possible down to a minimum supply voltage of 3V.

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 drain, the amplifier has 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 to reduce distortion.

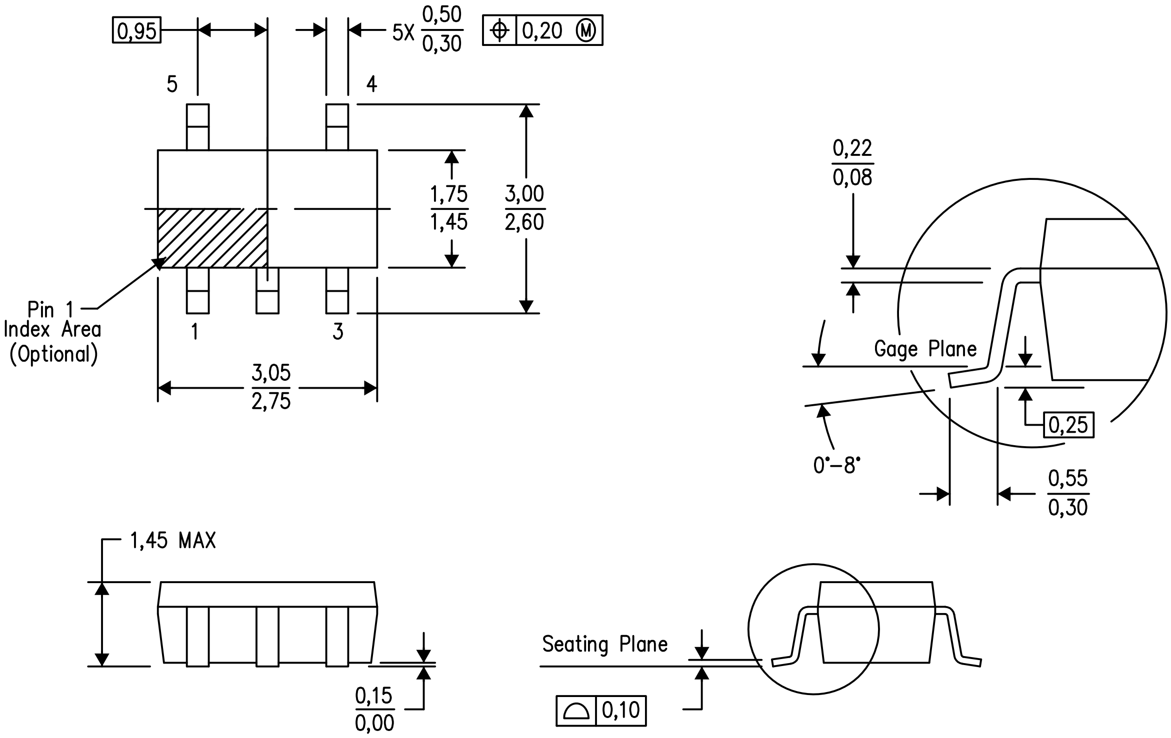
Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if large load capacitance must be driven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

The bias network of the LM321 establishes a supply current which is independent of the magnitude of the power supply voltage over the range of from 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 junction temperatures. The larger value of output source current which is available at 25°C provides a larger output current capability at elevated temperatures than a standard IC op amp.

The circuits presented in the section on typical 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.

DBV (R-PDSO-G5) PLASTIC SMALL-OUTLINE PACKAGE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
- D. Falls within JEDEC MO-178 Variation AA.

the swiss power source

renata batteries

CR1225

3V Lithium Battery
Swiss Made

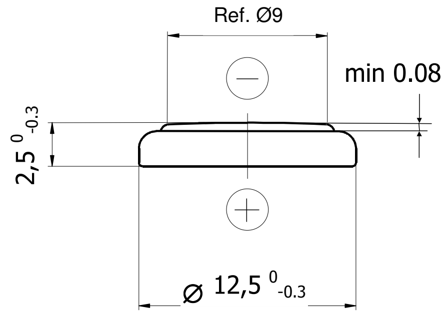
Technical Data Sheet

Specifications

Chemical System	Li / MnO_2
Nominal Voltage	3 V
Rated Capacity	48 mAh
Standard Discharge Current	0.1 mA
Max. Cont. Discharge Current	1.0 mA
Average Weight	0.9 g
Operating Temperature*	-40 - +85 °C
Self Discharge at 23°C	< 1% / year

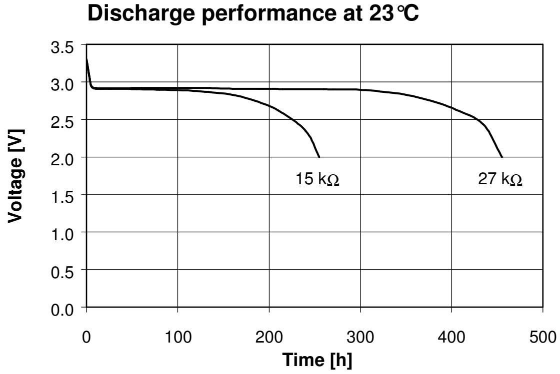
Dimensions

(According to IEC 60086)

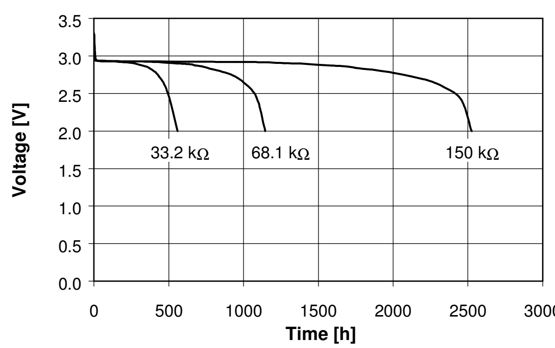


Performance

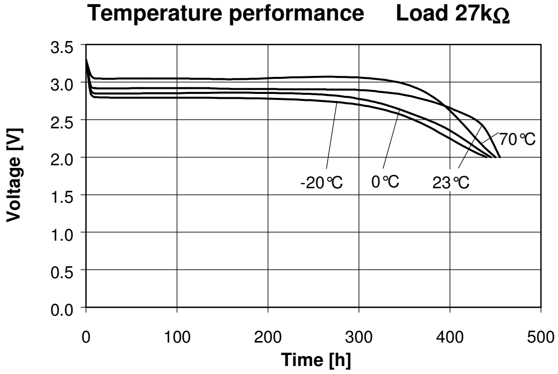
Discharge performance at 23°C



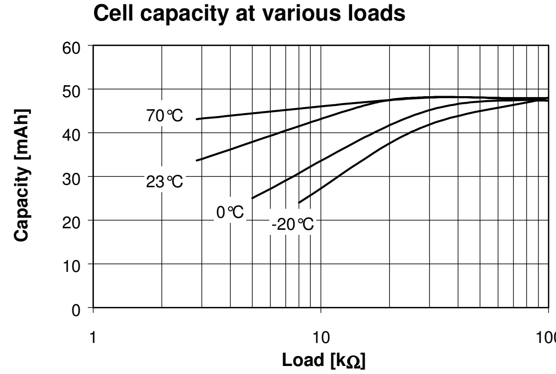
Discharge performance at 23°C



Temperature performance Load 27kΩ



Cell capacity at various loads



In applications where the battery is exposed to temperatures above 70 °C, please contact Renata for consultancy.

Information and contents in this data sheet are for reference purpose only. They do not constitute any warranty or representation and are subject to change without notice. For most current information and further details, please contact your Renata representative.

Rev. 1225.06 / 12.06

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sales@renata.com
www.renata.com

A COMPANY OF THE SWATCH GROUP

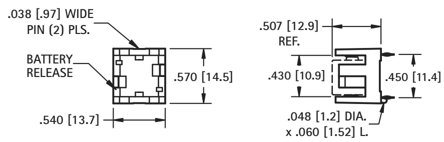
THRU-HOLE (THM) & SURFACE MOUNT (SMT) COIN CELL HOLDERS

DESIGN ADVANTAGES...
- Reliable spring tension assures low contact resistance
- Retains battery securely to withstand shock and vibration
- Base material UL Rated 94V-0. Impervious to most industrial solvents
- Operating temperature range: -60°F to +293°F (-50°C to +145°C)

IDEALLY SUITED FOR...
- Computer memory, power transfer and back-up systems
- Video and telecommunications power back-up
- Microprocessors and Microcomputer memory hold (desktop and laptop applications)
- Industrial and commercial security and alarm systems
- PC/104 application

"1/3N"

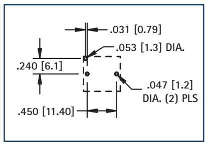
THRU HOLE MOUNT



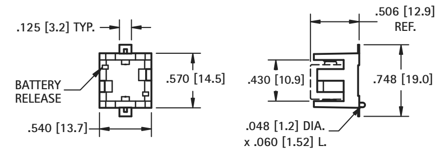
MATERIAL:
Base: High Temperature Nylon 46, UL Rated 94V-0
Contacts: .012 (.30) Phosphor Bronze, Tin Plate

CAT. NO.	CELLS	BATTERY REFERENCE
503	1	DL1/3N, K58L, CR1/3N
	2	SR44, 357, MS76, G-13, 303, V313, PX76A

Mounting Detail



AVAILABLE ON TAPE AND REEL

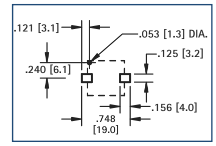


SURFACE MOUNT

MATERIAL:
Base: High Temperature Nylon 46, UL Rated 94V-0
Contacts: .012 (.30) Phosphor Bronze, Gold Plate (Flash)

CAT. NO. BULK	ON TAPE & REEL	CELLS	BATTERY REFERENCE
498	498TR	1	DL1/3N, K58L, CR1/3N
		2	SR44, 357, MS76, G-13, 303, V313, PX76A

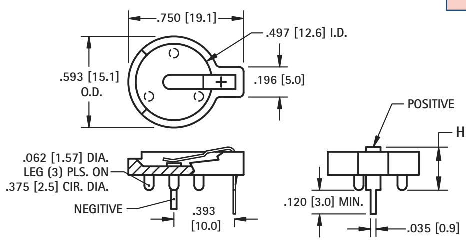
Pad Layout



Tape & Reel Spec's: 44mm wide; 20mm pitch; 13 inch reel (200 pieces per reel)

12mm

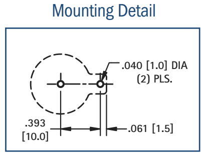
THRU HOLE MOUNT



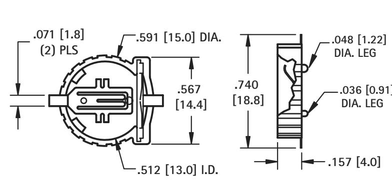
MATERIAL:
Base: PBT, UL Rated 94V-0
Positive Contact: .015 (.38) Spring Steel, Tin-Nickel Plate
Negative Contact: .035 (.89) Dia. Steel, Tin-Nickel Plate

CAT. NO.	HEIGHT (H)	CELLS	BATTERY REFERENCE
500	.280 (7.1)	1	BR1212, CR1216, CL1220, CR1225
501	.380 (9.7)	2	BR1212, CR1216, CL1220, CR1225

Mounting Detail



AVAILABLE ON TAPE AND REEL

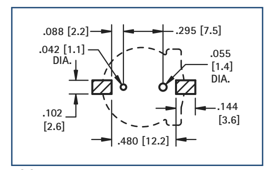


SURFACE MOUNT

MATERIAL:
Base: Glass Filled PPS, UL Rated 94V-0
Contacts: .008 (.20) Phosphor Bronze, Gold Plate (Flash)

CAT. NO. BULK	ON TAPE & REEL	CELLS	BATTERY REFERENCE
1056	1056TR	1	CR1220, BR1220

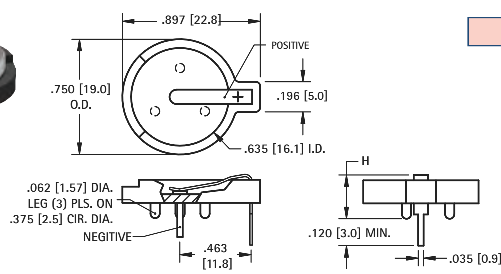
Pad Layout



Tape & Reel Spec's: 32mm wide; 20mm pitch; 13 inch reel (500 per reel)

16mm

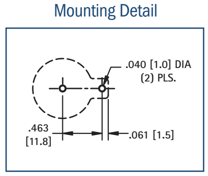
THRU HOLE MOUNT



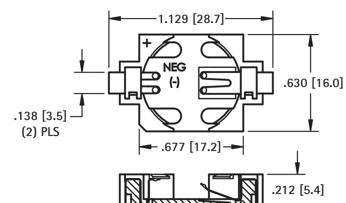
MATERIAL:
Base: PBT, UL Rated 94V-0
Positive Contact: .015 (.38) Spring Steel, Tin-Nickel Plate
Negative Contact: .035 (.89) Dia. Steel, Tin-Nickel Plate

CAT. NO.	HEIGHT (H)	CELLS	BATTERY REFERENCE
502	.285 (7.3)	1	CR1612, CL1616, CL1620
		2	CR1612
502-3	.330 (8.4)	1	BR1625, CR1632
		2	BR1616, CR1620, CL1620

Mounting Detail



AVAILABLE ON TAPE AND REEL

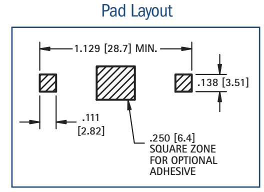


SURFACE MOUNT

MATERIAL:
Base: Glass Filled LCP, UL Rated 94V-0
Contacts: .006 (.15) Phosphor Bronze, Gold Plate (Flash)

CAT. NO. BULK	ON TAPE & REEL	CELLS	BATTERY REFERENCE
504	504TR	1	BR1625, CR1625

Pad Layout

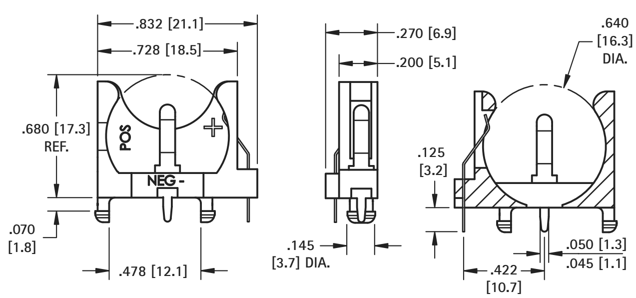


Tape & Reel Spec's: 44mm wide; 24mm pitch; 13 inch reel (500 per reel)

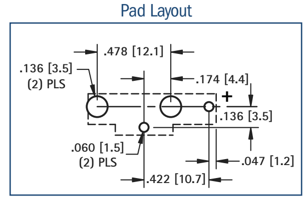
16mm VERTICAL

MATERIAL:
Base: PBT, UL Rated 94V-0
Contacts: .010 (.25) Steel, Tin-Nickel Plate
Battery Reference: **(1) cell:** BR1612, CR1616, CL1620, CR1625, BR1632

CAT. NO. 1069



Pad Layout



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MIXED SIGNAL MICROCONTROLLER

FEATURES

- Low Supply Voltage Range 1.8 V to 3.6 V
- Ultra-Low Power Consumption
  - Active Mode: 220 µA at 1 MHz, 2.2 V
  - Standby Mode: 0.5 µA
  - Off Mode (RAM Retention): 0.1 µA
- Five Power-Saving Modes
- Ultra-Fast Wake-Up From Standby Mode in Less Than 1 µs
- 16-Bit RISC Architecture, 62.5-ns Instruction Cycle Time
- Basic Clock Module Configurations:
  - Internal Frequencies up to 16 MHz With Four Calibrated Frequencies to ±1%
  - Internal Very Low-Power Low-Frequency Oscillator
  - 32-kHz Crystal
  - External Digital Clock Source
- 16-Bit Timer_A With Two Capture/Compare Registers
- On-Chip Comparator for Analog Signal Compare Function or Slope A/D (MSP430F20x1)
- 10-Bit 200-ksps A/D Converter With Internal Reference, Sample-and-Hold, and Autoscan (MSP430F20x2)
- 16-Bit Sigma-Delta A/D Converter With Differential PGA Inputs and Internal Reference (MSP430F20x3)
- Universal Serial Interface (USI) Supporting SPI and I2C (MSP430F20x2 and MSP430F20x3)
- Brownout Detector
- Serial Onboard Programming, No External Programming Voltage Needed, Programmable Code Protection by Security Fuse
- On-Chip Emulation Logic With Spy-Bi-Wire Interface
- Family Members:
  - MSP430F2001
    - 1KB + 256B Flash Memory
    - 128B RAM
  - MSP430F2011
    - 2KB + 256B Flash Memory
    - 128B RAM
  - MSP430F2002
    - 1KB + 256B Flash Memory
    - 128B RAM
  - MSP430F2012
    - 2KB + 256B Flash Memory
    - 128B RAM
  - MSP430F2003
    - 1KB + 256B Flash Memory
    - 128B RAM
  - MSP430F2013
    - 2KB + 256B Flash Memory
    - 128B RAM
- Available in 14-Pin Plastic Small-Outline Thin Package (TSSOP), 14-Pin Plastic Dual Inline Package (PDIP), and 16-Pin QFN
- For Complete Module Descriptions, See the *MSP430x2xx Family User's Guide* (SLAU144)

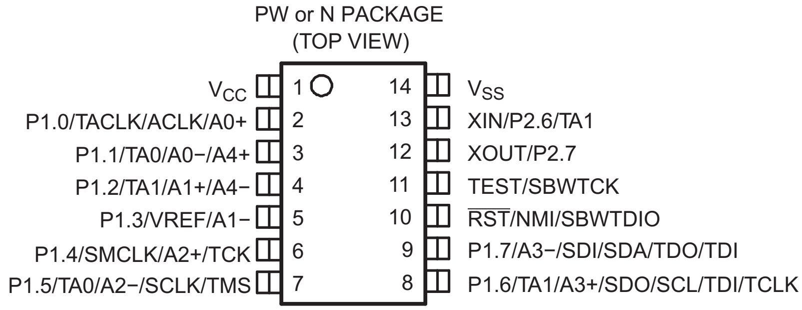
DESCRIPTION

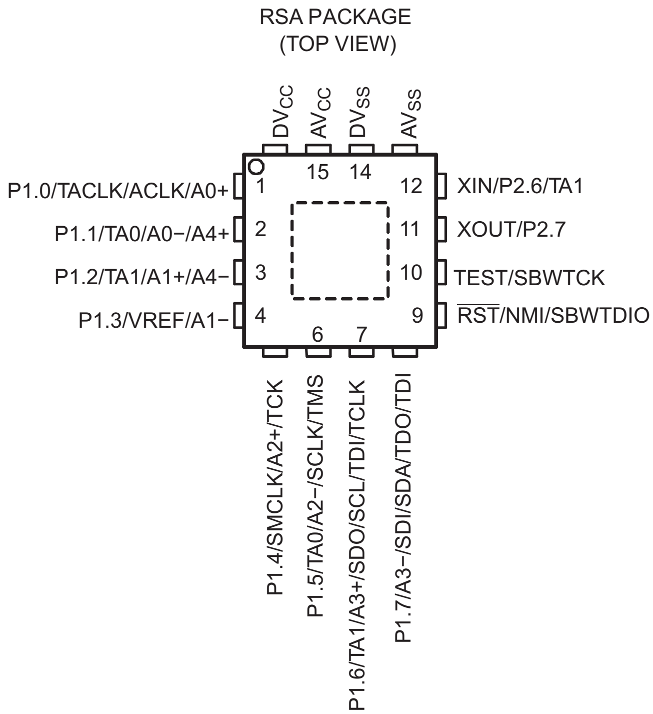
The Texas Instruments MSP430 family of ultra-low-power microcontrollers consist of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs.

The MSP430F20xx series is an ultra-low-power mixed signal microcontroller with a built-in 16-bit timer and ten I/O pins. In addition, the MSP430F20x1 has a versatile analog comparator. The MSP430F20x2 and MSP430F20x3 have built-in communication capability using synchronous protocols (SPI or I2C) and a 10-bit A/D converter (MSP430F20x2) or a 16-bit sigma-delta A/D converter (MSP430F20x3).

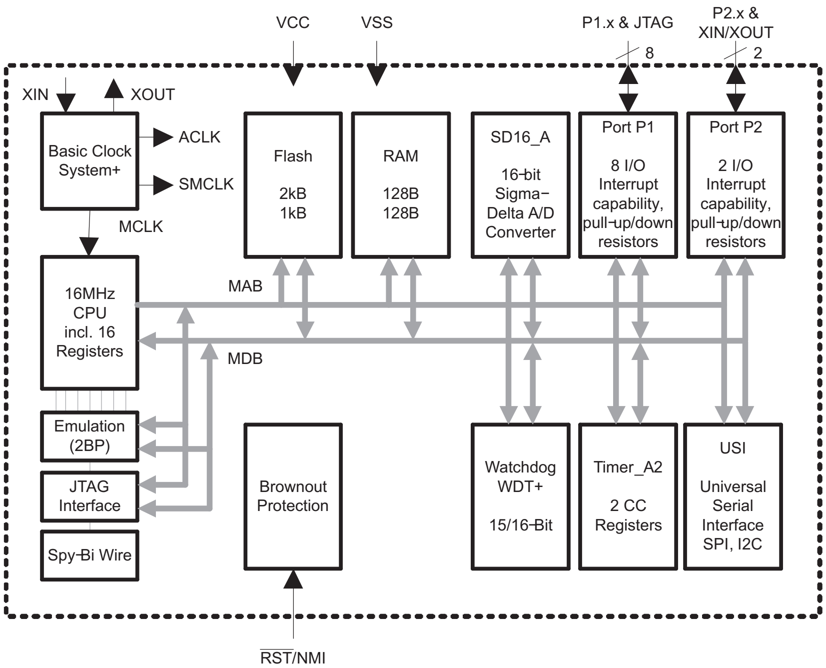
Device Pinout, MSP430F20x3

See port schematics section for detailed I/O information.

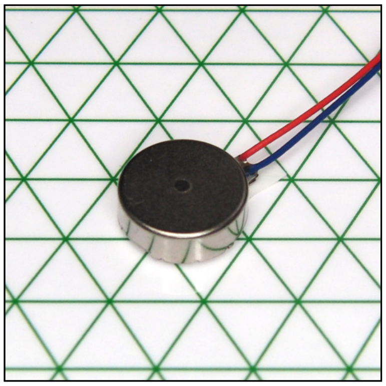




Functional Block Diagram, MSP430F20x3



NOTE: See port schematics section for detailed I/O information.



10mm Vibration Motor - 3.4mm Type
Shown on 6mm Isometric Grid

PRECISION MICRODRIVES™

Product Data Sheet
Pico Vibe™
10mm Vibration Motor - 3.4mm Type

Model: 310-113

Ordering Information

The model number 310-113 fully defines the model, variant and additional features of the product. Please quote this number when ordering.
For stocked types, testing and evaluation samples can be ordered directly through our online store.

Datasheet Versions

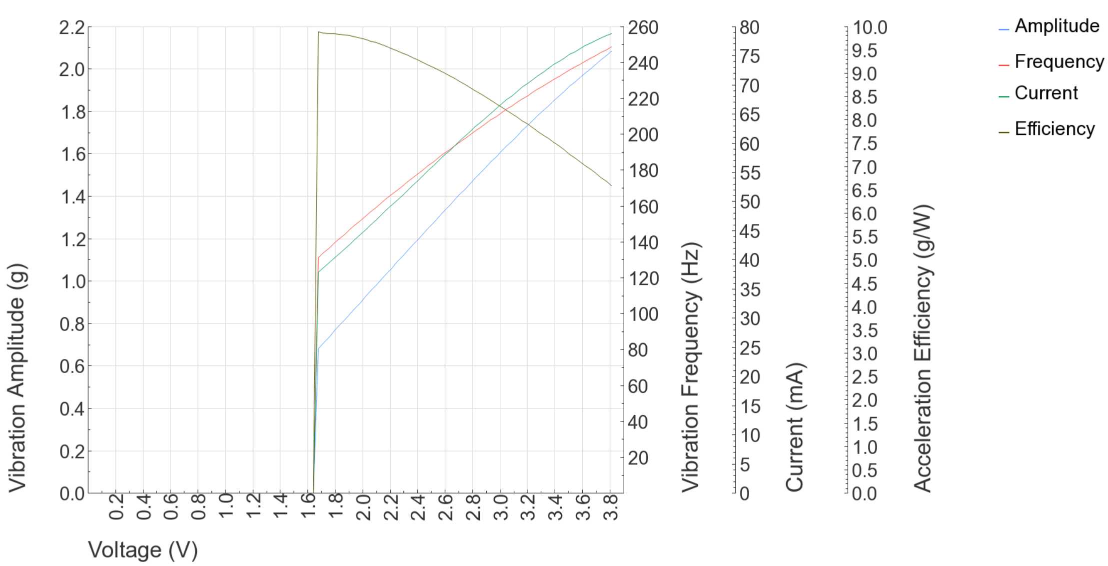
It is our intention to provide our customers with the best information available to ensure the successful integration between our products and your application. Therefore, our publications will be updated and enhanced as improvements to the data and product updates are introduced.
To obtain the most up-to-date version of this datasheet, please visit our website at:
www.precisionmicrodrives.com
The version number of this datasheet can be found on the bottom left hand corner of any page of the datasheet and is referenced with an ascending R-number (e.g. R0002 is newer than R0001). Please contact us if you require a copy of the engineering change notice between revisions.

If you have any questions, suggestions or comments regarding this publication or need technical assistance, please contact us via email at:
enquiries@precisionmicrodrives.com or call us on +44 (0) 1932 252 482

Key Features

Body Diameter:	10 mm
Body Length:	3.4 mm
Typical Operating Current:	63 mA
Typical Power Consumption:	190 mW
Typical Normalised Amplitude:	1.4 G
Rated Voltage:	3 V
Rated Speed:	12,000 rpm
Lead Length:	100 mm
Lead Wire Gauge:	32 AWG

Typical Vibration Motor Performance Characteristics



Physical Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Body Diameter	Max body diameter or max face dimension where non-circular	10 mm	+/- 0.1 mm
Body Length	Excl. shafts, leads and terminals	3.4 mm	+/- 0.1 mm
Unit Weight		1.2 g	
Counterweight Radius	Radius from shaft for non-cylindrical weights	0 mm	
Counterweight Length		0 mm	

Construction Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Motor Construction		Flat Coreless	
Commutation		Precious Metal Brush	
No. of Poles		6	
Bearing Type		Sintered Bronze	
No. of Output Shafts		0	

Leads & Connectors Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Lead Length	Lead lengths defined as total length or between motor and connector	100 mm	+/- 2 mm
Lead Strip Length		1.5 mm	+/- 0.5 mm
Lead Wire Gauge		32 AWG	
Lead Configuration		Straight	

Conformity Limits Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Rated Voltage		3 V	
Inertial Test Load	Mass of standard test sled	100 g	
Max. Start Current	At rated voltage	105 mA	
Max. Operating Voltage		3.8 V	
Certified Start Voltage	With the inertial test load	2.3 V	
Rated Speed	At rated voltage using the inertial test load	12,000 rpm	+/- 2,500 rpm
Min. Vibration Amplitude	Peak-to-peak value at rated voltage using the inertial test load	1 G	
Max. Operating Current	At rated voltage using the inertial test load	75 mA	

Important: The characteristics of the motor is the typical operating parameters of the product. The data herein offers design guidance information only and supplied batches are validated for conformity against the specifications on the previous page.

Typical Electrical Characteristics

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Typical Operating Current	At rated voltage using the inertial test load	63 mA	
Typical Power Consumption	At rated voltage and load	190 mW	
Typical Vibration Amplitude	Peak-to-peak value at rated voltage using the inertial test load	1.4 G	
Typical Normalised Amplitude	Peak-to-peak vibration amplitude normalised by the inertial test load at rated voltage	1.4 G	
Typical Vibration Efficiency	At rated voltage using the inertial test load	7.3 G/W	
Typical Max. Terminal Resistance		60 Ohm	
Typical Max. Terminal Inductance		530 uH	
Min. Insulation Resistance	At 50V DC between motor terminal and case	10 MOhm	
Typical Start Voltage	With the inertial test load	1.6 V	
Typical Start Current	At rated voltage	105 mA	

Typical Haptic Characteristics

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Typical Lag Time	At rated voltage using the inertial test load	37 ms	
Typical Rise Time	At rated voltage using the inertial test load	92 ms	
Typical Stop Time	At rated voltage using the inertial test load	116 ms	
Typical Active Brake Time	Time taken from steady-state to 0.04 G under inverse polarity at max. voltage	46 ms	

Typical Mechanical Characteristics

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Typical Min. Counterweight Pullout		0 N	
Typical Max. Mech. Noise		50 dB(A)	

Environmental Characteristics

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Min. Operating Temp.		-20 Deg.C	
Max. Operating Temp.		70 Deg.C	
Min. Storage Temp.		-30 Deg.C	
Max. Storage Temp.		80 Deg.C	

Typical Packing Conditions

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Carton Type		**Boxed Trays**	

Reliability Analysis

This section presents information regarding the longevity test performed on the motor. The Mean Time to Failure reported in this page should not be interpreted as a guaranteed lifetime. Please check our Application Notes for further information.

Our longevity test consists of powering the motors at their rated voltage for 2 seconds, then turning them off for 2 seconds. This cycle is repeated over the total test time.

The test is performed by our custom longevity machine which drives the motors and collects performance data. The test parameters and results can be seen below.

Test Parameters

- Motors tested: 48
- Test time: 720 hours
- Cycle period: 4 seconds
- Duty cycle: 50%
- Test voltage: 3.0 V
- Temperature: 32 °C

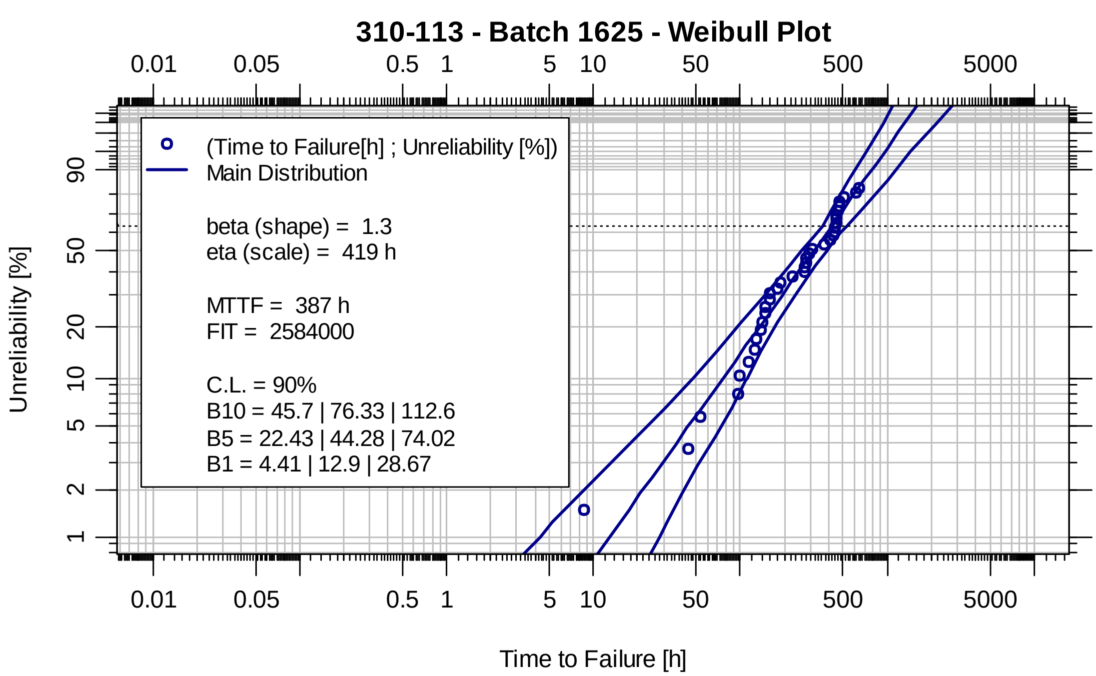
Formulas to derive the key reliability figures from a Weibull distribution:

$$MTTF = \eta * \Gamma\left(1 + \frac{1}{\beta}\right)$$

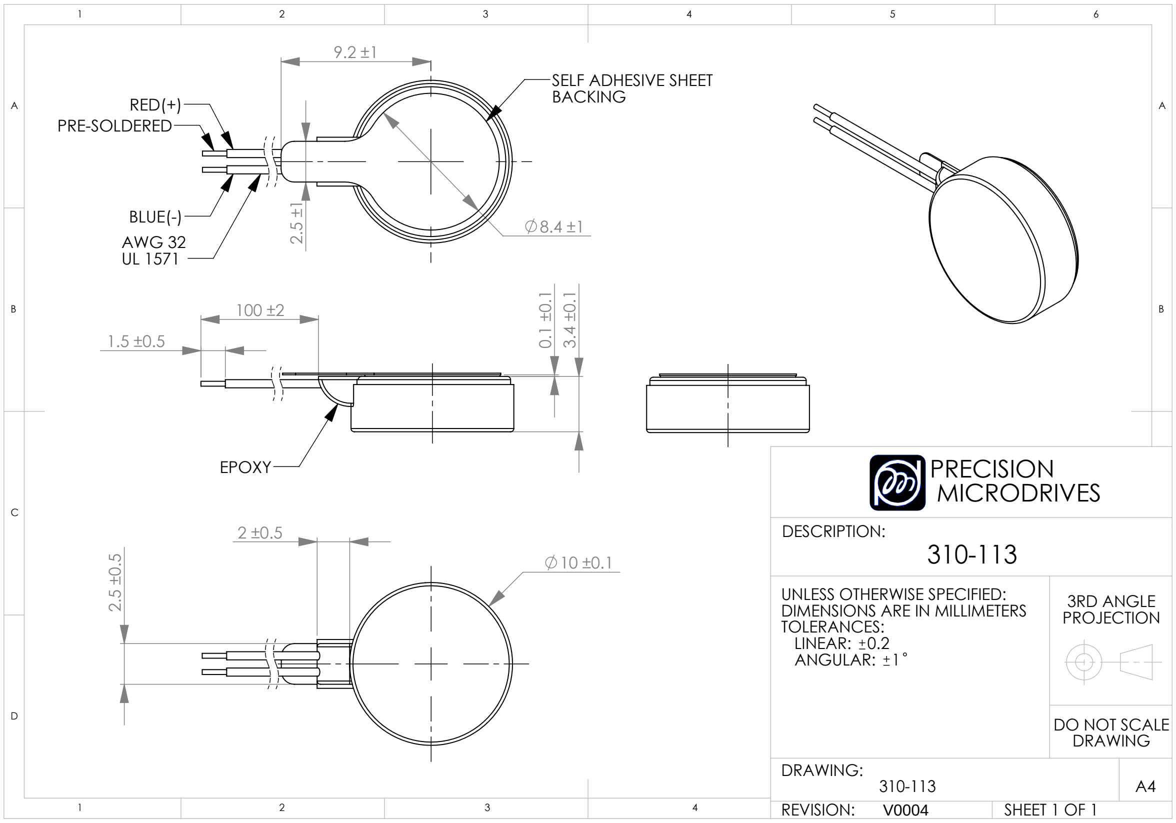
$$FIT = 10^9 / MTTF$$

Test Result

The results for the longevity test are presented in a Weibull plot. From the fitting distribution it is possible to obtain an estimate of the Mean Time to Failure.



Product Dimensional Specification



Life Support Policy

PRECISION MICRODRIVES PRODUCTS ARE NOT AUTHORISED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF PRECISION MICRODRIVES LIMITED.
As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Registered in England and Wales No. 5114621
VAT registration. GB 900 1238 84

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