We can help you brew that perfect beer . . .
or anything else that demands a constant temperature

PROGRAMMABLE THERMAL REGULATOR

by Tim Blythman and Nicholas Vinen

Precision temperature control is an integral part of many industrial processes. If you are interested in making your own brewed or fermented foods as a hobbyist, you will find that it's important to accurately maintain the temperature of the process to get the best results.

From time to time, we have tried to make our own cheese, beer and cider (not at the office, of course!).

For beer, malted barley is fermented by yeast to create alcohol and develop flavours. The fermenting activity also adds effervescence to the finished product.

The fermentation (say, for homebrew beer or cider) takes place in a food-grade plastic container. Good results *may* be achieved by merely keeping the vessel in a room where the temperature does not vary much, perhaps wrapping it with a blanket in the cooler months.

But for consistency and to ensure that fermentation completes correctly (if it doesn't, that's when bottles start to explode!), you need a way to monitor and control the brew temperature. Proper temperature regulation is one reason that commercial breweries can ensure that each batch of beer tastes the same as the others.

Even keeping the brew vessel in a thermostatically controlled room may not be sufficient.

As the fermentation progresses, the yeast activity rises and falls. The heat generated varies, which can alter the temperature of the brew from the inside, even if the outside temperature is steady.

Thus we need a means of both measuring and changing the temperature of the brew.

We have chosen Peltier devices for this as they have the ability to both heat and cool; they only require a low-voltage DC supply, and they are easy to control. They are not the most efficient devices, but are adequate for small scale operations.

Sous-vide cookery

Another application for the Thermal Regulator is sous-vide cookery. While the term French 'sous-vide' literally translates to 'under vacuum', the vacuum is not critical. The success of sous-vide cookery is mostly due to precise temperature control.

We'll go into a bit more detail about this later, but the important thing is that a tightly controlled temperature leads to consistent and repeatable results.

By keeping the food hot enough for long enough, you ensure that any bacteria is killed, and thus it is safe to eat.

Other areas of cookery which work well with precise temperatures include the tempering of chocolate. Taking the chocolate along a well-defined temperature profile alters its structure and produces a glossy appearance and crisp texture when the chocolate hardens.

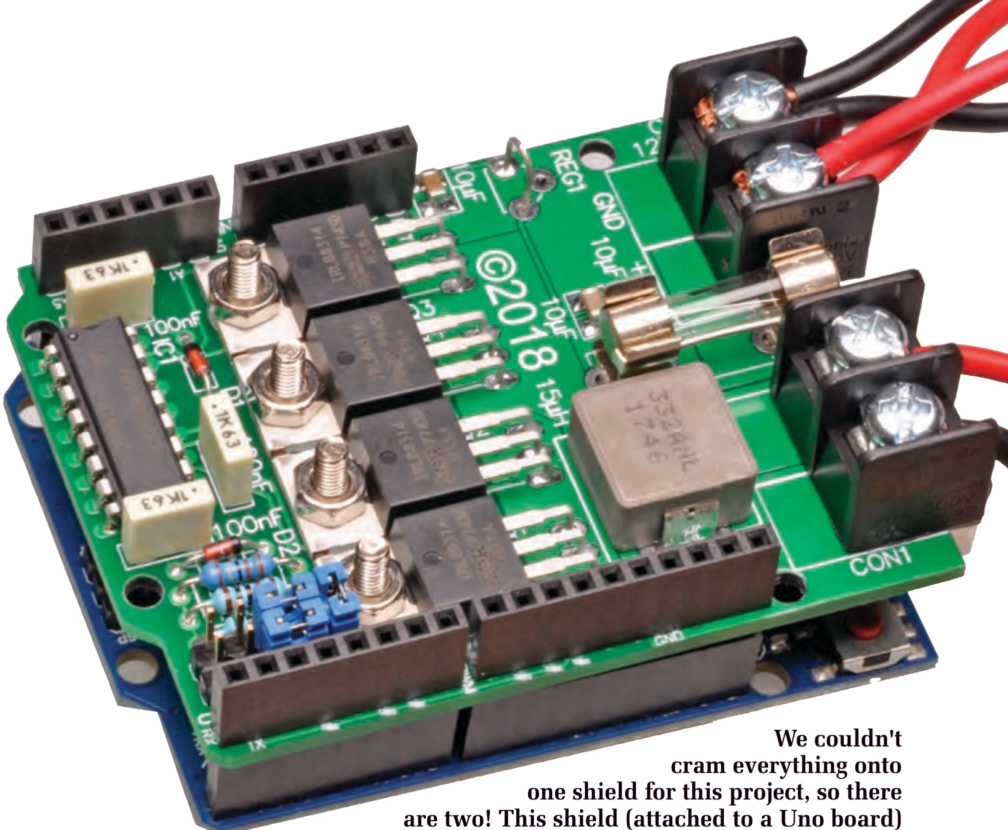
One of the intriguing possibilities with this device is that you could use it to keep food at a safe storage temperature (around 4°C, like the inside of a refrigerator) for many hours and then at a preset time, heat it up and cook it, so it is ready for you to eat.

If doing this, we suggest you modify the software to trigger an alert if the food temperature went significantly above 4°C in storage mode, so you know that it is safe to eat.

And more

Many people who have worked in a laboratory will be familiar with the laboratory water bath as a way of keeping test samples at a fixed temperature. Naturally, the Thermal Regulator is well suited to this application too.

We've even joked about using the Thermal Regulator as a personal air-conditioner. Joking aside, the radiator does produce a refreshing breeze when it's set to heat, so we reckon it actually would do that job pretty well.



We couldn't cram everything onto one shield for this project, so there are two! This shield (attached to a Uno board) is designed to drive Peltier devices at up to 20A in bridge mode, meaning the current can be reversed and the Peltier can be used to perform heating or cooling. There's a number of surface mounted devices on this shield, but none of them are too small, so construction is not difficult.

Thermal Regulator electronics

The Thermal Regulator electronics consists of three main parts. An Arduino Uno board (or compatible) provides a microcontroller as well as some power regulator circuitry.

A Peltier Driver shield (Arduino add-on board) implements a high-power full H-bridge which is controlled by the Arduino. This is used to drive the Peltier devices.

A second shield (the Interface shield) has numerous inputs and outputs; it is primarily concerned with sensing what is happening with the Peltier devices and can also drive other devices such as pumps and fans.

We'll expand on these later. You will need to be familiar with the Arduino IDE to construct this project; it can be downloaded for free from siliconchip.com.au/link/aatq

As this circuitry has so many potential uses, we've designed the control circuit to be as flexible as possible. Before continuing, you may wish to read the accompanying panel, which describes how Peltier devices work.

The inspiration for this article

It was thinking about projects like the 2003 Peltier Esky ("Tinnie Cooler") which gave us the idea for this series of articles.

That project involved quite a large heatsink and fan attached to a single Peltier module to try to get all the waste heat out and keep the Peltier running efficiently. If you use several Peltier devices to try to pump more heat, you end up needing a huge heatsink.

While simple and relatively cheap, this is not an ideal solution.

Features:

- *Active cooling and heating*
- *Controls 200W+ worth of Peltier devices*
- *Utilises multiple temperature sensors*
- *Arduino-based for flexibility*

Possible uses:

- *Cheesemaking*
- *Beer/Wine/Cider/Kombucha brewing*
- *Tempering chocolate*
- *Sous-vide cooking*
- *Computer cooling*
- *Laboratory water bath*
- *Aquariums (especially large tropical)*
- *Personal air-conditioner*
- *Improved cooling for laser cutters*

Consider, for example, that a car engine puts out a vast amount of heat (hundreds of kilowatts in some cases). While early engines were air-cooled, most manufacturers quickly moved to liquid cooling. It is much easier to remove all that heat with a bit of water flow, which can then go to a large radiator with sufficient surface area to transfer that heat to the air.

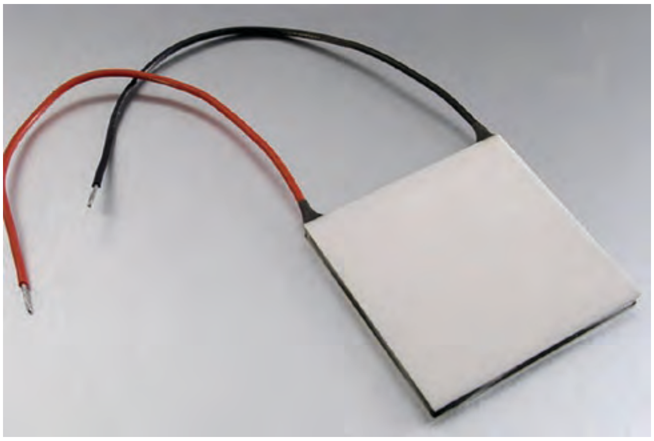
So we thought, why not apply the same principles to Peltier devices? Small radiators as used in water-cooled computers are now readily available at modest cost, and the required fans, pumps and tubing do not cost much either. We then bought some parts and performed a series of experiments which brought us to develop what we are presenting here.

One example

Sous-vide cookery is a good example to demonstrate what our resulting hardware can achieve.

As we mentioned, the term 'sous-vide' translates to 'under vacuum'. This term has little to do with the process except that the items to be cooked (typically meat, fish or eggs) are usually vacuum-sealed into a waterproof bag before being

How Peltier devices work



A Peltier device is effectively an electric heat pump with no moving parts. An electric current through the device causes heat to move from one side to the other. It consists of one or multiple junctions of dissimilar metals, across which a voltage is applied. The general construction of such a device is shown in the accompanying figure.

The laws of thermodynamics do not allow heat or coldness to be 'created'; these are merely a consequence of energy being moved from one place to another. For example, electric heaters convert electrical energy to heat energy in a 1:1 ratio. Unfortunately, the law of entropy means that we must expend energy to move this heat energy around. Hence the process cannot be 100% efficient.

The reverse of the Peltier effect is called the Seebeck effect, where a temperature difference is converted into a voltage. The energy delivered by that voltage comes from the thermal energy flowing from the hot side to the cold side. This is the effect used by temperature-sensing thermocouples and thermopiles.

The Seebeck effect can also be observed in Peltier devices, although they are not designed with this in mind and so are not very efficient. For example, if power is applied to a Peltier device for a few seconds (enough to cause a temperature difference) and then removed, a voltage can be measured at the device's terminals. This is due to the Seebeck effect of electricity generated from the residual temperature difference.

A Peltier device consists of an array of alternating materials, resulting in alternating junctions with opposing behaviours. They are arranged so that heat is transferred from one side to the other, by keeping each type of junction on its own side.

We last published a project using a Peltier device in 2003 (**siliconchip.com.au/Article/3969**). This involved adding active cooling to a small Esky (chilly bin) to help get drink cans cold. That project also had a feature in that it could be used as a heater; one upside of the Peltier effect is that it is reversible. If the direction of the current is reversed, then the heat flows in the opposite direction.

You may have used this type of cooler. They do a fair job, but most are no competition for a regular household refrigerator or air-conditioner, which use a compressor and do not suffer from the side-effects noted below.

While Peltiers have the benefit of reversibility and no moving parts, they do have their downsides. In particular, the materials which provide the strongest Peltier effect are not good thermal insulators; in effect, the heat can leak from the hot side back to the cold side. This effect becomes stronger as a higher temperature difference is generated across the device.

Practical Peltier devices are typically made of semiconductor materials with a finite resistance. As such, they are also subject to resistive heating due to the current flowing through them. This is calculated as I^2R, so a doubling of current will result in four times as much dissipation. But the amount of heat that is pumped is proportional to the current, so Peltier devices work best when demands on them are modest.

Peltier devices are also typically made out of brittle ceramics. These are necessary to provide electrical insulation while allowing heat to be effectively conducted to the working surfaces.

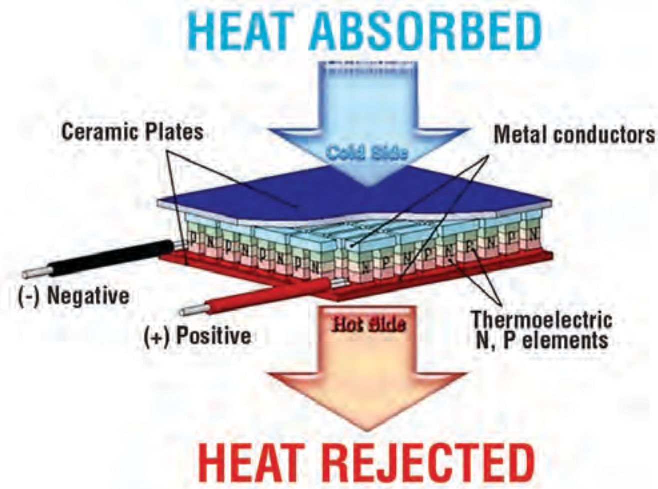
Safely driving a Peltier

Rapid changes in current can cause a temperature gradient; the resulting temperature changes can create thermal stress and even cracking. Using techniques like PWM (pulse width modulation) to modulate the current must be done carefully to avoid damage. At the very least, the PWM frequency should be high enough to sidestep these effects.

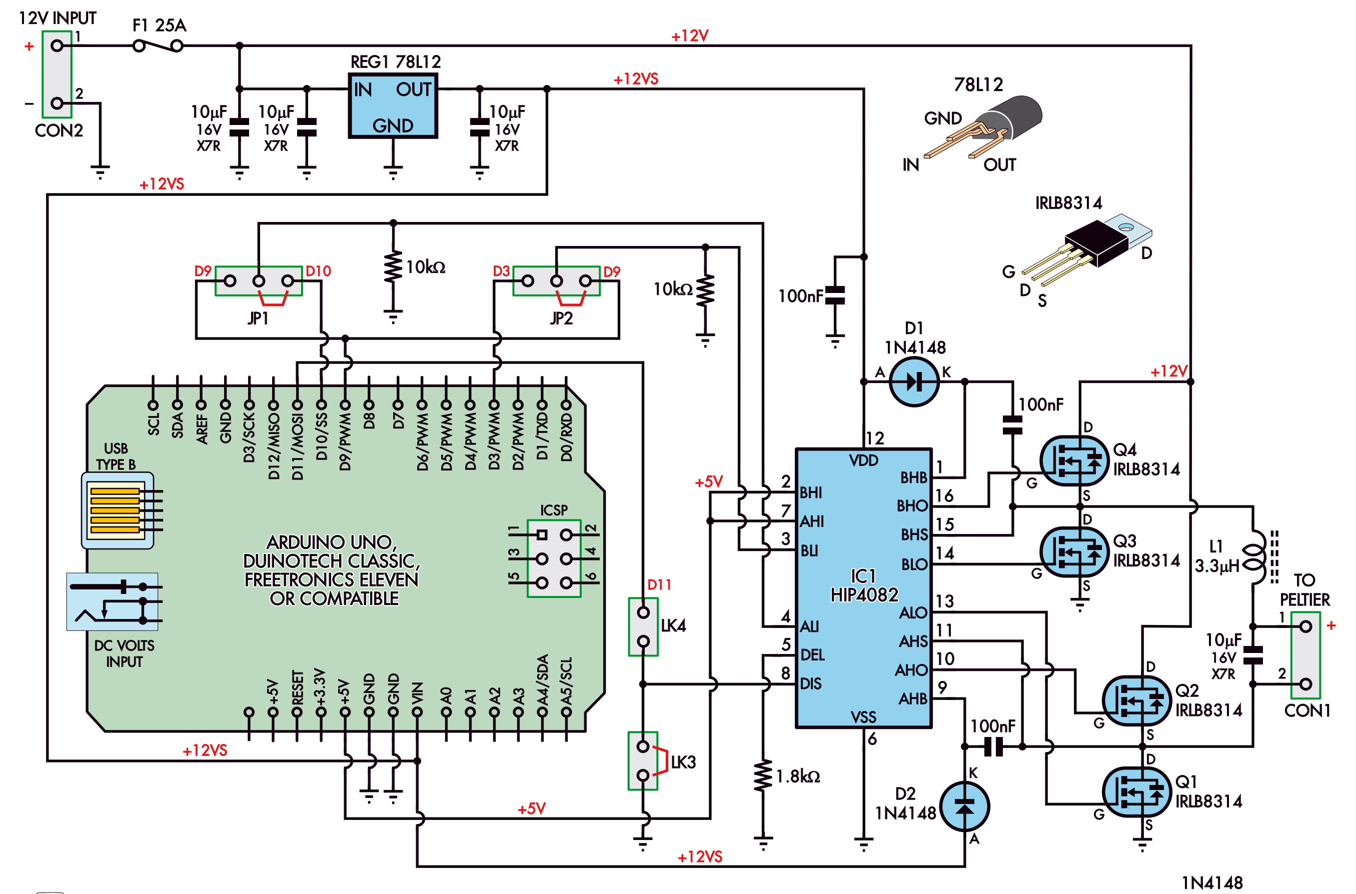
Many Peltier device manufacturers specify that low ripple power (of the order 5-10%) should be supplied to the devices. For optimal results, a pure DC voltage should be applied.

There is another reason to avoid PWM. Consider the case of pure 6V DC being applied to a Peltier device compared to 12V DC at a 50% duty cycle. When we look at the I^2R losses, we can see that these are doubled in the 12V case. Although the 50% duty cycle means power is applied half the time, double the voltage means that the I^2R effect is quadrupled.

Our Peltier Driver shield has been designed with these factors in mind. It delivers nearly pure variable DC across the full range of positive and negative voltages, allowing both heating and cooling. This also has the effect of making the power source's life a lot easier!



A Peltier device is usually made from an array of semiconductors which are electrically connected in series, but thermally in parallel due to the way the interconnectors are arranged. This way, when a voltage is applied, heats flows from one side to the other, depending on the voltage polarity. Image source: after https://cpb-us-e1.wpmucdn.com/sites.suffolk.edu/dist/f/759/files/2014/02/2.jpg



THERMAL REGULATOR PELTIER DRIVER SHIELD

Fig.1: the Peltier Driver shield has four Mosfets in an H-bridge configuration (Q1-Q4), an LC filter to smooth the voltage across the Peltier devices and one HIP4082 bridge driver (IC1). Its control pins can go to different Arduino pins depending on the settings of links LK1-LK4.

immersed in a temperature-controlled water bath.

A cheap alternative is to use a 'snap-lock' type sandwich bag. Careful sealing of the bag can ensure that most of the air is removed before sealing.

The bag has the effect of keeping the water separate from the food so that it does not dilute any flavours.

The removal of air by the vacuum process also means that there are no air bubbles which might cause the bag to float to the surface and not be fully immersed.

The aim then is to use the water bath to achieve a precise food temperature. For example, a piece of beef cooked medium rare should have a core temperature of 60°C.

Immersion in the water bath is a good way to accurately and consistently hit this target.

Thus our Thermal Regulator needs to be able to reach and maintain a steady temperature in a water bath to be useful in this application; ideally, it should be capable of heating to well over 60°C (we hit 75°C+ in testing).

One of the interesting things about sous-vide cooking is that you can cook at much lower temperatures than you might expect, as long as you maintain that temperature for long enough. This creates textures and flavours that are very different from what you get with boiling, baking, frying etc.

There's a lot more to sous-vide cookery than this; we simply want to explain why you might need such a thing as a precisely controlled water bath.

There are many guides to the sous-vide process, and you should do further research before trying this technique (eg, via a Google search).

We also mentioned that brewing and fermenting could be enhanced by implementing accurate temperature controls.

In this case, your brewing or fermenting vessel can be placed inside the water bath, such that the temperature-controlled water practically surrounds it.

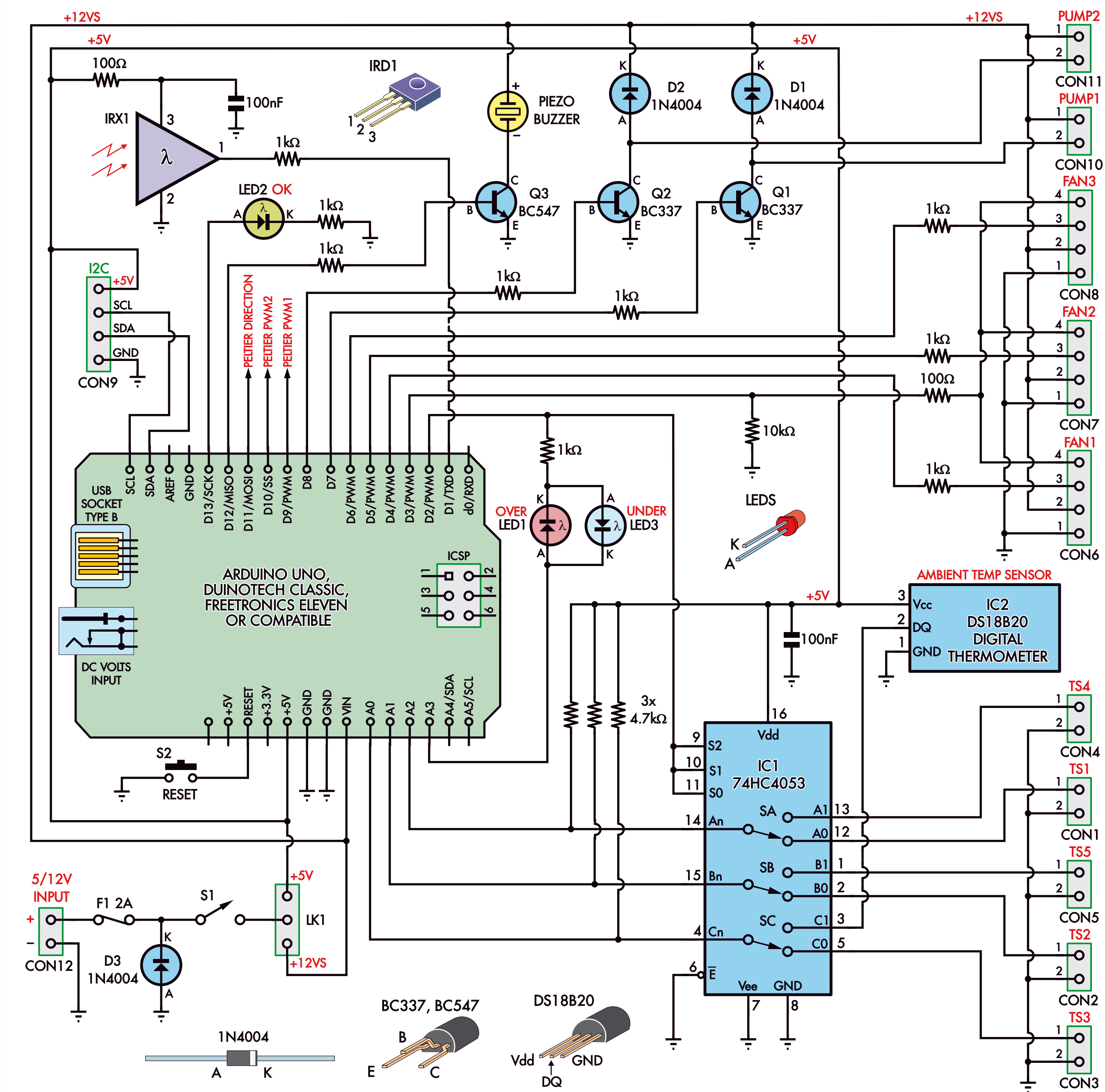
Having the bath itself being inside a well-insulated container (we used a small foam cooler for our experiments) reduces the demands on the Peltier devices and minimises external effects such as drafts.

The Peltier Driver shield

Fig.1 shows the circuit of the Peltier Driver shield. As mentioned earlier, it is based on a high-power H-bridge. DC power is fed in via terminal block CON2 and fuse F1, then to optional 12V regulator REG1.

REG1 is only needed if the supply voltage is above 15V, as many Arduino boards cannot sustain more than 15V at their VIN pin.

Otherwise, REG1 can be linked out or omitted entirely if 12V is available from one of the other attached boards. The regulated 12V power (from whichever source) is also fed to the VDD pin (pin 12) of IC1, an H-bridge Mosfet driver IC. It also has a maximum VDD of 15V, although it can control a bridge which handles up to 80V.



THERMAL REGULATOR INTERFACE SHIELD

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Fig.2: the Interface shield monitors up to five thermistors, and it can drive several auxiliary 12V devices which may be required, including fans and pumps. Multiplexer IC1 allows through analog inputs to sense six temperature sensors, as some analog inputs are reserved for I²C serial communications.

IC1 has its control inputs fed from jumper links LK1-LK4. These allow IC1's input pins to be connected in different combinations to various PWM capable pins on an Uno board. Two 10kΩ pull-down resistors ensure that the pins are in safe states (with the H-bridge shut down) when the Uno is in reset, not programmed etc.

The 1.8kΩ resistor connected to IC1's DEL pin (pin 5) sets the turn-on delay and thus the dead-time of the Mosfets to around 200ns.

Diodes D1 and D2, and their associated 100nF capacitors form the 'bootstrap' circuits which provide high enough voltages to drive the gates of high-side Mosfets Q2 and Q4, using the output square waves to form a charge pump.

IC1 also has its own 100nF supply bypass capacitor.

Mosfets Q1-Q4 are four IRLB8314 N-channel types in an H-bridge configuration.

These can switch 30V at over 100A with sufficient cooling, although the current is limited by other parts of the circuit such as PCB tracks and connectors.

Using an H-bridge means that the direction of current flow can be reversed, and the duty cycle can also

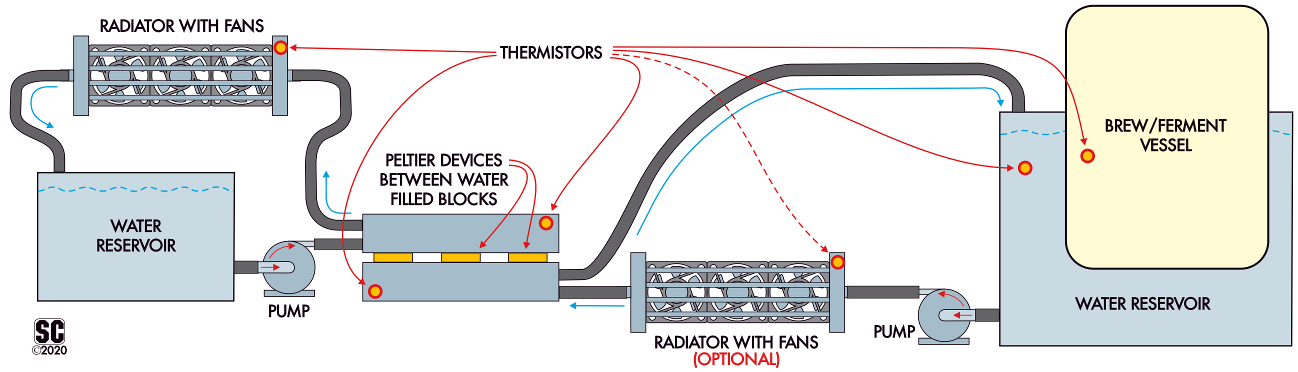


Fig.3: this 'circuit' shows how the Thermal Regulator could be used to control a sous-vide cooker or for making cheese or fermenting beer or wine. While the two loops make the hardware a bit more complex, this makes it capable of moving more heat around, necessary to achieve the higher temperatures needed for cooking.

be controlled by rapidly switching the H-bridge between two states.

The driver (IC1) is needed as the high-side Mosfets are N-channel varieties.

Thus their gates need to be taken above their source pins, ie, above the supply rail; the bootstrap circuit provides the means to do this. The driver also ensures that the Mosfet gate capacitances can be charged and discharged rapidly to provide a high PWM frequency so that we can filter it to get a smooth voltage across the Peltiers.

The Mosfets' low on-resistance of around 2.4mΩ means that minimal heatsinking is required; at modest currents (up to about 20A), the PCB itself provides sufficient heatsinking.

Between the output of the H-bridge and the output connector, CON1, is an LC low-pass filter comprising 3.3µH inductor L1 and a 10µF multi-layer ceramic capacitor. This forms a sort of crude 'buck' DC/DC step-down converter.

When a high enough frequency PWM signal is applied to the control inputs of IC1 (around 300kHz), the output is effectively DC. This also means that the current drawn from the nominally 12V rail is effectively DC, so no bulky bypass capacitors are required on the board.

One way of analysing this circuit is to assume that the Peltier devices have an effective resistance of around 1Ω (12A @ 12V).

We can then calculate that the 300kHz PWM signal is attenuated by a factor of 100 (around 40dB) and so the ripple is kept well below the recommended 5%.

This shield is suitable in any case where variable, relatively smooth high-current unregulated DC power is required.

The part chosen for L1 in our prototype has an 19A rating, but even if this is upgraded, the PCB traces and connectors max out at around 20A. The Mosfets limit the supply voltage to 30V.

Interface shield

The Interface shield (circuit shown in Fig.2) connects to up to six temperature sensors, can drive up to three PWM-capable fans and two small pumps.

One of the temperature sensors is a DS18B20 fitted to the PCB to sense ambient temperature; the remaining five channels suit either DS18B20 digital sensors or low-cost NTC thermistors (via CON1-CON5).

The shield also provides three status LEDs (red, green and blue), a buzzer and an infrared receiver for user input.

Four-way header CON9 breaks out the Arduino's I²C peripheral. Though this suits many sensors and modules, our primary intent is to drive a character LCD module similar to those we described in March 2017 (siliconchip.com.au/Article/10584).

This sort of display is easy to drive and well suited to showing a large number of changing parameters, such as temperatures and fan speeds, in near real-time.

No I²C pull-ups are provided on the board, as these are fitted on the LCD interface module.

CON12 allows power at 5V or 12V (set by JP1) to be fed into the shield. D3 provides reverse polarity protection by conducting enough current to blow fuse F1 if the supply is reversed. Switch S1 can be used to switch this supply on or off.

If JP1 is set to the 12V position, power is fed to the Uno's VIN pin which in turn provides regulated 5V back to the shield via the Uno's 5V regulator and pin. The 5V position feeds power directly to the 5V pin.

The jumper can also be left off, if, for example, 12V (VIN) and 5V rails are available from elsewhere, such as an attached Peltier Driver shield.

Although the Uno has six ADC channels (analog inputs), two of these pins are shared with the I²C peripheral and so cannot be used. Thus IC1, a 74HC4053 triple two-way analog multiplexer, is used to switch the A0, A1 and A2 analog input pins between CON2, CON3 and CON1 respectively in one state, and IC2 (the DS18B20), CON4 and CON5 respectively in the other state.

The control inputs for all three multiplexer channels are connected together, to digital pin D2 on the Uno. The output-enable ($\overline{E}$) pin is connected to ground, so the three switches in IC1 are always active.

The A0, A1 and A2 pins have separate 4.7kΩ pull-up resistors to the 5V rail, which provides parasitic power if a DS18B20 is fitted or forms the top half of a voltage divider circuit if an NTC thermistor is fitted.

CON6, CON7 and CON8 are four-way plugs for the connection of PWM-capable fans. Their 12V and GND supplies are taken from the VIN pin and GND pin of the shield.

The tachometer outputs are fed to Arduino pins D4, D5 and D6 respectively via 1kΩ resistors. These can be set as digital inputs to sense the fan speeds.

A common PWM signal to the fans is provided from Arduino pin D3 via a 100Ω resistor. This line also has a

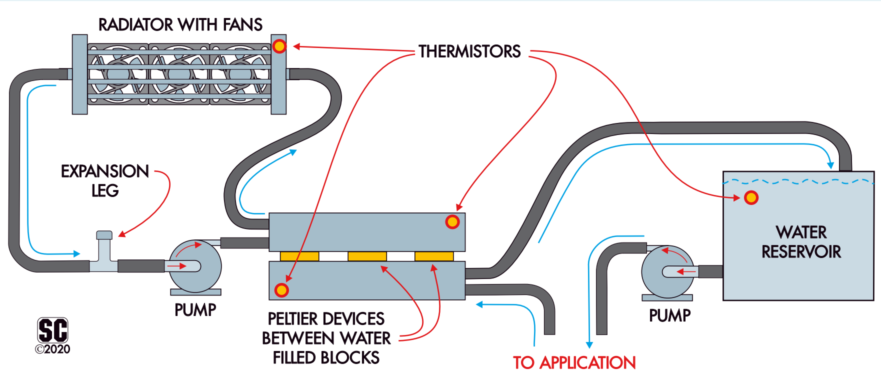


Fig.4: this is a variant of Fig.3. The vessel on the left-hand loop has been replaced by an expansion leg, the opening of which should be the highest part of the loop to avoid spillage. You can use the water from the right-hand loop to cool or heat whatever you need (such as a personal air-conditioner made from another radiator and some fans).

10kΩ pull-down, so the fans are off during reset.

CON10 and CON11 are for the control of small 12V pumps. Each is switched by a low-side NPN transistor (Q1 and Q2), controlled by Uno pins D7 and D8 via 1kΩ resistors.

Snubbing diodes D1 and D2 are connected directly across the outputs at CON10 and CON11, to absorb any back-EMF spikes when the pumps switch off.

Similarly, piezo buzzer PB1 is controlled by NPN transistor Q3. Its base is driven from Arduino pin D12 via a 1kΩ current-limiting resistor.

Of the three onboard LEDs, LED2 is driven directly by pin D13 going high and sourcing current through a 1kΩ resistor. LED1 and LED3 are connected in anti-parallel between pins D2 and A3 with a 1kΩ series resistor. LED1 lights when A3 is high and D2 is low; LED3 lights when D2 is high and A3 is low.

Naturally, both cannot be on at the same time. This arrangement means that the LEDs may flicker when D2 is being switched to scan the temperature sensors, but this only happens briefly.

Infrared receiver IRX1 is powered via a 100Ω resistor and bypassed by a 100nF capacitor. Its output is fed to Arduino pin D1 via a 1kΩ resistor. The UART peripheral also uses D1, so it cannot be used at the same time as the receiver.

Pins D9, D10 and D11 are left free and are intended to be used to control the Peltier Driver shield.

We have written several functions and routines to control the Interface shield, including such things as thermistor calibration curves and interrupt-based tachometer speed signal processing.

A minor limitation of the code as written is that it only supports the single DS18B20 fitted to the PCB. It's possible to read the temperature from other DS18B20s running on parasitic power from CON1-CON5 by altering the code, but this will considerably slow down temperature sampling.

We did this because we found the performance of the cheap NTC thermistors to be adequate.

Power

Anything to do with moving significant amounts of heat around requires a fair amount of power. We used four 5A Peltier devices in our prototype. The fans, pumps and shield add up to no more than an amp.

Most Peltier devices are rated to run at up to 15V. Thus we need around 21A at approximately 15V. The reduced I^2R losses are a good reason to use a slightly lower voltage like 12V, which is also more common.

For our prototype, we used an ATX computer power supply capable of delivering 22A from its 12V rail.

While this sounds quite close for comfort, the supply's other output rails (5V, 3.3V etc) have practically no demand.

Hence, the power supply stays comfortably within specification overall, and the power supply did not show any signs of stress under continuous operation.

Alternatives include a 15V or 13.8V open-frame power supply module or a high-current bench power supply.

We even did some initial testing using our 45V/8A supply from October-December 2019 (siliconchip.com.au/Series/339), although this is a poor use of its talents!

We'll show how we rigged up the ATX power supply; other options will probably be quite simple in comparison.

Other hardware

As you might imagine, there's a bit more to this project than the electronics. Fortunately, most of the parts are readily available at online sites such as AliExpress and eBay.

Before construction, we recommend you thoroughly read about our designs to see what you need, as there is a fair bit of flexibility possible.

As mentioned above, our main heat transfer medium is water. It has a good heat capacity (it can hold a lot of thermal energy for a given mass) and it has fair thermal conductivity (it's easy to move heat energy in or out of water). Plus, there is a lot of off-the-shelf equipment suitable for working with water.

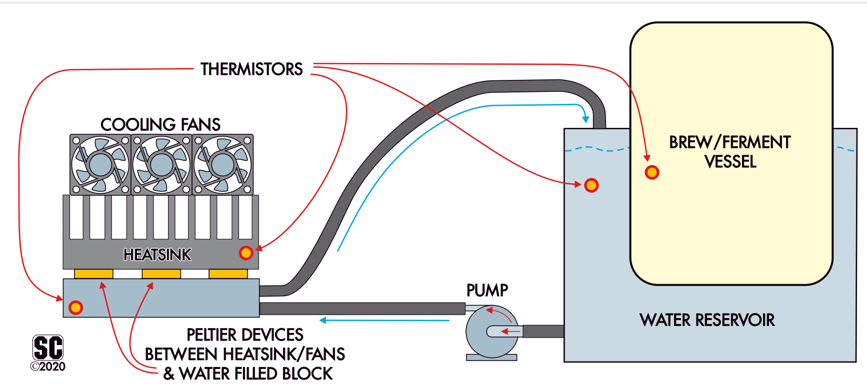


Fig.5: the minimal viable hydraulic circuit. For simplicity, we use a fan and heatsink combination instead of a second water loop. While not quite as effective as a radiator, this sort of configuration can move a few hundred watts of heat.

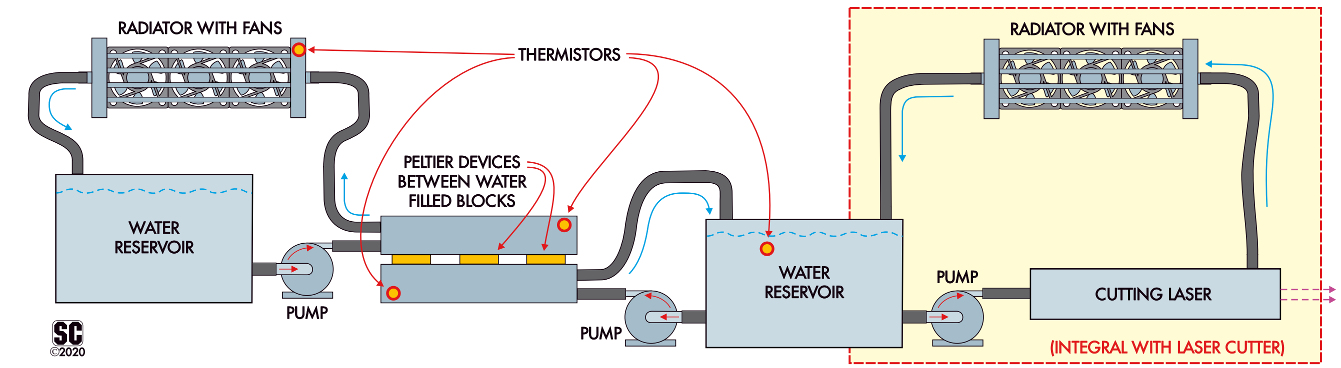


Fig.6: this is the arrangement that we have installed onto our laser cutter, to help 'boost' the laser cooling on hot days. It reduces the laser temperature by around 6°C compared to purely passive cooling (which is pretty good when you consider that with passive cooling, it operates at 10°C above ambient).

For example, the pumps we are using are similar to what might be used to circulate water in an aquarium.

Naturally, you should take care that there is no chance of water getting in the electronics (or vice versa).

The thermal loop

We manage the temperature of the water bath by circulating water through one or more loops. The movement works to keep the water mixed so that there are no hot and cold spots. Figs.3-6 show some variations on the water 'circuits' that are possible with our hardware.

Fig.3 shows the set-up that you might use for fermentation, while Fig.4 shows a general heating/cooling application and Fig.5 shows a simplified fermentation application (which would be cheaper to build but possibly less effective).

Fig.6 shows how we used the Thermal Regulator to pre-cool the water for our laser cutter, reducing the laser's operating temperature on hot days (more on that later).

You may realise from these diagrams that the water loop(s) mean that we can keep the radiators/heatsinks/fans which dump the 'waste heat' into the air well away from what we are trying to regulate.

This is a key benefit to using water to transfer heat.

Using a larger volume of water means that the setup will be more robust to external changes, but will take longer to reach its target setpoint. The aim here is to move the heat to or from where we want it as effectively as possible. The loops allow the heat to be moved easily.

The parts required

Many of the parts we used were obtained as part of a kit. These kits are typically sold for water cooling computers (eg, for overclocking). We also had to get a few other miscellaneous bits and pieces.

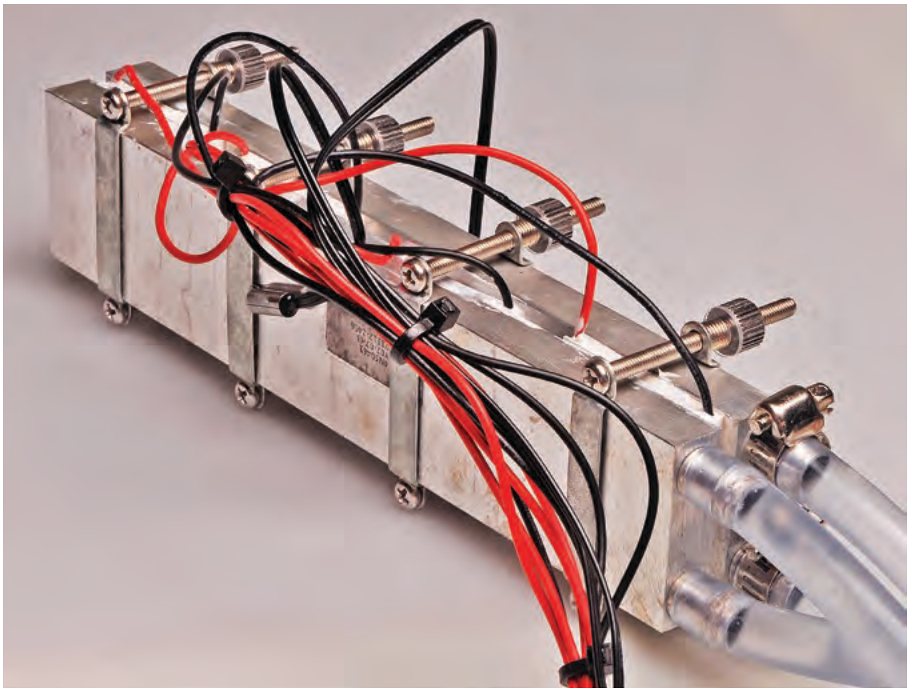
The water is moved by small 12V submersible pumps. These are cheap and draw around 300mA each. The water is not being pumped to any great height, as it is generally around a closed circuit, so a high pressure or 'head' is not needed. Generally, as long as the water is moving to some degree, we can maintain the level of heat transport we need.

To join everything together, we used flexible silicone tubing. We obtained this as part of our kit, although you can also get it from hardware stores like Bunnings or camping stores. We found that the most useful size has an inside diameter of approximately 8mm and is a good friction fit to the barbed fittings on the other parts.

Although the tube is a tight fit, we

These pumps are small and only draw around 300mA. They are sealed and thus fully immersible (the impeller is coupled to the shaft by magnets). Since they are not raising the water to any great height, not much power is needed. The main thing to ensure is that the intake is always fully submerged, as they are not self-priming.

The brass fittings are a snug fit for the transparent hose we used and did not show any signs of becoming detached. But we still used hose clamps to make sure. The tubing that was supplied with our kit with quite soft, so we replaced this with some thicker tube bought locally.



This assembly is held together by clamps, with the Peltier devices sandwiched between water blocks. The black wires visible lead to thermistors which are also held in place by the clamps. Not visible is a small amount of thermal compound between the heat-conducting surfaces.

didn't trust this completely. To secure the tubing, we used small (6mm-16mm) hose clamps.

Where we needed to bend the tube at a sharp angle, we used small barbed brass elbows and T-pieces. These too should be secured in place with hose clamps.

The final part of our primary circuit is the water block. This consists of a block of aluminium with two barbed fittings at one end. It provides a good thermal interface between the water and the Peltier devices, allowing heat to be readily transferred.

The water enters at one end, passes up and back along the block and back out the other fitting. While aluminium is not the best thermal conductor, it is cheap and easy to work with.

In a typical application, the Peltier devices are clamped to the flat surfaces of the water block with thermal compound in between, forming a tight fit over a large area that conducts heat well.

Naturally, the Peltier devices have two sides, and whatever heat is removed from one side needs to be dealt with on the other side. The simplest method is to use a heatsink block which is actively cooled by fans.

In our 45V 8A PSU design (see earlier link), we used a pair of high-powered fans on a heatsink and found this to be capable of dispersing a few hundred watts.

We ran some trials using this technique with Peltiers and it fared well, but not as well as a proper radiator.

The better technique uses a second water loop to remove heat from the other side of the Peltier device.

This uses a second pump and associated piping similar to the water bath. The water from the second loop goes through a fan-cooled radiator.

The radiator is like a smaller version of the radiator in a car. Water passes through the radiator and air is moved over it by the fans.

If the water is warmer than the air, then the water is cooled (and the air is warmed). If the water is cooler than the air, then it is warmed.

The radiator works better because it has a larger area for transporting heat and moves more air, but it is also a more complex arrangement.

This is the arrangement we have fitted to our laser cutter.

In these photos, you can see the various thermistors used throughout the rig. We can tell a lot about how the system is performing by the temperature readings. In particular, the temperatures at the hot and cold sides of the Peltier devices indicate how hard they are working and indicates the best strategy is for extracting the best thermal performance.

We will explain more later, but at times it is beneficial to switch off power to the Peltier devices. And of course, we use other sensors to measure the temperature at our water bath to be able to reach the target temperature, and know when we have done so.

Water vessel for brewing ...

Another part that is not included in typical computer water-cooling kits is the water reservoir. The choice of this will depend on your application.

For our final implementation of a 'boost' cooler for our laser cutter, we simply used the existing water reservoir, which was a plastic lunchbox. You can see the original passive cooling system we built for our laser cutter in our article from June 2016 (**siliconchip.com.au/Article/9960**).

While you might be tempted to think that, for the fermentation application, you could circulate the fermenting liquid directly past the Peltiers, we strongly recommend against this. We could see no assurances anywhere that the parts we used were food safe and in any case, any beer left behind in the fluid circuits would be very difficult to clean out.

Beer is slightly acidic, and many cleaning solutions are strongly

This radiator is more effective at removing heat than the heatsink and fans. This is due to its larger effective surface area.

Parts lists – Programmable Thermal Regulator (Arduino/Peltier)

1 set of fluid-handling hardware (see text and below)
1 Arduino Uno R3 or compatible (ATmega328-based) board
1 Peltier Driver shield (see below)
1 Interface shield (see below)
1 high-current DC power supply (see text)
1 20x4 alphanumeric LCD screen with I^2C interface
  [Silicon Chip Online Shop Cat SC4203]
1 length of light-duty figure 8 cable (for LCD screen)
1 4-way polarised header plug plus pins (for LCD screen)
1 universal infrared remote control
  [Jaycar XC3718, Altronics A1012]

Fluid-handling hardware (single loop)

4 5A Peltier devices
1 water vessel to suit your application
1 small 12V DC water pump
  [eg, www.aliexpress.com/item/32810010753.html]
1 40x200mm aluminium water block
  [eg, www.aliexpress.com/item/4000299552495.html]
1 water block mounting kit
  [eg, www.aliexpress.com/item/32323128854.html]
1 200mm-long heatsink (to suit water block)
  [Jaycar HH8530, Altronics H0536]
2 80mm 12V fans or to suit heatsink
  [Jaycar YX2512, Altronics F1050]
mounting hardware to suit fans
a few metres of 8mm internal diameter flexible silicone tubing
several elbows and tees to suit tubing
4+ 6-16mm hose clamps
1 tube of thermal paste
various cable ties

Fluid-handling hardware (twin loops)

4 5A Peltier devices
2 water vessels to suit your application
2 small 12V DC water pumps
  [eg, www.aliexpress.com/item/32810010753.html]
2 40x200mm aluminium water blocks
  [eg, www.aliexpress.com/item/4000299552495.html]
2 water block mounting kits
  [eg, www.aliexpress.com/item/32323128854.html]
a few metres of 8mm internal diameter flexible silicone tubing
several elbows and tees to suit tubing
8+ 6-16mm hose clamp
1 tube of thermal paste
various cable ties
1 fan radiator, 360mm type recommended
  [eg, www.aliexpress.com/item/32833463954.html]
1-3 12V fans to suit radiator (eg, 120mm fans)
  [Jaycar YX2574, Altronics F1165]
mounting hardware to suit fans

Peltier Driver shield parts

1 double-sided PCB coded 21109182, 53.5mm x 68.5mm
1 10-way stackable header (11mm pin height)
1 8-way stackable header (11mm pin height)
2 6-way stackable headers (11mm pin height)
2 2-way barrier terminals, 8.3mm pitch (CON1,CON2)
1 5x2-pin header (LK1-4)
3 jumper shunts (LK1-4)
2 M205 PCB-mount fuse clips (F1)
1 25A M205 fuse (F1)
1 3.3µH 19A SMD inductor, 14.0 x 12.8mm
  [eg, Pulse PA4343.332ANLT; Digi-Key 553-4025-1-ND]
4 M3 x 9mm machine screws
4 M3 hex nuts

Semiconductors
2 1N4148 small signal diodes (D1,D2)
1 HIP4082 H-bridge driver, DIP-16 (IC1)
  [Digi-Key HIP4082IPZ-ND]
1 78L12, TO-92 (REG1; optional – see text)
4 IRLB8314 N-Channel Mosfets, TO-220 (Q1-Q4)
  [Digi-Key IRLB8314PBF-ND]

Capacitors
3 100nF MKT or multi-layer ceramic
4 10µF 16V* X7R ceramic, 3216/1206 SMD package
  [Digi-key 1276-6641-1-ND]
  ** higher voltage versions required if DC supply >15V*

Resistors (all axial 1/4W 1% metal film)
2 10kΩ 1 1.8kΩ

Peltier Interface shield parts

1 double-sided PCB coded 21109181, 53.5mm x 68.5mm
1 10-way male pin header
1 8-way male pin header
2 6-way male pin headers
1 PCB-mount blade fuse holder (F1; optional)
1 2A blade fuse (F1)
5 2-way vertical polarised headers (CON1-CON5)
4 4-way vertical polarised headers (CON6-CON9)
3 5.08mm-pitch PCB-mount two-way screw terminals
  (CON10-CON12)
1 SPDT R/A PCB-mount toggle switch (S1; optional)
  [Altronics S1320]
1 3-pin header and jumper shunt (LK1)
1 6mm tactile switch (S2)
1 piezo buzzer (PB1) [Jaycar AB3459, Altronics S6104]
5 10kΩ/100kΩ NTC thermistors with cables
  [eg, www.aliexpress.com/item/32916207487.html
  or www.aliexpress.com/item/33057351310.html]
5 two-way polarised header plugs with pins (if thermistors
  don't come with a suitable plug)
light-duty figure-8 cable (if sensor wires are not long enough)

Semiconductors
1 74HC4053 triple 2-channel analog multiplexer, DIP-16 (IC1)
1 DS18B20 digital temperature sensor, TO-92 (IC2)
2 BC337 NPN transistors, TO-92 (Q1,Q2)
1 BC547 NPN transistor, TO-92 (Q3)
1 red 5mm LED (LED1)
1 green 5mm LED (LED2)
1 blue 5mm LED (LED3)
3 1N4004 400V 1A diodes (D1-D3)

Capacitors
2 100nF MKT or multi-layer ceramic

Resistors (all 1/4W axial 1% metal film)
3 4.7kΩ 1 10kΩ 9 1kΩ 2 100Ω

alkaline. The fittings may not be able to withstand these sort of chemicals.

Thus for brewing and fermenting applications, we suggest using a large water bath in which the brew vessel is placed. Assuming that you are using one of the plastic 25L units, a plastic storage container like those available from discount variety stores and hardware stores is the simplest option.

The larger container behaves as a water jacket. It does not need to enclose the smaller brew vessel completely, but should come most of the way up the sides of it to improve the surface area over which heat is transferred. A hole cut in the larger vessel's lid (forming a seal of sorts around the brew vessel) will reduce the amount of evaporation that might occur and thus reduce the power needed to maintain temperature.

Such a large vessel can lose (or gain) heat from the surroundings due to its large surface area, so a modest amount of insulation may help; something as simple as a towel may suffice.

... and cooking

As we mentioned, the higher temperatures used for sous-vide cookery will tax the Peltier devices more. For this application, we recommend that you use a small foam cooler. We used one designed to hold six drink cans during testing. Its small size minimises the area through which heat is lost and also the volume of liquid to be heated. But it's large enough to fit most items you would cook.

These coolers can be found online or at disposals and outdoor stores. Check that it comes with a lid, as a fair degree of evaporation can occur at the temperatures used. You must also take care during use as the temperatures reached can be high enough to cause scalding.

Because the food is sealed into waterproof bags during the sous-vide process, there is minimal risk of contamination due to contact with non-food-safe parts. You might like to double-bag to be sure.

To implement the two-loop variant of our design, you will need a second vessel. The insulation on this is not so critical as the radiator and fans are simply trying to keep the second loop's temperature near ambient anyway. It may be handy to have a lid, though, to prevent a long-term loss of water through evaporation. We used a plastic ice-cream tub as the second water vessel for our tests.

Another thing to be cautious about is the possibility of bacterial/algal contamination, particularly if you are using the Thermal Regulator for cooking. Bacteria and algae can flourish in warm water. For example, the circulation of warm water which is exposed to the air has been implicated in cases involving Legionnaire's disease, such as those found in industrial cooling towers.

Naturally, you should take care to prevent the water from the cooling loops coming near anything that may be consumed. You should also discard and replace the loop water regularly as this will help limit the accumulation of pathogens.

If you are familiar with the brewing process, you will know how crucial proper cleanliness is for good results.

Measured performance

We found that under well-insulated conditions, our water bath got up to around 70°C with an ambient temperature of 18°C. For these tests, our main water vessel contained around two litres of water in an insulated foam cooler; the second loop was about a litre held in a (clean) ice-cream container.

In these tests, a good amount of water vapour is produced, resulting in evaporative cooling which forces the Peltier devices to work harder.

We got down to around 2°C when cooling. Getting close to the freezing point of water is the limiting factor. We saw frost on the Peltier devices, so it was clear that some parts were dropping below freezing.

The typical time to reach these extremes is about half an hour using four standard 5A devices running at around 11V. So you can see that the temperature ramp is not rapid. Good thermal insulation is necessary for reaching the temperature extremes.

We calculated that the secondary water loop cooled by the radiator has about double the heat removal capacity as the simple heatsink solution.

Consider that in all cases we are effectively trying to move heat between an ambient atmosphere (the air being circulated by the fans and through the radiator) and the water bath, the closer these temperatures are, the easier our task will be. Indeed, it is when the temperature differential across the Peltier devices is the largest that they struggle most.

For example, during some of our initial testing, while trying to cool hot water, we noted that it was more effective to shut down the Peltier devices and allow thermal conduction to move the heat. Powering the Peltier devices simply added more heat to the system (I^2R losses), which also had to be removed.

Sous-vide cookery is the application we envisage that requires the most extreme temperatures, so insulation is essential for good results there. In some cases, you could pre-heat the water using a kettle and then let the Thermal Regulator reach the target temperature and keep it there; that would be faster than starting with cold water.

Coming next month

That's all we have space for in this issue.

Next month, we will describe how to build the two shields, program the Arduino and put the whole system together. In the meantime, if you want to build a Thermal Regulator, now would be a good time to figure out the system configuration you will need and order the parts. You may be able to start building the piping and heat transfer assemblies if those parts arrive quickly.

The software we'll also present next month has several different operating modes, such as setting a target temperature which the unit then maintains, providing maximum heating or cooling, as well as one mode where it follows a preset temperature 'profile' when triggered. SC

A small foam cooler such as that shown here is a good choice for sous-vide cookery with the Thermal Regulator. A high degree of insulation is needed, and the snug-fitting lid minimises the amount of water and heat that is lost to evaporation.