UNITRODE

Design Note

Closed Loop Temperature Regulation Using the UC3638 H-Bridge Motor Controller and a Thermoelectric Cooler

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Have you ever wanted to test an IC over temperature, but couldn't put the entire application circuit in the oven? Maybe you needed to access critical circuit nodes for troubleshooting, or observe the effects of temperature on only one component. Freeze sprays and hair dryers may be good for benchtop troubleshooting, but the temperature (and temperature slew rate) is highly uncontrolled and may actually damage the part. Forced air systems which direct temperature controlled air to a specific area are available, but they are large, cumbersome and expensive. What is needed is a portable, low cost, temperature forcing system.

One solution is to use a thermoelectric cooler. Thermoelectric coolers (TEC's) employ the Peltier effect, acting as small, solid state heat pumps when a DC current is passed through them. They are relatively small, flat devices which transfer heat from one side to the other. The direction of heat transfer can be reversed, for heating or cooling, by simply reversing the direction of the current. The amount of heat transfer is controlled by the magnitude of the current. A temperature difference across a TEC of up to 50°C or more can be achieved using a single element if proper heatsinking is provided on one side of the device. Larger temperature gradients can be produced by stacking multiple elements. They can be used effectively as part of a closed loop temperature regulation system.

A number of methods can be used to regulate the magnitude and direction of the TEC current, since they operate at a relatively low DC voltage (maximum current ranges from 1A to 10A, depending on size). Linear regulation can be used, but would be very inefficient and would require bipolar supplies, or some means of switching polarity to reverse the direction of current flow. Switching techniques, using pulse width modulation, can be used to improve efficiency. If heat transfer is only required in one direction, for heating or cooling (but not both), a simple buck topology, operating from a single supply voltage, can be used to regulate the output current in one direction. However, in this case, to allow both closed loop heating and cooling from a single supply, a bridge topology is necessary . A simplified block diagram of the closed loop temperature control system is shown in Figure 1.

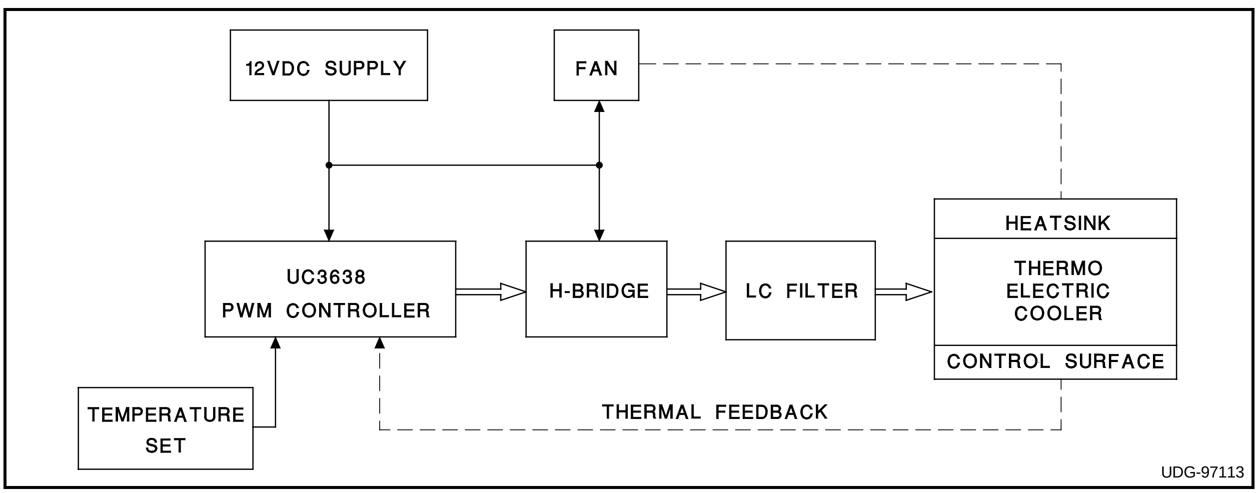

Figure 1. Temperature Controller Block Diagram

Pulse width modulation minimizes conduction losses in the control electronics, but requires a sophisticated PWM controller, especially to prevent problems such as bridge cross-conduction. The building blocks required for closed loop PWM control, such as a voltage reference, error amplifier, pulse width modulator, oscillator, current sense amplifier, and FET drivers, as well as features such as undervoltage lockout (UVLO) and pulse-by-pulse current limiting, are all contained in the UC3638. The biasing circuitry needed for single supply operation is also included. A block diagram of the IC is shown in Figure 2.

The circuit in Figure 3 uses the UC3638 H-bridge controller, four FET's, a differential LC filter and a TEC to form a closed loop temperature regulator. A PWM frequency of 100kHz is set by R15 and C13. This frequency was chosen as a compromise to limit switching losses in the bridge while minimizing the size of the LC filter components. The deadtime between commutation of the bridge switches is set by the voltage on the DB pin, using the divider of R12-R14. The voltage on PVSET determines the amplitude of the triangle wave oscillator used in the PWM modulator.

MOSFET's Q1-Q4 form the bridge, while BJT's Q5-Q8 act as high side FET drivers, since outputs AOUT1 and BOUT1 of the UC3638 are open collector. AOUT2 and BOUT2 can drive the low side MOSFET's directly. Schottky diodes D1 and D2 clamp any ringing below ground due to stray circuit inductance. Sense resistor R6 is chosen to limit the peak output current to 5 Amps. The current sense voltage is amplified by the UC3638, and any noise spikes are filtered by C12 and a 100Ω resistor internal to the IC.

The LC output filter, formed by L1, L2 and C2-C6, is required to convert the PWM output from the bridge back to a DC voltage. This is necessary because AC ripple is detrimental to the TEC, and its efficiency drops off rapidly. Less than 10% ripple is recommended. The resulting architecture is a low bandwidth class D amplifier, which can deliver a variable DC voltage up to

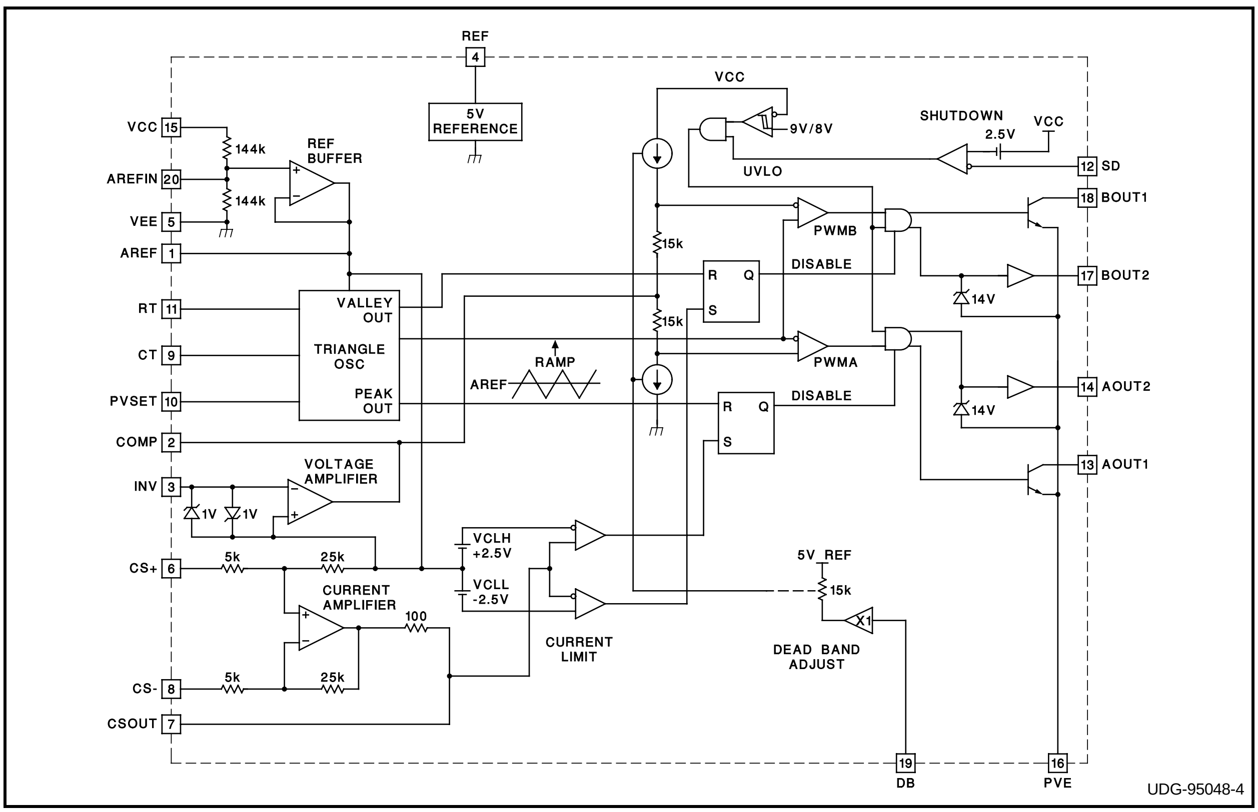

Figure 2. UC3638 Block Diagram

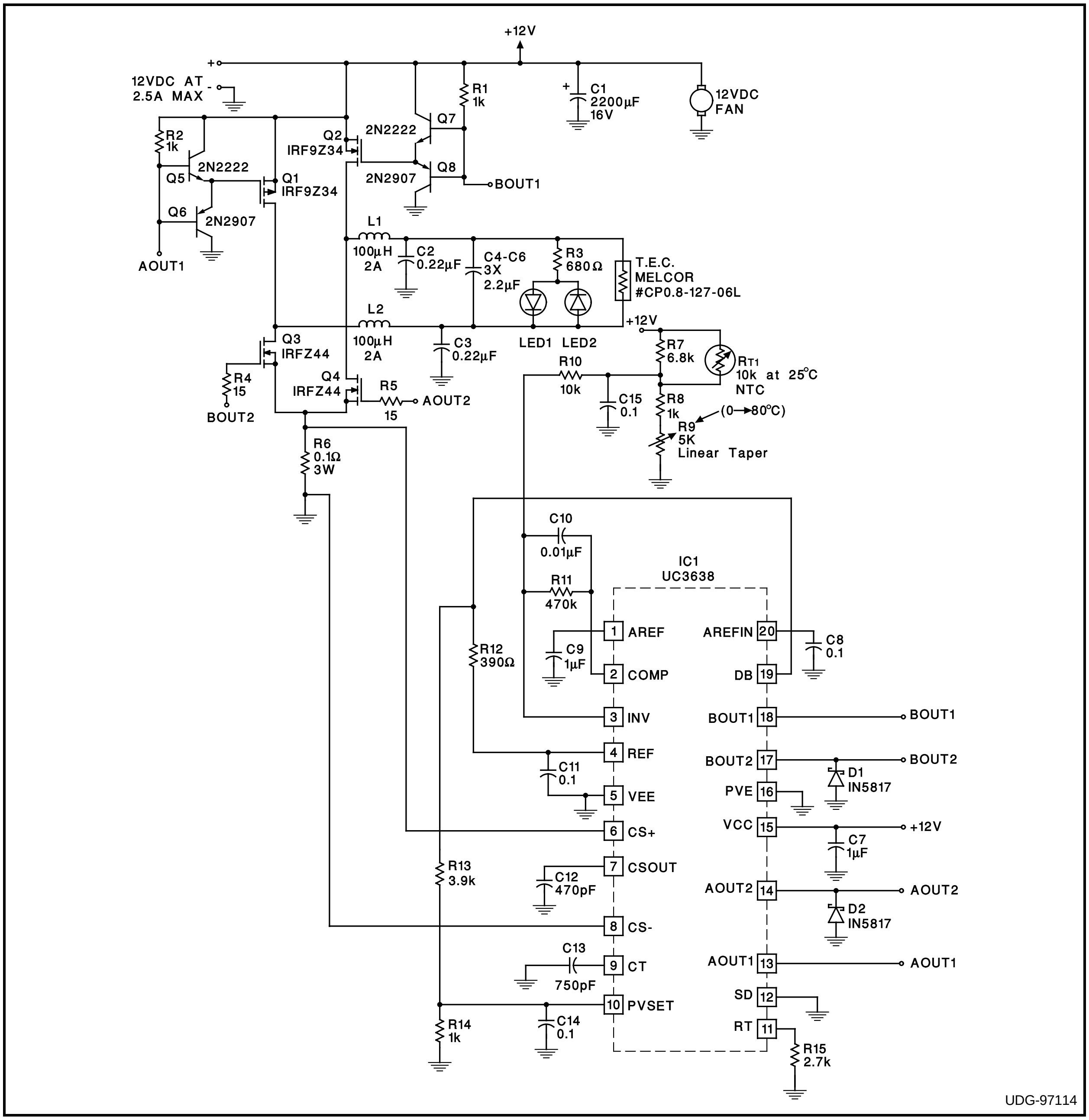

Figure 5. Thermal Firing of SCR Output

±12V at several amps to the TEC. At these currents, no heatsinking of the MOSFET's is required. If a higher current TEC is used, heatsinking of the MOSFET's may be required, primarily due to conduction losses. Another alternative is to use MOSFET's with a lower R_{DSON}.

To dissipate the heat transferred and generated by the TEC losses, a heatsink and 12VDC fan are mounted in close thermal contact with one side of the device. An aluminum "cold plate" is mounted on the other side, forming a sandwich with the TEC in the middle. The aluminum plate, acting as the control surface, adds thermal mass to help stabilize the loop while protecting the brittle ceramic surface of the TEC. This plate is placed in intimate thermal contact with the item to be temperature controlled.

RT1, an NTC thermistor, is placed in a hole in the side of the aluminum plate to provide good thermal feedback to close the loop. A parallel resistor helps to linearize the thermistor's response. This is not critical, since the temperature control pot will be calibrated, compensating for any non-linearities.

The UC3638 error amplifier compensation uses proportional gain, since it can be difficult to compensate an integral loop due to the long thermal time constant of the mechanical system. The DC gain of the error amplifier, determined by R10 and R11, is high enough so that a temperature error of <1°C will produce full output voltage to the TEC. C10 provides a pole to filter out any noise before reaching the modulator. Note that the amplitude of the triangle wave oscillator (set by R13 and R14) also affects overall loop gain.

Temperature control pot R9 is calibrated using a thermocouple temporarily mounted to the aluminum plate. Once calibrated, it is accurate and repeatable to within 1°C. LED's across the output of the filter give a visual indication of whether the TEC is heating or cooling, depending on the polarity of the output voltage.

The entire system, using the TEC shown, operates off a 12VDC, 2.5A power supply and provides closed loop temperature regulation of a surface about 1 inch square. The temperature of the control surface can be varied from 0°C to +80°C in a room ambient environment. Hotter and colder temperatures are possible if multiple devices are stacked and proper heatsinking is provided. Remember that cooling can only take place if the heat, including that produced by the efficiency losses in the TEC, can be dissipated on the opposite surface. Note that the maximum temperature is ultimately limited by the temperature rating of the solder within the TEC. Devices with ratings of up to +200°C are available.

TEC's can be used in many temperature control applications. They are available in a wide variety of shapes, sizes, power and voltage ratings from a number of manufacturers. Some manufacturers also supply heatsinks, cold plates and fans. However, low cost Pentium style heatsink and fan combinations can often be adapted.

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