RK Electronics

Design Manual for Engineers and Hobbyists

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Welcome and Revision Details

First of all I would like to thank you for your interest in this project and my work. It is my hope that you will find this project useful and may decide to build yourself, or at least be a good read.

Revision 1.1 note - Connection to the 7 segment displays needs to be reviewed. There is a possible connection error between segments F and G. If you find that the numbers are not displayed correctly, it is likely that segments F and G are the wrong way round. To correct this break copper tracks for F and G, and using a pair of small gauge wires, swap the connections around.

Design Brief

This project is for the design of a tortoise egg incubator heat lamp controller, designed to maintain the local environment temperature to within a set operating band.

Safety

This project is designed to operate from mains electricity. I **cannot** emphasize enough about the **dangers** of using and or building a circuit which operates from mains power. Incorrect use or incompetence (including but not limited to touching transformer primary side connections) **can kill you!** If you do not have experience or do not feel comfortable using mains power, please use an off the shelf pre-built mains adapter instead.

Please note that I do not take any responsibility for any loss, damage or harm caused by the building of this project. This project book comes 'as is'. I have built this project and can confirm it works, and to the best of my ability is safe to use.

Assumptions

This project assumes that you have basic knowledge of electronics and have worked with mains electricity. This report also assumes that you have some experience with using PIC microcontrollers.

Principle of Design

General Operation

A tortoise egg incubator is designed to provide a dedicated micro-environment, which is conducive to the development of tortoise eggs. In theory this incubator controller can be designed to suit most incubators other than tortoises, with some adjustment to the microcontroller program.

The controller provides four key functions;

1. Provide the local egg soil temperature, to within an accuracy of +/- 0.5ºC.
2. Provide a controlled mains power outlet for heat lamp control.
3. Provide the user a series of control inputs to set the minimum and maximum allowed operating temperature.
4. Provide the user a series of control inputs to set the minimum and maximum alarm set points; to alert the user when an unacceptable temperature has been reached.

Depending upon the species of tortoise, the allowed egg temperature conditions can vary however, typically the temperature range is between 24 - 32 °C. In the case of a Hermans Tortoise (Testudo Hermanni) the egg temperature should be set to be in the region of 25 - 29 °C (some experts may advise on different ranges). Either way, the controller will ensure that if the temperature drops below the minimum allowed temperature, a heat lamp will be switched on. If the temperature exceeds the maximum allowed temperature, the heat lamp will be switched off, and the micro-environment allowed to cool.

The alarm temperatures are usually set to around 1 -2 °C either side of the required operating temperature, to alert the user that the environment has become unstable or inadequate. This may be due to a heat lamp not being adequately placed, in-operable heat lamp (blown bulb), or local environment too hot.

Figure 1 describes a typical operating method, and the response of the controller.

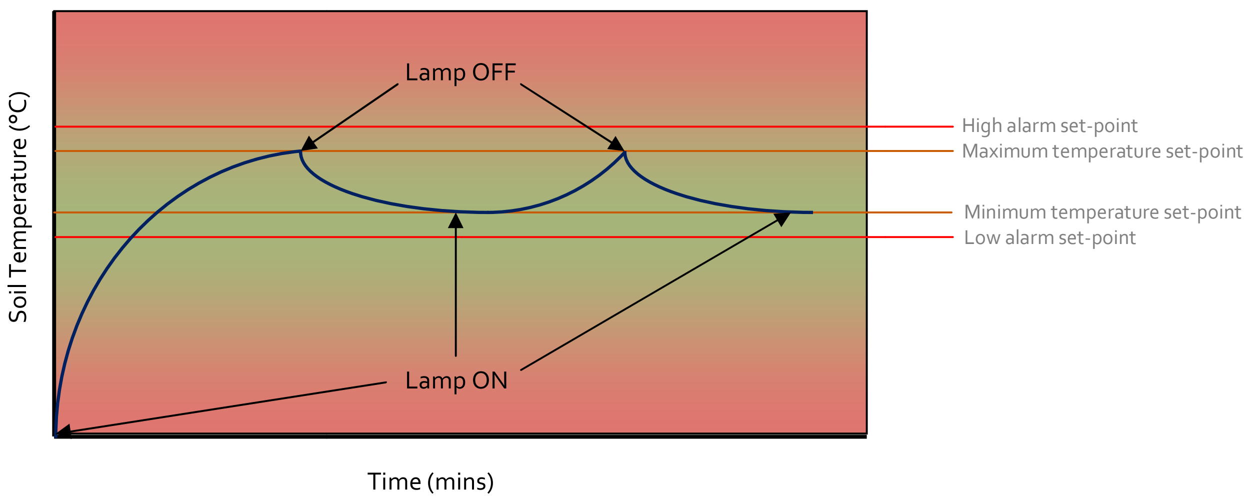


Figure 1 - Controller temperature control profile

Controller Architecture

To achieve temperature control, a number of components and electronic circuits are required. The temperature controller uses the following processes;

1. Analogue to digital temperature sensor capture (to read the temperature sensor)
2. A digital numerical display to indicate the temperature.
3. Control circuit to read the temperature sensor, output a temperature the digital display, allow user set point control and provide the temperature control function.

The architecture of the controller is shown below in figure 2.

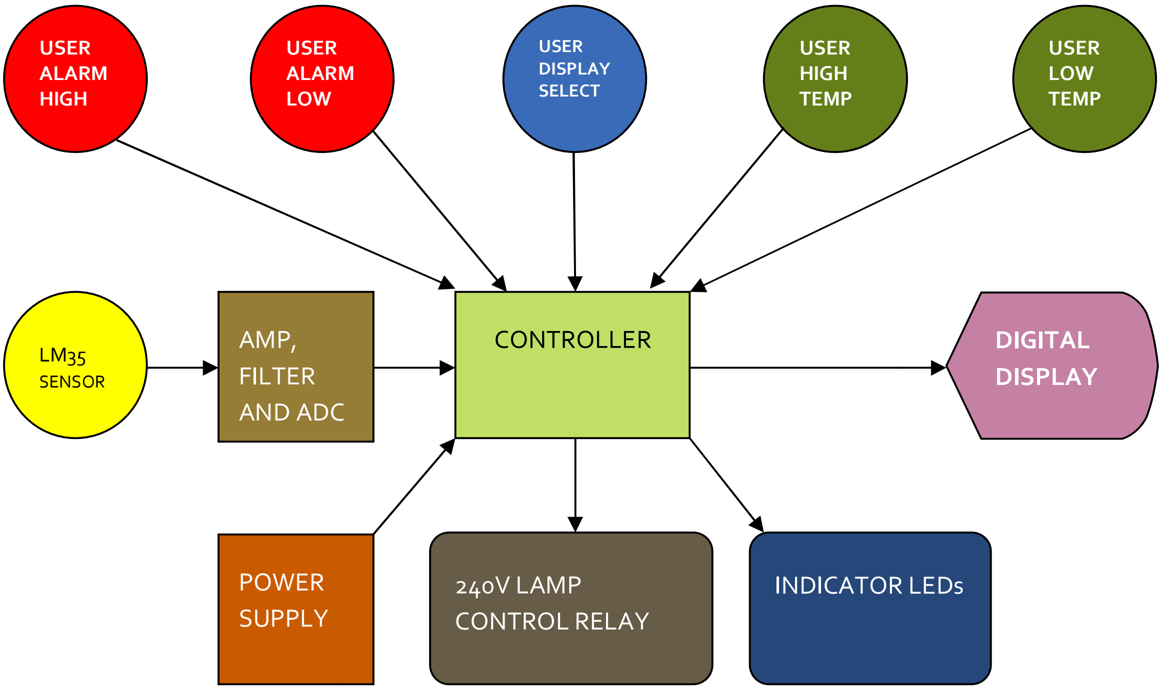


Figure 2 - Incubator temperature controller architecture

User High Alarm

The user high alarm is a variable resistor type control, which allows the user to set the high temperature alarm set-point. Should the LM35 temperature sensor sense a temperature above this set-point, the controller will annunciate an alarm. This set-point would typically indicate either heat lamp control failure or high external temperature preventing adequate temperature control. The high alarm temperature set-point can be adjusted between **27 - 35 °C**.

It is recommended that a multi-turn variable resistor is used for this input.

User Low Alarm

The user low alarm is a variable resistor type control, which allows the user to set the low temperature alarm set-point. Should the LM35 temperature sensor sense a temperature below this set-point, the controller will annunciate an alarm. This set-point would typically indicate either heat lamp control failure or low external temperature preventing adequate temperature control (insufficient heat from the heat lamp). The low alarm temperature set-point can be adjusted between **21 - 29 °C**.

It is recommended that a multi-turn variable resistor is used for this input.

User High Temperature

The user high temperature is a variable resistor type control, which allows the user to set the maximum temperature set-point. Should the LM35 temperature sensor sense a temperature above this set-point, the controller will switch off the heat lamp. The allowed range for the high temperature set-point is between **26 - 33 °C**.

It is recommended that a multi-turn variable resistor is used for this input.

User Low Temperature

The user low temperature is a variable resistor type control, which allows the user to set the minimum temperature set-point. Should the LM35 temperature sensor sense a temperature below this set-point, the controller will switch on the heat lamp. The allowed range for the high temperature set-point is between **23 - 30 °C**.

It is recommended that a multi-turn variable resistor is used for this input.

User Display Select

The user display select is a 5 position selector switch, which selects which temperature value is to be displayed on the digital display. The following positions and display output is shown below in table 1.

Table 1 - User select switch options

Switch Position	Temperature value sent to the digital display
1	LM35 live temperature reading
2	Low temperature set-point
3	High temperature set-point
4	Low temperature alarm set-point
5	High temperature alarm set-point

The selector switch common connection is sent to the +5v supply, and the outputs are sent to the microprocessor on Port B4 - B8.

LM35 Temperature Sensor

The LM35 temperature sensor is a high accuracy analogue temperature sensor, that is temperature calibrated. The LM35 sensor outputs a voltage that is proportional to the sensor temperature equal to 10mV/°C. Baseline temperature of 25 °C has the equivalent voltage output of 250 mV. For this reason, on a single rail power supply the LM35 sensor can only measure positive temperatures above 0.1 °C.

The accuracy of the LM35 is +/-0.25 °C (for temperature ranges between 20 - 70 °C).

240v Relay Output

The relay output board is a circuit board which connects the mains voltage from the fused inlet, to the mains transformer and to the heat lamp via a relay controlled switch. The relay is a 5v operated optio-isolated thyristor (solid-state) relay. A 5v control signal is provided from the microprocessor.

Indicator LEDs

The indicative LEDs provide the user with the controller operating status, and confirms if the display selector switch is in a position other than 'live LM35 temperature reading'. Table 2 below describes the LED indications.

Table 2 - LED indicator description

LED Condition	Description of Operation
No LEDs on	Display is showing live LM35 temperature sensor reading
Green 1 LED	Display is showing low temperature set-point
Green 2 LED	Display is showing high temperature set-point
Green 3 LED	Display is showing low temperature alarm set-point
Green 4 LED	Display is showing high temperature alarm set-point
Yellow LED	Heat lamp is ON
Red LED	Alarm condition

Digital Display

The digital display is a 3 digit 7 segment numerical display, designed to show temperatures between 0.00 - 40.9 °C. The 7 segment numerical digits are controlled by the Motorola MC14489 driver IC. Communication between the controller MPU and the driver IC is via SPI.

The SPI communication is sent in two parts. The first part is an 8 bit transmission which sets the type of character to be displayed on each segment (either number or a series of special characters), and a second 24 bit transmission which is decoded into 6 nibbles (4 bits). Each nibble encodes the hexadecimal value for each segment (the MC14489 supports up to 5 segments) and a nibble to place the decimal point.

In this project only numerical characters are used, and the decimal point is always set to illuminate on the second segment. Segments 4 and 5 are not used. The first segment (referred to bank 1 on the MC14489) is used for one-tenths of a degree

centigrade. The second segment is used to indicate 1 degree (units). The third segment is used to indicate tens of degrees (tens).

Amp, filter and ADC

This circuit is the LM35 sensor circuit, which interfaces the LM35 temperature sensor to the MPU controller circuit. The LM35 sensor circuit is broken down into three distinct stages;

1. Amplifier section to increase the output from the LM35 from 250 mV at 25°C to 2500 mV. The purpose of this increase is to use a wider range of the ADC, to improve accuracy and minimize noise and conversion error.
2. 5th order, low cutoff frequency (6Hz) low pass Butterworth filter to remove mains noise and signal interference.
3. A 12 bit analog to digital converter which reads the output of the filter and converts the voltage to a 12 bit digital word value.

The amplifier is designed to increase the voltage from the LM35 sensor, mainly to ensure that the temperature range extends over a wider voltage range more suited to the ADC. The amplifier also has an adjustable gain such that any voltage losses from the filter can be compensated for. The gain should be set such that a gain factor of 10 is achieved between the LM35 sensor input, and the filter output.

The 5th order Butterworth filter is designed to remove any residual mains interference or noise that has been amplified, in the previous amplifier stage. The filter also provides a lag function which prevents the controller from spurious responses. Generally for a new temperature to be accepted by the controller, the temperature must be maintained for short period of time. Rapid fluctuations in temperature are not accepted by the filter.

The last stage is the analog to digital conversion. The ADC is set to a 4.096 v voltage reference. This ensures a 1 mV to bit conversion rate, or 0.01°C per bit is achieved over the range of 0 - 40.9°C. Each 0.1°C (the accuracy which the controller and display works to) requires 10 adc bits. This takes into consideration, and mitigates any error within the ADC itself (the MCP3201 error is +/- 2bits). Communication between the ADC and MPU controller circuit is via SPI, using a single 16 bit word. The use of SPI also ensures good ADC sample timing via the SPI clock.

Power Supply

The power supply is the source of electrical energy to the various circuits of the project. The power to the LM35 sensor circuit and display board is routed via the SPI data cable connections on the controller board. The power supply therefore routes directly to the controller board.

The power supply provides a voltage of 5v and a current up to 500 mA. In order to achieve good ADC and LM35 accuracy, maintenance of the 4.096v reference voltage circuit and good microcontroller stability, the power supply needs to provide a good DC quality.

One of the problems with simple AC to DC conversions is the incomplete rectification of AC to DC (often referred to as DC ripple). The use of a linear regulator will maintain the voltage, however there is still a variance in the power supply output of up to 400 mV. This 400 mV variation can cause up to 0.5°C error in the analog conversion. It is essential therefore to minimize any DC ripple as much as possible. In this project the reduction in DC ripple is achieved using a

capacitor/inductor/capacitor (CLC) circuit upstream of the regulator, to provide a well stabilized DC signal before the regulation. The circuit shown in this project has a voltage variance of around 50 mV.

Controller

The controller is the main part of the project. It provides all the control and user interface. The microcontroller connects to the display board and LM35 board via a 2x5 dual in line 2.54mm centre line ribbon wire connection. All other interfaces are via a screwed terminal block wire to board connections.

All the user interfaces (variable resistors and display mode rotary switch) connects direct to the microcontroller via the screwed wire to board terminal connectors.

There are two main types of user interface, the first is a five position rotary switch and the second; four potentiometers.

The five position rotary switch as mentioned previously, sends a control signal to various microcontroller inputs, which in turn is used to select what temperature is displayed on the display board.

The potentiometers allow the user to select the set point temperatures. These potentiometers are connected to ground and Vdd of the power supply. A voltage dividing output from the potentiometers are sent to the microxontroller. The onboard ADC of the microcontroller converts this voltage into a binary value, which is then in turn converted to a set point temperature.

The controller also provides a 5v control signal to the solid state relay to activate the heat lamp. The controller also provides an alarm signal via a 5v buzzer.

The principle of the controller is to maintain the soil temperature of an incubator, within a operating range set by the set-point temperatures. To calculate the temperature, or the user temperature set-points; the controller must first use its own internal ADC (for user set-points) and via SPI use the external ADC for the LM35 temperature reading. The binary value from the ADCs are then converted into a temperature value by linear scaling.

The temperature calculations used within the microcontroller software, calculates the temperature as a single 16 bit binary word (or whole number), not as it might be expected for example 32.6 °C. Instead the temperature calculated is actually tens time higher, so 32.6 °C would be represented as the integer number of 326. This number is also sent to the display board (which can only accept whole numbers!) and the decimal point artificially placed to recreate the appearance of 32.6 °C. It is important to note that, all comparator code which uses the LM35 temperature value and compares the temperature against the user set points, also uses this method. As a result, the user set-point temperatures are also calculated in the same way as the LM35 temperature.

An example is shown below in dataset 1.

Dataset 1 - Example of user temperature set point and LM35 temperature calculation

LM35 Temperature

example: LM35 temperature = 32.6 °C => LM35 voltage output = 0.326 v

voltage at the external ADC and downstream of noise filter = 3.260 v

12 bit ADC with 4.096 v reference should provide a binary value of = $\frac{3.260\ v}{4.096\ v}$ x4096 = 3260 or $0CBC in hex.

here the temperature is equal to the ADC value divided by 10.

User set-points

The user set-points use potentiometers, to set the control voltage from 0 - vdd (ADC values 0 - 4095), the linear equations therefore are;

Using linear interpolation equation y = mx + c

Table 3 - Equation summary

User set point	Minimum Temp. (°C)	Maximum Temp. (°C)	Equation	M	C
Low temp.	23	30	(0.00171 x adc value) + 23	0.00171	23
High temp.	26	33	(0.00171 x adc value) + 26	0.00171	26
Low alarm	21	29	(0.00195 x adc value) + 21	0.00195	21
High alarm	27	35	(0.00195 x adc value) + 27	0.00195	27

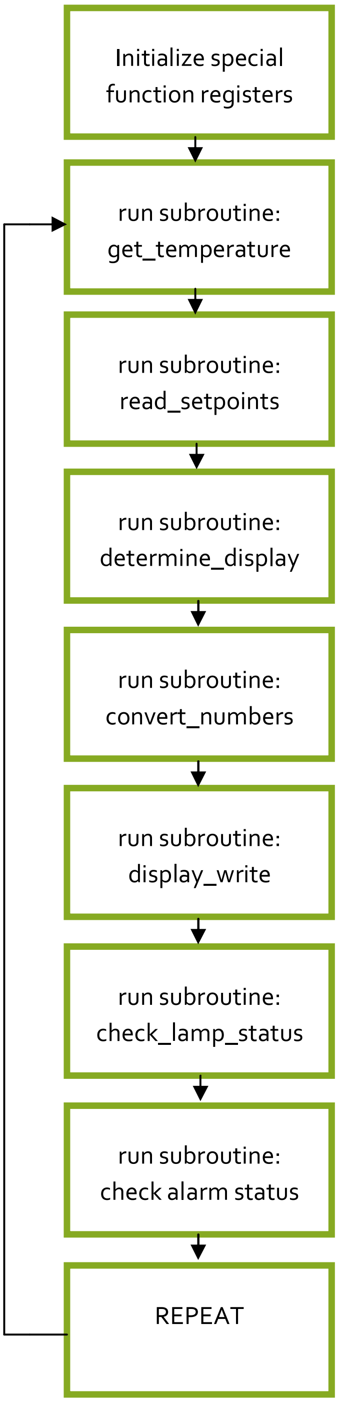
Each equation is then multiplied by ten to covert the temperature into a three figure value.

The control feature of the microcontroller is the comparator code. Here the LM35 temperature is compared against the low and high set points. If the temperature is below the low temperature set point, the lamp control relay will be active (heat lamp illuminates). If the temperature is above the high temperature set point the lamp control relay will be de-activated (heat lamp off). The cycle is repeated indefinitely.

The alarm works in the same way, but instead uses the alarm set points. If the LM35 temperature is below the low alarm temperature set point or above the high alarm temperature set point, the alarm buzzer and LED will be activated. In all other cases the alarm buzzer and LED will be de-activate.

Microcontroller code (Flow chart)

Main program



get_temperature

The sub-routine gets the analog temperature value from the external ADC. First the SPI module is set for 16 bit word (as standard for the MCP3201). The value is then divided by ten to calculated the temperature as a three digit integer, as discussed in earlier chapters. This value is the n added to an accumulator variable, and the process of reading the ADC is repeated 100 times. At the end of the loop the average temperature value is calculated.

The average value is taken to remove/dampen spurious temperature readings. This method provides the final method in noise and spurious temperature reading suppression (the previous methods are as discussed in LM35 sensor circuit).

In order to prevent a significant time delay should the user change the display output switch, this routine has a check for the display temperature switch position. If the switch is no longer indicating to show LM35 temperature, the loop is ended pre-maturely, by setting the loop counter variable (i) to 101, which will end the loop. There is also an 'if' routine which is executed if i equal 101, and immediately tells the microcontroller to put up the last reading from the low temperature set point. This has been included so that incorrect averaging errors do not cause an invertant or spurious alarm condition.

read_setpoints

This routine reads the user set points, by reading (using the PICs internal 12 bit ADC) the four control voltages, provided by the user input potentiometers. A binary value to temperature conversion equation for each of the set points is also carried out.

determine_display

This routine reads the user input of 'display select' The display select rotary switch routes to portb4 - 8. Depending on which input is active, determines the outcome of a select case routine. Depending on the selection, one of the temperature values (live LM35 or user set point temperature) is placed into a separate variable 'display_output'.

convert_numbers

This routine takes the selected temperature to be displayed, and converts it into three byte values. These byte values represent hundreds, tens and units. This routine will create the numbers that will be transmitted to the display board

display_write

This routine writes the two SPI communication packets to the Motorola MC14489 display driver IC. The configuration byte is always the same. The 24 bit communication uses the three byte values from 'convert_numbers' routine. The nibbles are placed into order by bit arrangement operations.

check_lamp_status

This routine is the comparator code. Here the LM35 temperature is compared against the user set points, and the lamp control relay activated or de-activated accordingly.

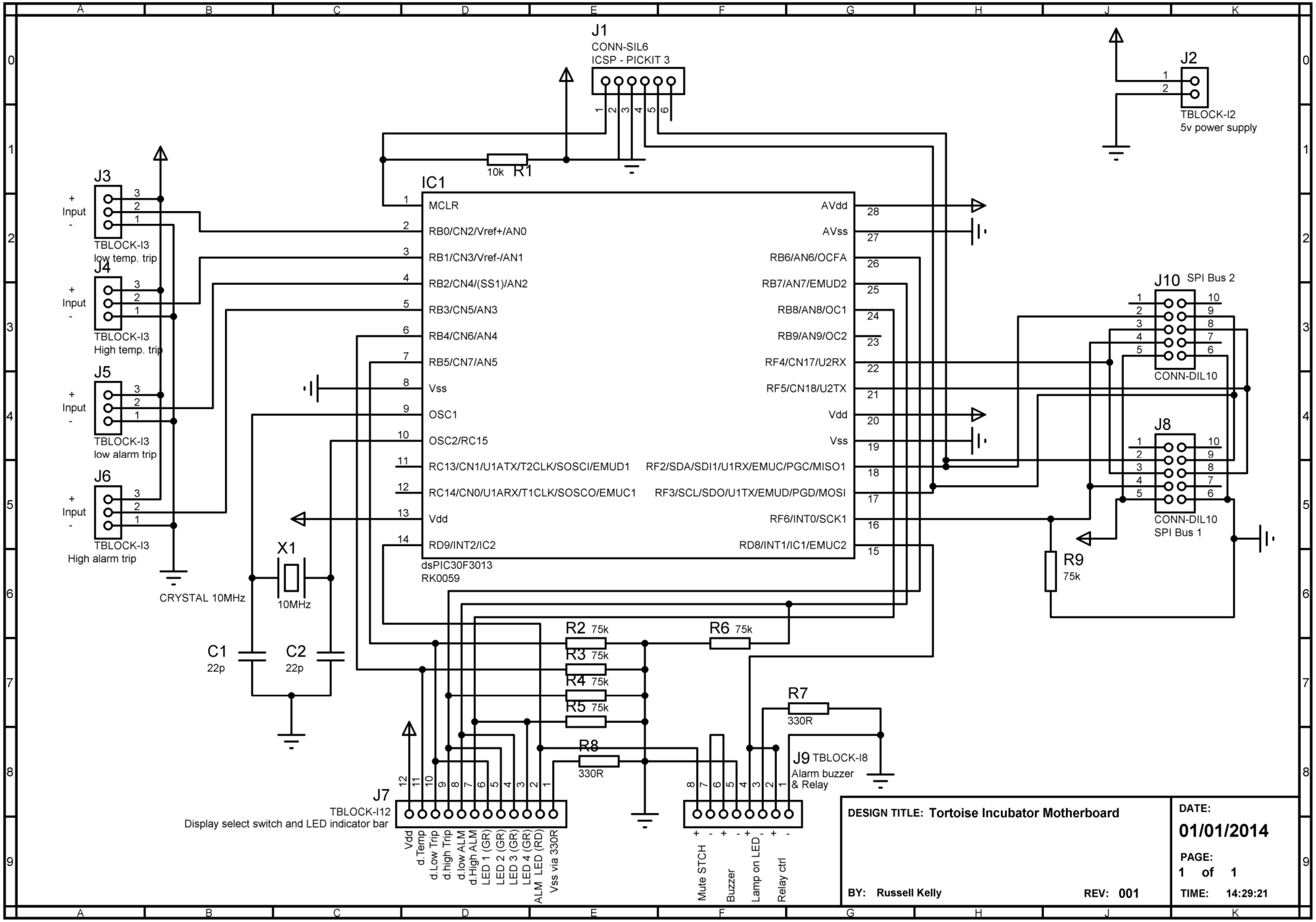
check_alarm_status

As with 'check_alarm_status', this routine is the comparator code for the alarm.

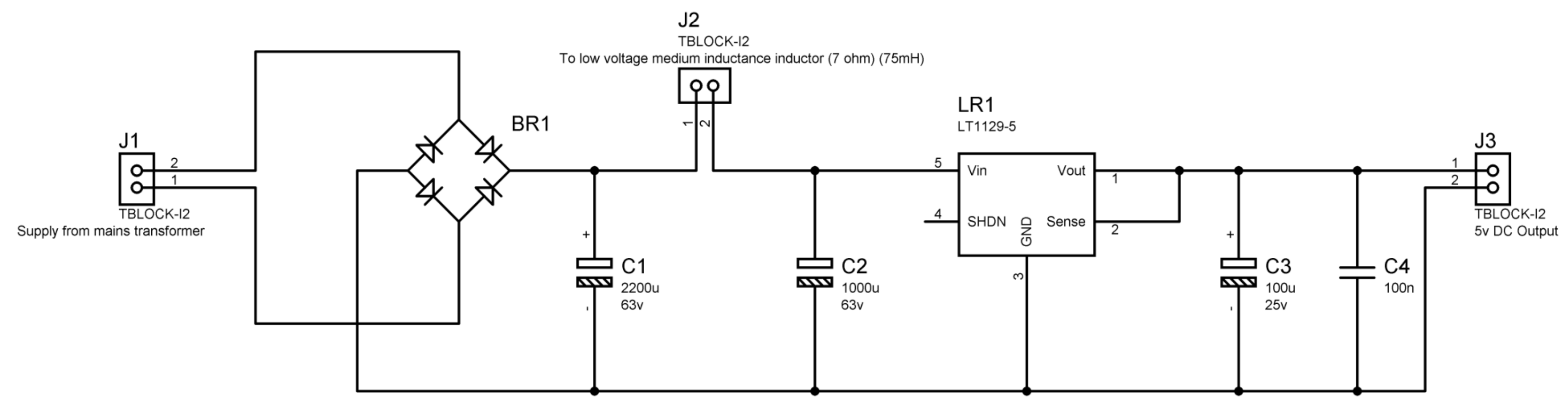
Schematic Diagrams

Schematic diagrams are shown on the next landscape pages;

Motherboard - Controller Board

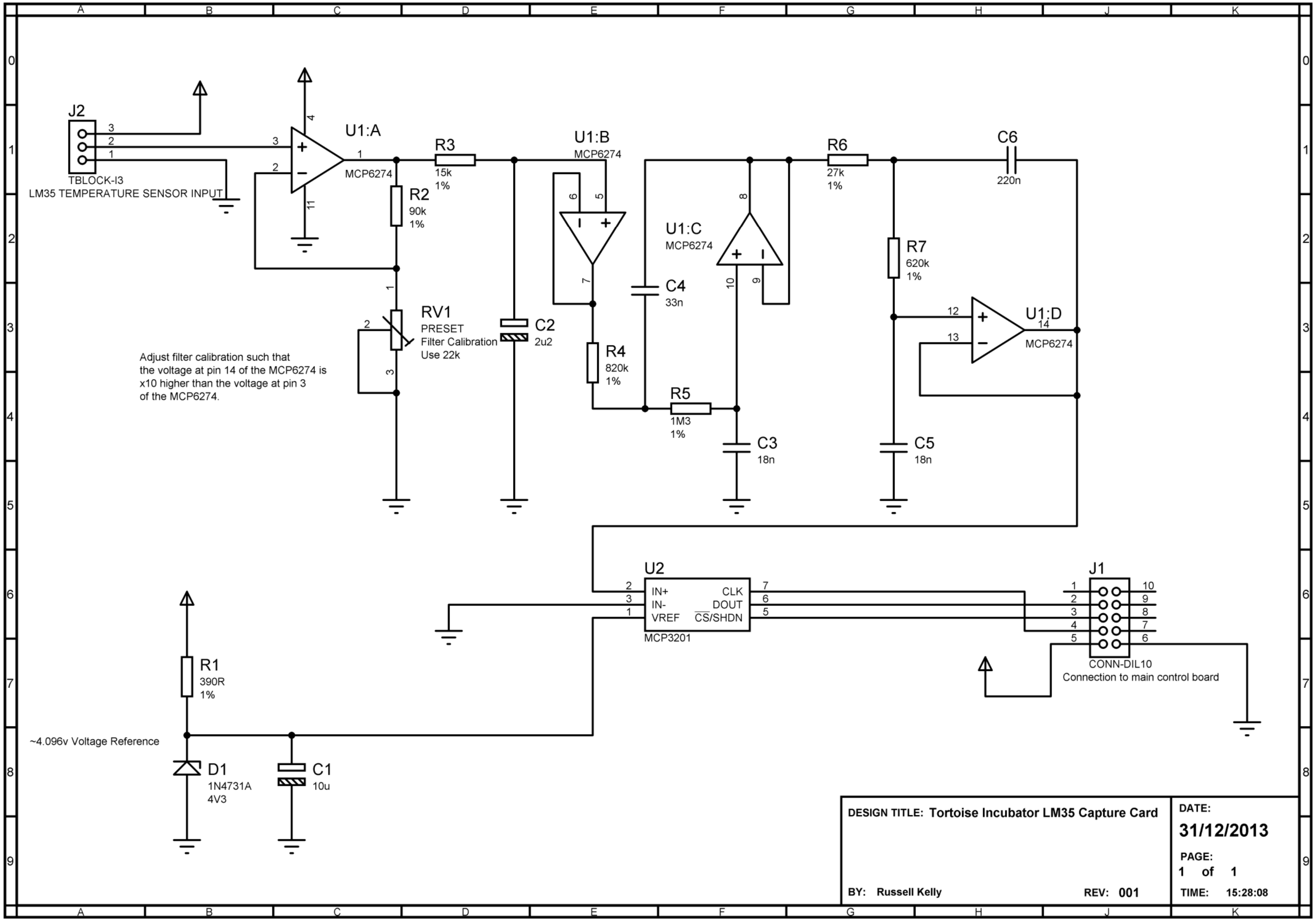


Power Supply

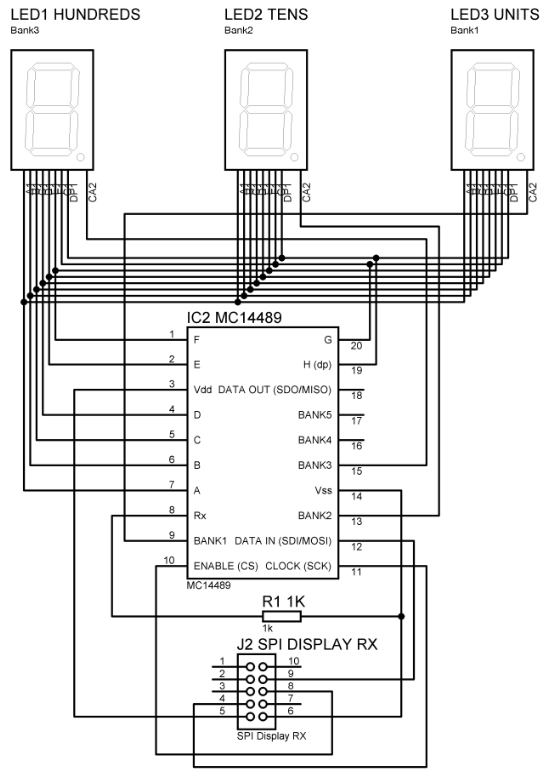


Project Name:	Tortoise Incubator	**DATE:**	31/12/2013
Sheet Name:	Power Supply	**PAGE:**	1 of 1
BY: Russell Kelly	**REV:** 001	**TIME:**	16:01:39

LM35 Sensor Board

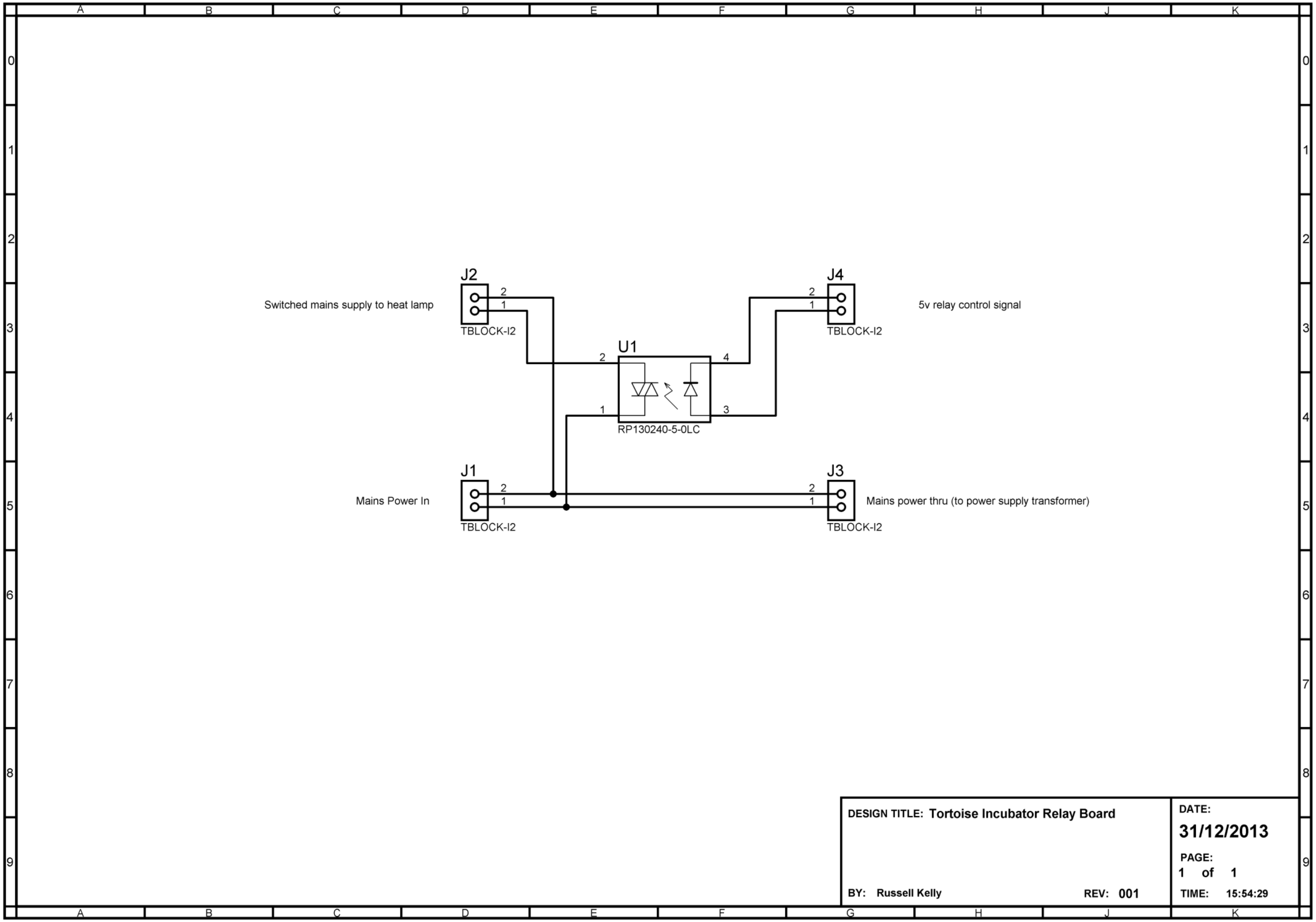


Display Board



FILE NAME:	Tortoise Incubator Display Board		DATE: 26/01/2014
			PAGE: 1 of 1
AUTHOR:	Russell Kelly	REV: 001	TIME: 19:12:23

Relay Board

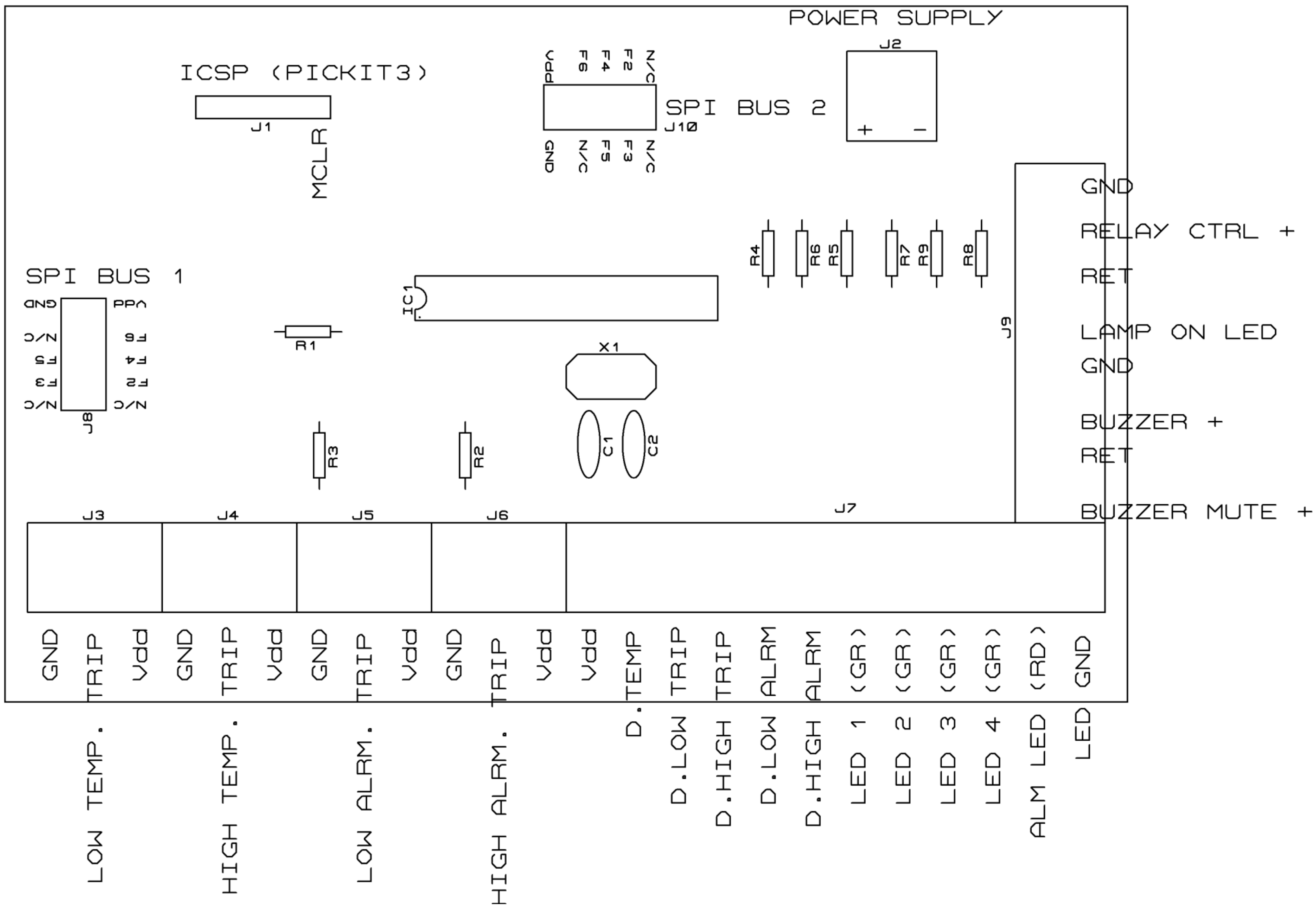

J2
2
1
Switched mains supply to heat lamp
TBLOCK-I2
J4
2
1
5v relay control signal
TBLOCK-I2
U1
2
4
1
3
RP130240-5-0LC
J1
2
1
Mains Power In
TBLOCK-I2
J3
2
1
Mains power thru (to power supply transformer)
TBLOCK-I2
DESIGN TITLE: Tortoise Incubator Relay Board
DATE: 31/12/2013
PAGE: 1 of 1
BY: Russell Kelly
REV: 001
TIME: 15:54:29

Circuit Boards

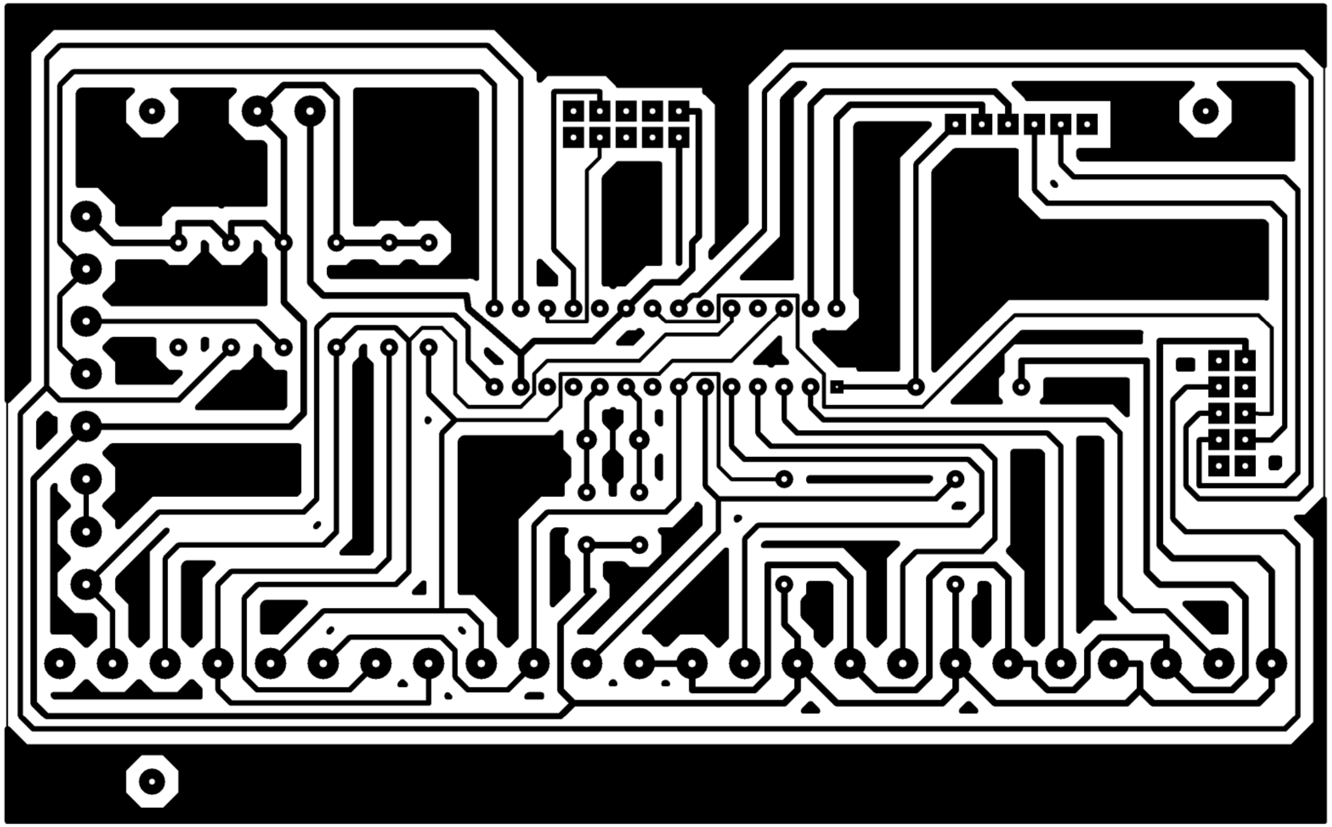
Circuit boards are displayed on the next few pages. For high resolution, correct scale toner print and UV print solder side art works, please refer to either the project folder supplied with this document. All art works may also be downloaded from my website;

www.rkelectronics.org

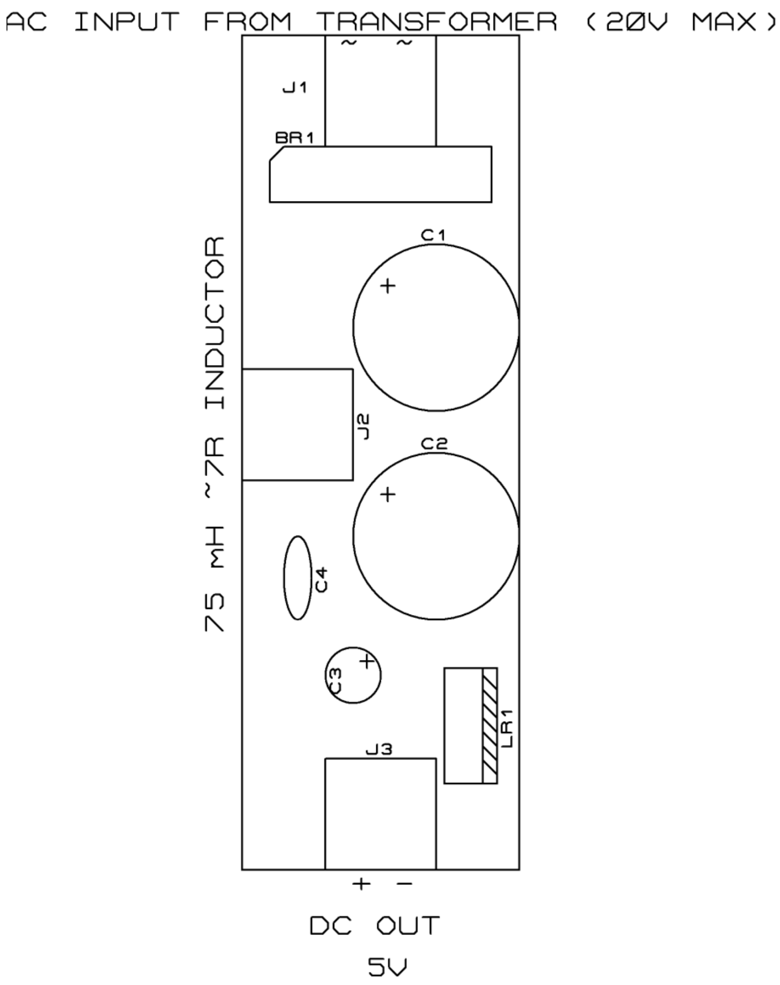
Motherboard Circuit Board (Component Side)

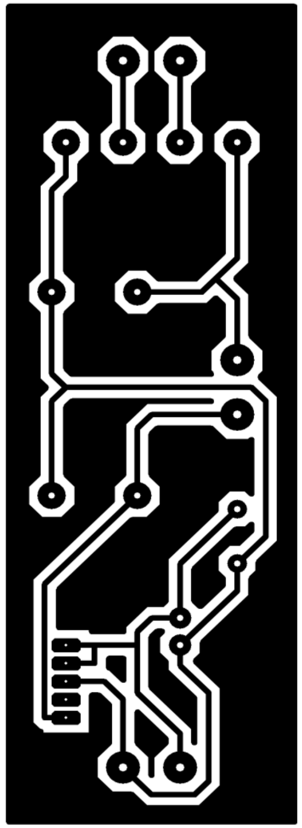


Motherboard Circuit Board (Solder Side)

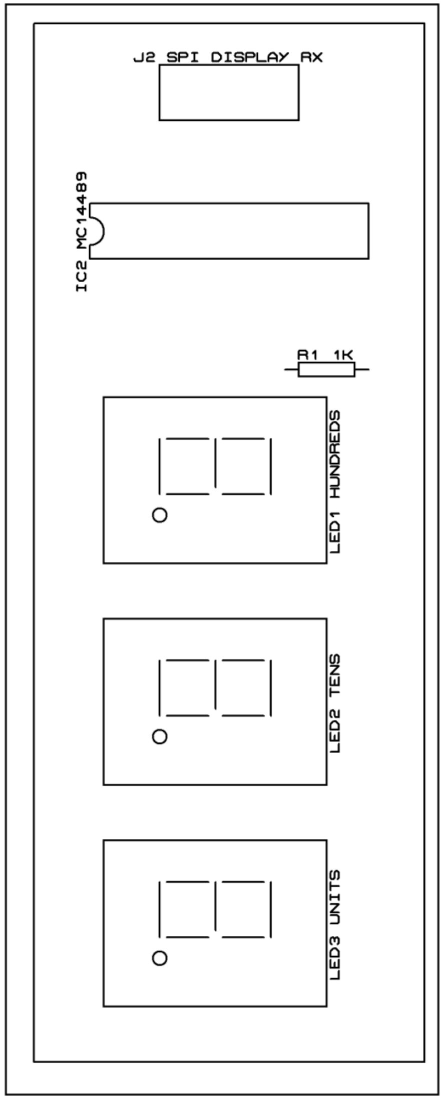


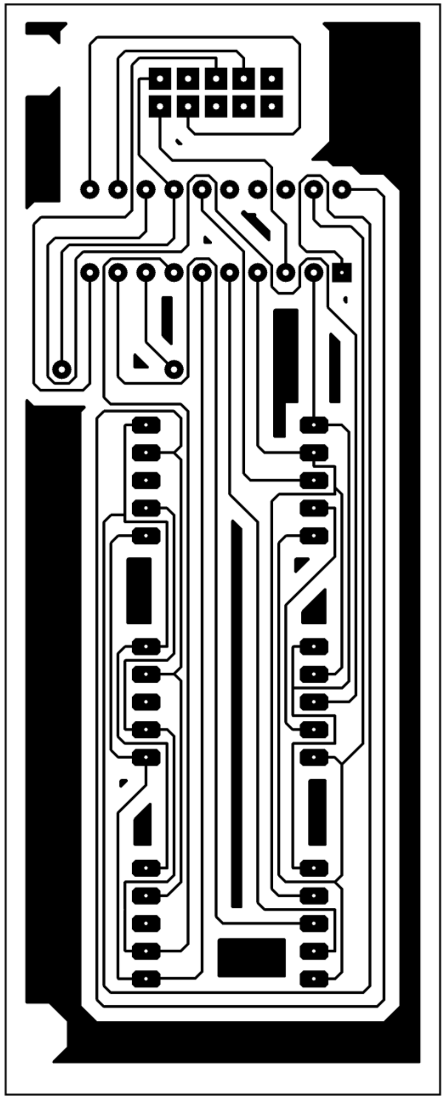
Power Supply Circuit Board



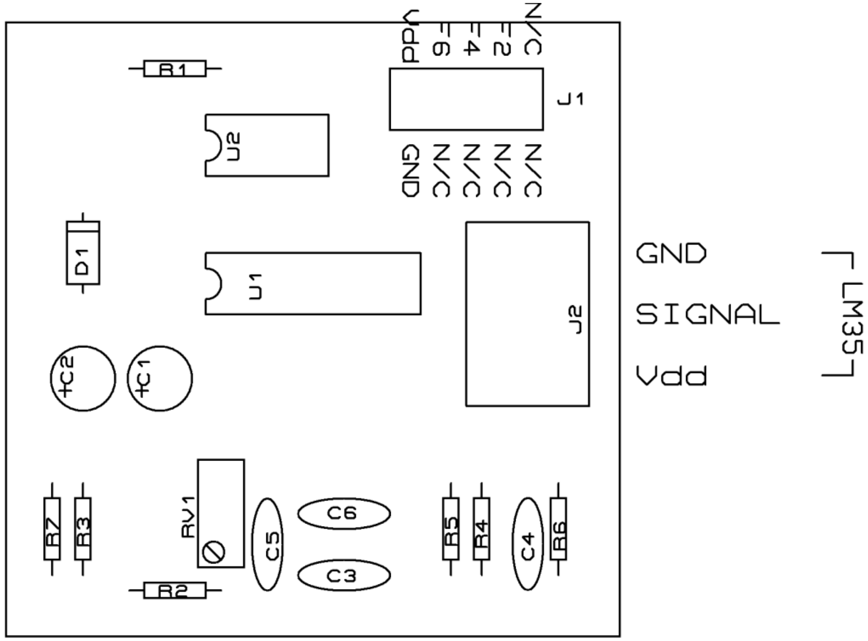


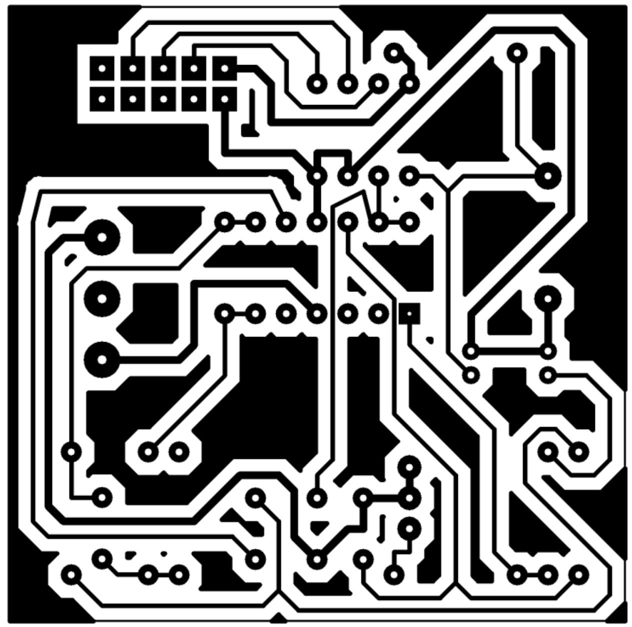
Display Circuit Board



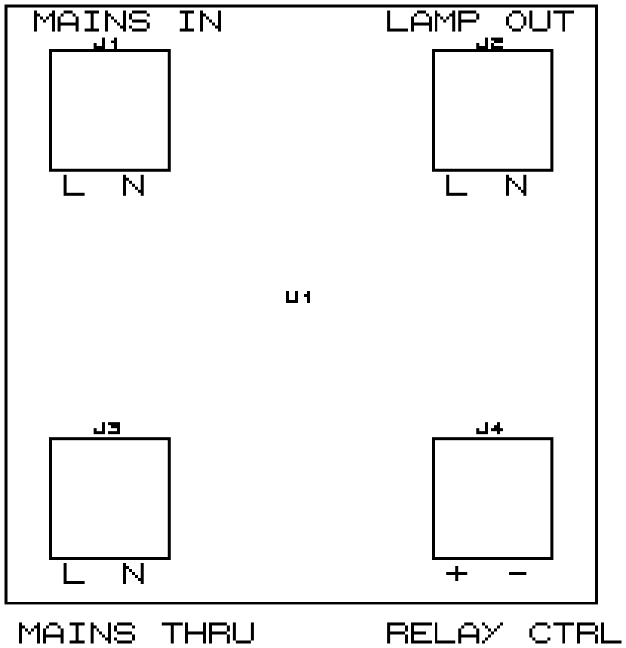


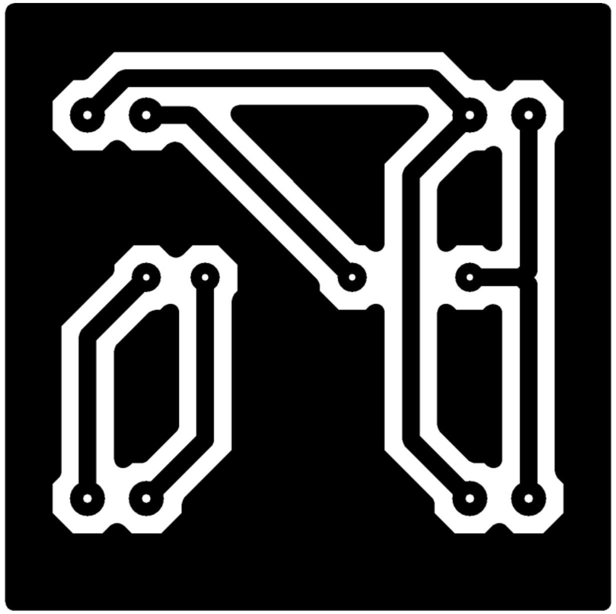
LM35 Input Card Circuit Board





Relay Circuit Board

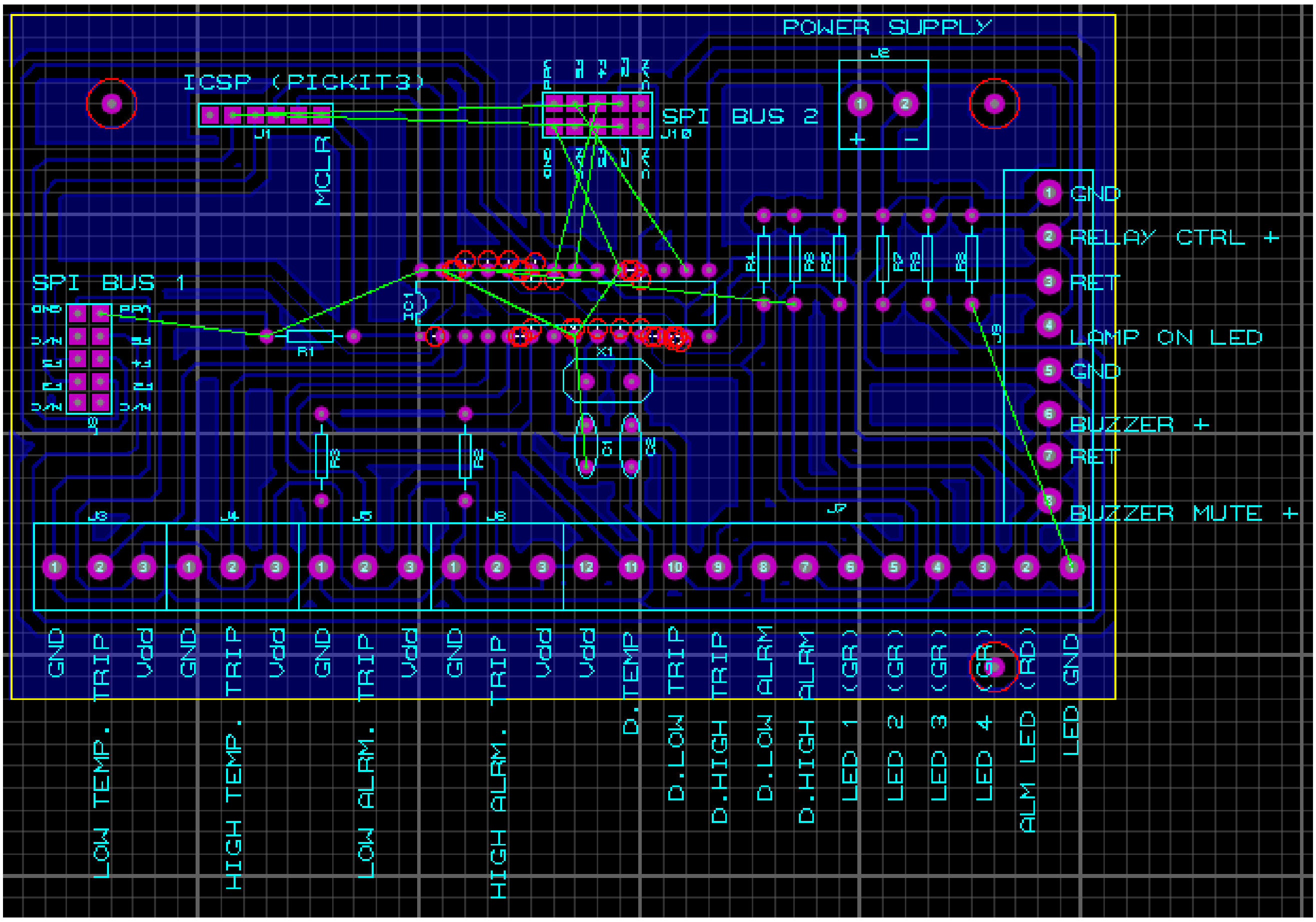




Circuit Board Corrections

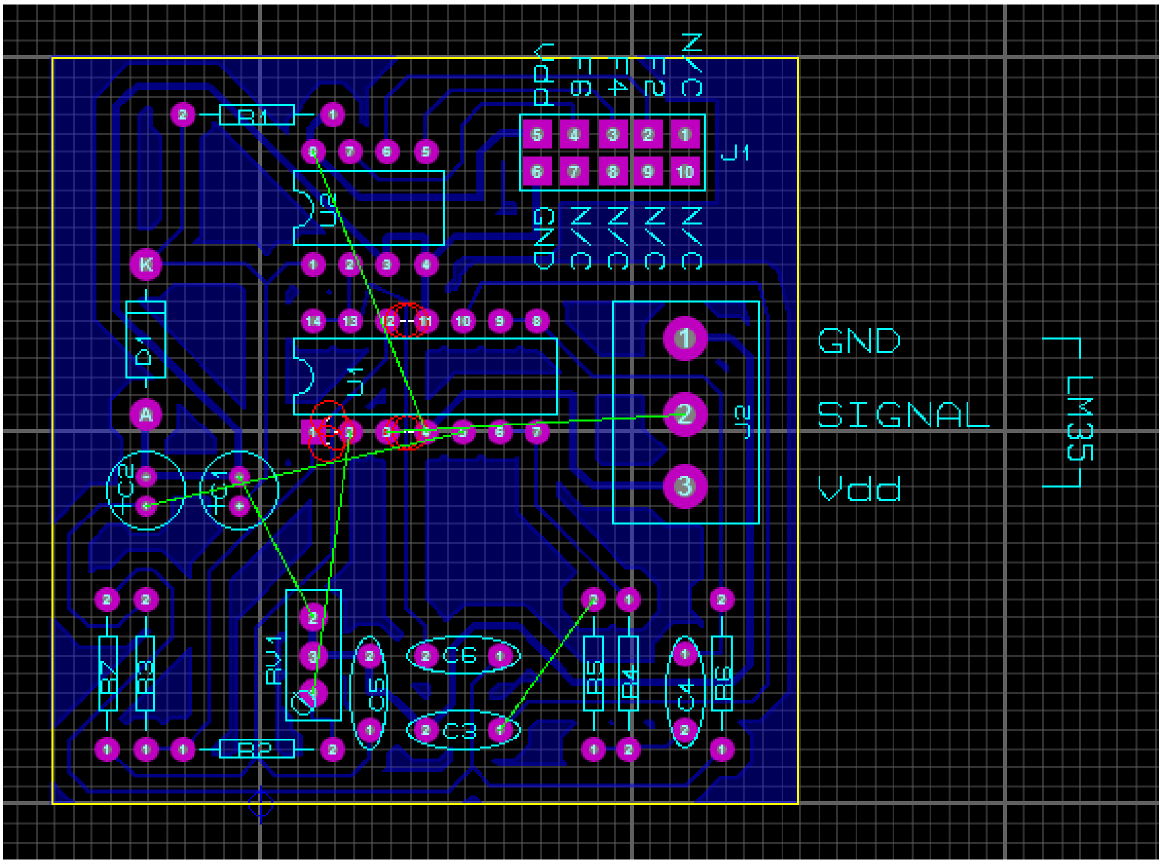
Motherboard

Green wires represent additional wire connections.



LM35 Input Card

Green wires represent additional wire connections.



Wiring Correction Summary

The following table represents the additional wiring required to complete the circuit boards.

Table 4 - Wiring corrections

Ref	Type	From	To	Circuit Board
1	Wire	J1 pin 5	J10 pin 2	Motherboard
2	Wire	J1 pin 4	J10 pin 9	Motherboard
3	Wire	J10 pin 3	PIC pin 22	Motherboard
4	Wire	J10 pin 8	PIC pin 21	Motherboard
5	Wire	J10 pin 4	PIC pin 16	Motherboard
6	Wire	J10 pin 6	PIC pin 19	Motherboard
7	Wire	J8 pin 5	R1 pin 2	Motherboard
8	Wire	R1 pin 2	PIC pin 28	Motherboard
9	Wire	PIC pin 25	R6 pin 2	Motherboard
10	Wire	PIC pin 28	PIC pin 20	Motherboard
11	Wire	PIC pin 27	PIC pin 8	Motherboard
12	Wire	PIC pin 8	C1 pin 2	Motherboard
13	Wire	PIC pin 19	PIC pin 8	Motherboard
14	Wire	R8 pin 1	J7 pin 1	Motherboard
15	100k resistor	PIC pin 17	Any GND	Motherboard
16	100k resistor	PIC pin 18	Any GND	Motherboard
17	Wire	MCP3201 pin 8	MCP6274 pin 4	LM35 Input Card
18	Wire	C2 positive	MCP6274 pin 5	LM35 Input Card
19	Wire	C1 negative	RV1 pin 2	LM35 Input Card
20	Wire	RV1 pin 1	MCP6274 pin 2	LM35 Input Card
21	Wire	MCP6274 pin 3	J2 pin 2	LM35 Input Card
22	Wire	C3 pin 1	R5 pin 2	LM35 Input Card

Bill of Materials

Table 5 - Bill of materials

Ref	Circuit	Circuit Reference	Component Type	Value	Quantity
1	Motherboard	C1-C2	Ceramic capacitor	22 pF	2
2		R1	Resistor	10 k	1
3		R2-R6/R9		75 k	6
4		R7-R8		330 R	2
5		R9-10	Additional resistors	100 k	2
6		dsPIC30F3013 (RK0059 firmware)	PIC microprocessor	-	1
7		J1	6 way connector		1
8		J2	2 way connector		1
9		J3-J6	3 way connector		4
10		J7	12 way connector		1
11		J8/J10	10 way connector (2.54mm centre line DIL)	Female	2
12		J9	8 way connector		1
13		X1	Quartz crystal	10 MHz	1
14	Display Board	R1	Resistor	1 k	1
15		MC14489	Numerical LED Driver IC		1
16		J2	10 way connector (2.54mm centre line DIL)	Female	2
17		LED	7 segment LED module		3
18	LM35 Input Card	C1	Electrolytic capacitor	10 µF	1
19		C2		2µ2	1
20		C3/C5	Ceramic capacitor	18 nF	2
21		C4		33 nF	1
22		C6		220 nF	1
23		R1	Resistor	390 R	1
24		R2		90 k	1
25		R3		15 k	1
26		R4		820 k	1
27		R5		1M3	1
28		R6		27 k	1
29		R7		620 k	1
30		MCP6274	Quad Op-amp IC		1
31		MCP3201	Single differential 12 Bit ADC SPI protocol		1
32		D1	4V3 Zenor Diode	1N4731A	1
33		J1	10 way connector (2.54mm centre line DIL)		1
34		J2	3 way connector		1
35		RV1	Preset variable resistor	22 k	1
36	Power Supply	C1	Electrolytic capacitor	2200 µF	1
37		C2		1000 µF	1

Ref	Circuit	Circuit Reference	Component Type	Value	Quantity
38		C3		100 µF	1
39		C4		100 nF	1
40					
41		BR1	Bridge rectifier	Minimum 1A	1
42		J1	2way connector		3
43		LR1	Linear regulator LT1129-5	5V @ 700 mA	1
44	Relay Board	J1-4	2 way connector		2
45		U1	Optio-isolated solid state relay	RP130240-5-0LC	1
46	Additional Items		Multi-turn variable Resistor	10 k	4
47			5 position single throw rotary switch		1
48			230 V to 12 V 15 VA step down transformer		1
49			SPST toggle switch		1
50			5V buzzer		1
51			Red LED		1
52			Yellow LED		1
53			Green LED		4
54			3 pin female 230 v 'kettle lead' socket (mains in)		1
55			3 pin male 230 v 'kettle lead' socket (output to lamp)		1
56			Fuse holder with 500 mA time delayed fuse		1
57			3 pin male or female screw fit port for LM35 sensor lead		1
58			75 mH choke < 7 ohms rated for 1A		1
59			10 way 1.24mm ribbon wire		1/4 m
60			Enclosure 257 x 190 x 85mm (maplin BZ77J)		1
61			Single sided copper clad etch PCB board	A4 size	1