DIGITAL TEMPERATURE CONTROLLER USING THERMOCOUPLE

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Digital temperature controllers are essential for temperature measurement and control of instrumentation in industries. These are used for home appliances too. Several types and makes of analogue and digital temperature controllers are available in the market but they are very costly and complex in design.

Here is a digital temperature controller that is highly reliable and accurate yet very easy and inexpensive to make. It can measure temperatures in the range of 0 to 999ºC.

Salient features of this digital temperature controller are:

1. Universal signal conditioning for any thermocouple input
2. Flexible design for any temperature range
3. Highly accurate and reliable due to 4½-digit analogue-to-digital converter (ADC) IC L7135
4. Easy temperature setting using digital thumbwheel switch
5. Suitable for home and industries
6. No programming or any other software required

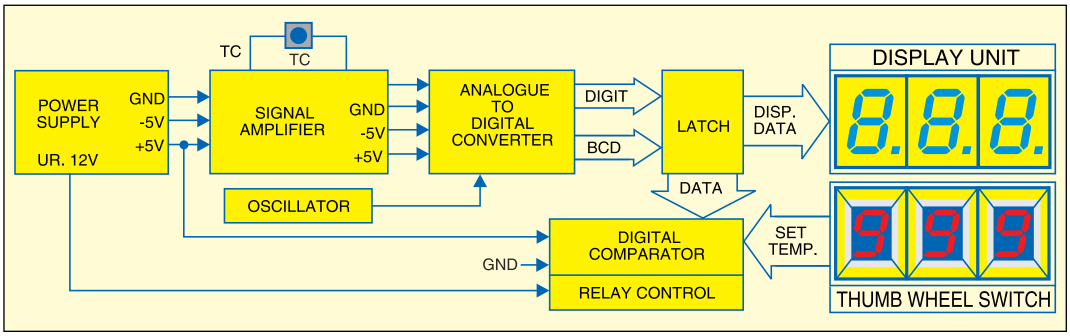

Fig. 1: Block diagram of digital temperature controller

Temperature measurement basics

There are two types of temperature measurement systems:

1. Direct temperature measurement system, for up to 999ºC
2. Indirect temperature measurement system, for a higher temperature range at which physical sensors may burn

Direct temperature measurement system is normally used to measure the temperature of a flame, hot air/gas, or hot body of a metallic surface, in the form of some electrical unit like microvolt (µV) or miliampere (mA), or resistance change as input signal to the measuring instrument.

Indirect temperature measurement system is used where direct temperature measurement is not possible as the temperature sensor may burn due to high temperature or there is no physical contact with the sensor for measurment. In such cases, an indirect temperature measurement technique called 'optical pyrometery' is used. Pyrometer is used for indirect temperature measurement through UV rays and photo-sensors.

The selection of a temperature controller is dependent on the range of temperature and temperature sensor—the most important and critical part of any temperature measurement and control system.

There are many types of sensors for different ranges of temperature measurement:

1. For temperature range of 0-100ºC, the most common sensor is a thermistor or semiconductor sensor.
2. For temperature range of 0-250ºC, the most common sensor is RTD PT-100.
3. For temperatures up to 1000ºC or more, thermocouples are used as sensors.

Here we are concerned with the direct method of measurement for temperatures up to 1000ºC, using K-type of thermocouple as the input temperature sensor.

A thermocouple forms when two different metals join together to make a junction. When heated, this junction of two different metals produces electrical energy in microvolts. In other words, heat energy is converted into electrical energy due to thermal effect of materials joined together at a junction.

In K-type thermocouples, the combination of metals like chromel (Ni-Cr) and alumel (Ni-Al) forms the junction. K-type is low-cost and one of the most popular general-purpose thermocouples. Its operating range is around -180ºC to +1350ºC. Sensitivity is approximately 42 μV/°C and it is most suited for oxidising environments.

Details of thermocouple types and temperature table are included in this month's EFY-CD. See the K-type thermocouple temperature chart for calibration of the digital temperature controller.

Circuit description

Fig. 1 shows the block diagram of the digital temperature controller. It comprises a signal amplifier, ADC, display unit, comparator along with relay control and power supply. A thermocouple is used as the temperature sensor. Its output is amplified by the signal amplifier and converted into a digital signal using the ADC. This digital data is shown on a 7-segment display (with the help of the display driver) and simultaneously compared with the preset temperature data. When the temperature (digital data) crosses the preset temperature data, the relay energises to control the heating element of the oven.

Fig. 2 shows the circuit of the digital temperature controller using thermocouple. At the heart of the circuit is the signal amplifier along with the ADC.

Signal amplifier. The signal amplifier is nothing but the thermocouple voltage amplifier. Linear operational amplifier μA741 (IC1) is used for thermocouple voltage amplification. The input signal for the amplifier (approximately 42 μV/°C) is generated by thermal effects of the thermocouple. The thermocouple-generated microvolt signal is amplified to millivolt (mV) with variable-gain adjustment by feedback preset VR1 connected from inverting input pin 2 to output pin 6 to set the required amplifying factor as per the requirement. Preset VR2 is used for offset-null (zero) adjustment. Output pin 6 of μA741

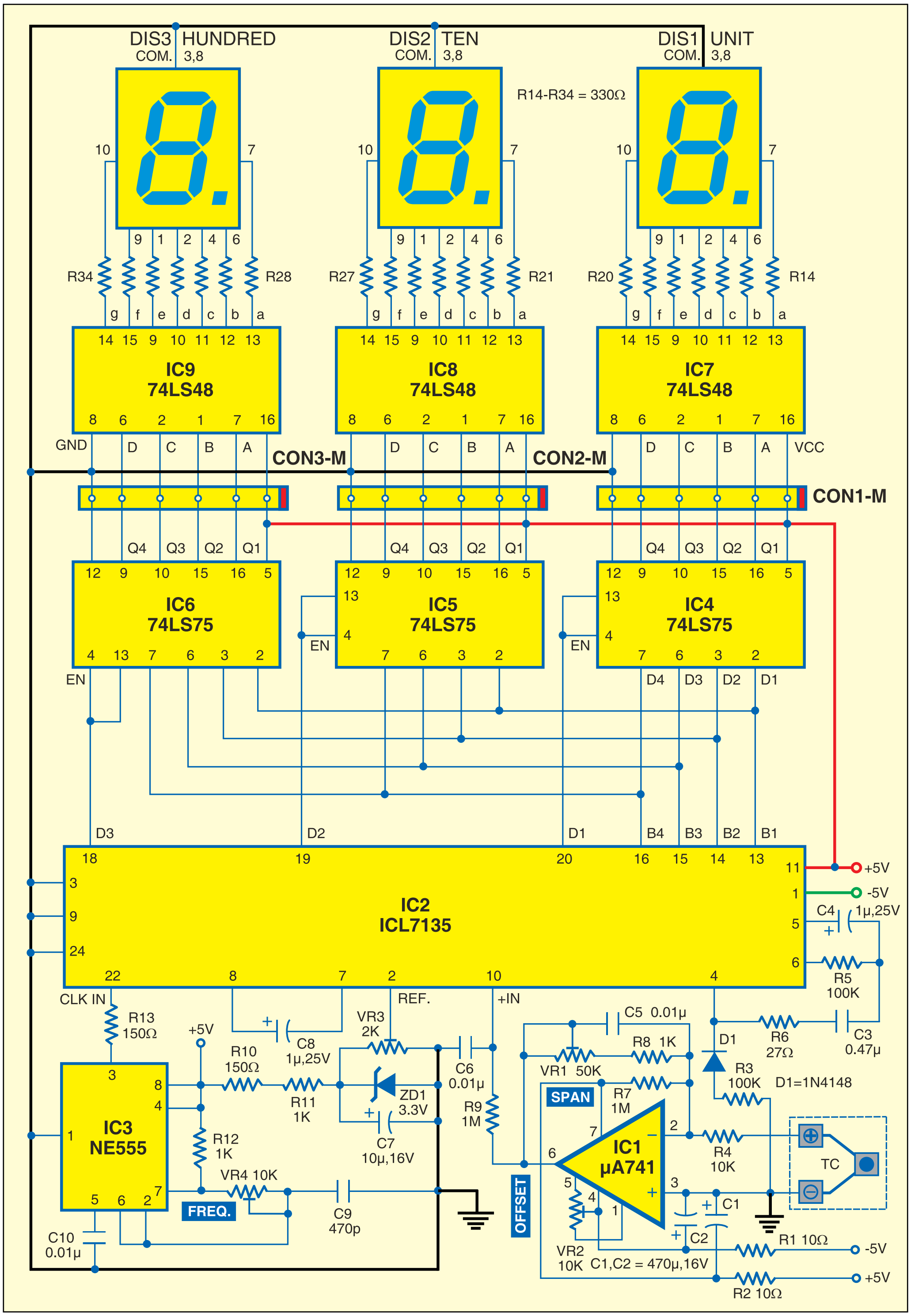

Fig. 2: Digital temperature controller using thermocouple

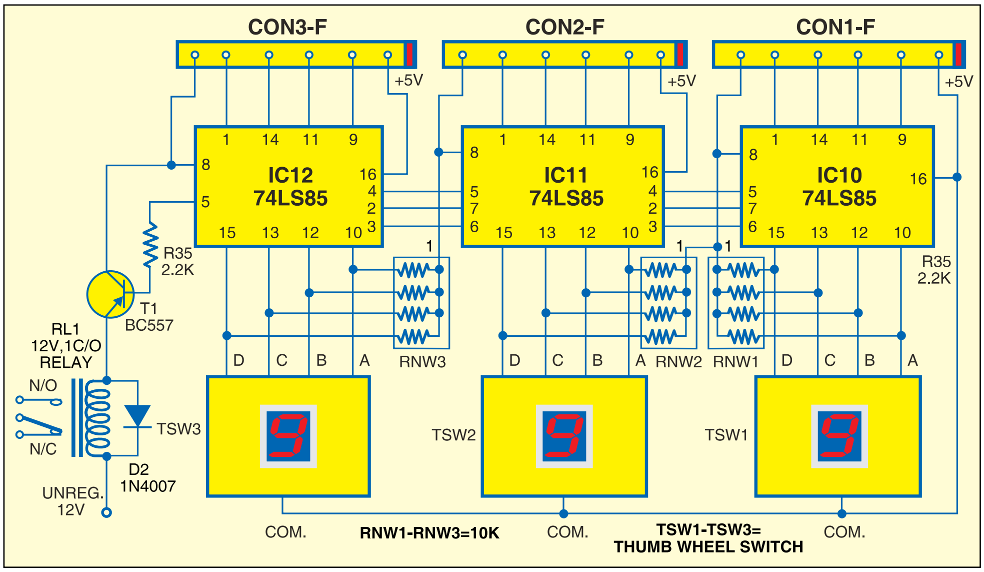

Fig. 3: Comparator unit of digital temperature controller

is connected to input pin 10 of ADC ICL7135 (IC2).

Analogue-to-digital converter. IC L7135 is a 4½-digit ADC. This dual-slope integrating ADC provides interface for the visual display. ICL7135 is available in a 24-pin plastic dual-in-line package (PDIP). The output of signal amplifier op-amp µA741 is fed to input pin 10 of ADC ICL7135 to get multiplexed binary-coded decimal (BCD) outputs B1 through B4 and digits D1 through D3 from pins 13 through 16 and pins 20 down through 18, respectively. Pin 22 of ICL7135 is connected to the output of IC NE555 (IC3).

IC NE555 is configured as a free running oscillator for multiplexing of the digital output inside ADC ICL7135. Preset VR4 is used to set the frequency of oscillations at 120 kHz. Latches 74LS75 (IC4 through IC6) are used to get stable, individual unit's, ten's and hundred's digits from three-digit multiplexed output of IC 7135 for displaying the actual temperature through three 7-segment display units. At the same time, the temperature comparator unit compares the actual temperature value with the preset value, to energise relay RL1 to control the heating element of the oven or furnace. A connector is provided at the output of latches 74LS75 (IC4 through IC6) to interface other digital instruments for further temperature study, temperature recording, temperature processing, data logging and data storage on the hard disk of a PC.

Temperature display unit. The three-digit BCD output of latches (IC4 through IC6), representing unit's, ten's and hundred's digits, is fed to the temperature display unit as an input for BCD-to-7-segment decoder 74LS48 (IC7 through IC9). Three 7-segment displays are used to display the actual temperature in three decimal digits (up to 999ºC).

Digital comparator unit. Fig. 3 shows the circuit of the digital comparator unit. The three-digit BCD output of 74LS75 (IC4 through IC6) is also fed to the digital comparator unit. Three 4-bit 74LS85 magnitude comparators are used here for comparison of the actual temperature with the preset temperature value. Three BCD thumbwheel switches TWS1 through TWS3 are used for temperature setting. If the actual temperature value is higher than the preset temperature value, pin 5 of the most significant digit comparator (IC12) goes low. This drives transistor T1 into saturation and relay RL1 energises to control the heating element of the oven.

Power supply unit. Fig. 4 shows the circuit of the power supply. The 230V, 50Hz AC mains is stepped down by transformer X1 to deliver a secondary output of 9V-0-9V, 1A. The transformer output is rectified by a full-wave rectifier comprising diodes D3 through D6, filtered by capacitors C11 and C12, and regulated by ICs 7805 (IC13) and 7905 (IC14) to get regulated +5V and -5V, respectively. Capacitor combinations C13-C15 and C14-C16 bypass ripples, if any, in the positive and negative power supplies, respectively. LED1 acts as the power indicator and R36 limits the current through LED1.

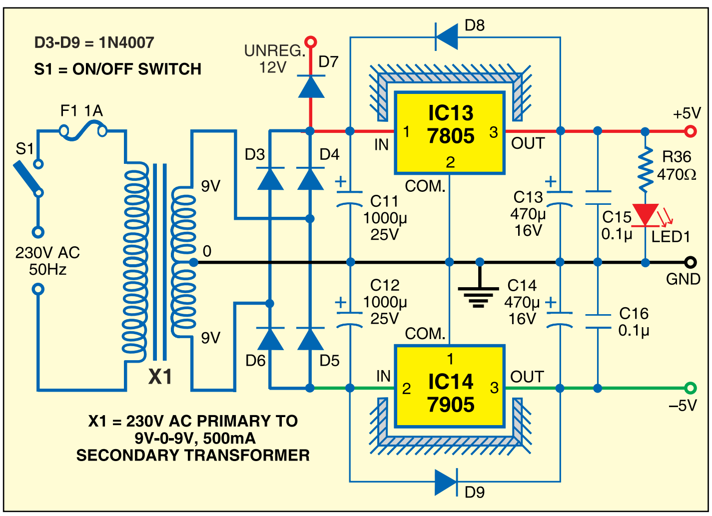

Fig. 4: Power supply

Construction

An actual-size, single-side PCB for the digital temperature controller is shown in Fig. 5 and its

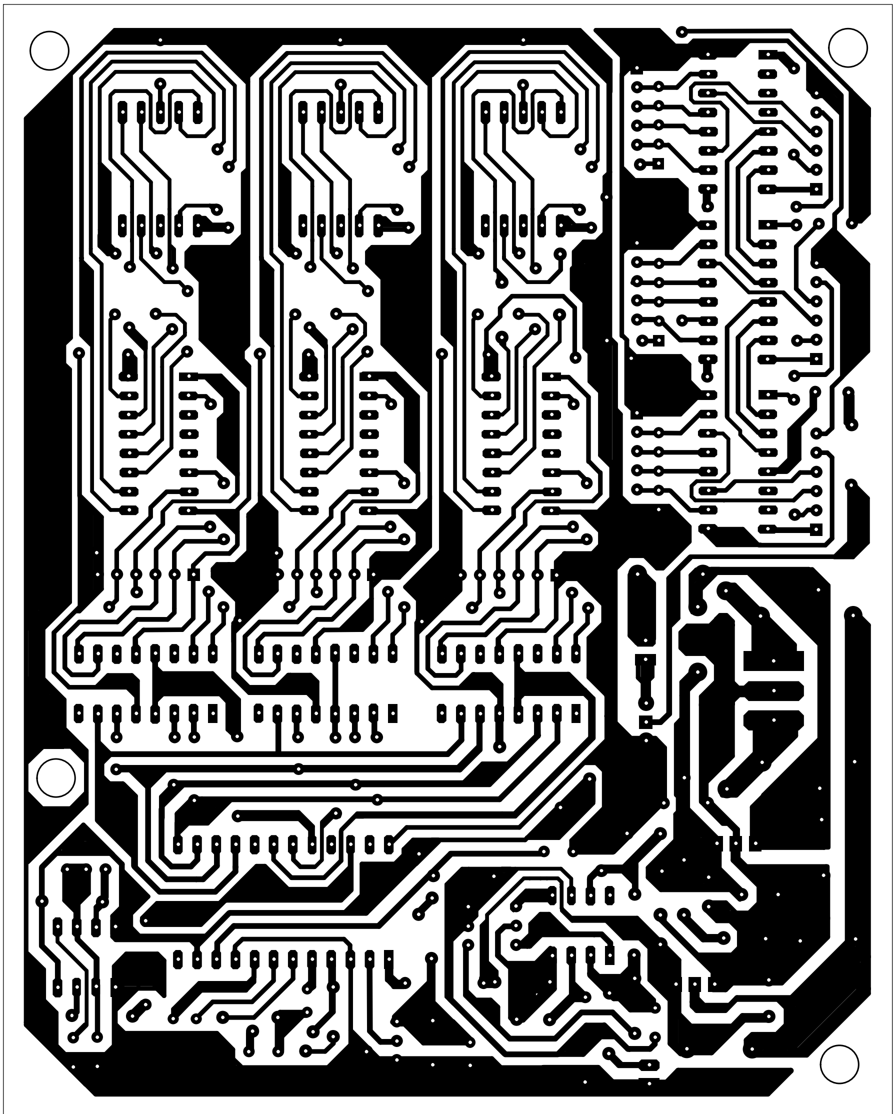

Fig. 5: An actual-size, single-side PCB for the digital temperature controller using thermocouple

PARTS LIST	
Semiconductors:	
IC1	- μA741 operational amplifier
IC2	- ICL7135 4½-digit ADC
IC3	- NE555 timer
IC4-IC6	- 74LS75 quad latch
IC7-IC9	- 74LS48 BCD to 7-segment decoder
IC10-IC12	- 74LS85 magnitude comparator
IC13	- 7805, +5V regulator
IC14	- 7905, -5V regulator
T1	- BC557 pnp transistor
ZD1	- 3.3V zener diode
D1	- 1N4148 switching diode
D2-D9	- 1N4007 rectifier diode
LED1	- 5mm LED
DIS1-DIS3	- LTS543 common-cathode 7-segment display
Resistors (all ¼-watt, ±5% carbon):	
R1, R2	- 10-ohm
R3, R5	- 100-kilo-ohm
R4	- 10-kilo-ohm
R6	- 27-ohm
R7, R9	- 1-mega-ohm
R8, R11, R12	- 1-kilo-ohm
R10, R13	- 150-ohm
R14-R34	- 330-ohm
R35	- 2.2-kilo-ohm
R36	- 470-ohm
RNW1-RNW3	- 10-kilo-ohm resistor network
VR1	- 50-kilo-ohm preset
VR2, VR4	- 10-kilo-ohm preset
VR3	- 2-kilo-ohm preset
Capacitors:	
C1, C2	- 470μF, 16V electrolytic
C3	- 0.47μF ceramic disk
C4, C8	- 1μF, 25V electrolytic
C5, C6, C10	- 0.01μF ceramic disk
C7	- 10μF, 16V electrolytic
C9	- 470pF ceramic disk
C11, C12	- 1000μF, 25V electrolytic
C13, C14	- 470μF, 16V electrolytic
C15, C16	- 0.1μF ceramic disk
Miscellaneous:	
X1	- 230V AC primary to 9V-0-9V, 1A secondary transformer
S1	- On/off switch
TWS1-TWS3	- BCD thumbwheel switch
RL1	- 12V, 1C/O relay
F1	- 1A fuse
TC	- K-type thermocouple
CON1-M-CON3-M	- 6-pin berg strip male connector
CON1-F-CON3-F	- 6-pin berg strip female connector

component layout in Fig. 6. Suitable connectors are provided on PCB for comparators, thumbwheel switches and relay. Assembling the circuit on a PCB minimises time and assembly errors. Carefully assemble the components and double-check for any overlooked error. Use bases to avoid damage to ICs due to direct soldering and over-heating.

Testing and calibration

For testing and calibration of the digital temperature controller, you need a good-quality, 4-digit millimeter capable of reading microvolts to 100V DC in different ranges and a stable and accurate voltage injector capable of injecting microvolts to volts in variable mode as per the requirement of the K-type thermocouple.

After assembling and wiring the circuit, connect 230V, 50Hz mains supply to the primary winding of the transformer of the power supply unit and check +5V and –5V supplies. If both the supplies are okay, switch off the supply by opening switch S1 and insert appropriate ICs into IC bases on the PCB.

Zero setting. Short the inverting and non-inverting pins (pins 2 and 3) of op-amp μA741 and connect the digital millivoltmeter to pin 6 of μA741. Set the reading to '000' on multimeter by varying preset VR2 (connected to pins 1 and 5). When the display shows 000, remove shorting.

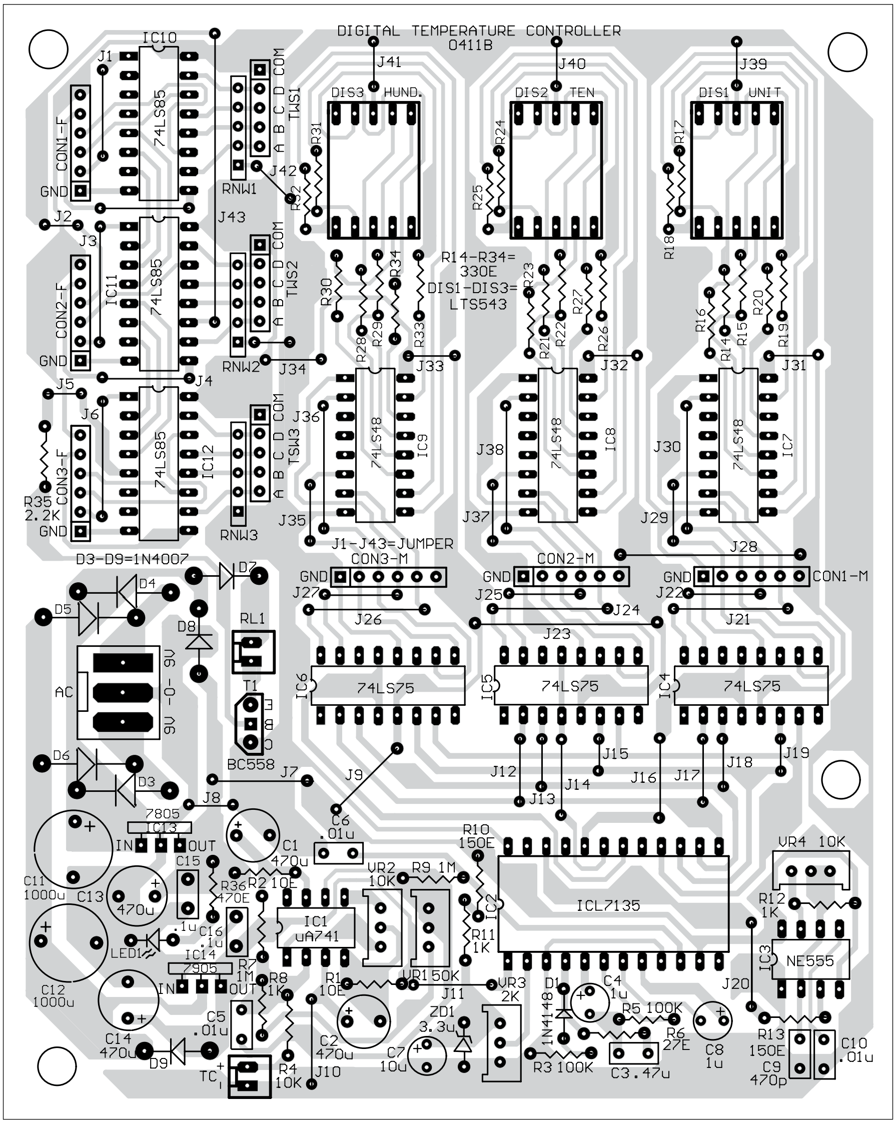

Fig. 6: Component layout for the PCB

Span setting. Connect the microvolt injector unit through positive and negative leads to pins 2 and 3 of µA741, respectively. Set the oscillator frequency to 120 kHz using preset VR4. Feed the microvolt signal as per the K-type thermocouple chart (given in the EFY-CD).

Preset VR1 connected between pins 2 and 6 of op-amp µA741 is used to get full-scale temperature reading on the display unit according to injection voltage. Preset VR3 is used for reference setting.

After proper calibration, connect the K-type thermocouple between resistor R4 (connected to pins 2 of IC1) and pin 3 of op-amp µA741. It will display the room temperature after connection of thermocouple. Dip the thermocouple in boiling water and check temperature in display. It will display around 100ºC.

Relay control setting. Set any temperature through the thumbwheel switch and feed the signal voltage (as per the K-type thermocouple temperature chart) through the voltage injector. When the signal voltage crosses the set temperature voltage, the relay energises to disconnect the heating element of the oven.

EFY note. The controller has been tested up to 300°C. ●