AN2446
Application note

STEVAL-IHT002V1
Intelligent thermostat for compressor based on ST7Ultralite MCU

Introduction

The STEVAL-IHT002V1 is a very low-cost evaluation board designed with the intent to replace the existing mechanical thermostat.

While driving a compressor, the evaluation board is able to drive the RUN winding, replace the PTC and drive directly the START winding too. Stall rotor detection is also implemented. Both functions are oriented to reduce the total power consumption.

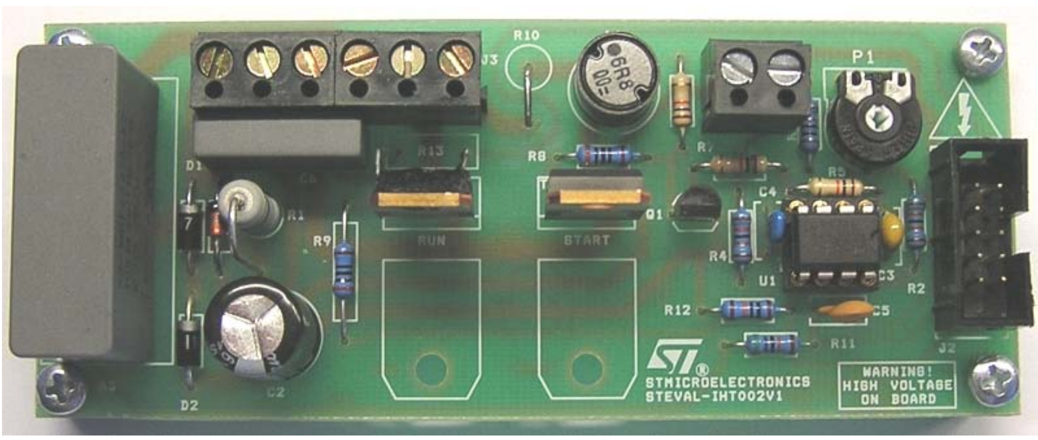
The evaluation board is based on the new low-cost, 8-pin, 8-bit ST7Ultralite microcontroller (MCU), which controls the entire process. The MCU is equipped with a programmable Flash memory, 1 MHz internal clock source and runs 1 KByte C-based software.

Even if the evaluation board is especially designed for driving small-size or mid-size compressors, it is fully customizable and adaptable to any other application where thermostat or temperature control is required.

An STMicroelectronics Patent Application is pending for the compressor control device and the method for controlling a compressor described in this document.

This document provides a complete description on how to customize the evaluation board.

STEVAL-IHT002V1 evaluation board



Contents

1 STEVAL-IHT002V1 overview 3

2 Circuit description 4

3 How the system works 5

3.1 Cabinet temperature regulation 5

3.2 Dead-time 5

3.3 Compressor start-up sequence 5

3.4 Stall rotor detection 6

4 Scope waveforms 7

5 Customization: software and hardware modifications 9

5.1 Cabinet temperature offset 9

5.2 START winding duration 9

5.3 Stall rotor control duration 9

5.4 Dead-time duration 9

5.5 Gate pulse duration 10

5.6 Disabling the stall rotor detection 10

5.7 Different START winding management 10

6 Revision history 12

1 STEVAL-IHT002V1 overview

The STEVAL-IHT002V1 evaluation board includes a capacitive power supply on the left side with the AC switches located in the middle of the board. Both AC switches can work without a heatsink. The temperature sensor used to detect the stall rotor condition is mounted on the top of the AC switch driving the RUN winding.

The 8-pin MCU and the ICC programming connector are on the right side of the board.

Figure 1. STEVAL-IHT002V1 evaluation board

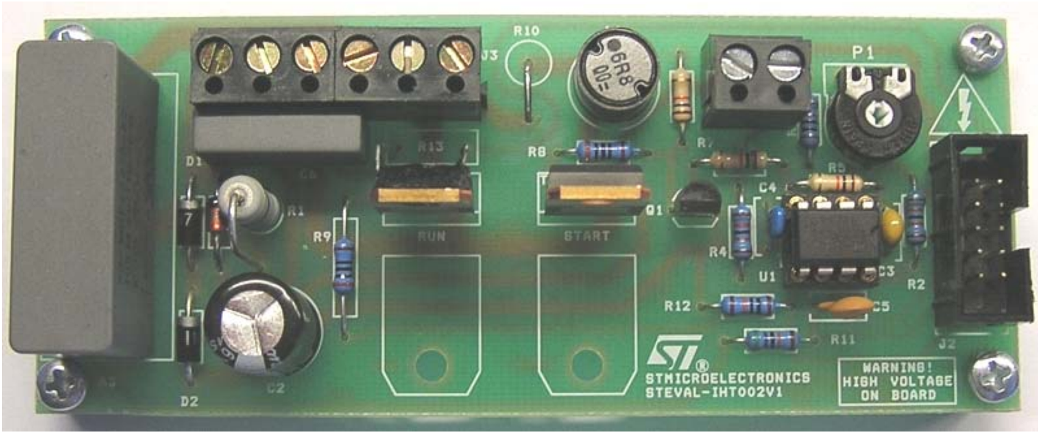
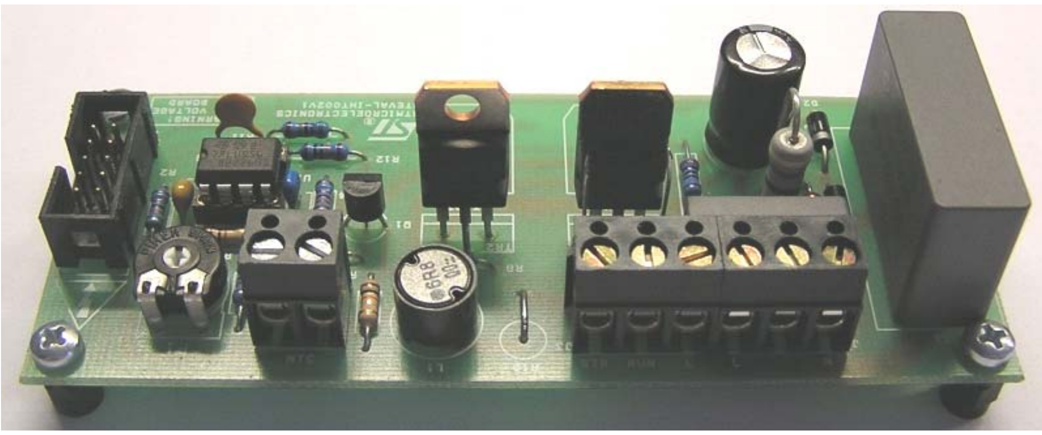


Figure 2. STEVAL-IHT002V1 (reverse angle)



On the left side are the potentiometer to set the cabinet temperature and the connector where to plug the external NTC sensor. The connector where to plug the compressor and the voltage mains is on the right side. The AC switch on the left is the one driving the START winding and the right one drives the RUN winding.

2 Circuit description

The circuit can be divided into a few simple parts.

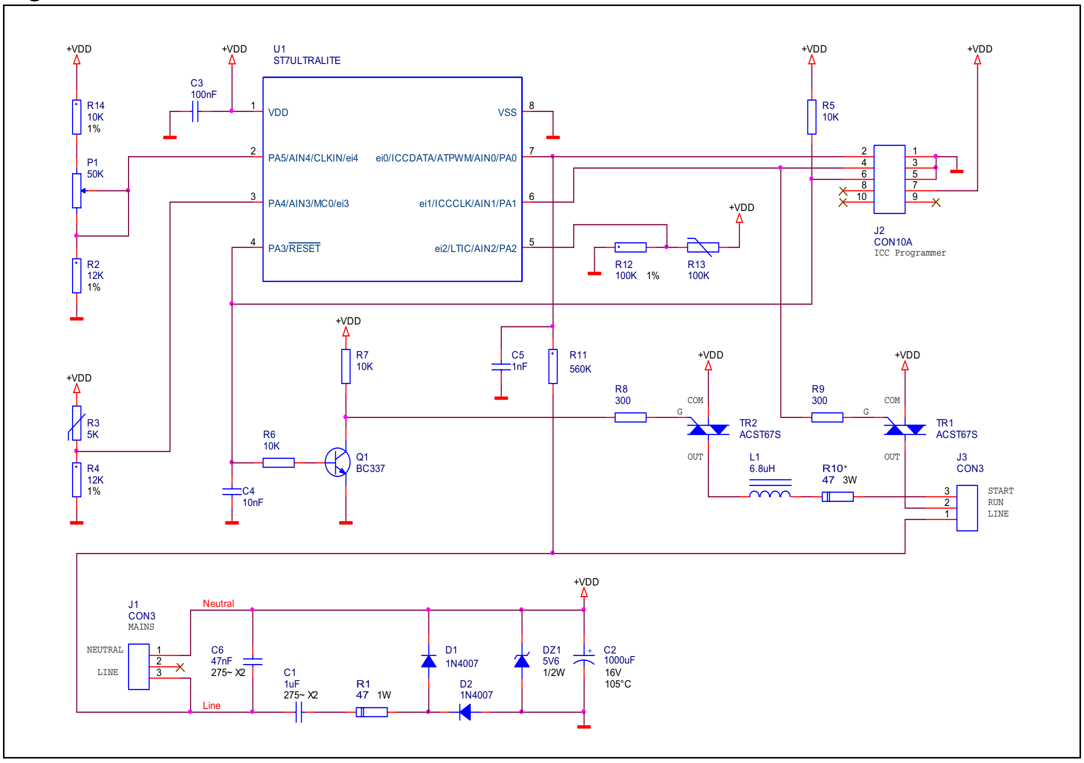
VDD (5 VDC) is obtained by means of a classic capacitive power supply directly taken from the mains (220 VAC 50 Hz). Capacitor C1 is sized to provide about 30 mA. VDD supplies the MCU and all the analog circuitry.

Potentiometer P1 sets the temperature of the cabinet. The signal is sent directly to the MCU for A/D processing (pin 2). The cabinet temperature is read by means of a negative temperature coefficient (NTC) thermistor. This signal is also sent directly to the MCU for A/D processing (pin 3). MCU also generates the gate pulses to drive the AC switches. The gate current is about 15mA for each AC switch.

Since pin 4 is not able to deliver a current higher than 5mA, a transistor is necessary. Pin 6 indeed has a high current capability up to 20mA; therefore the sole gate resistor is enough to drive the AC switch.

The gate pulses have to be synchronized with the mains voltage: pin 7 captures the signal and generates an external interrupt when the mains voltage crosses the zero, on the falling edge only (one time per period). A resistor divider is applied to pin 5 of the MCU. R13 is glued on the top of the AC switch driving the RUN winding. R13 is a temperature sensor used to detect the stall rotor condition by reading the temperature of the AC switch. The signal is then processed directly by the MCU. The evaluation board is equipped with an ICC connector to in-circuit program the MCU (care has to be taken while programming the MCU, please refer to the User's manual for more details).

Figure 3. STEVAL-IHT002V1 schematic



3 How the system works

The evaluation board can be tested with or without load. In fact, even if no compressor is connected to the evaluation board, all the signals are clearly visible by means of a scope.

Care has to be taken when using a scope with the evaluation board. For more details, please refer to the safety instructions described in the User's manual.

Please note that after the evaluation board has been powered on, there is a 3-second delay before the system starts to operate.

3.1 Cabinet temperature regulation

The potentiometer P1 can be adjusted to set the cabinet temperature in the range of -23 °C up to +10 °C. Both cabinet temperature and potentiometer settings are read once per period, meaning 50 times per second (with a mains frequency of 50 Hz).

Once the cabinet temperature rises over the level set by the potentiometer P1, the system turns the compressor on. The compressor stays on as long as the cabinet temperature remains below the threshold level set by the potentiometer P1. An offset in the temperature control is defined in order to avoid oscillations and spurious compressor turn on or off.

3.2 Dead-time

Once the compressor turns off, a delay is set. This delay is called “dead-time”. During this time, the compressor cannot be turned on again, even if the cabinet temperature exceeds the threshold level set by the potentiometer P1.

The dead-time is necessary is order to prevent the compressor from turning on immediately after it was turned off. In fact, the internal high pressure would not let the compressor to spin again (stall rotor condition).

The dead-time function also helps to avoid spurious compressor turn on and off, therefore saving in power consumption too.

3.3 Compressor start-up sequence

The evaluation board can drive both the RUN winding and the START winding of a small-size or mid-size compressor, replacing therefore the positive temperature coefficient (PTC) thermistor in the START winding.

When the system turns the compressor on, the following steps are performed:

- both RUN winding and START winding are supplied;
- after a certain time, the START winding is no longer supplied;
- RUN winding continues to be supplied as long as the compressor stays on.

The START winding is supplied for 500ms, and then turned off. This time is strictly dependent on the type of compressor and can be adjusted by modifying the software (see *Section 5.2: START winding duration*).

3.4 Stall rotor detection

The system performs the stall rotor detection immediately after the compressor is turned on.

The monitoring lasts 5 seconds. During this time, the system monitors the temperature of the AC switch driving the RUN winding.

After a normal turning on, meaning when the compressor regularly spins, the current flowing through the RUN winding is the nominal one. Of course at the very beginning, the in-rush current is higher than the nominal one, but after a while the current flowing is the nominal one.

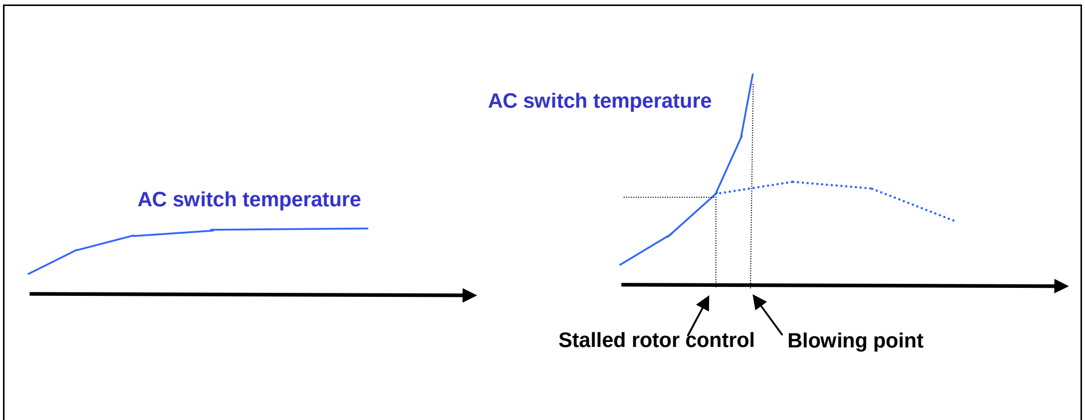
Therefore the increase of the AC switch temperature is smooth.

Attempting to turn on the compressor while the rotor is stalled will result in a higher current flowing through the RUN winding. Therefore the temperature of the AC switch will increase faster.

By reading the trend of the temperature, the system is able to determine if the compressor rotor is stalled or not. In stall rotor condition, the compressor is immediately turned off and the dead-time is set.

Moreover, the compressor is not turned on when the AC switch temperature goes over 85 °C or goes below 0°C. Dead-time is set as well.

Figure 4. Temperature behavior in normal condition and in stall rotor condition

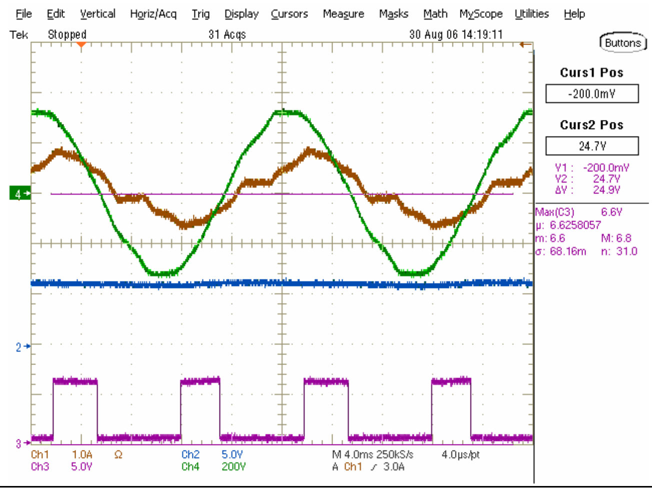


By reading the trend of the temperature, the compressor can be turned off faster than any mechanical device, saving in power consumption. Moreover, the system prevents the AC switch temperature from reaching the blowing point.

4 Scope waveforms

The following waveforms have been taken while testing the evaluation board in a real environment using a common domestic refrigerator.

Figure 5. Compressor while spinning



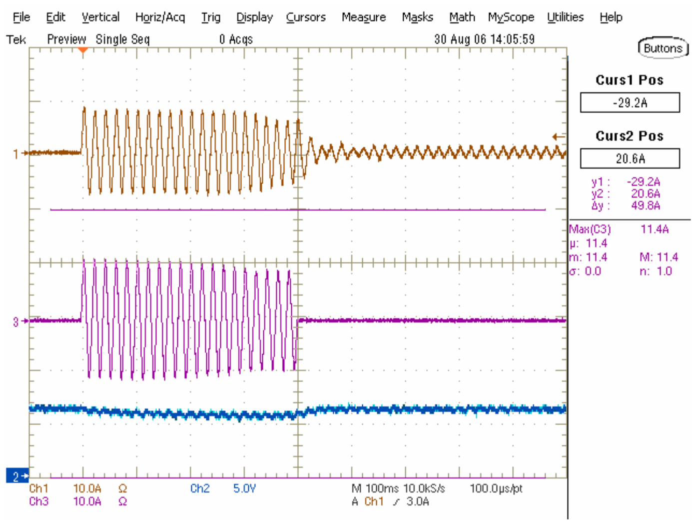
The mains voltage appears in green, while the brown waveform is the current flowing through the RUN winding while the compressor is spinning.

The blue waveform is the VDD which supplies the MCU and the analog circuitry.

Finally, the purple waveform represents the pulses applied to the AC switch driving the RUN winding.

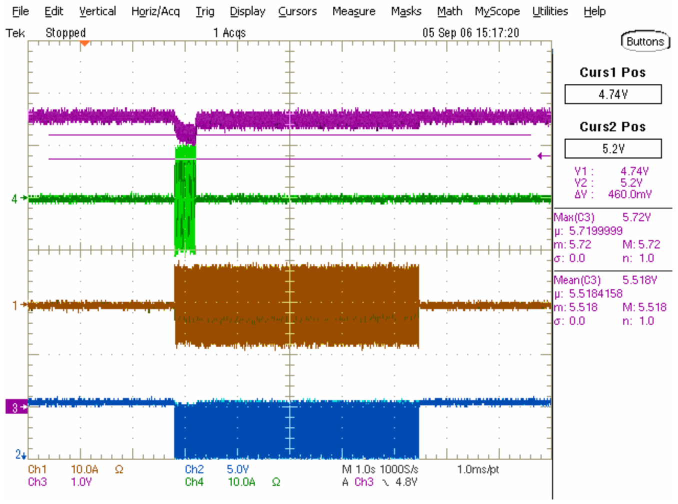
The gate is driven with negative current (or better by sinking the current from the gate pin of the AC switch). The pulse is applied when the mains voltage crosses the zero, and lasts about 6.8 ms (corresponding to an angle of 122.4°). The gate pulse is applied twice per period.

Figure 6. Compressor start-up sequence



When the compressor is turned on, both the RUN winding and the START winding are supplied. RUN winding is represented in brown, START winding in purple. The current flowing through the RUN winding at the very beginning is higher than the nominal one, due to the inrush current. The START winding is supplied for a certain time only (400 ms in the example), then switched off. The START winding will be supplied again on a new compressor start only. The blue waveform is the VDD. A voltage drop appears due to the current needed to drive the AC switches. In any case, the voltage drop is not big enough to affect the correct operation of the evaluation board.

Figure 7. Stall rotor detection



The compressor is turned on while the rotor is stalled. The green waveform is the START winding, the brown waveform the RUN winding and the blue one the gate pulses applied to the AC switches. After a certain time, the pulses are not applied anymore; the compressor is turned off and no voltage is present on the compressor windings. The stall rotor condition is detected by reading the temperature of the AC switch driving the Run winding. In the example the stall rotor has been detected after 4 seconds. Parameters how to detect the stall rotor condition can be modified by the user are described in *Section 5.3: Stall rotor control duration*.

5 Customization: software and hardware modifications

The STEVAL-IHT002V1 evaluation board can be fully adapted to the compressor the user intends to test. Different parameters such as the temperature offset or the dead-time period can be changed. Only a few easy software or hardware modifications are necessary.

5.1 Cabinet temperature offset

There is only one variable for the cabinet temperature offset. Therefore the positive offset is equal to the negative one.

The constant to be modified is named Offset, defined in the `main()` routine, where the defines are declared. The value is expressed in bits.

The range between 0°C and 5°C corresponds to 50 bits. So 1 °C is approximately 10 bits.

Default value: 15 (possible range: 0 to 255)

5.2 START winding duration

When the compressor is turned on, both the RUN winding and the START winding are supplied. After a while, the START winding is no longer supplied.

The time the START winding is supplied can be changed. The constant to be modified is named `START_Period`, defined in the `main()` routine, where the defines are declared. The value is expressed in periods.

A value of 10 means therefore 10 periods, equal to 200 milliseconds (mains frequency 50 Hz).

Default value: 25 (possible range: 0 to 255).

5.3 Stall rotor control duration

The stall rotor control starts as soon as the compressor is turned on and lasts a certain time. This time can be changed. The constant to be modified is named `Window_Period`, defined in the `main()` routine, where the defines are declared. The value is expressed in tens of milliseconds.

A value of 1000 means 10000 milliseconds, or 10 seconds. It is suggested not to exceed a value of 10000.

Default value: 500 (possible range: 0 to 65535, in any case, do not exceed 10000).

5.4 Dead-time duration

The dead-time is set once the compressor is turned off or when a stall rotor condition has been detected. During this time, the compressor cannot be turned on, even if the cabinet temperature rises up over the threshold set by the user.

There is one constant only. Therefore the dead-time set after the compressor turn off and the dead-time set after a stall rotor detection are the same.

The constant to be modified is named `Dead_Time_Period`, defined in the `main()` routine, where the defines are declared. The value is expressed in tens of milliseconds.

A value of 10000 means 100000 milliseconds, or 100 seconds, or 1 minute and 40 seconds.

Default value: 12000 (possible range: 0 to 65535).

5.5 Gate pulse duration

The gate pulses are applied to the AC switches, which in turn drive the RUN winding and the START winding of the compressor. The gate pulse applied to the RUN winding has the same duration of the one applied to the START winding.

The gate pulses are applied when the mains voltage crosses the zero. Therefore, twice per period.

The constant to be modified is named `DURATION`, defined in the `ports()` routine, where the defines are declared. One point is equal to 400 µs.

A value of 10 means 4000 µs, or 4 ms, or an angle of 72°. Since half of a period is 10 ms (mains frequency 50 Hz), care has to be taken while changing this constant.

Default value: 17 (possible range: 0 to 255, in any case do not exceed 25).

5.6 Disabling the stall rotor detection

Basically, the stall rotor detection reduces the power consumption when attempting to turn on a stalled compressor, also keeping the AC switch from getting damaged.

In any case, when testing a small compressor (meaning 1 A nominal current and 5A when in stall condition), the stall rotor detection can be disabled without damaging the AC switch.

No software modification is required. Simply unsolder the R13 temperature sensor and replace it with a 100 KΩ 5% ¼ W resistor.

5.7 Different START winding management

The evaluation board drives directly the START winding avoiding the use of the PTC.

If the PTC cannot be removed from the original circuitry, the AC switch will simply switch the PTC off after the compressor is spinning.

The PTC can drive the START winding without using the AC switch too. In this case, the evaluation board will drive the RUN winding only. No hardware or software modifications are required.

Appendix A Bill of materials

Table 1. Bill of materials

Item	Quantity	Reference	Part	Supplier
1	1	C1	1µF 275VAC X2	
2	1	C2	1000 µF 16 V	
3	1	C3	100 nF ceramic	
4	1	C4	10 nF ceramic	
5	1	C5	1 nF ceramic	
6	1	C6	47 nF 275VAC X2	
7	1	DZ1	5.1 V Zener 1.3 W	
8	2	D1, D2	1N4007	
9	2	J1, J3	CON3	
10	1	J2	CON10A	
11	1	L1	6.8 µH 20% 2.8 A	
12	1	P1	50 KΩ potentiometer	
13	1	Q1	BC337	
14	2	R1, R10(1)	47 Ω 2 W flame proof	
15	2	R2, R4	12 KΩ 1% ½ W metal oxide	
16	1	R3	M2020/5K/A206 NTC	EPCOS
17	3	R5, R6, R7	10 KΩ 5% ¼ W carbon	
18	1	R14	10 KΩ 1% ½ W metal oxide	
19	2	R8, R9	300 Ω 1% ½ W metal oxide	
20	1	R11	560 KΩ 5% ¼ W carbon	
21	1	R12	100 KΩ 1% ½ W metal oxide	
22	1	R13	100 KΩ NTC 2381 633 5.104	VISHAY
23	2	TR1, TR2	ACST67S TO-220	ST
24	1	U1	ST7FLITEU5Y0B6	ST

1. Used during internal test only (short circuited during normal operation)

6 Revision history

Table 2. Revision history

Date	Revision	Changes
14-Feb-2007	1	Initial release.