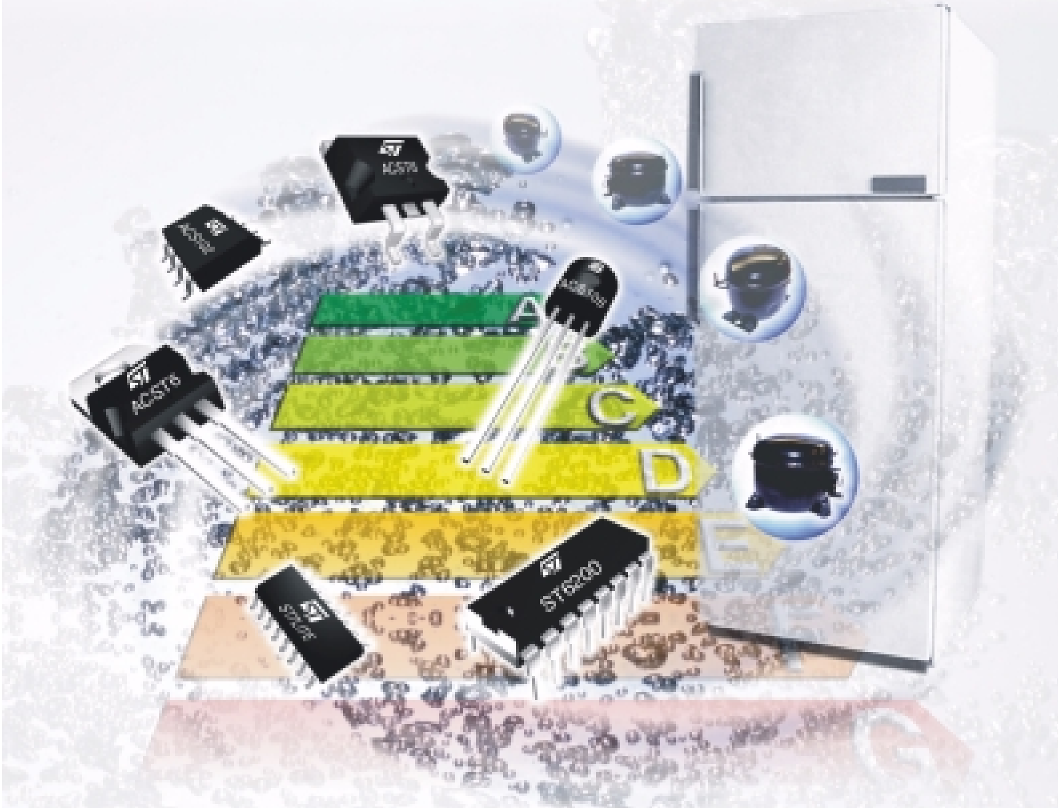
REFRIGERATOR

CONTROL EVALUATION BOARD



User Manual

July 2001

DOC-THERMOSTAT Evaluation Board

REFRIGERATOR CONTROL EVALUATION BOARD

USER MANUAL

1 INTRODUCTION

1.1 TARGET APPLICATION

The THERM01EVAL board is designed to be a complete MCU-controlled thermostat application when used with a M2020 12k NTC thermal sensor, from EPCOS (supplied with the kit). This thermostat can be used to control a single-phase induction motor, and works with a 220-240 V RMS 50 Hz mains voltage. The board can operate in an ambient temperature range of 0 to 60 °C. The exact maximum temperature will depend on the power of the loads (see Section 3.1).

This type of motor, used to drive a compressor, usually has an auxiliary winding that only works during the first 0.5 s of operation, in order to apply a higher torque at start-up. Traditionally, a PTC resistor is used to switch-off this winding after start-up. The THERM01EVAL board allows this PTC to be switched-off, after motor turn-on, or to be completely removed, in order to reduce the power consumption caused by the PTC heating up. In fact, the two windings can be controlled by two triacs. However, only one triac can be used to drive the compressor if the PTC is to be left working.

Warning: The MCU is directly linked to the mains voltage. No insulation is ensured between the accessible parts and the high voltage. The THERM01EVAL board must be used with care and only by persons qualified for working with electricity at mains voltage levels.

This document gives all the information needed to make the board work (how to connect it, how it works). To have specific information at design level, in order to modify certain parameters, please refer to the two following Application Notes:

- AN1353: ST6200C Software Description for Cooling Thermostat Applications
- AN1354: Single-phase Induction Motor Drive for Refrigerator Compressor Applications

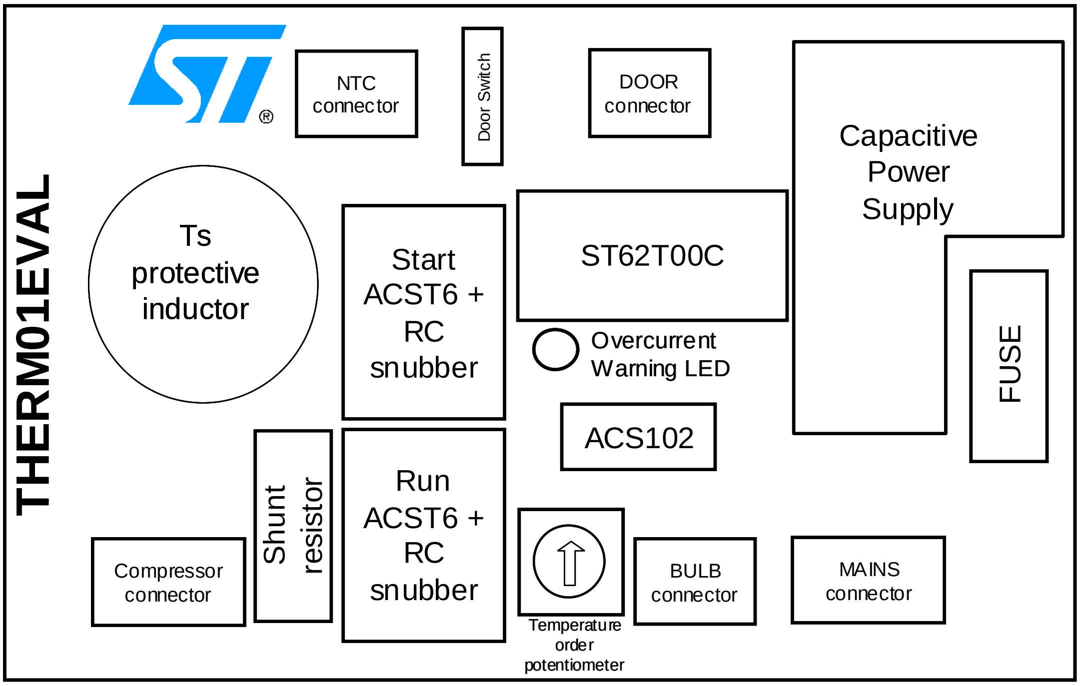
Rev. 1.1

Table of Contents

1.2 BLOCK DIAGRAM

Figure 1 shows the block diagram of the THERM01EVAL board.

Figure 1. Thermostat evaluation board block diagram



1.3 LIST OF CONTENTS

The following items are supplied in this package:

- A thermostat board (ref.: THERM01EVAL) (including the ST62T00C MCU programmed with the software described in Application Note AN1353)
- A M2020 12 k EPCOS NTC
- A CD-ROM, including ST and EPCOS product presentations and datasheets, and the SOFTWARE programmed in the ST62T00C microcontroller (demov1r3.st6 file)
- A User Manual (this document).

1.4 GETTING STARTED

To operate the THERM01EVAL board correctly, use the following procedure:

1. Check that the programmed pulses for generating the current for the ACS / ACST gates, are compatible with the motor to be controlled (see Section 3.2).

   This means that the START and RUN winding currents must be lower than the ACST6 holding and latching currents (25 and 50 mA respectively) in a 2.8 ms window, starting

0.45 ms after the Zero Crossing point of the mains voltage (see Figure 2).

To change the pulse timing, refer to Application Note AN1353.

Two motor control parameters should also be checked, i.e. the length of the START winding conduction and the delay after which the overcurrent subroutine operates (cf. AN1353 & AN1354).

These two times can be lengthened if they are too short and do not meet the requirements of the motor you are using.

2. Check that the power of the motor and the bulb to be controlled is not too high (see Section 3.1):

   –Bulb power < 25 W

   –Compressor power < 150 W

3. Check that the programmed threshold level (4 °C by default) of the temperature Hysteresis control is compatible with the temperature variation of the evaporator to be controlled.

   If not, you can change this threshold by modifying the "THRES" variable in the software (see Appendix 1 and AN1353).

4. If you have changed the software in steps 1 and 3 above, don't forget to program the Option Byte as follows in your MCU:

   D1 = 1 (Hardware Watchdog activation)

   D6 = 1 (RC network oscillator selection)

   D8 = 1 (LVD reset activation).

   Unused memory should also be filled as described in Section 2.3.2.

5. Connect the board as follows (see. Figure 1):

   a. Connect the bulb to the "BULB" connector

   b. Connect the NTC to the "NTC" connector, and put the sensor terminal on the evaporator in the fridge or freezer to be controlled.

   c. Connect the switch of the appliance door (if it is not connected to any electrical potential) to the "DOOR" connector. Alternatively, instead of using an external switch you can use the "DOORSWITCH" on the board to switch the bulb ON or OFF.

   d. Connect the Compressor to the "MOTOR" connector. Take care to connect the "START", "RUN" and "LINE" properly to the right terminals on the motor (see appendix 2 and AN1354).

   e. ***Warning***: all the following actions have to be done by a electrically-skilled technician, because the board has to be plugged to the MAINS voltage, and because NO INSULATION is implemented between the MAINS voltage and the accessible conductive parts.

When all safety precautions have been taken, the mains voltage can be plugged into the "MAINS" connector.

Note: The Protective Earth (PE) pin is not connected to any part of the board (but just to a floating pad, in case it is needed).

6. Use an insulated screw-driver to switch the motor ON by turning the "TEMP ORDER" potentiometer towards the "COLD" indication. Note that the temperature order is refreshed every 5 seconds. The potentiometer should so not be turned too fast in order to let the microprocessor take the new order into account . The potentiometer should not be turned completely to the COLD position in order to avoid the fridge cooling excessively and the motor operating too long. It is recommended to check the evaporator temperature with a second temperature sensor.

   Check that the motor is being controlled properly, for example by using an oscilloscope to display the START and RUN winding currents (their waveforms should be sinusoidal).

7. If there are problems:
   – If the overcurrent LED is switched on several times at each motor start-up, this means that the START winding conduction and/or the overcurrent subroutine start delay are too short and must be changed.
   – Check that the board is correctly powered on by changing the "DOORSWITCH" position. The bulb should go ON and OFF.
   – Check if the FUSE is blown (disconnect the mains voltage before unplugging the fuse).
   – Reset the MCU by unplugging the mains voltage and waiting for V_{DD} to drop below 0.7 V. Then, apply the mains voltage and try again to see if the board operates.

2 FUNCTIONAL DESCRIPTION

2.1 PERFORMANCE

The THERM01EVAL board is designed to meet the following requirements:

– **Low cost**: the complete board material, plus the sensor, can reach a cost close to electro-mechanical solutions, for high volume ranges (1 Million units per year); a lower target can also be reached if all the options are removed (only one triac to drive the compressor, no LED, no ACS to drive the bulb, smaller PCB area).

– **Electromagnetic Compatibility**: the board is able to withstand bursts of more than 3 kV during IEC61000-4-4 standard tests without any operational problems (and up to 4.5 kV without any damage). Surge tests have also been performed (IEC61000-4-5 standard): 2 kV bursts can be applied without any damage to the semiconductors.

– **Safety standards** have also been taken into account. Hence, a 2 mm creepage is ensured between all high voltage parts and low voltage parts (to achieve the functional insulation level). The thermal sensor is a class II sensor.

2.2 MAIN FEATURES

2.2.1 Temperature control

The thermal sensor is an NTC resistor from EPCOS (M2020 12 k 2%). It should be placed on the evaporator of the fridge or the freezer. The controlled temperature range should be between –30 to 0 °C. The range can be modified by changing the value of the resistor placed in series with the NTC (see Appendix 1).

Its resistance value decreases, following an exponential variation, when the temperature increases. Then, to get back the temperature data, the MCU could use a numerical table. In the THERM01EVAL board, a simple resistor has been added in series with the NTC in order to linearize its thermal response (refer to Appendix 1). Two advantages come from this choice:

– Memory area savings

– Easy way to measure the temperature (refer to Appendix 1).

Temperature regulation is performed by hysteresis control. The linear temperature information is then simply compared to the voltage given by the "TEMP. ORDER" potentiometer. The hysteresis threshold can be changed by software (see Application Note AN1353).

2.2.2 Motor control

The motor is driven by two ACST6-7ST devices:

– Tr: "RUN" Switch, ON when the temperature is too high, OFF when the temperature is low enough or when an overcurrent has been detected.

– Ts: "START" Switch, only ON for the first 0.5 seconds of each start-up, i.e. each time Tr is switched ON. Ts can be not used (refer to Appendix 2). In this case, only Tr controls the motor.

Both ACSTs are turned on whenever a Zero Voltage Crossing (ZVC) event occurs. In order to reduce the power supply rating, the ACSTs are triggered by a pulsed gate current.

2.2.3 Light bulb

A light bulb is driven by the ACS102-5T1 called "Tb". This device is ON or OFF when the "DOORSWITCH" is opened or closed respectively. Instead of using the switch on the board (S1), you can connect an external switch via the "DOOR" connector.

The ACS is turned on whenever a ZVC event occurs. In order to reduce the power supply rating, the ACS is triggered by a pulsed gate current.

2.3 HARDWARE DESCRIPTION

2.3.1 ACS & ACST devices

The THERM01EVAL board has an on-board ACS102-5T1 plus two ACST6-7ST devices. The datasheet of these devices can be found on the ST website (go to http://www.st.com/stonline/discretes/index.shtml and click on "Thyristors").

Table 1 sums up the main differences between ACS & ACST and traditional triacs.

Table 1. Differences between ACS/ACST and TRIACS

Parameter (min)	TRIAC 1 A / 5 mA sensitivity	ACS102 0.2 A / 5 mA sensitivity	TRIAC 6 A / 10 mA sensitivity	ACST6 6 A / 10 mA sensitivity
V_{BR}	Destruction if voltage > V_{BR}	Clamped at 600 V	Destruction if voltage > V_{BR}	Clamped at 900 V
(dV/dt)	20 V/µs	300 V/µs	100 V/µs	200 V/µs
(dI/dt) at turn-on	10 A/µs	100 A/µs	20 A/µs	100 A/µs

2.3.2 ST6200C Microcontroller

The MCU used in the THERM01EVAL board is the ST62T00C. It is a basic ST6 microcontroller that embeds a large number of features at minimum cost.

The peripheral hardware requirements have been reduced to the minimum:

– No quartz crystal or external resonator is used. In fact, the internal RC-oscillator of the ST62T00C is used to generate the clock.

– No external RESET circuit is required, as the ST62T00C has an internal circuit.

When programming the MCU EPROM, you have to set the following three options:

– D1: Hardware Watchdog Activation (as it is not done by software)

– D6: RC network oscillator selection

– D8: Low Voltage Detection option (in order to start a RESET subroutine when the board is plugged to the mains).

– The ST62T00C program memory size is 1024 bytes. The size of the implemented software is 974 bytes. In order to test longer programs, the ST62X01C (with 2K bytes of program memory) can be installed instead of the ST62X00C in the DIL16 socket.

– Unused memory space must be filled with a NOP instruction (04H). The three last bytes must be filled with: "0D D8 01" (hex.), in order to generate a RESET if the PC points to unused locations.

2.3.3 Capacitive power supply

In order to reduce the board price as much as possible, a capacitive power supply is used on the board instead of a transformer-based supply. This supply can only source an average current lower than 10 mA. For higher current the C1 capacitor (see Appendix 3) can be replaced by one with a higher value.

One particularity of this power supply is to be a "negative" one. Indeed, the V_{DD} terminal is connected to Neutral. This means that the V_{SS} voltage is 5V below Neutral. This type of connection is mandatory when the MCU drives ACS devices directly. In fact, ACSs can only be triggered by a negative current (i.e. sourced from the gate).

3 USING THE EVALUATION BOARD

3.1 CURRENT LOADS

Initially, there is no heat sink mounted on the TO220-AB of the ACST6-7ST devices. In this case, Figure 2-2 of their datasheet shows that the maximum permanent allowed current is 1.5 A RMS, for an ambient temperature of under 40 °C. If the RUN triac has to sink a higher current, or work at a higher temperature, a heat sink can be added.

As the START triac works for a short time only, no heat sink is normally required. For example, reliability tests have shown that ACST6-7ST can withstand 11 A RMS for half a second, for more than 300 k cycles (refer also to AN1354).

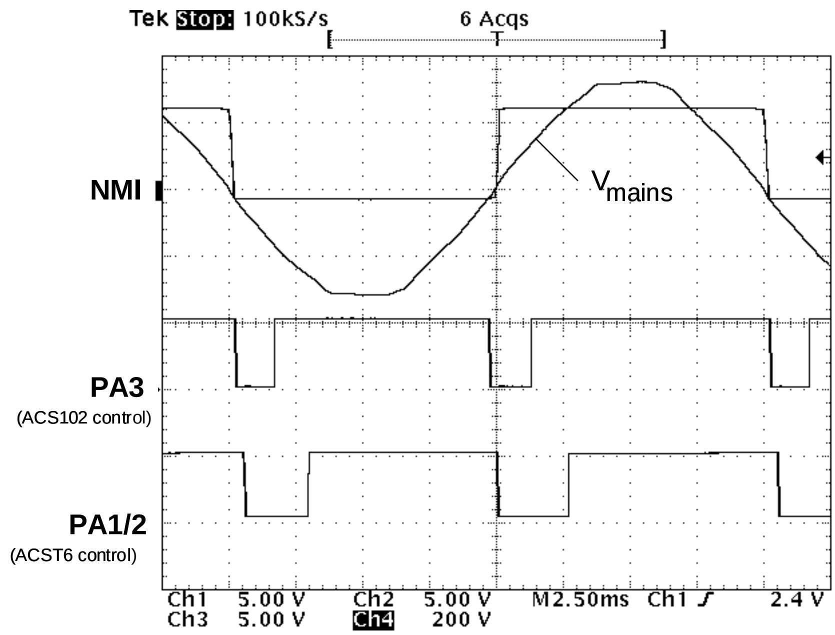
The ACS102-5T1, which has an SO8 package, can withstand a 0.2 A RMS permanent current in an ambient temperature of up 90 °C. And this is reached with a very low copper area on the COM terminals (approx. 2 mm^2). Based on this information, we can assume that the ACS102-5T1 can drive the common types of light bulb found in fridges or freezers without any problem. In fact, a 25 W bulb will always sink a current lower than 150 mA.

3.2 CONTROL PULSES

Figure 2 shows how the gate current pulses are defined, for the two loads. The choice of these durations is explained in Application Note AN1354.

If the loads used sink a different current, or with a different power factor, there is the risk of missing firing the triac for one or several half cycles. So you should check that the programmed angles are compatible with the loads connected to the board. If not, refer to AN1353 and AN1354 to change these values.

Figure 2. Gate current pulses



3.3 OVERCURRENT DETECTION

The overcurrent detection is active one second after motor start-up. This delay is needed to differentiate a start-up transient current from a real overcurrent caused by a stalled rotor. After an overcurrent detection, the D1 LED is switched on for 10 seconds.

The overcurrent is detected by measuring the RUN current through the 0.05 Ω shunt resistor (R10 in Appendix 3). Each measurement is performed approximately 7 ms after ZCS, when the V_{LN} voltage is negative. If the current peaks at a different time, this delay can be changed by software (see AN1353).

The overcurrent detection is based on an average of four measurements, in order to reduce measurement noise. The motor will then be stopped at least 80 ms after an overcurrent has appeared.

3.4 MEASUREMENT POINTS

Figures 3 and 4 show where the V_{DD} and V_{SS} planes are placed and also the measurement points that can be used.

Figure 3. Top layer view (from component side)

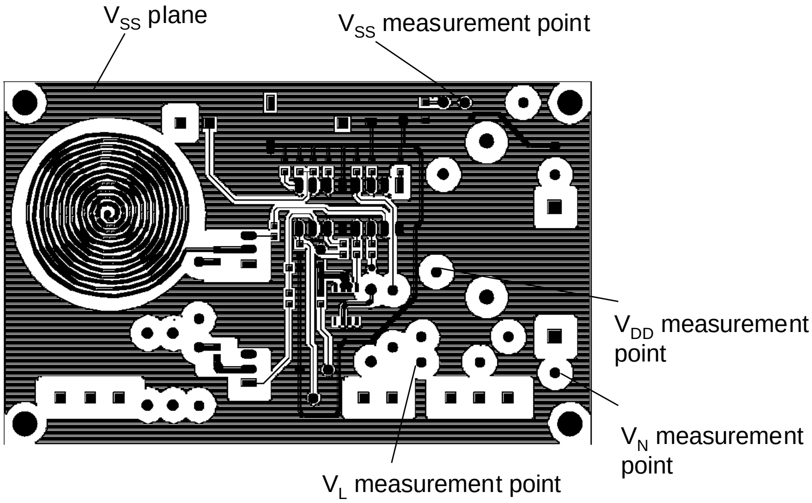
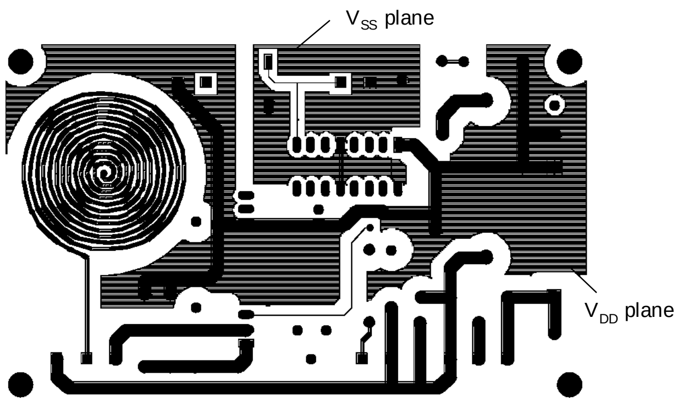


Figure 4. Bottom layer view (from component side)



4 CONCLUSION

The guidelines provided in this document have been given to help you use the THERM01EVAL board properly. The board is designed for conventional monophase induction motors in fridge and freezer applications (especially for 1/5 horse-power compressors).

The main thing to check is that your loads, especially the compressor load, correspond to programmed data (pulse, delay for detecting the overcurrent, etc.). Then, after some adjustment to your software (and using the EPROM version of the ST6200 MCU), you can perform tests with a freezing system. One interesting measurement to carry out would be to see how much the temperature regulation is improved and how much the power consumption is reduced by removing the PTC and decreasing the motor operation duty cycle.

Information on these two last points is also given in Application Note AN1354.

Appendix 1 – Thermal Sensor Linearization

A NTC thermistor is a resistor whose value decreases when its temperature increases. The thermal law is exponential, as presented in Equation 1.

Equation 1: $$Rc(T) = Ro \cdot \exp\left[B \cdot \left(\frac{1}{T} - \frac{1}{To}\right)\right]$$

To build a simple voltage sensor, it is better to linearize the temperature response using a constant resistor (R1) added in series with the NTC (Rc). This creates a voltage divider. The voltage across R1 will follow the supply voltage (V_{DD}) according to the relationship below:

Equation 2: $$Vs = \frac{Rc(T)}{Rc(T) + R1} \cdot V_{DD}$$

To make the relationship of Equation 2 to vary linearly, it's enough to ensure that the second order derivative will be zero. Equation 3 gives the R1 value to ensure this condition.

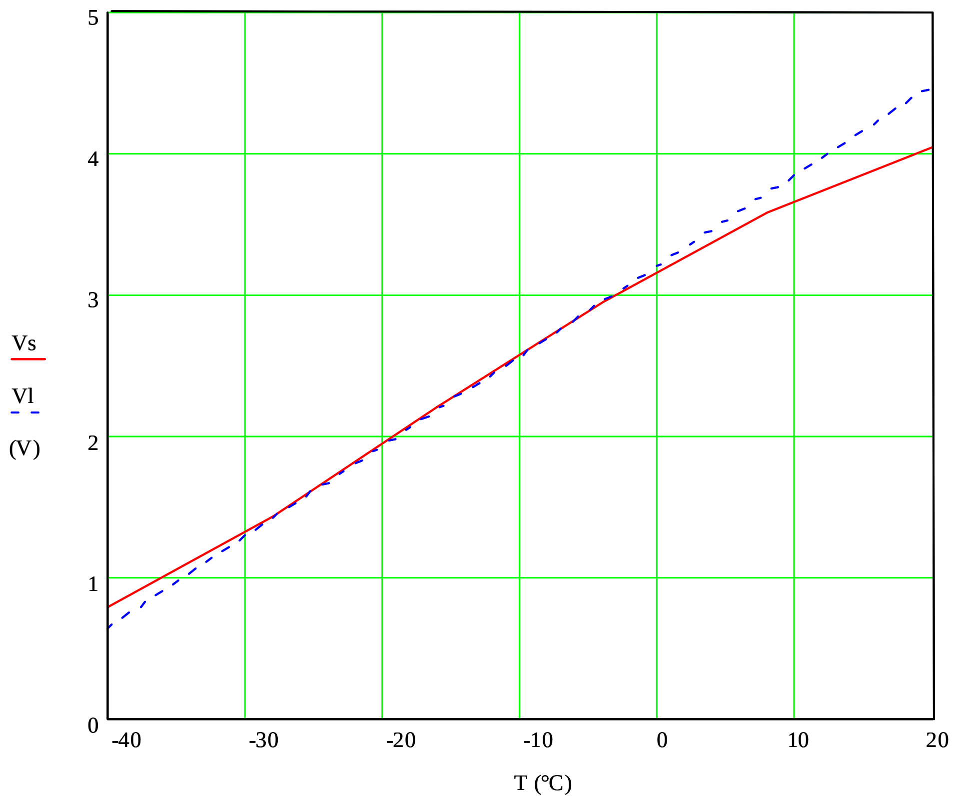
Equation 3: $$R1 = \frac{2 \cdot \left(\frac{d}{dT} Rc(T)\right)^2}{\frac{d^2}{dT^2} Rc(T)} - Rc(T)$$

To linearize the voltage response of a M2020 12 k from EPCOS, between –30 and –5 °C, a 62 kΩ resistor should be chosen for R1. In this temperature range, Vs varies according to Equation 4, for a 5 V supply:

Equation 4: Vs(T) = (T+50.1)/15.625

Figure 5 gives the variation of Vs and the linear value given by Equation 4 (refer to VI), versus the temperature sensed by the CTN.

Figure 5. Linear voltage response of the NTC resistor (for a 5 V supply)

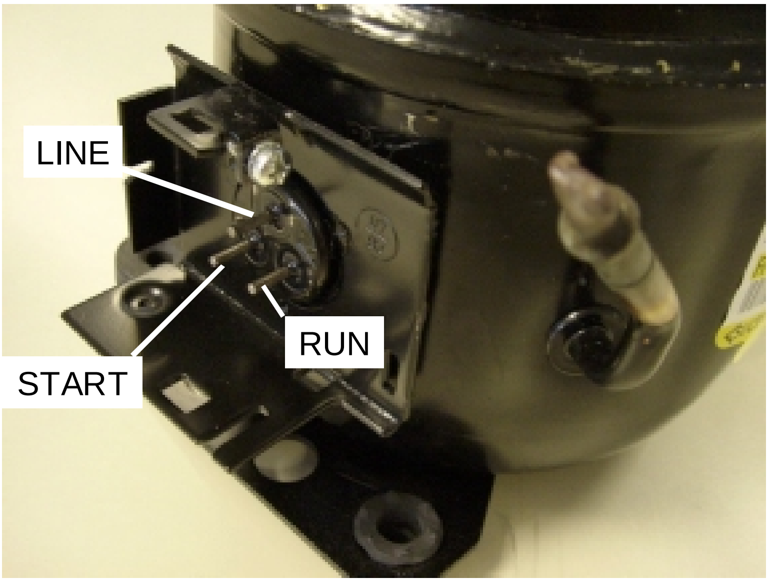


Appendix 2 – Wiring connections

For the NTC, you only have to cut its connector (standard connector for M2020 sensors) and to screw the wires in the "NTC" connector. It can be connected in both ways as it is just a resistor. For the motor, things are more complex.

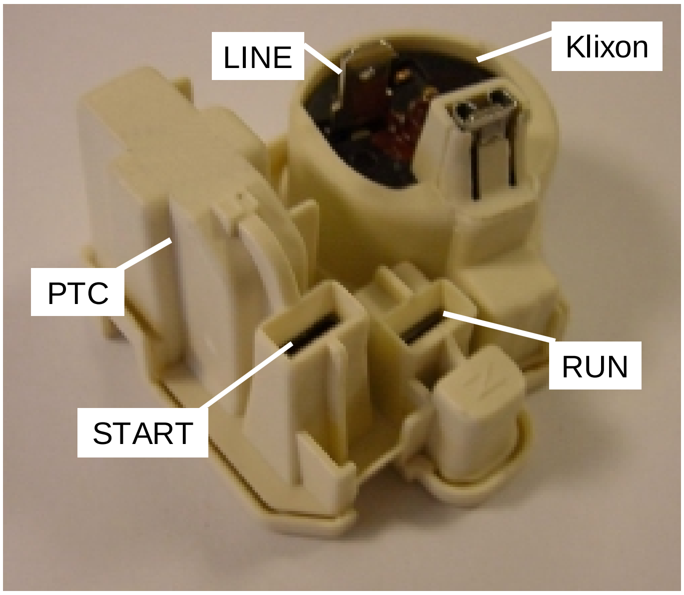
Figure 6 shows how the wires are generally accessible in compressor motors. These three pins may be connected directly to the THERM01EVAL connector.

Figure 6. Compressor connections



Often, compressor motors are used with a starter that includes a thermal protection against excessively high currents or overheating. This protection is called a "klixon", and is shown in Figure 7. When you are using the THERM01EVAL board its better to keep this starter, in order to let the klixon work. In this case, the motor connections can still be accessible, this depends on the starter model, as shown in Figure 7.

Figure 7. Compressor starter

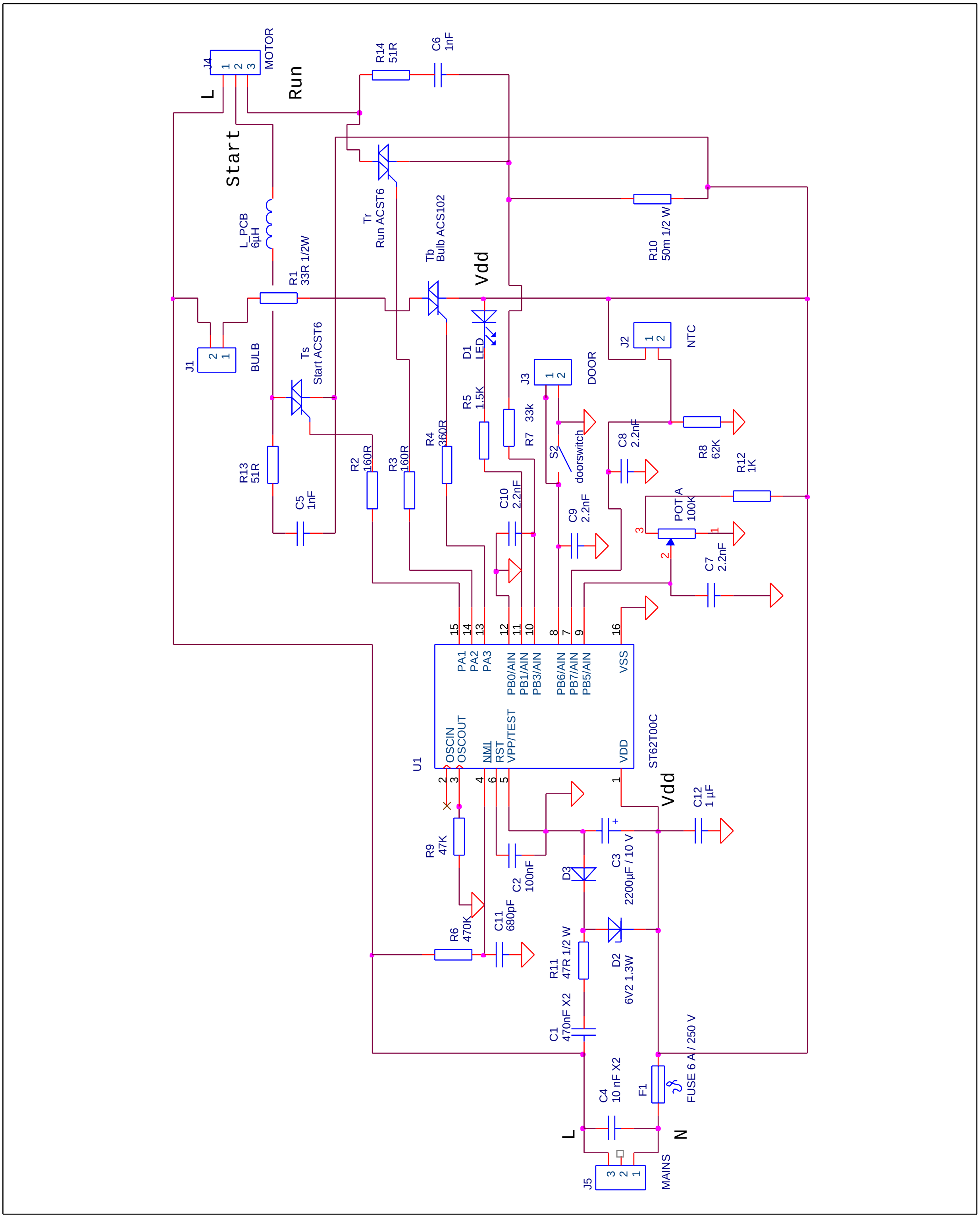


If you want to keep the PTC acting inside the starter, then the RUN pin must not be connected to the "RUN" connector of the THERM01EVAL board.

If you remove the PTC, it is better to put an insulation layer in its place, in order to avoid spurious short-circuits between the RUN and START windings.

Appendix 3 – THERM01EVAL Schematics

Figure 8. THERM01EVAL schematic



Appendix 4 – Bill of Materials

N°	DESCRIPTION
R1	Resistor ½ W Through_Hole 33 Ωhm 5%
R2 / R3	Resistor 1/8 W SMD 160 Ωhm 5% 0805
R4	Resistor 1/8 W SMD 360 Ωhm 5% 0805
R5	Resistor 1/8 W SMD 1.5 KΩhm 5% 0805
R6	Resistor 1/4 W Through_Hole 470 KΩhm 5%
R7	Resistor 1/8 W SMD 33 KΩhm 5% 0805
R8	Resistor 1/8 W SMD 62 kΩhm 5% 0805
R9	Resistor 1/8 W SMD 47 KΩhm 5% 0805
R10	Resistor ½ W Through_Hole 0.05 Ωhm 5%
R11	Resistor ½ W Through_Hole 47 Ωhm 5%
R12	Resistor 1/8 W SMD 1 KΩhm 5% 0805
R13	Resistor 1/8 W SMD 51 Ωhm 5% 0805
R14	Resistor 1/8 W SMD 51 Ωhm 5% 0805
C1	Cond. 250 V X2 470 nF 20% (Ref. EPCOS: B81130C1474M)
C2	Cond. SMD 6V3 100 nF
C3	Cond. Radial 10 V 2200 µF 20% (Ref. EPCOS: B41821A3228-M)
C4	Cond. 250 V X2 10 nF 20% (Ref. EPCOS: B81130C1103M)
C5 / C6	Cond. 250 VAC 1 nF 20%
C7 / C8 / C9 / C10	Cond. SMD 6V3 2.2 nF
C11	Cond. SMD 6V3 680 pF
C12	Cond. SMD 10V 1 µF 1206
F1	Fuse 5x20 mm 6 A 250 V
S1	Switch
POT	Potentiometer Single-Turn 100 K
D1	Red LED / diameter: 5 mm / 5 V / 2 mA
D2	Zener 6V2 1.3 W SMD
D3	Rectifier 1N4148 SMD
TS	ASCT6-7ST (TO220)
TR	ASCT6-7ST (TO220)
TB	ASC102-5T1 (SO8)
U1	Microcontroller ST62T00C (DIP16 – Through Hole)

Appendix 5 – Procedure for IEC61000-4-4 Voltage Burst Test

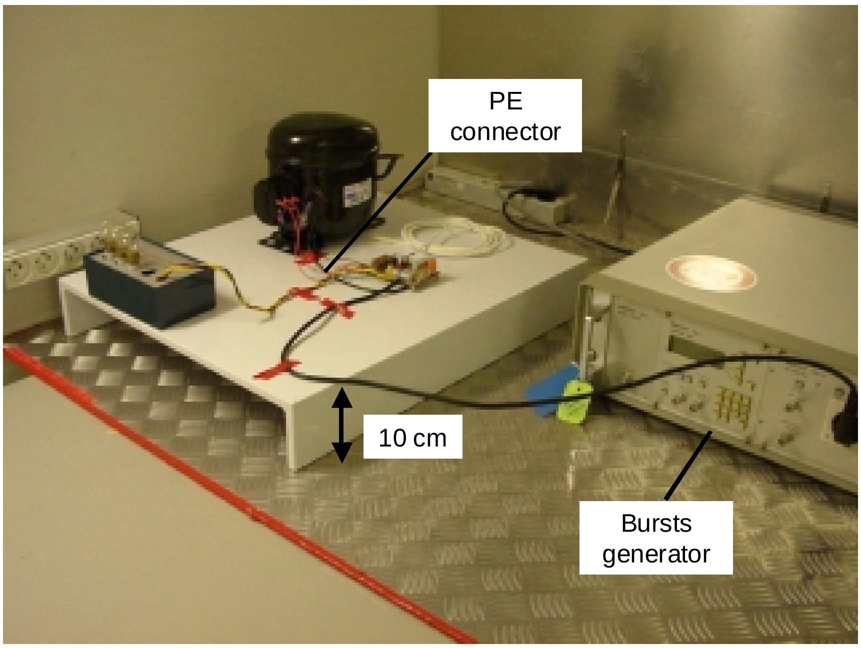
Fast transient voltage tests have been performed, according to the EN61000-4-4 standard, on THERM01EVAL boards connected to a compressor and three 25 W light bulbs. One of these bulbs is the fridge internal lamp. The two other ones are placed in parallel with the motor windings. This enables any spurious device firing to be easily detected. In fact, as soon as one switch conducts a few milliseconds, the bulb will emit some light.

The test layout, shown on Figure 9, have been done in order to implement very high stress tests, but still in accordance with the EN61000-4-4 standard. The main characteristics of the setup are:

- THERM01EVAL Board, loads and mains wires are placed 10 cm above the ground reference.
- The mains wire is shorter than 1 m.
- The compressor protective earth is linked to the PE of the board through a 30 cm cable.

Each operating cycle has been tested (all loads OFF, lamp ON, Motor ON, lamp + motor ON). The burst withstanding level is in the range of 3 to more than 4.5 kV (maximum generator capability), depending on the coupling mode (to L, N, PE, etc.).

Figure 9. EN61000-4-4 test layout



Notes: