

Getting started with the Cold Thermostat Kit based on AC switches and ST7LITE MCU

Introduction

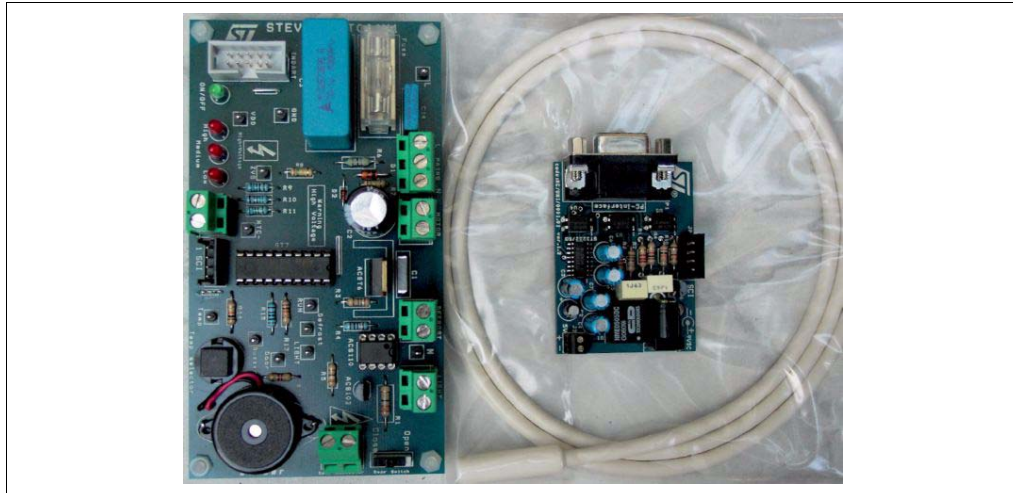
The STEVAL-IHT001V1 Thermostat Kit (figure below) is designed to control a refrigerator or a freezer. This thermostat kit enables the control of a single-phase induction motor, a light bulb and a defrost resistor (or a fan) working on 230 V_{RMS} 50/60 Hz mains voltage.

The board can operate in an ambient temperature range of 0 to 40 °C. The exact maximum temperature depends on the power of the loads ([Section 3.1: Load power](#)).

The kit includes a Graphic User Interface (GUI) for sending commands to the ST7LITE39F2 Microcontroller or to access MCU information via the Serial Communication Interface (SCI). This enables users to easily change MCU software parameters and acquire measurements during appliance testing.

This document provides all the information needed to make the board work (how to connect it, how it works). For specific information about modifying MCU parameters, please refer to the “Help” section of the GUI software.

STEVAL-IHT001V1 Thermostat Kit



The main goals of this tool are:

- Evaluate full ST solution (microcontroller + AC switch) for cold thermostat applications
- Measure and save the appliance main parameters during operation (load status, compressor operation duty cycle and running period, evaporator temperature)
- Check and analyze efficiency gains by reducing the Hysteresis threshold or adapting the defrost resistor management
- Check the board immunity against fast transient voltages (without GUI connection).

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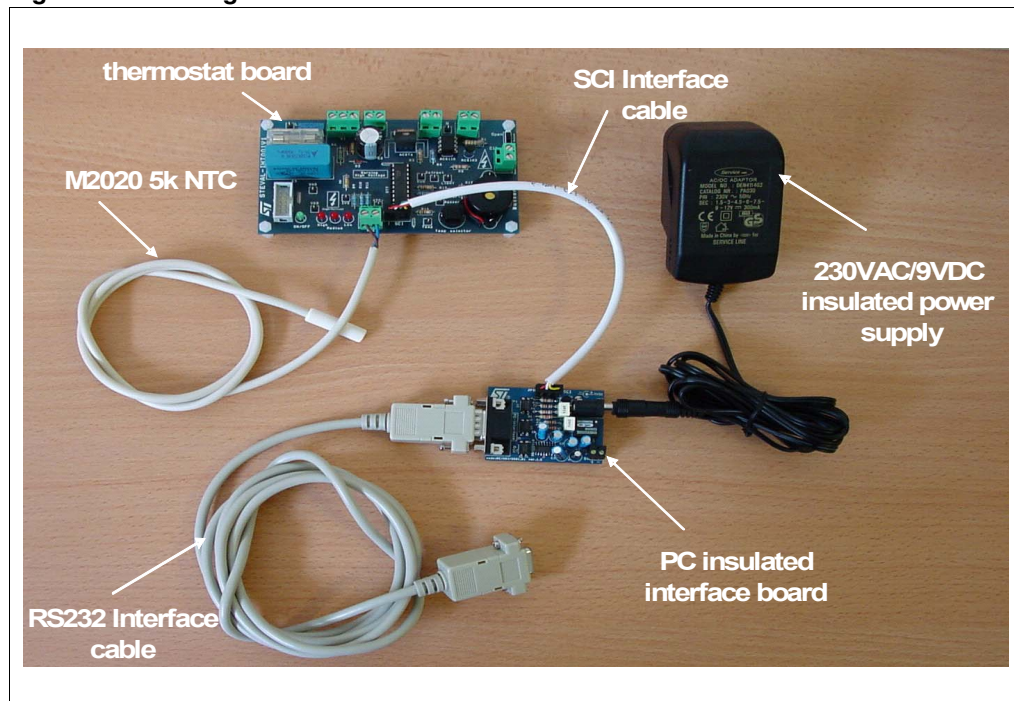
1 Kit introduction

1.1 Package contents

This package (*Figure 1*) includes the following items:

- A thermostat board (ref.: STEVAL-IHT001V1)
- A M2020 5k NTC thermistor from EPCOS (ref.: M2020/5k/A17)
- A CD-ROM, including products presentations and data-sheets, user manual, Application Notes and the GUI software.
- “Getting Started” User Manual (this document)
- The insulated PC interface board (ref.: MC/UNI/0001.01 PC-INTERFACE ver.1.1)
- A 230VAC/9VDC insulated power supply for the SCI interface board
- One RS-232 Interface cable
- One SCI Interface cable

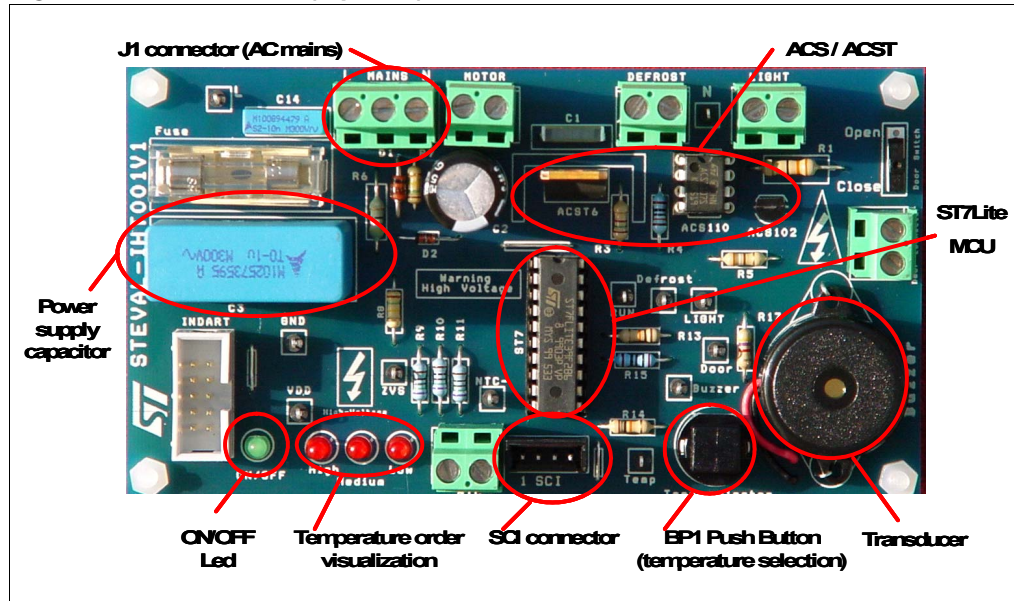
Figure 1. Package contents



1.2 Board presentation

Figure 2 shows the STEVAL-IHT001V1 board and the main components used on this board.

Figure 2. Power board (top view)



This board mainly embeds (refer to [Appendix C](#) for the complete schematic):

- A capacitor power supply. The average output current of the capacitor power supply is approximately 25 mA with the embedded 1 μ F C3 capacitor (for a 230V-50Hz Line RMS voltage)
- A ST7LITE39F2 MCU
- AC Switches: one ACS102-6TA, one ACS110-7SB2 and one ACST6-7ST to control respectively a light bulb, a defrost resistor or fan, and a compressor
- ON/OFF LED. This LED switches ON when the board is powered
- Temperature order visualization. Three LEDs indicate the temperature order using three different settings: low, medium and high
- BP1 Push Button, to change the temperature order setting
- Transducer (or buzzer) to warn the user if the door is opened for an extended time
- SCI connector, for communication between the board and a computer (using the GUI software)
- An In-Dart connector, to load the firmware in the MCU

Warning: To avoid electrical shock through the computer, if the In-Dart connector is used to connect a computer, the STEVAL-IHT001V1 board must be plugged into an insulated mains plug.

2 Functional description

2.1 Performances

This board meets the following requirements:

- Medium-end appliances: this thermostat board can control the loads traditionally used in medium-end cold appliances (compressor, light, defrost resistor).
- Electromagnetic Compatibility: the board is able to withstand bursts of more than 2.3kV during IEC61000-4-4 standard tests without any operational problems (and up to 4.5kV without any damage). Surge tests have also been performed (IEC61000-4-5 standard): 2 kV bursts can be applied without any damage for the semiconductors.
- Safety standards have also been taken into account. A 2-mm creepage is ensured between all high voltage parts and low voltage parts (to achieve the functional insulation level). The (NTC) thermistor is a class II sensor, and can be put on non-earthed accessible and conductive parts.

2.2 Ensured functions

2.2.1 Temperature control

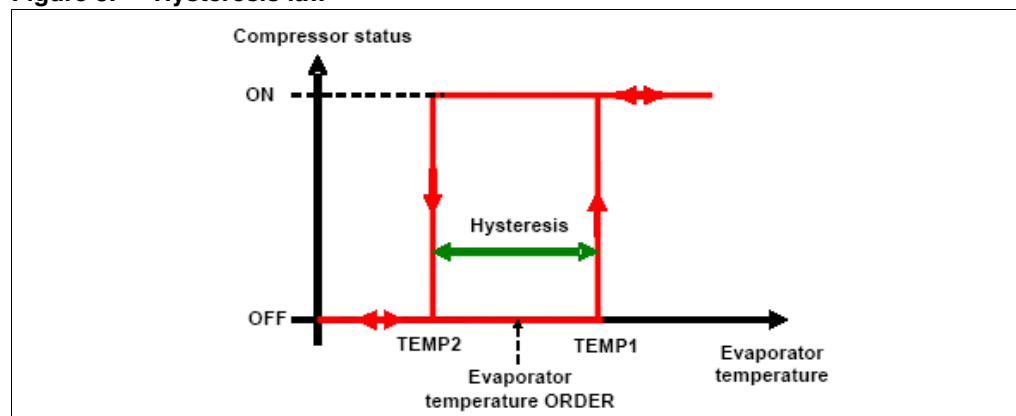
The thermal sensor used is an NTC thermal resistor (thermistor) from EPCOS (M2020 5 k 2%). It should be placed on the evaporator of the fridge or the freezer. The controlled evaporator temperature range should be between -20 and 5 °C. The range can be modified by changing the value of the resistor placed in series with the NTC (refer to [Appendix A](#)).

The NTC 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 STEVAL-IHT001V1 board, a simple resistor has been added in series with the NTC in order to linearize its thermal response (refer to [Appendix A](#)). Two advantages come from this choice:

- Memory area savings
- Easy way to measure the temperature.

Temperature regulation is achieved by Hysteresis control (see [Figure 3](#)).

Figure 3. Hysteresis law



The linear temperature information is then simply compared to the temperature order. TEMP1 is the upper limit of the Hysteresis cycle. It is equal to the temperature order plus a threshold value (Temperature Hysteresis divided by 2). TEMP2 is equal to the same temperature order minus this threshold. The compressor is switched on if the detected temperature is above TEMP1, and switched off when this temperature becomes lower than TEMP2.

The temperature order can be set to low, medium or high levels using the GUI software or using push button PB1 on the board. Moreover, the Hysteresis value can only be changed using the GUI software. For more information, see [Section 3.5.1: Temperature control](#).

2.2.2 Compressor control

An ACST6-7ST AC switch (refer to mark Q1 in [Appendix C](#)) is used to turn on and off the compressor according to the evaporator temperature detected by the NTC thermistor. Note that such compressor motors usually present an auxiliary winding that only works during the first seconds of operation in order to apply a higher torque at start-up. A PTC thermal resistor is used to switch off this winding after start-up. In the STEVAL-IHT001V1 thermostat kit, this PTC is not replaced by a TRIAC as proposed on our previous THERM01EVAL kit (refer to AN1354).

2.2.3 Light bulb and buzzer operation control

A light bulb is driven by the ACS102-6TA AC switch (refer to mark Q3 in [Appendix C](#)). This device is ON or OFF when the “Door” switch (J12) is opened or closed respectively. Instead of using the switch placed on the board (J12), one can connect an external switch using the “Door” connector (J13).

Note that if the fridge door or the “Door switch” is in “open” position more than one minute, the buzzer will ring and the LEDs will flash. The buzzer can be stopped by pressing the “temp selection” button or using the GUI software (refer to the Help menu of the GUI). When the door is open, the temperature order can only be changed using the GUI software.

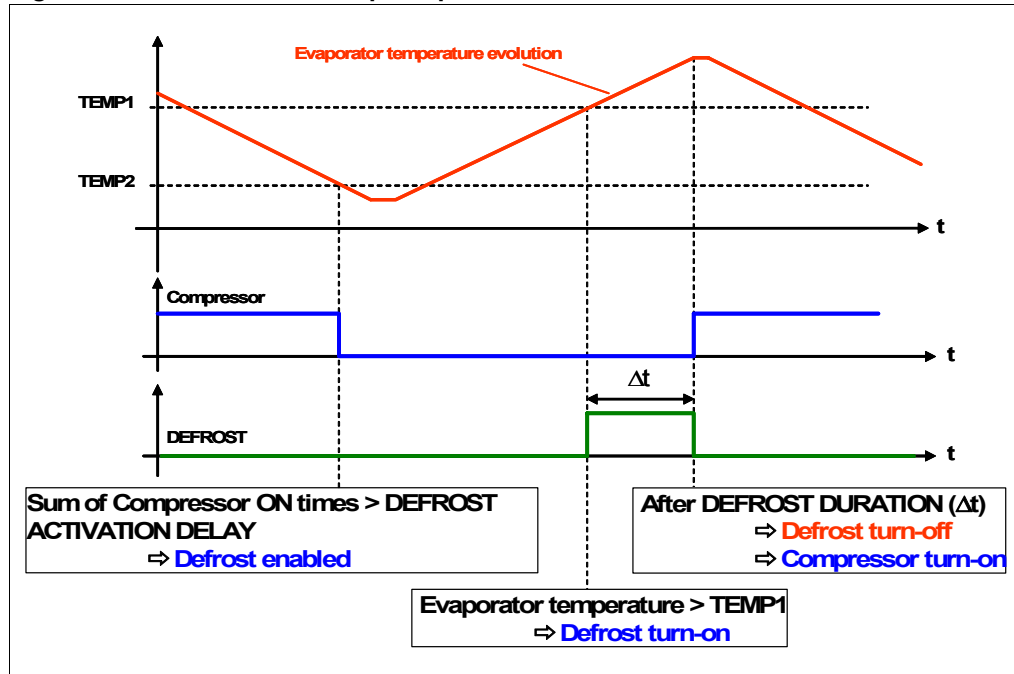
Note that a resistor (R1) has been added in series with ACS102-6TA AC switch (Q3). Indeed, at the end of the lamp lifetime, the filament breaks and the overall filament can be short-circuited by the flashover resulting in a load current that is no longer limited. This current can exceed the $i^2.t$ capability of the ACS and destroy it (refer to AN1172). To avoid destroying the ACS102 switch at each lamp flashover, a power resistor is added in series with the light. This resistor (refer to the [Appendix C](#)) is rated in order to limit the ACS current to its ITSM value (10 A for a 10 ms half sinus conduction). In this case, a 33Ω/2 W resistor is sufficient.

2.2.4 Defrost resistor (or fan) control

The defrost resistor is driven by the ACS110-7SB2 AC switch (refer to mark Q2 in [Appendix C](#)). This device is ON following the “Defrost activation delay” parameter time defined using the GUI software. This time is compared to the sum of Q1 TRIAC ON times. When this sum is higher than the “Defrost activation delay”, Q2 TRIAC is switched ON ([Figure 4](#)).

But the software (MCU) waits for the next compressor conduction cycle before turning on the Defrost. Then, the Defrost is switched on when the evaporator temperature is the higher value. This helps reduce power consumption and improve appliance efficiency. Switch Q2 remains on during the “Defrost duration” parameter defined on the GUI software.

Figure 4. Defrost activation principle



Note: The ACS110-7SB2 switch can drive a fan instead of a defrost resistor in order to move the air around the coils inside the refrigerator. This fan helps to increase the cooling efficiency, and also speeds up the defrost process.

2.3 Hardware features

2.3.1 ACS and ACST devices

The STEVAL-IHT001V1 board embeds one ACS102-6TA, one ACS110-7SB2 and one ACST6-7ST switches. The datasheet of these devices can be found in our web site (go to www.st.com/thyristors). Table 1 sums up the main differences between ACS and ACST switches and traditional TRIACs.

Table 1. Differences between ACS/ACST and TRIACs

Device	1A TRIAC	ACS102	1A TRIAC	ACS110	6A TRIAC	ACST6
I _{gt} (mA)	5	5	10	10	10	10
Overvoltage Protection	No	Yes	No	Yes	No	Yes
(dV/dt)	20 V/μs	300 V/μs	50 V/μs	500 V/μs	100 V/μs	200 V/μs
(dI/dt) at turn-on	10 A/μs	20 A/μs	20 A/μs	50 A/μs	20 A/μs	100 A/μs

2.3.2 ST7LITE39F2 microcontroller

The MCU used in the thermostat kit is the ST7LITE39F2. It belongs to the ST7LITE39F2 MCU family. It embeds a large number of features at the minimum cost. The peripheral hardware requirements are then reduced to the minimum:

- No crystal oscillator or external resonator is used. Indeed, the internal RC-oscillator of the ST7LITE39F2 is used to generate the clock.
- No external RESET circuit is used, due to the internal circuit of the ST7LITE39F2.

In case of MCU firmware change, four options have to be set:

- Software watchdog activation
- RC oscillator selection
- PLL disabled
- Low Voltage Detection selection

2.3.3 Capacitive power supply

To reduce the board price as much as possible, a capacitive power supply is used on the board. The maximum average current sunk by the board is about 30mA for 4ms gate current pulse widths (see [Table 2](#)). In this case, a 1 μ F C3 capacitor value should be used in order for the board to work correctly under typical application conditions (nominal capacitor value, 230V RMS line voltage).

Table 2. Maximum average current sunk by the board

Devices	Average current consumption	Comments
MCU	2.5mA	Maximum supply current in Run Mode. $f_{CPU} = 1\text{MHz}$ and $V_{DD} = 5.5\text{V}$
LEDs	2.7mA	LEDs switch ON/OFF alternatively on each AC mains polarity in order to reduce the current consumption. $V_F = 1.6\text{V}$ @ $I_F = 4\text{mA}$, $V_{DD_Max} = 5.5\text{V}$ and $R_9 = R_{10} = R_{11} = 750\Omega \pm 1\%$
Gate average current necessary to control AC switches	21mA	Switches Q1 (Compressor) and Q2 (Defrost) cannot be switched ON at the same time. The gate average current is only defined according to the Q2 (Defrost) and Q3 (Light Bulb) gate current. $V_{DD_Max} = 5.5\text{V}$, $R_{DSON_MCU} = 25\Omega$, $R_4 = 130\Omega \pm 5\%$, $R_5 = 390\Omega \pm 5\%$ and 4ms gate currents pulses widths
Others (Push Button, NTC supply, Buzzer)	4.3mA	$V_{DD_Max} = 5.5\text{V}$, $R_{NTC@0^\circ\text{C}} = 16\Omega$, $R_{14} = 10\text{k}\Omega \pm 5\%$ and $R_{15} = 200\Omega \pm 5\%$ (I_{Buzzer} supply current = 4mA)
Total	30.5mA	

For higher or lower currents, the C3 capacitor can be changed. [Table 3](#) lists the maximum allowed average current versus the different C3 capacitor values for typical application conditions (nominal capacitor value, 230 V_{RMS} line voltage) and worst application case (nominal C3 capacitor value -10%, 198 V_{RMS} line voltage), for a 50Hz mains frequency.

For more information about the design of the capacitive power supply please refer to Application Note AN1476.

Table 3. Maximum output DC average currents

C3 capacitor	Max. output DC current for typical application conditions	Max. output DC current for worst application case
220nF	7.1mA	5.5mA
330nF	10.7mA	8.3mA
470nF	15.2mA	11.8mA
680nF	22.1mA	17.1mA
1µF	32.5mA	25.2mA
1.5µF	48.8mA	37.8mA

In order to reduce the surge current, a R6 resistor is used in series with the C3 capacitor. The power dissipation of this resistor is limited to ½ Watt. In this case, with a 30 mA output DC average current, a 47Ω resistor value can be used on the board for typical application conditions (100/230 V_{RMS} line voltage and 50/60 Hz mains frequency).

[Appendix G](#) defines, in typical application conditions (nominal capacitor value, nominal RMS line voltage), the C3 capacitor value for a 30mA output DC current versus different AC mains and frequency values used in different countries. Moreover, the typical and minimal (nominal capacitor value -10%, minimum RMS line voltage) output DC current capabilities are given for information.

One particularity of the STEVAL-ITH001V1 board power supply is to be a “negative” one. Indeed, the V_{DD} terminal is connected to Neutral. This means that the GND voltage is 5V below Neutral. Such a connection is mandatory for driving ACS devices. Indeed, ACSs can only be triggered by a negative current (i.e. sourced from the gate).

2.4 Graphic user interface (GUI)

A Graphic User Interface (GUI) is provided to set ST7LITE39F2 Microcontroller parameters and to access MCU information through the Serial Communication Interface (SCI). The GUI provides the following features (refer to the “Help” menu of the GUI software for more information):

- Sliding buttons to change MCU parameters:
 - temperature hysteresis
 - evaporator temperature order
 - gate current pulse widths and delays
 - time before defrost activation and defrost duration
 - ZVS delay (synchronization of MCU commands with the mains voltage)
- Virtual graduated potentiometer to set the evaporator temperature between low, medium or high levels
- Virtual switch to force the loads to ON or OFF states (Light, Defrost, Compressor) for easier board validation
- Measurement and storage of several parameters during operation (duty cycle and running period of the compressor, evaporator temperature evolution, mains frequency and loads status)

3 Getting started

3.1 Load power

Initially, there is no heat sink mounted on the TO220-AB of the ACST6-7ST device. In this case, Figure 2.1 of their datasheet shows that the maximum permanent allowed current is 1.5 A RMS, for an ambient temperature lower than 40 °C. If the ACST6-7ST must sink a higher current, or works at a higher temperature, a heat sink can be added. Also refer to AN1354 for more information on single-phase compressor control.

The ACS102-6TA, in a TO-92 package, can withstand a 0.2 A RMS permanent current up to an ambient temperature of 90 °C. The ACS102-6TA can drive the common light bulbs found in Fridge or Freezer without any problem. Indeed, a 25 W bulb will always sink a current lower than 150 mA. The ACS110-7SB2, in DIL-8 package, can withstand a 1 A RMS permanent current up to an ambient temperature of 90 °C. In this case, the ACS102-6TA can drive a maximum 200W defrost resistor. Moreover, this AC switch can drive a fan (with a RMS current lower than 1 A) instead of a defrost resistor without any additional snubber.

3.2 Measure points

[Figure 5](#) shows the GND map and where the test points are placed on the board. [Table 4](#) defines the measurement points.

Figure 5. Measurement points (top layer view)

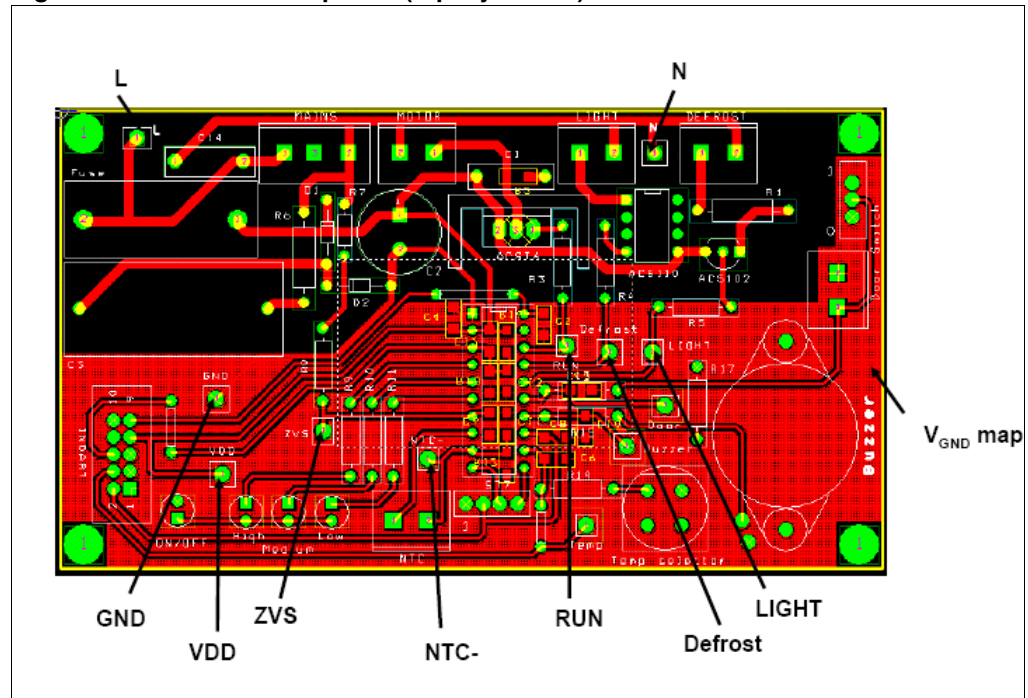


Table 4. Measurement points

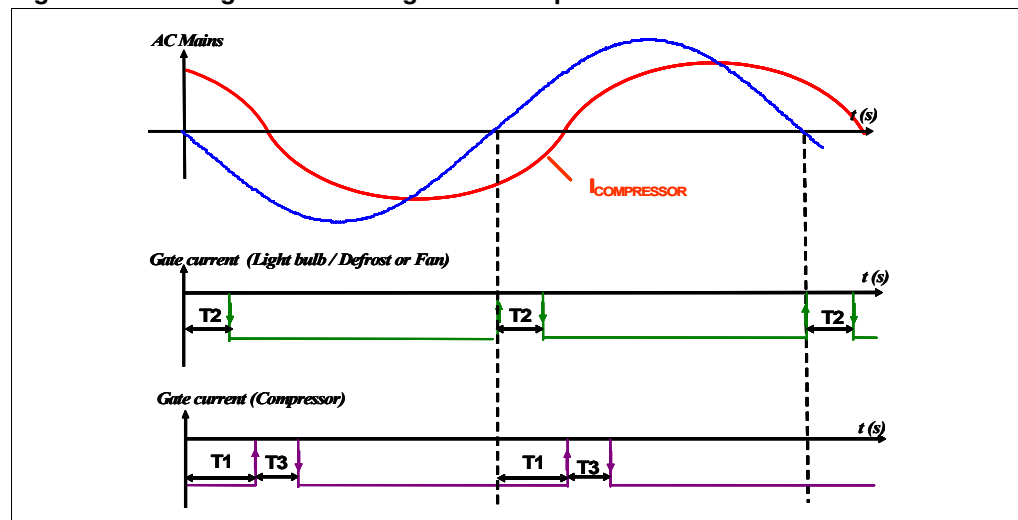
Footprint Name	Description
L	Line
N	Neutral
VDD	+5V power supply (also connected to ACS/ACST cathodes)
GND	GND power supply
ZVS	Zero Voltage Signal at MCU Input
NTC-	NTC value at MCU Input
RUN	Gate control of the ACST6 (compressor) at MCU Output
LIGHT	Gate control of the ACS102 (light bulb) at MCU Output
DEFROST	Gate control of the ACS110 (Defrost) at MCU Output

3.3 Pulse control

All loads are controlled in full cycle mode by a pulsed gate current. The MCU senses both the mains rising and falling edges to synchronize the gate pulse with the mains supply. Their delays and widths can be adjusted using the GUI from 0 to 4 ms in order to ensure a correct control of loads (especially in case of different phase shift for the compressor than the default value: 0.5 to 1.5 ms). [Figure 6](#) shows the different times useful to understand when the gate current pulses are applied for the three AC switches (Q1, Q2 and Q3):

- T1 is the mains voltage / compressor current phase shift. It helps to apply the gate current pulse just when the Q1 current reaches zero, in order to control the compressor in full cycle mode. Rq: a higher delay could be applied to test the compressor in phase angle mode.
- T3 is the gate current pulse width for switch Q1 (compressor)
- T2 is the gate current pulse width for switches Q2 and Q3 (light bulb and defrost resistor)

Figure 6. Timing definition for gate current pulses



Note: The gate currents are negative (i.e. they are sunk from the gates).

3.4 Getting started

Warning: The Kit is not electrically isolated from the AC input. The MCU is directly linked to the mains voltage. No insulation is ensured between the accessible parts and the high voltage.

The STEVAL-IHT001V1 Kit must be used with care and only by persons qualified for working with electricity at mains voltage levels. All measurement equipment must be isolated from the mains before powering the board.

When using an oscilloscope with the Kit, it is safer to isolate it from the AC line. This prevents a shock from occurring as a result of touching any SINGLE point in the circuit, but does NOT prevent shocks when touching TWO or MORE points in the circuit.

To operate the STEVA-LIHT001V1 board correctly, use the following procedure:

- Connect the NTC thermistor to the “NTC” connector on the thermostat board.
- Connect the DOOR switch (if you use an external door switch) to the “Door” connector on the thermostat board
- Push the board “Door” switch to the “Close” position in order to allow “temperature selection” push-button operation
- Connect the loads on the thermostat board:
 - Compressor to “MOTOR” connector
 - Defrost resistor to “DEFROST” connector
 - Light bulb to “LIGHT” connector
- In case of control with a computer (using the GUI), please go to [Section 2.3.3: Capacitive power supply](#).
- Apply the mains wire to the “MAINS” connector. Plug this wire to the mains voltage.
- After a few seconds:
 - The “ON/OFF” green LED must light ON
 - The “medium” red LED must light ON
 - The compressor switches ON if the sensed temperature is above the temperature order (should be the case if the NTC thermistor is at ambient temperature).
 - The Light Bulb is switched ON if the DOOR switch is on “open” position.
- Troubleshooting:
 - If no LED is ON: replace the fuse.
 - If LEDs seem OK, unplug the board from the mains. Discharge the VDD supply with a short-circuit between VDD and GND. Plug back the board to the mains.

Note: The temperature order can be changed using the BP1 push button on the thermostat board. Each time the BP1 push button is pressed, the red LEDs light on alternatively.

Note: If the “Door” Switch is in “Open” position or if the fridge door is opened, the temperature order cannot be changed from the thermostat board (only by using the GUI software).

3.4.1 Using the GUI software

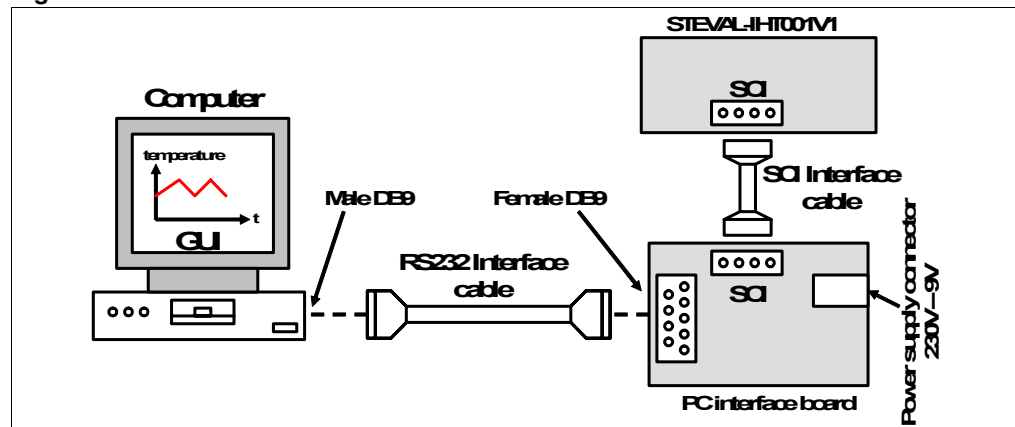
In order to use the GUI of our STEVAL-IHT001V1 kit, a recent version of Windows®, such as Windows 98, Windows 2000 or Windows XP must be installed on your computer. The version of the Windows OS installed on your PC may be checked by clicking on the “System” icon on the Control Panel.

To install the PC software (GUI) tool:

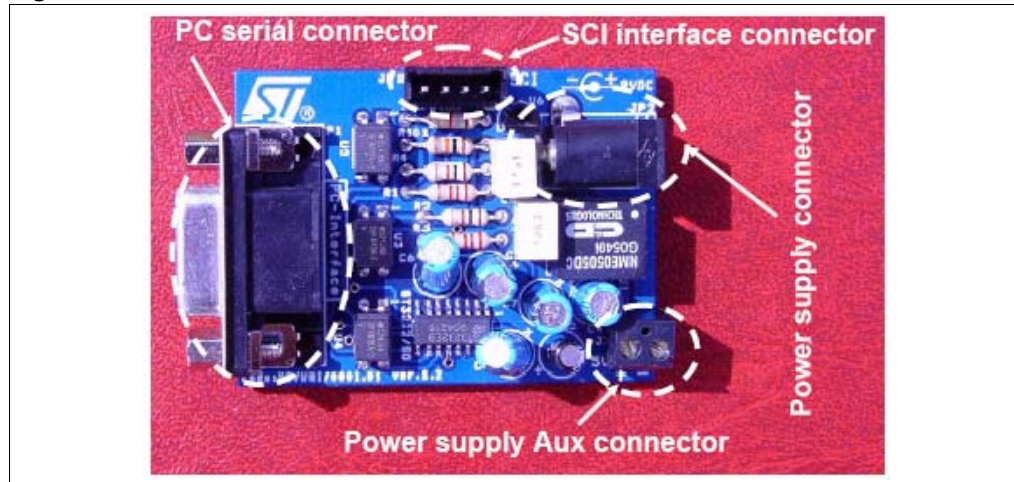
- Put the companion CDROM into the PC.
- Browse the CDROM directory to locate the GUI setup executable.
- Double-click on the GUI setup executable file.
- Follow the instructions as they appear on the screen.

[Figure 7](#) explains how to connect the different STEVAL-IHT001V1 kit boards and the computer.

Figure 7. STEVAL-IHT001V1 thermostat kit connections



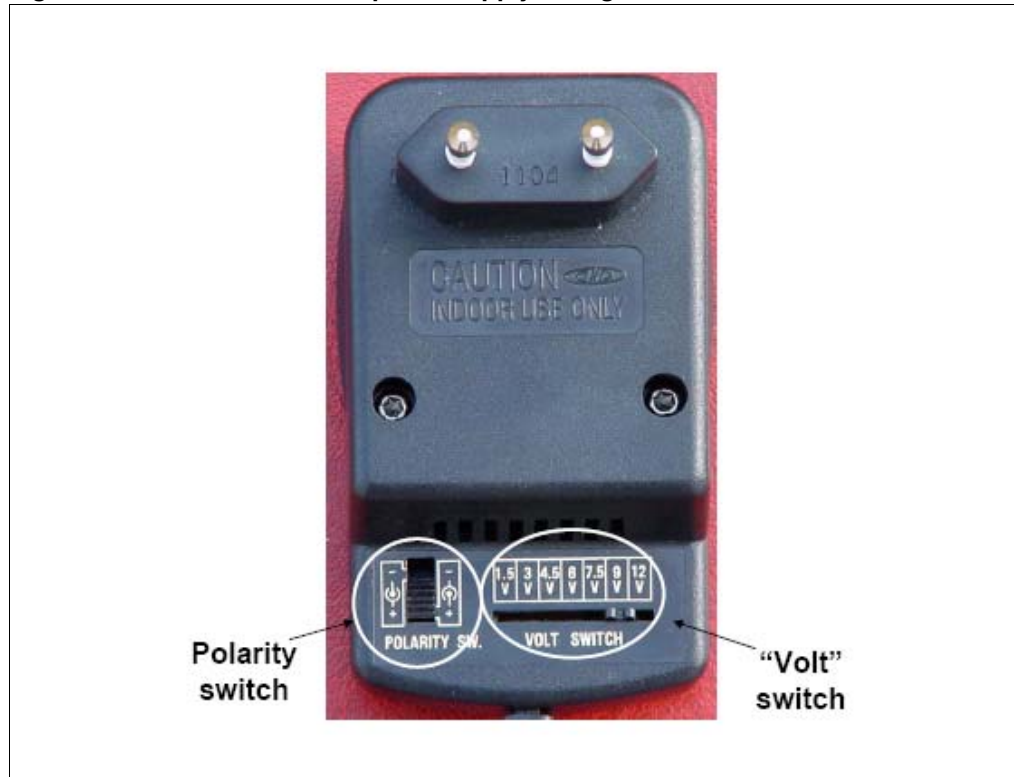
An insulated interface is required in order to control the different parameters of the fridge ([Figure 8](#)). The SCI insulated interface board is used in order to insulate the PC from the STEVAL-IHT001V1 Kit Board and converts the RS-232 levels (about +10 and -10V) to TTL voltage (0 and +5V) used by MCU, and vice versa, without requiring anything else than a +9V power supply.

Figure 8. Interface board

Perform the following start-up procedure for the GUI:

1. Connect the insulated PC interface board to the PC via the RS232 Interface cable and to the thermostat board via the SCI Interface wire.
2. Connect the 230V/9V insulated power supply to the SCI interface board. First check that the 230V/9V insulated power supply is correctly set: the Volt switch to the "9V" position and the Polarity switch to the "Positive" position (*Figure 9*).
3. In case of a problem, ensure that the "selected Serial Communication Port number" (COM1 or COM2) in the options dialog box is correct.
4. In order to enable communication between the GUI software and the thermostat board, it is necessary to push the "connected" button ("Connected" LED switch ON).

Note: Refer to the "Help" menu of the GUI software for more information.

Figure 9. 230V/9V insulated power supply configuration

3.5 GUI windows description

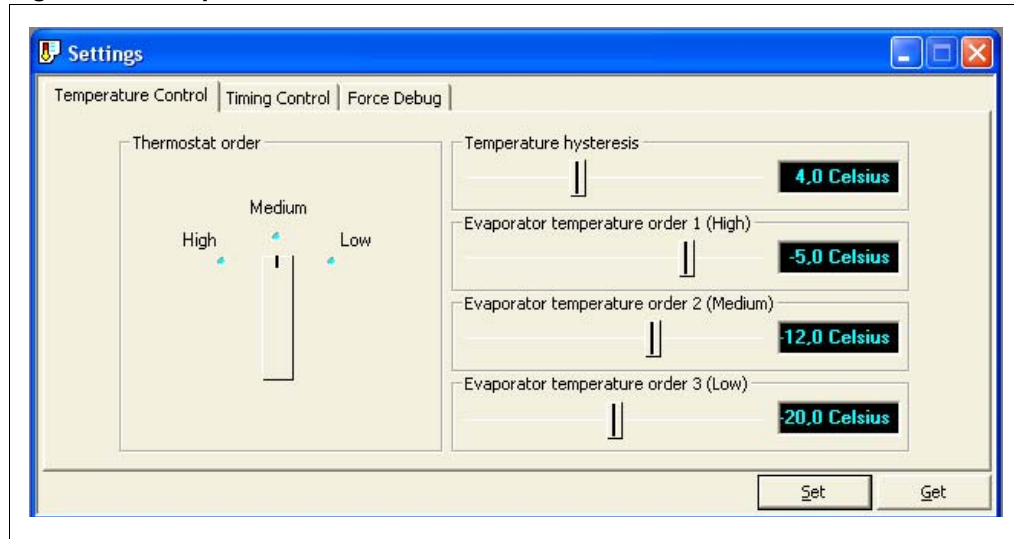
3.5.1 Temperature control

Use the “Thermostat Order” switch position on the GUI ([Figure 10](#)) or the “Temp Selector” push button on the board to select the correct temperature order. Note:

- If “Thermostat order” or “LED temperature” = High, then the Evaporator Temperature Order is “Evaporator Temperature Order 1”.
- If “Thermostat order” or “LED temperature” = Medium, then the Evaporator Temperature Order is “Evaporator Temperature Order 2”.
- If “Thermostat order” or “LED temperature” = Low, then the Evaporator Temperature Order is “Evaporator Temperature Order 3”.

The value of the three temperature orders must be set according to the appliance and the desired cabinet temperature for each operation point (Low, Medium or High).

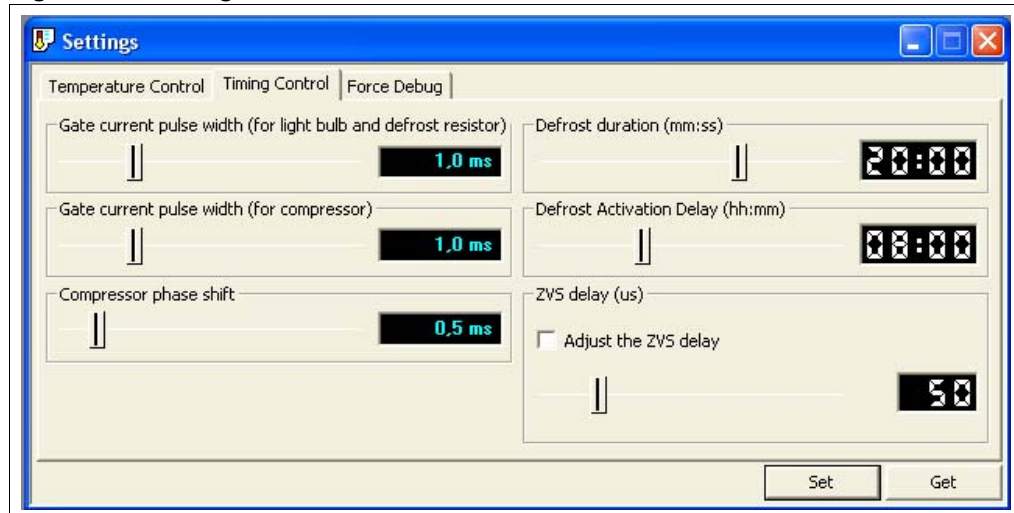
Figure 10. Temperature control tab



3.5.2 Timing control

The Timing Control tab ([Figure 11](#)) controls the gate current width for the TRIACs, the delay to switch ON the TRIACs Q1 (for compressor), the ZVS delay, the delay to activate defrost and the defrost duration. Note that the initial parameters are given in [Appendix F](#). These parameters are sent and received by clicking on “Set” or “Get” buttons, respectively.

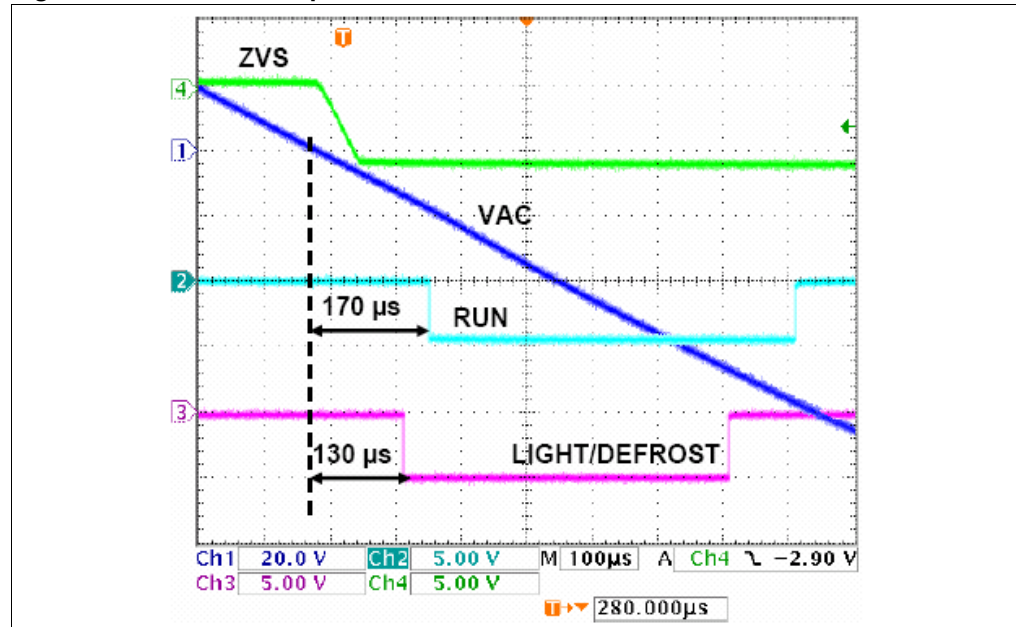
Figure 11. Timing control tab



The ZVS delay is the delay between the AC mains zero voltage and the detection of this zero voltage by MCU in order to synchronize the MCU orders with the AC mains voltage. The MCU uses Zero Voltage Crossing (ZVC) events to synchronize the TRIACs' gate current pulses. The LINE voltage is connected to the input pin through two resistors (R7 and R8). An interruption will then occur at each ZVC event. As soon as the ZVC is detected, the AUTO-RELOAD Timer is started and a routine is launched to define the PORT A configuration. The required time introduces then a delay from the ZVS. The maximum delay

measured to switch ON the TRIACs which controls the Light Bulb and the Defrost resistor is approximately $130\mu\text{s}$ for the AC mains negative cycle ($230\text{ V}_{\text{RMS}}$ 50 Hz line). The maximum delay measured to switch ON the compressor is approximately $170\mu\text{s}$ for the AC mains negative cycle (see [Figure 12](#)).

Figure 12. Gate current pulses

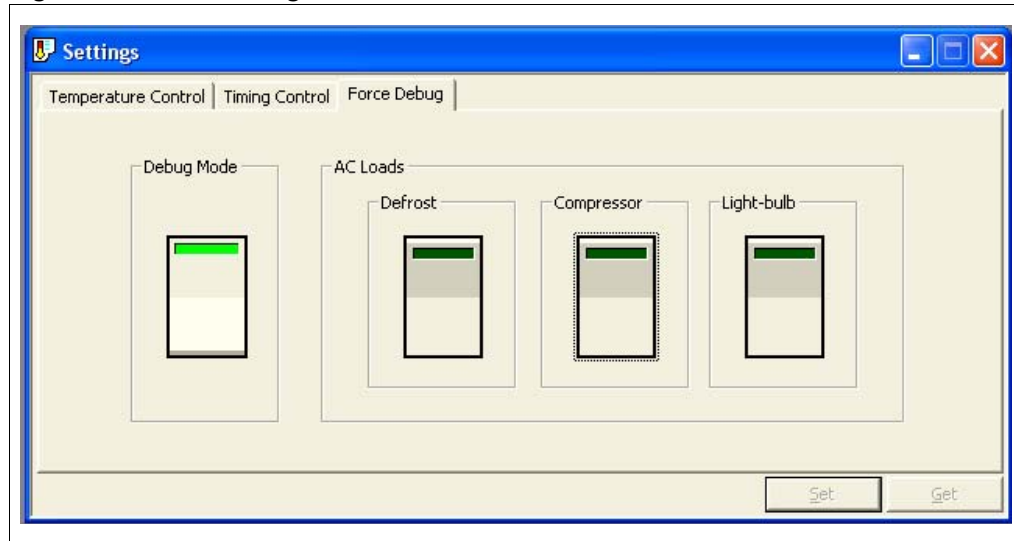


3.5.3 Force debug

The Force Debug tab is used to force the AC loads state regardless of the control state defined by the MCU for easier board validation ([Figure 13](#)). In order to control these AC Loads, it is necessary to click the “Debug Mode” button. In this case, the green lights of the AC Loads buttons are ON, if the associated loads are also ON, otherwise:

- Clicking the “Compressor” button will turn on Q1, and then the compressor is running.
- Clicking the “Bulb” button will turn on Q2, and then the light bulb is lit.
- Clicking the “Defrost” button will turn on Q3, and then the defrost resistor is heating.

- Note:*
- 1 The Defrost and Compressor cannot be switched ON at the same time. Setting Defrost resets Compressor, and vice-versa.
 - 2 In order to return to “Normal” mode, click the “Debug Mode” button. In this case, all the green lights turn off.

Figure 13. Force debug tab

3.5.4 Parameter measurements

The GUI can detect and display all the various parameters of the MCU, such as the temperature order, the evaporator temperature, the AC load states, the compressor cycle information (running period and duty cycle) and the Mains frequency. For more information, refer to the "Help" menu of the GUI software.

To enable data acquisition, press the "Acquisition" button. If the acquisition is successful (MCU firmware parameters and measurements obtained), the "ACQUISITION" LED turns green. If the "ACQUISITION" LED remains OFF, the acquisition function is disabled. If red, a samples acquisition error occurred.

4 Conclusion

This document will help cold-appliance designers to use our STEVAL-IHT001V1 thermostat kit to:

- Check the immunity of this ST solution
- Easily check the efficiency gains by hysteresis threshold reduction
- Define the better management of the defrost cycles to improve the overall efficiency
- Adapt the software and hardware for other dedicated designs (different compressors, potentiometer control, added loads, etc.)

Appendix A Thermal sensor linearization

An NTC thermistor is a thermal resistor whose value decreases when its temperature increases. The thermal law is exponential, as presented in [Equation 1](#).

Equation 1

$$R_c(T) = R_o \cdot \left(\frac{1}{T} - \frac{1}{T_o} \right)^B$$

To achieve a simple voltage sensor, it is better to linearize the temperature response using a constant resistor (R12) added in series with the NTC. A voltage divider is then achieved. The voltage across R12 will follow the supply voltage (V_{dd}) according to the relationship below:

Equation 2

$$V_s = \frac{R_c(T)}{R_c(T) + R_{12}} \cdot V_{dd}$$

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 R12 value to ensure this condition.

Equation 3

$$R_{12} = \frac{2 \cdot \left(\frac{d}{dT} R_c(T) \right)^2}{\frac{d^2}{dT^2} R_c(T)} - R_c(T)$$

To linearize the voltage response of a M2020 5 k NTC thermistor from EPCOS, between -20 and +5 °C, a 30 kOhm resistor should be chosen for R12.

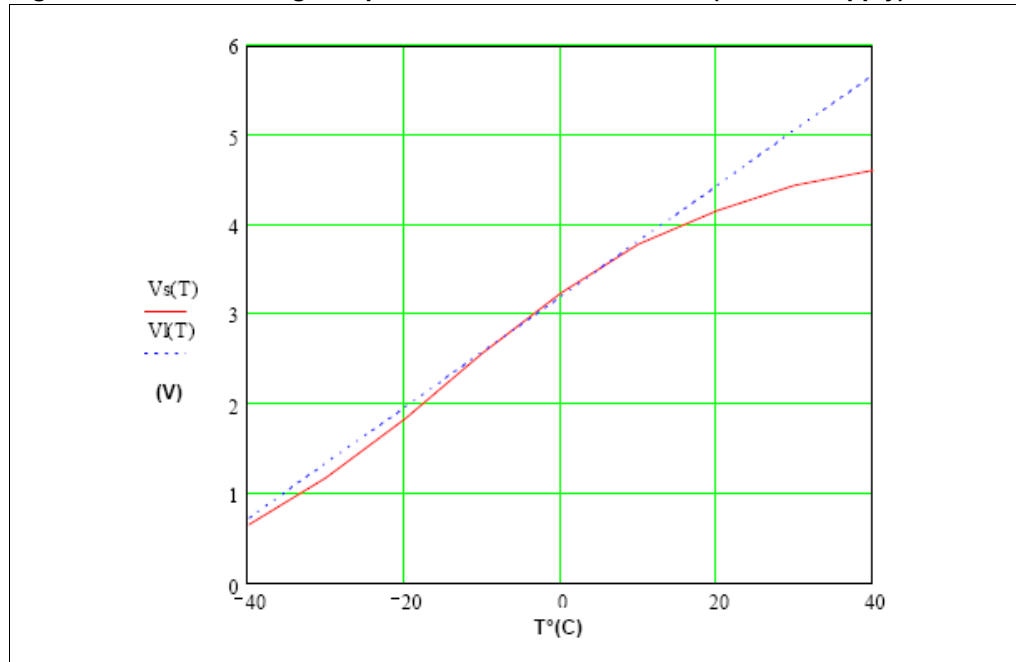
In this temperature range, V_s varies according to [Equation 4](#), for a 5 V supply:

Equation 4

$$V_l(T) = \frac{T + 51.84}{16.1943}$$

[Figure 14](#) gives the variation of V_s and the linear value given by [Equation 4](#) (V_l), versus the temperature sensed by the NTC thermistor.

Figure 14. Linear voltage response of the NTC thermistor (for a 5V supply)



Appendix B Wiring connections

For the NTC thermistor, you just have to connect its terminals to the “NTC” connector. Its wires can be connected in any way as it is just a resistor.

The same procedure can be achieved for the Light Bulb and Defrost resistors.

For the motor, things are more complex. The two following figures show where the RUN and LINE terminals are usually located for most compressor starters. These two terminals must be connected to the board “motor” header.

Figure 15. Compressor starter, case 1

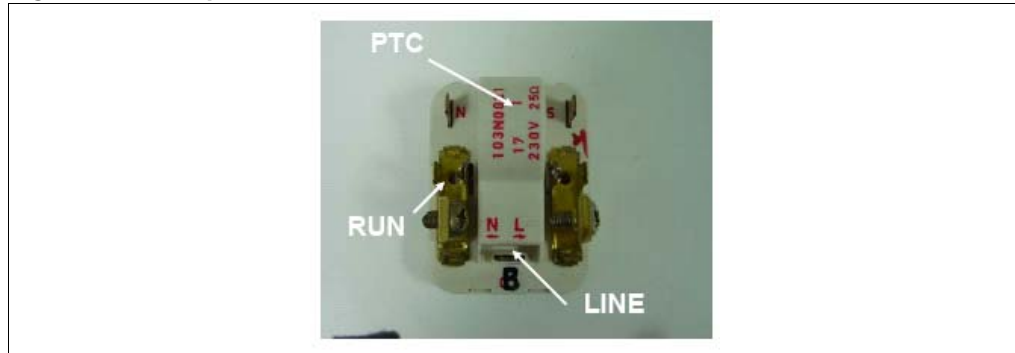
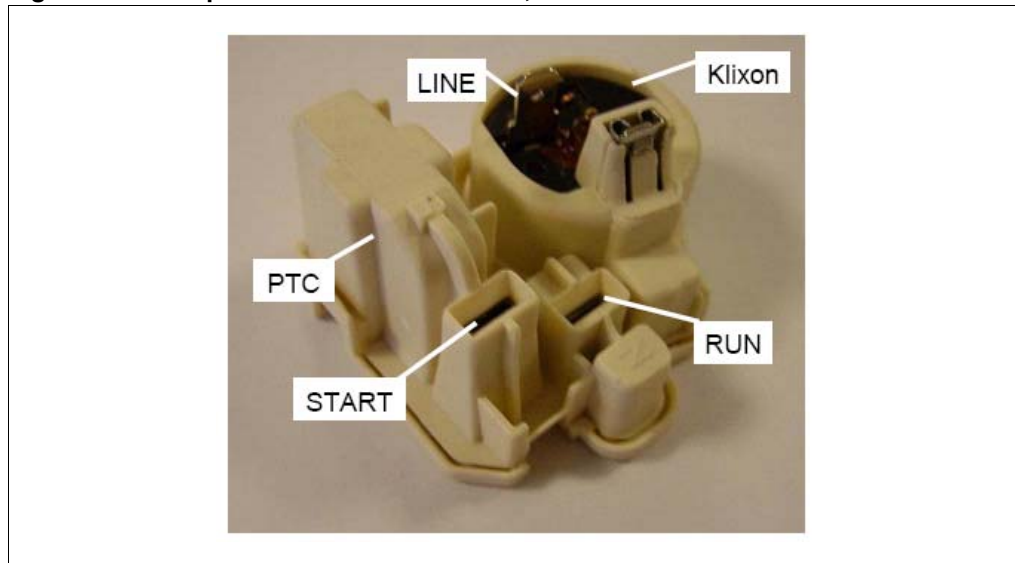
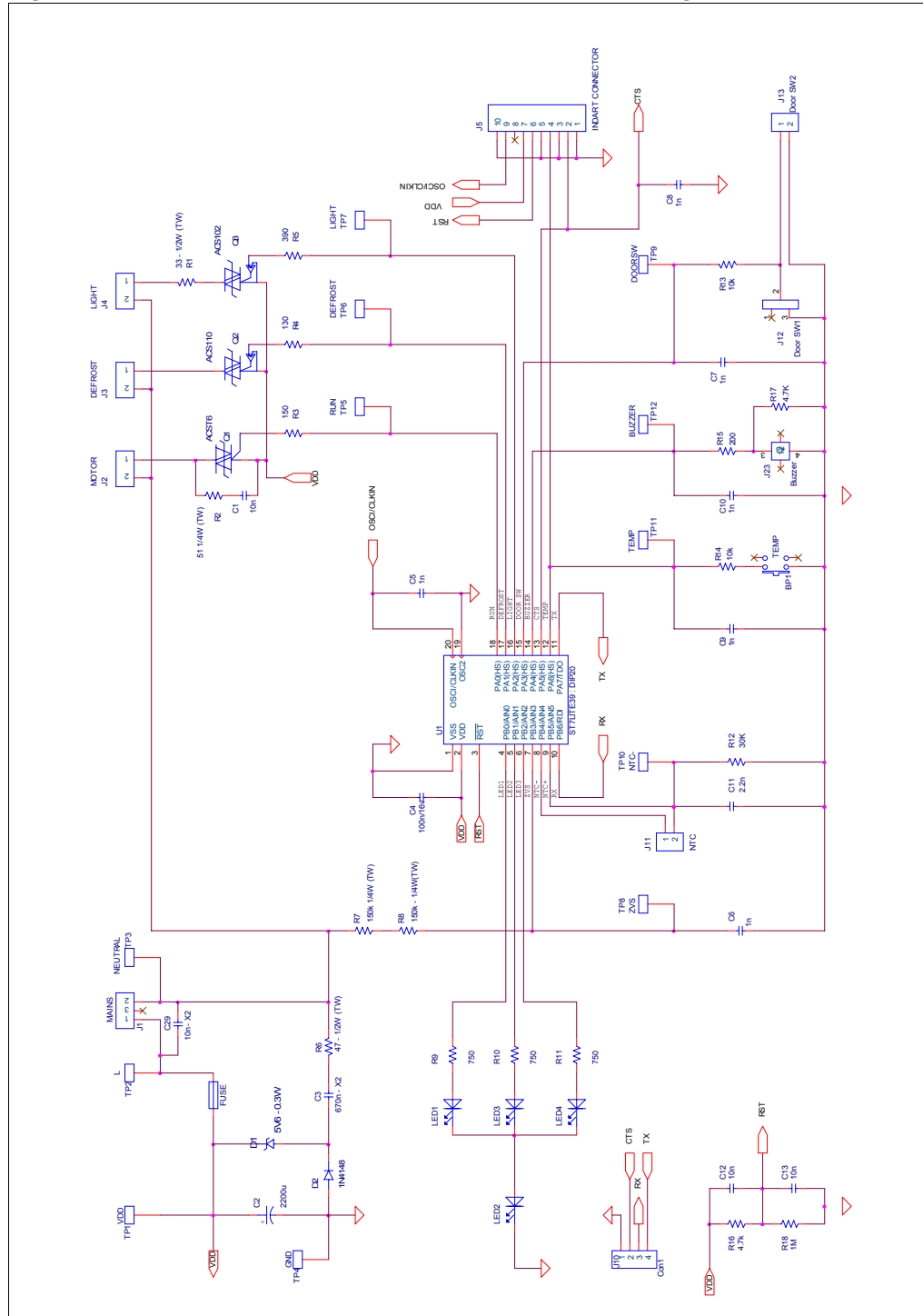


Figure 16. Compressor starter with Klixon, case 2



Appendix C STEVAL-IHT001V1 thermostat kit

Figure 17. STEVAL-IHT001V1 evaluation board schematic diagram



Appendix D Bill of materials

Table 5. Bill of materials

Name	Designation	Comment
R1	Resistor 33 Ohm-1/2W - 5%	
R2	Resistor 51 Ohm-1/4W - 5%	
R3	Resistor 150 Ohm-1/4W - 5%	
R4	Resistor 130 Ohm-1/4W - 5%	
R5	Resistor 390 Ohm-1/4W - 5%	
R6	Resistor 47 Ohm -1/2W - 5%	
R7	Resistor 150 kOhm-1/4W - 5%	
R8	Resistor 150 kOhm-1/4W - 5%	
R9	Resistor 750 Ohm-1/4W - 5%	
R10	Resistor 750 Ohm-1/4W - 5%	
R11	Resistor 750 Ohm-1/4W - 5%	
R12	Resistor 30 kOhm-1/4W - 5%	
R13	Resistor 10 kOhm-1/4W - 5%	
R14	Resistor 10 kOhm-1/4W - 5%	
R15	Resistor 200 Ohm-1/4W - 5%	
R16	Resistor 4.7 kOhm-1/4W - 5%	No connected
R17	Resistor 4.7 kOhm-1/4W - 5%	
R18	Resistor 1 MOhm-1/4W - 5%	
C1	Capa. Polyester - 400 Vcc (220V ca) 10nF 10%	
C2	Capa. Radial Electrolytic 16V 2200µF 20%	
C3	Capa. 1uF - 400V - X2 - 10%	
C4	Capa SMD 100 nF NPO 50V	
C5	Capa. SMD NPO 50V	No connected
C6	Capa. SMD NPO 50V	No connected
C7	Capa. SMD NPO 50V	No connected
C8	Capa. SMD NPO 50V	No connected
C9	Capa. SMD NPO 50V	No connected
C10	Capa. SMD NPO 50V	No connected
C11	Capa. SMD 2.2nF NPO 50V	
C12	Capa. SMD NPO 50V	No connected
C13	Capa. SMD 10nF NPO 50V	
C14	Capa. 10nF - 400V - X2 - 10%	

Table 5. Bill of materials (continued)

Name	Designation	Comment
D1	Zener 5V6 - 0.5W	
D2	Rectifier 1N4148	
Led1	Red LED / 7mA	High temperature order
Led2	Green LED / 7mA	ON/OFF state
Led3	Red LED / 7mA	Medium temperature order
Led4	Red LED / 7mA	Low temperature order
J1	Female connector 3 inputs	Mains
J2	Female connector 2 inputs	Motor
J3	Female connector 2 inputs	Light
J4	Female connector 2 inputs	Defrost
J5	Female connector HE10 - 2x5	Indart
J10	Centerline-AMPMODU Headers	For RS232 communication
J11	Female connector 2 inputs	NTC
J12	Switch	
J13	Female connector 2 inputs	DOOR Switch
U1	ST7FLITE39F2B6	DIP20
N/A	DIP 20 Socket	Socket for MCU
Q1	ACST6-7ST	Motor switch
Q2	ACS110-7SB2	Defrost switch
N/A	DIP8 Socket	
Q3	ACS102-6TA	Light switch
TP1	TEST PLOT	VDD
TP2	TEST PLOT	Line
TP3	TEST PLOT	Neutral
TP4	TEST PLOT	GND
TP5	TEST PLOT	Run
TP6	TEST PLOT	Defrost
TP7	TEST PLOT	Light
TP8	TEST PLOT	ZVS
TP9	TEST PLOT	Door Sw
TP10	TEST PLOT	NTC-
TP11	TEST PLOT	TEMP
TP12	TEST PLOT	Buzzer
BP1	Push Button	Temperature order setting
	Buzzer KB-26	

Table 5. Bill of materials (continued)

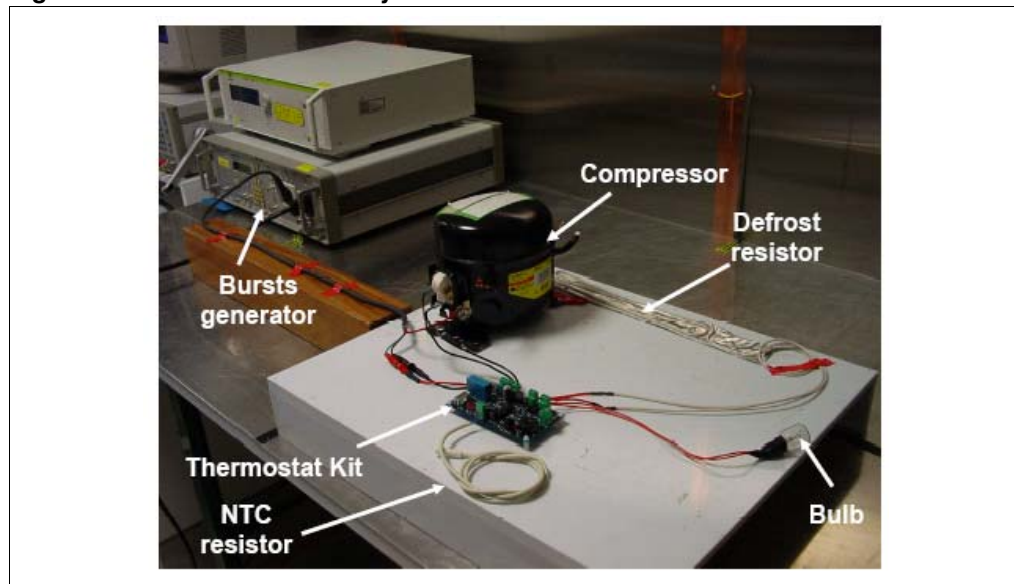
Name	Designation	Comment
S1	STRAP	Length is given from pad to pad
S2	STRAP	
S3	STRAP	
J6/J7/J8/J9	Corner Spacer: Screw	
J6/J7/J8/J9	Corner Spacer: Nut	
Fuse	Fuse 5x20mm 8A 250V	
N/A	Fuse socket	
N/A	Socket hood	

Appendix E Procedure to apply IEC 61000-4-4 bursts test

To perform fast transient voltage tests in compliance with EN61000-4-4 specifications on thermostat boards connected to a compressor, a 15W light bulb and a 25W defrost resistor, we have implemented the arrangements shown in [Figure 18](#). These arrangements ensure very stressful tests, but still comply with EN61000-4-4 specifications. These main arrangements are:

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

Figure 18. EN61000-4-4 test layout



Each operating cycle has been tested (all loads OFF, lamp ON, Motor ON, lamp + motor ON). The burst withstanding level is in the range from 2.3kV to more than 4.5kV (maximum capability of our generator) depending on the coupling mode (to L, N, PE, etc.).

Appendix F PC interface parameters description

Table 6. PC interface parameters description

Parameter	Software type	Unit	Initial setting	Allowed range	Setting step
Temperature Hysteresis	Input / Output	°C	4	0.5 to 10°C	0.1
Thermostat order	Input / Output	N/A	2	1 to 3	1
Evaporator temperature order 1	Input / Output	°C	-5	-50 to 10°C	0.5
Evaporator temperature order 2	Input / Output		-12	-50 to 10°C	0.5
Evaporator temperature order 3	Input / Output		-20	-50 to 10°C	0.5
Forced Defrost Control	Input	N/A	0	0 (OFF) or 1 (ON)	-
Forced Compressor Control	Input	N/A	0	0 (OFF) or 1 (ON)	-
Forced Bulb Control	Input	N/A	0	0 (OFF) or 1 (ON)	-
Forced Bulb Control	Input	N/A	0	0 (OFF) or 1 (ON)	-
Compressor phase shift (T1)	Input / Output	ms	0.5	0.1 to 4	0.1
Gate current pulse width (for compressor, T3)	Input / Output	ms	1	0.1 to 4	0.1
ZVS delay	Input / Output	µs	50	5 to 255	5
Gate current pulse width (for defrost resistor, T2)	Input / Output	ms	1	0.1 to 4	0.1
Defrost Activation Delay	Input / Output	Hours & Minutes	8	00:10' to 24:00 (10' to 24)	10'
Defrost duration	Input / Output	Minutes & seconds	20	00:10 to 30:00 (10" to 30")	10"
Compressor running period	Output	Hour & Minutes	N/A	00:01 to 04:30 (1' to 4h30')	N/A
Compressor duty cycle	Output	%	N/A	0 to 100%	
Light-bulb Status	Output	Green LED for ON	N/A	N/A	
Defrost Status	Output	Green LED for ON	N/A	N/A	
Compressor Status	Output	Green LED for ON	N/A	N/A	
Mains frequency	Output	Hz	N/A	50 or 60 Hz	
Evaporator temperature	Output	°C	N/A	40 to -50°C	
Evaporator temperature order	Output	°C	N/A	40 to -50°C	

Appendix G Capacitor value according to country

Table 7 indicates the capacitor value for a 30mA average current for typical application case (nominal capacitor value, nominal RMS line voltage) versus different AC mains and frequency values used in different countries.

Moreover, the typical and minimal (nominal capacitor value -10%, minimum RMS line voltage) output DC current capabilities are included for information.

Table 7. C3 capacitor value according to the country

Country	Typical RMS Voltage	Minimum RMS voltage	Frequency	C3 capacitor	Output DC current for typical application conditions	Min. output DC current capabilities for worst application case
Japan	100V	90V	50/60Hz	2.2 μ F	31.1mA	25.2mA
USA	120V	100	60Hz	1.5 μ F	30.5mA	22.9mA
Brazil, Mexico	120V to 240V	102V to 204V	50/60Hz	2.2 μ F	37.3mA	28.5mA
Europe, China, Korea, Australia	220V to 240V	187V to 204V	50/60Hz	1 μ F	31.1mA	23.8mA

Revision history

Table 8. Document revision history

Date	Revision	Changes
28-Aug-2006	1	Initial release.

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