UM0575
User manual

STEVAL- IHT003V1, e-STARTER demonstration board based on the ACST6 and X02

Introduction

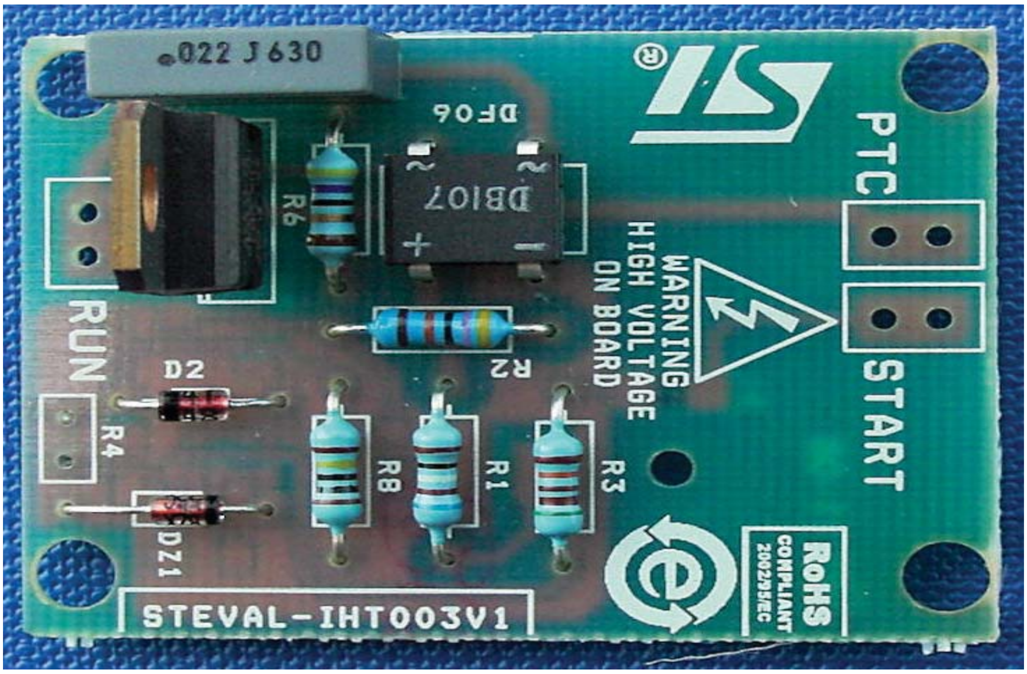
The e-STARTER demonstration board (*Figure 1*) presents an innovative solution, patented by STMicroelectronics, to reduce the power losses due to the positive thermal coefficient (PTC) resistors in compressor starter circuits.

This solution features an ACST6 device which is used to turn off the PTC current after the motor startup. It should be noted that the traditional PTC is still used in the electronic starter circuit because it increases safety in case of ACST short-circuit or diode-mode failure (ref. EN60335-1). This solution allows the starter standby losses to be decreased from typically 2.5 W to 380 mW or 40 mW, respectively for 230 V and 100 V applications.

The e-STARTER operation principle along with detailed schematics are given as well as demonstration board performances and the method to adapt the circuit to a dedicated compressor.

It should be noted that this board is not a "plug and play" solution. First, the PTC behavior has to be checked (especially V_{PTC1} & V_{PTC2} levels as explained in *Section 3.1*) and then the R4 resistor value has to be chosen before using the board with a compressor.

Figure 1. STEVAL- IHT003V1, e-STARTER demonstration board



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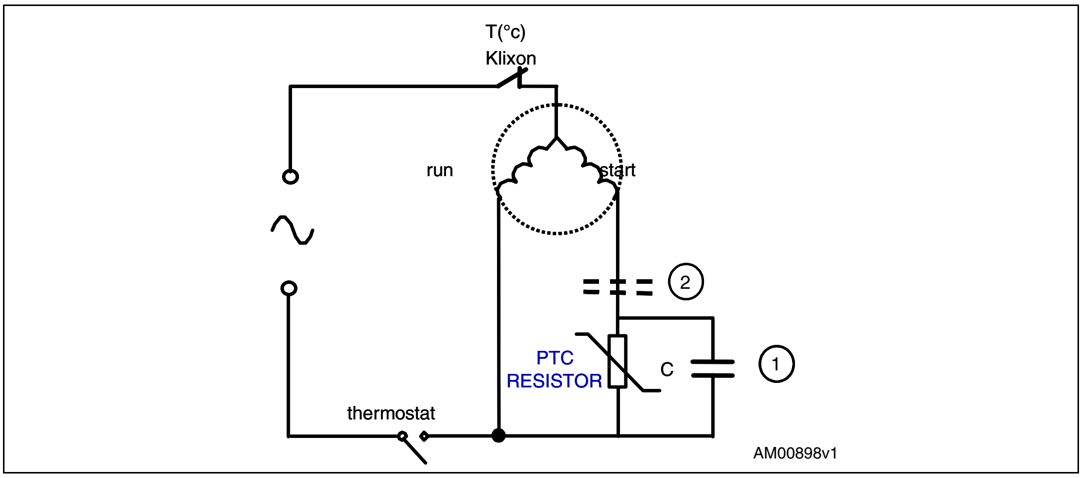
1 Operation principle

1.1 Compressor starter application

Single-phase induction motors, used for compressor control, use an auxiliary winding. This winding permits a higher torque to be applied at startup. The most popular method to control the start winding is to add a positive temperature coefficient (PTC) resistor in series with this winding and the thermostat (*Figure 2*). Then, each time the thermostat is closed, the current flows through the start winding and begins to heat the PTC. After a few hundreds of milliseconds, the PTC value rapidly increases from a few W to several tens of kW. This results in reducing the start winding current to a few tens of mA. This winding can then be considered as open. The PTC then behaves like a switch in OFF state, but with a high leakage current, resulting in high power losses (approx. 2.5 W).

Figure 2 gives the typical schematics of this application where a run or a start capacitor can be connected in parallel (point 1) or in series (point 2) respectively with the PTC.

Figure 2. Compressor starter application



1.2 Standard PTC behavior

The transition between PTC ON and OFF states brings a voltage increase across this variable resistor. *Figure 3* and *Figure 4* show two oscillograms of the same PTC in two different operating conditions, for a 230 V compressor which can use both a start and run capacitor. We see that, at the end of the PTC conduction, the voltage across it reaches approximately 250 V (refer to "VPTC_OFF" indication). This voltage level is similar whatever the operating conditions are (min or max RMS line voltage, run capacitor or not, etc.). The PTC could be turned off as soon as this level has been reached. *Section 1.3* explains how to implement an electronic solution to achieve this function.

Figure 3. PTC operation, no RUN cap. (compressor OFF time > 10' mains: 198 V RMS)

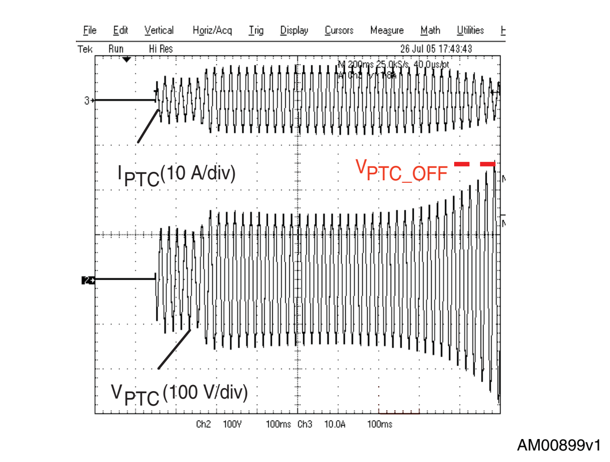
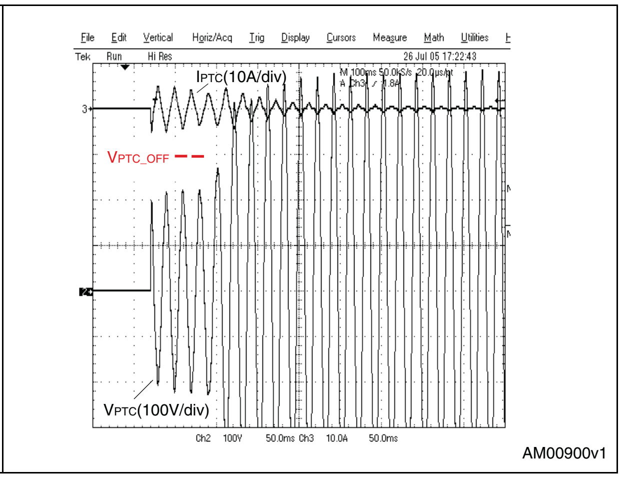


Figure 4. PTC operation with RUN cap.(compressor OFF time < 1' mains: 264 V RMS)



1.3 e-STARTER operation mode

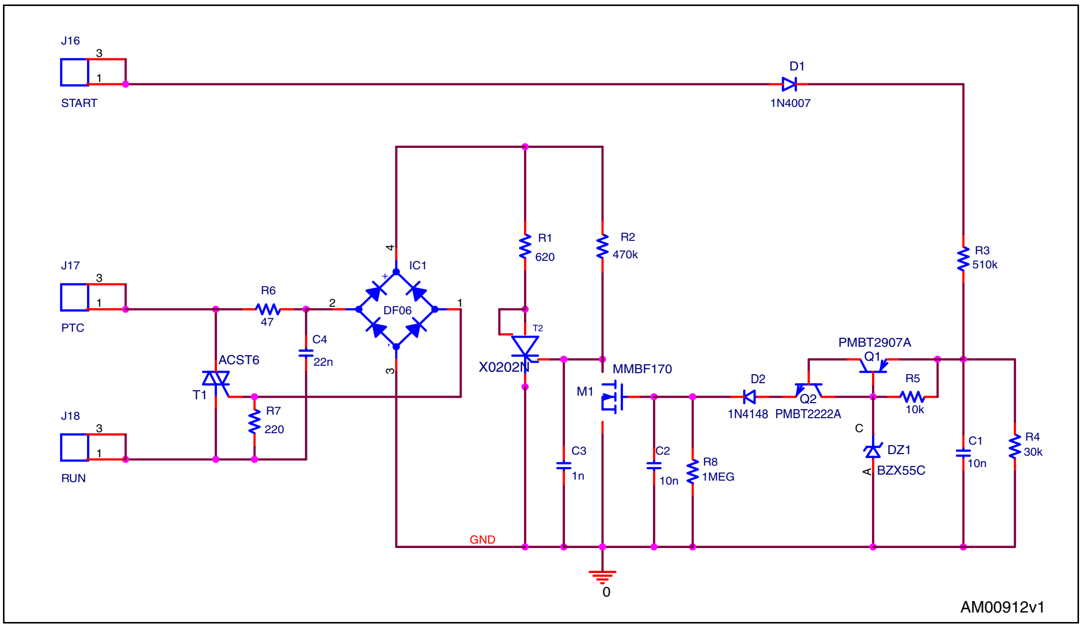
1.3.1 Schematics

Figure 5 gives the typical schematics of an "e-STARTER" for a 230 V application. The demonstration board presented here also features some optional pads to add a snubber (components R6 and C4) as shown in *Appendix A* and *B*. The figure also gives the names of the main electrical parameters which will be detailed in the following sections.

The traditional PTC resistor has to be connected between the "START" and the "PTC" solder pads (refer also to *Section 3.2*).

Note: The C3 capacitor is not soldered on the breadboards. It can be added if one wants to evaluate its impact on board immunity.

Figure 5. e-STARTER schematics



1.3.2 ON state

As soon as the mains voltage is applied:

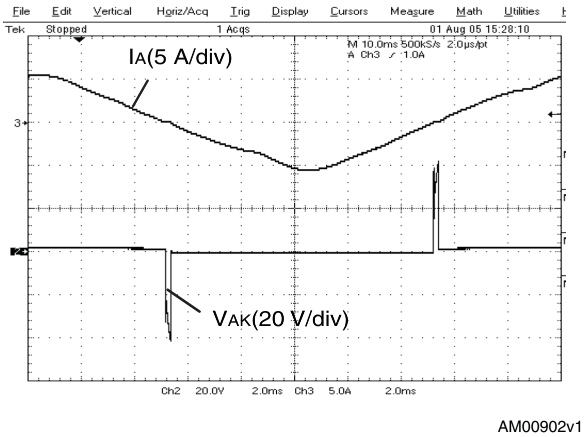
- M1 is OFF because the voltage drop across the PTC is not high enough to reach the DZ1 clamping level
- T2 is then turned on, thanks to the gate current provided by R2
- T1 is turned on thanks to the gate current provided by T2

Both T1 and the PTC are then ON.

At each zero-current crossing point, the ACST6 turns off. The reapplied voltage across T1/T2 triggers back T1 which results in some voltage spikes at each zero-current crossing point (typically around 40 V as shown in *Figure 6* for a 230 V compressor).

Applying the click test of norm EN55014, the noise duration could last more than 200 ms (depending on the type of compressor and PTC). The individual spikes last a few hundreds of microseconds and are spaced at intervals of 10 ms, so the limits of continuous disturbance are applicable. Since the spike peaks are less than 100 V, the e-STARTER solution should fulfill the requirements of EN55014. It should be noted that tests results greatly depend on the compressor used during the tests.

Figure 6. Voltage spikes at zero current



When the PTC conduction time has been sufficient to start the compressor, its voltage suddenly rises. This voltage rise is sensed by the R3/R4 divisor bridge.

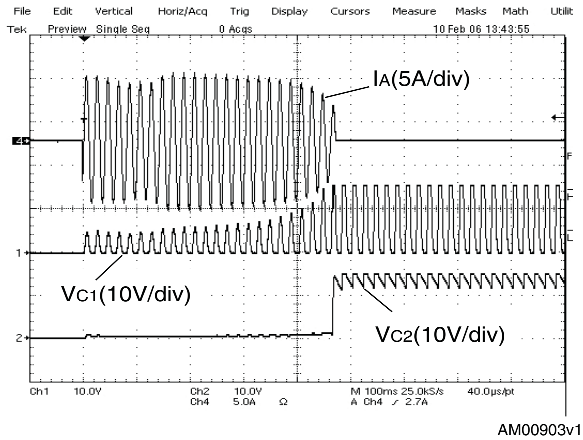
If the level is higher than the DZ1 clamping level, the thyristor, consisting of Q1 and Q2, is latched. M1 is then turned on.

As M1 is ON, there is no more gate current to trigger T2, so T1 also stays OFF. The PTC is then turned off.

No more current circulates through the PTC, thus no power is dissipated in it.

Figure 7 shows the typical behavior of this circuit. The C1 capacitor voltage gives an image of the PTC voltage. When its value reaches the DZ1 clamping level (15 V), the MOS gate is latched to 15 V. The PTC is then turned off (refer to the IA ACST6 current waveform).

Figure 7. PTC turnoff



2 Board performances

2.1 Maximum current

During e-STARTER conduction, the power losses are similar to those of the standard PTC solution as the same current circulates through this resistor. The only difference is that a small part of the voltage is also held by T1.

In the case of an ACST6, its forward voltage drop can be considered to be a constant forward voltage, V_{t0}, of at worst 0.8 V and a dynamic resistance, R_d, of at worst 80 m. So even with a 10 A peak current, the voltage drop is less than 1 V.

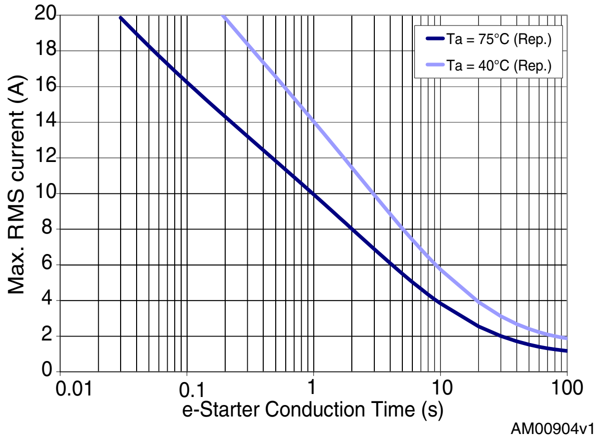
This forward voltage drop should be taken into account mainly to evaluate the junction temperature elevation of the semiconductor switch.

For an ACST6 in the TO220AB package, without any heatsink, this junction temperature elevation is equal to:

- 30° C after a 5 A RMS current during 3 s (worst case of typical 100 V/60 Hz compressors)
- 50° C after an 11 A RMS current during 0.5 s (worst case of typical 230 V/50 Hz compressors)

This ensures that T_J remains below its maximum allowed temperature (125° C), even with a 75° C initial temperature. *Figure 8* gives the maximum repetitive RMS current that the ACST6-7ST can withstand without any heatsink. This curve is given for 40° C and 75° C ambient temperatures. As with the e-STARTER solution, the heating time of the PTC is not long enough to warm the electronic devices, so the 40° C curve is closer to the real e-STARTER operating conditions.

Figure 8. e-STARTER maximum current versus conduction time



2.2 Standby power losses

During e-STARTER standby, the losses are caused only by the resistors, which are still connected to the mains voltage. Indeed, the ACST leakage current is in practice very much lower than 20 µA so that the resulting losses can be neglected.

The two resistors which are mainly dissipating power at standby are:

- R2 - used to provide T2 with gate current during the e-STARTER on state
- R3 - used to sense the voltage level across the PTC

As R2 is connected just behind the diodes' bridges, the V_{AK} voltage is applied across it, in full-wave mode. R3 senses only half the voltage across the PTC and T1. This voltage is also equal to V_{AK} as T1 is OFF, and so no current is circulating through the PTC.

We can neglect the voltage drops of M1 and of C1, which are lower than 0.6 V and 16 V respectively. The power losses, dissipated by the two resistors, are given by the following equations:

Equation 1

$$\begin{cases} P_{R2} = \dfrac{V_{AK}^2}{R2} \\ P_{R3} = \dfrac{1}{2} \cdot \dfrac{V_{AK}^2}{R3} \end{cases}$$

An example with R2 = 470 kΩ and R3 = 510 kΩ gives:

- For a 230 V / 50 Hz application using a run capacitor, V_{AK} can reach up to 350 V RMS. The overall power losses then equal 380 mW.
- For a 100 V / 60 Hz application using or not a run capacitor, V_{AK} stays around the line voltage, i.e at worst 115 V RMS. The overall power losses then equal 41 mW.

2.3 Fast transient voltages

Immunity tests, as described by the IEC 61000-4-4 standard, have been performed with the schematics of *Figure 5*, connected in series with a compressor without a RUN or START capacitor. e-STARTER spurious triggerings have not been detected with spikes up to 2 kV.

This high immunity level has been reached thanks to:

- the high dV/dt capability of the ACST6
- the improved dV/dt capability of the very sensitive SCR X0202M (20 µA < Igt < 50 µA) thanks to the fact that its gate is short-circuited to the cathode via M1 in OFF state, and also thanks to the R6-C4 snubber circuit
- the R_{GK} (R7) resistor which is added on the ACST6 device to derivate the current provided by R2 when M1 is ON
- the immunity provided by the layout of the printed circuit board (refer to *Figure 15*)

It should be noted that spurious triggering of the e-STARTER is not a problem as such behavior is not seen by the end user, and as these turn-ons do not lead to any component failure.

2.4 Surge voltages

The ACST6 device is an overvoltage protected device which means that it can be used without any varistor in parallel with its terminals. If a high energy surge is applied to the mains, as described in the IEC 61000-4-5 standard, when the e-STARTER is off, two cases can occur:

- A no-run capacitor is connected across the e-STARTER: the surge voltage is then entirely held by the ACST6. If the energy is high enough, the leakage current of the device can exceed its break-over level, leading to a turn-on of the e-STARTER lasting at worst 10 ms (refer to *Figure 9*).
- A run capacitor is used: the surge energy is absorbed by this capacitor. The voltage level is then limited below 1 kV, which is the typical clamping level of the ACST6. No spurious turn-on occurs in this case (refer to *Figure 10*).

It should be noted that in case of a spurious triggering in break-over mode, the ACST6 current is limited by the START winding inductance. The current value is then typically in the range of 2 A. This is far below the level guaranteed with ACST6, where a 47 Ω load can be used in such operation mode (refer to the ACST6 datasheet). With a 2 kV surge, the peak current then equals 40 A in this case.

Figure 9. Spurious e-STARTER triggering with a 2 kV surge (230 V compressor)

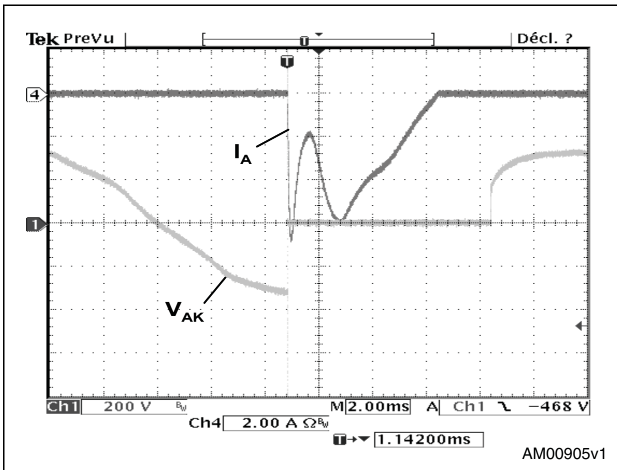
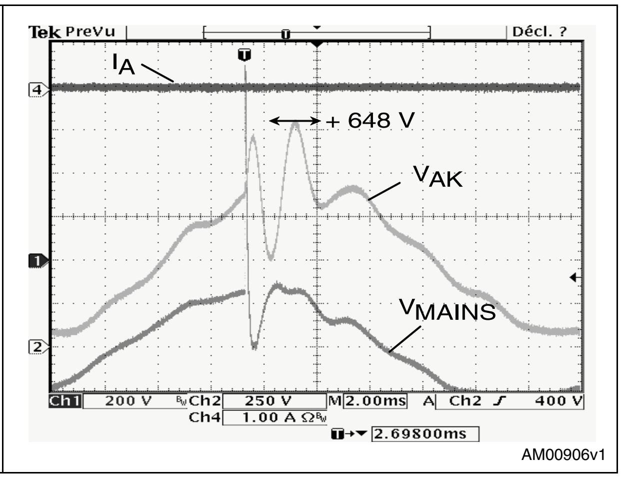


Figure 10. e-STARTER voltage limited to 648 V thanks to the RUN capacitor (2 kV IEC61000-4-5 surge)



2.5 Reliability and safety

Reliability tests have been performed with ACST6-7ST samples submitted to a current shape equivalent to an inrush current of 11 A RMS during 0.5 s. No parameter evolution of these samples has been detected after 450,000 cycles, which is representative of the lifetime of a refrigerator. This result demonstrates the excellent capability of these 6 A products even for applications with high inrush currents.

Concerning safety, the EN6033561 standard imposes the consideration of short-circuit or diode-mode failures of all silicon power switches involved in safety features. The failure of an entire e-STARTER cannot lead to safety issues (electrical or mechanical shock, fire). If the e-STARTER power switch dies in short-circuit or diode-mode, the start winding current is still limited by the PTC. The start winding is then protected and the compressor still works. Indeed, the starter function is still ensured by the PTC. The only drawback is that the standby losses increase back to 2.5 W.

If a failure occurs on the control side, leading to a short-circuit of both the power switch and the PTC, then the start winding could be damaged as its current would not be limited. The solution is then to use a thin copper track (*Figure 15*) between the start winding terminal and the e-STARTER control circuit. For example, a 130 µm track conducts the 1mA peak current in normal operation but blows if the whole start winding current, at least equal to 5 A RMS, circulates through it. The ACST6 then remains on the entire time the thermostat switch is closed. The behavior is the same as a standard PTC, without the power saving function of the e-STARTER.

3 Getting started

3.1 Voltage level setting

To make the demonstration board operate with a given compressor-PTC couple, the only thing to do is to check the divisor ratio of the R3/R4 resistors bridge.

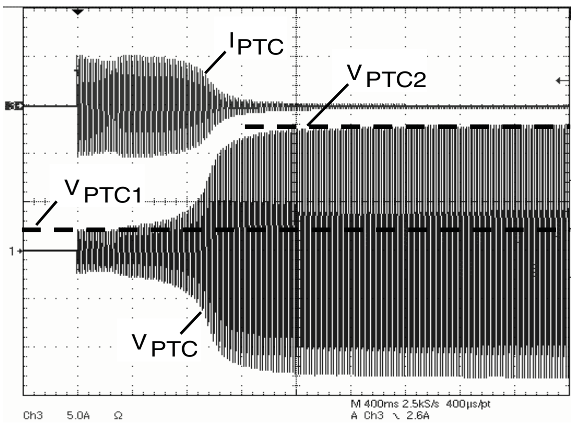
First, the PTC voltage level, which is representative of a long enough START winding activation, has to be defined. This level is called "$V_{PTC\text{-}OFF}$".

To proceed, we propose to measure the PTC peak voltages in ON and in OFF state for the whole range of operation, that is:

- min and max values of the line voltage
- at least one sample of all different compressors that could be used with the e-STARTER
- min and max values of the ambient temperature.

The PTC peak voltages in ON and in OFF state are called V_{PTC1} and V_{PTC2} respectively (refer to the dashed lines in *Figure 11*).

Figure 11. V_{PTC1} and V_{PTC2} definitions



Then, the "$V_{PTC\text{-}OFF}$" level has to be chosen higher than the maximum value of V_{PTC1} in order to ensure that the ACST6 has indeed been turned on at the beginning. The "$V_{PTC\text{-}OFF}$" level also has to be lower than the minimum value of V_{PTC2} in order to turn off the ACST6 at the end of the required PTC conduction time.

In order to ensure a safe margin between these two levels, $V_{PTC\text{-}OFF}$ should be calculated using the following equation:

Equation 2

$$V_{PTC\_OFF} = \frac{V_{PTC1MAX} + V_{PTC2MIN}}{2}$$

According to *Figure 4*, the maximum V_{PTC1} level is 220 V. According to *Figure 3*, the minimum V_{PTC2} level (198 V RMS line, no RUN cap, test conditions) equals 320 V (from the figure). Using *Equation 2*, we then choose a 250 V level for V_{PTC_OFF} to give the end of START winding conduction information.

To achieve this level detection, R4 has to be chosen according to the value of R3, using the following equation:

Equation 3

$$R4 = R3 \cdot \frac{V_{DZ1}}{V_{PTC\_OFF} - V_{DZ1} - V_{BE\_Q1}}$$

where V_{DZ1} is the clamping level of the Zener diode and V_{BE_Q1} is the forward voltage drop of the base-emitter junction of the Q1 transistor.

With R3 remaining at 510 kΩ (to reduce the power losses), V_{DZ1} and V_{BE_Q1} are 15 V and 0.6 V respectively, then R4 equals:

Equation 4

$$R4 = 510 \cdot 10^3 \cdot \frac{15}{250 - 15 - 0.6} = 32.6 \cdot 10^3 \cong 30\,k\Omega$$

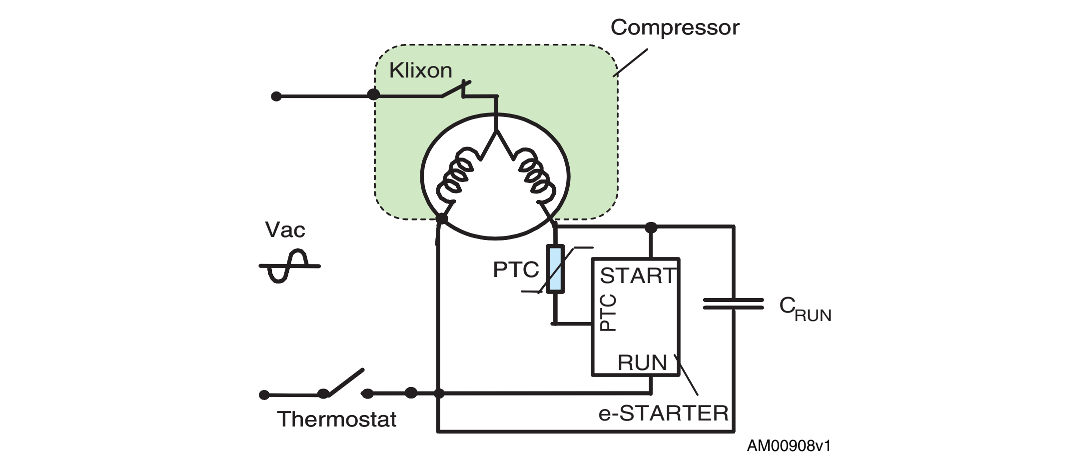
3.2 Connections

Before beginning any test, please take note of the following warnings:

1. The board has to be used by electrically-skilled technicians or engineers because the board has to be plugged into the mains and because no insulation is used between the mains voltage and the accessible conductive parts.
2. There is no insulation varnish on solders. Care should be taken when performing measurements (for example, voltage probes have to be connected only when the line and the power supply voltages are removed).

The e-STARTER has to be connected to a PTC and a compressor as shown in *Figure 12*, according to the instructions given on the topside silk screen. The RUN capacitor (CRUN) is optional and has to be used according to the compressor type. A start capacitor could also be placed in series between the PTC and the e-STARTER.

Figure 12. e-STARTER connections



4 Conclusion

This demonstration board promotes a full ST silicon kit for thermostat applications and allows users to:

- check the immunity of our solution
- easily check the efficiency gains
- adapt the hardware for dedicated compressors & PTCs.

The e-STARTER allows the designers of cold appliances to upgrade the efficiency class of refrigerators or freezers with a very low cost solution. This solution allows the starter standby losses to be decreased from typically 2.5 W to 380 mW or 40 mW, respectively for 230 V and 100 V applications. The high reliability and immunity of this circuit are ideally suited to the severe requirements of a refrigerator or freezer application.

Appendix A Component layout and printed circuit board

Figure 13 and *Figure 14* give the layout of the components for the top and the bottom layers, respectively. *Figure 15* gives the copper side of the e-STARTER demonstration board.

Figure 13. e-STARTER topside silk screen

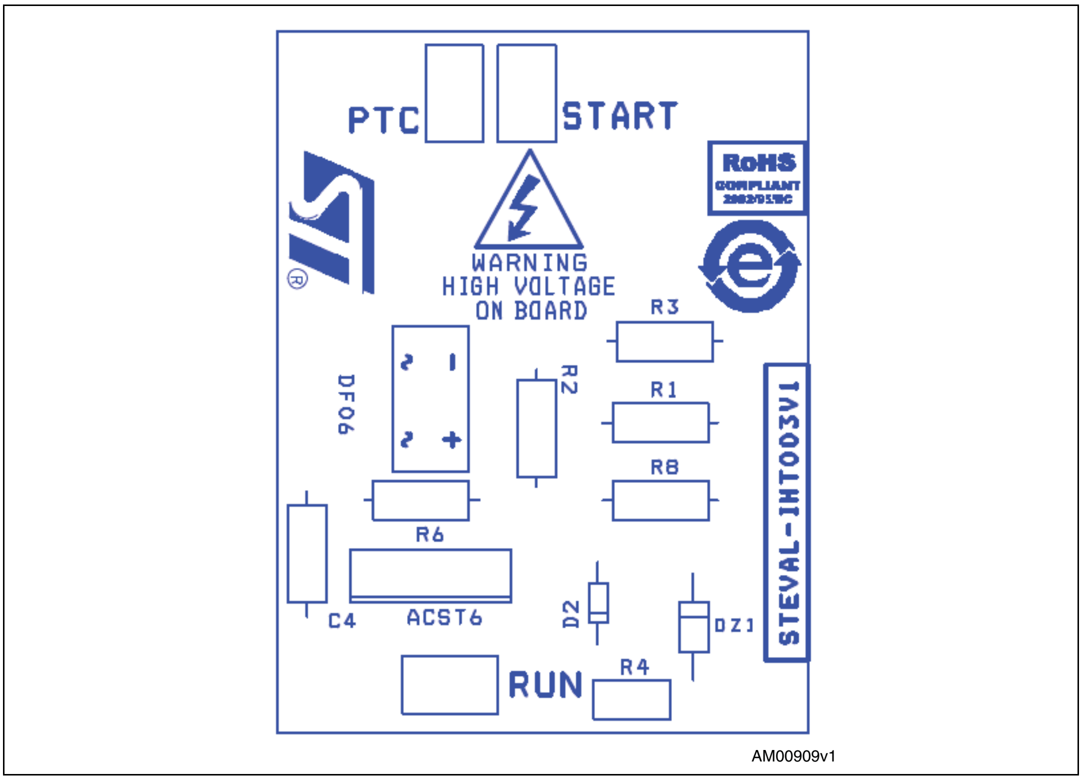


Figure 14. e-STARTER SMD components layout (bottom view)

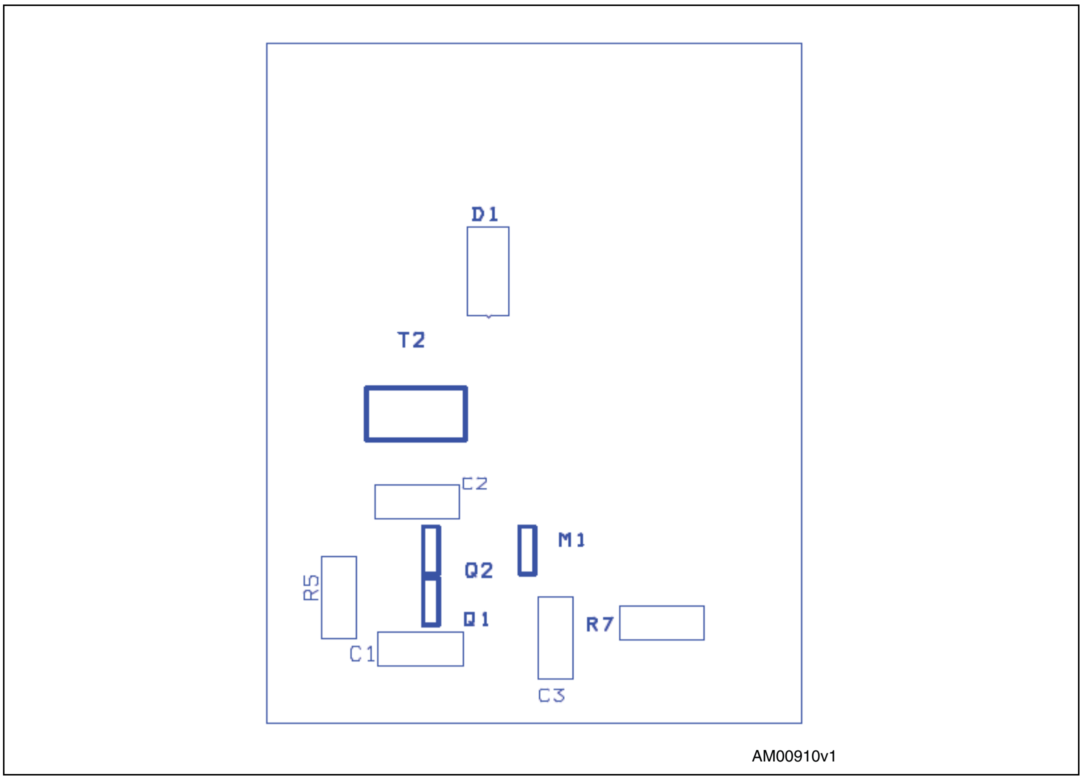
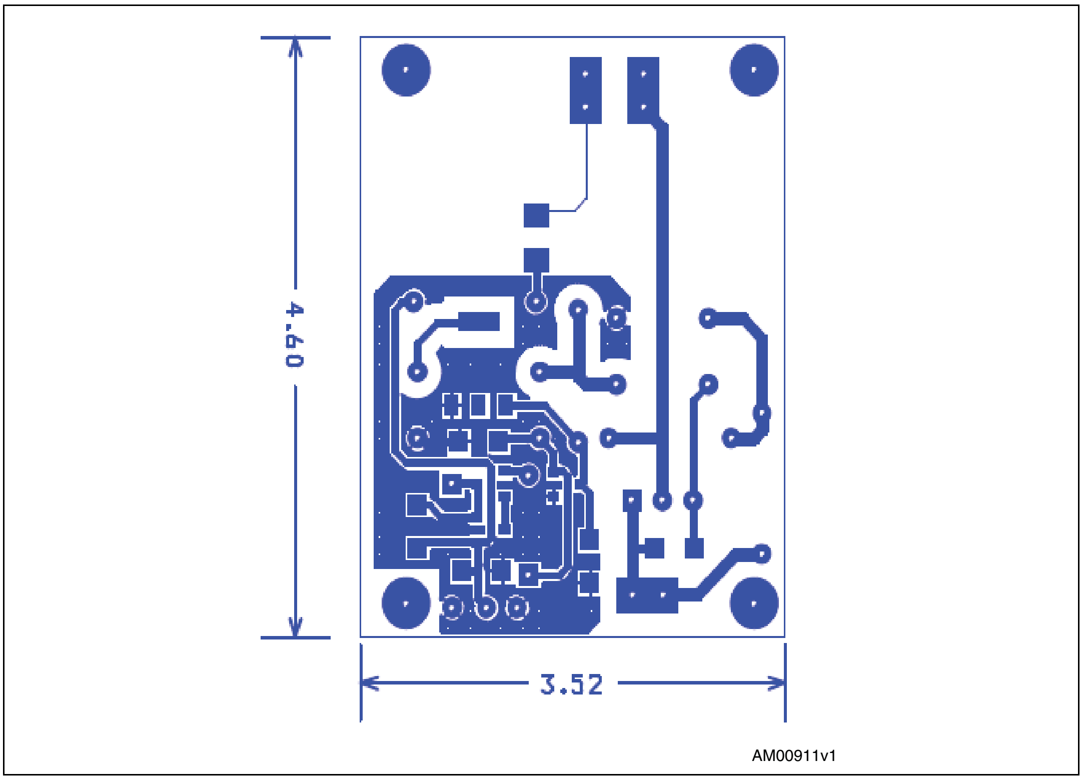


Figure 15. e-STARTER copper side (bottom view, dimensions in cm)



Appendix B Bill of material

The following table gives the bill of material of the e-STARTER board for a 230 V application. The values are given for indication as some values can be changed to adapt the voltage level detection (R3, R4, DZ1) or to increase the board immunity (R6, C4, R7, C2, C3, R8, C1).

Table 1. e-STARTER bill of material

Index	Qty	Reference	Name	Package	Manufacturer	Manufacturer's ordering code / orderable part number
1	1	TRIAC	T1	TO-220	STMicroelectronics	ACST6-7ST
2	1	SCR	T2	SOT-223	STMicroelectronics	X0202NN 5BA4
3	1	PNP transistor	Q1	SOT-23	Philips	PMBT2907A
4	1	NPN transistor	Q2	SOT-23	Philips	PMBT2222A
5	1	N-Channel transistor	M1	SOT-23	Fairchild	MMBF170
6	1	Resistor 620 kΩ 1/4 W 1%	R1	TH, Axial,0207		
7	1	Resistor 470 kΩ 1/4 W 1%	R2	TH, Axial,0207		
8	1	Resistor 510 kΩ 1/4 W 1%	R3	TH, Axial,0207		
9	1	Resistor 30 kΩ 1/4 W 1%	R4	TH,Axial,020, pitch 2,5		
10	1	Resistor 10 kΩ 1/4 W 1%	R5	TH,Axial,0207		
11	1	Resistor 0 1/4 W	R6	TH,Axial,0207		
12	1	Resistor 220 1/4 W 1%	R7	SMD 1206		
13	1	Resistor 1 M 1/4W 1%	R8	TH,Axial,0207		
14	1	Ceramic capacitor 10 nF/50 V 20%	C1	SMD 1206		
15	1	Ceramic capacitor 10 nF/50 V 20%	C2	SMD 1206		
16	1	No capacitor connected	C3	SMD 1206		
17	1	Capacitor 22 nF / 250 VAC	C4	TH, pitch 11		
18	1	Single phase bridge rectifier	DF06	DIL DB-1	WTE / GOOD-ARK	DF06

Table 1. e-STARTER bill of material (continued)

Index	Qty	Reference	Name	Package	Manufacturer	Manufacturer's ordering code / orderable part number
19	1	General purpose rectifier, 1N4007 (1000 V,1 A)	D1	DO214 SMA		
20	1	Small signal diode, 1N4148 (75 V,0.15 A)	D2	DO-35		
21	1	Zener diode	DZ1	DO-35	Fairchild / Vishay	BZX55C 15

Revision history

Table 2. Document revision history

Date	Revision	Changes
13-Feb-2008	1	Initial release