AN4363
Application note

How to select the Triac, ACS, or ACST that fits your application

Introduction

This document gives basic guidelines to select the AC switch device according to the targeted application requirements. These guidelines will allow the appropriate Triac, ACS or ACST to be selected, for most of the applications. Some very specific cases could require a higher level of expertise to ensure a reliable and efficient operation.

Contents

1 Current rating selection

1.1 Load current and operating temperature

The maximum current an AC switch (we call AC switch Triac, ACS or ACST in this document) can handle is limited only by the maximum allowed operating temperature, except for specific applications where the turn-off capability of the AC switch can also become a limiting factor (refer to *Section 1.2: Turn-off limitation for specific applications*).

But, for most applications, where the current waveform is sinusoidal, the current of the AC switch will depend only on the operating temperature and the device power losses.

For an AC switch, as the switching times (around 100 ns) are very low compared to the switching period (50 Hz or 60 Hz for most cases), the device power losses are considered as only linked to the conduction losses.

Then, the junction temperature will be (refer to STMicroelectronics Application note AN533 for further information):

Equation 1

$$T_j = T_a + P_d \cdot R_{th(j-a)}$$

or:

Equation 2

$$T_j = T_c + P_d \cdot R_{th(j-c)}$$

With respectively:

T_j: junction temperature

T_a: ambient temperature

T_c: case temperature

P_d: conduction losses

For a sinusoidal current, P_d is given by:

Equation 3

$$P_d = \frac{2 \cdot \sqrt{2}}{\pi} \cdot V_{t0} \cdot I_{RMS} + R_d \cdot I_{RMS}^2$$

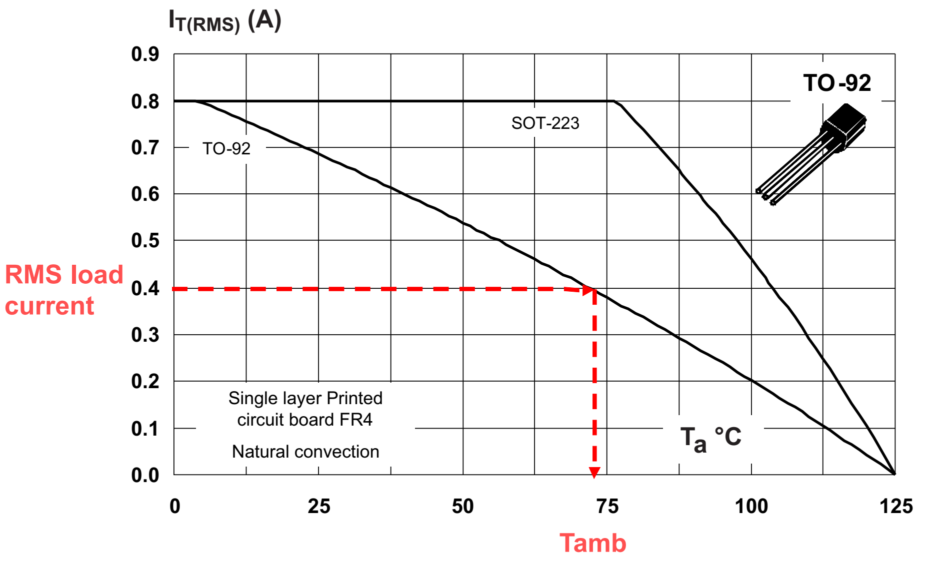
Where V_{t0} and R_d are respectively the threshold voltage and the dynamic resistance of the AC switch ON-state voltage drop.

For each device, the datasheet gives the maximum allowed current calculated so that the associated power losses (with *Equation 2*) will keep the junction temperature below the maximum operating temperature (with *Equation 1*). This maximum temperature is usually 125 °C or 150 °C for high temperature devices.

Figure 1 and *Figure 2* give the example of such datasheet curves for respectively an ACS108-6SA and a T1635T-8FP. As the ACS108-6SA package is a TO92, there is no way to add a heatsink to the device to evacuate its power losses. That is the reason why the curve is given versus the operating ambient temperature.

For example, for a 0.4 A rms current, this device has to work with a maximum ambient temperature lower than approximately 72 °C. In other words, up to 72°C, the ACS108-6SA can control a maximum rms current of 0.4 A.

Figure 1. Maximum rms current versus ambient temperature for an ACS108-6SA



For the T1635T-8FP, as the device package is a TO220FPAB, and as this device can handle up to 16 A for a 150 °C junction temperature, a heatsink is used in most of the cases. The curve is then given versus the operating case temperature as shown in *Figure 2*.

This figure shows that for instance, for a 12 A rms current, the package case temperature has to be lower than 107 °C. So the used heatsink has to ensure of evacuating the power conduction losses (P_d = 13 W for 12 A rms current, as shown in *Figure 3*) while keeping the case temperature below 107 °C.

Figure 2. Maximum rms current versus ambient temperature for a T1635T-8FP

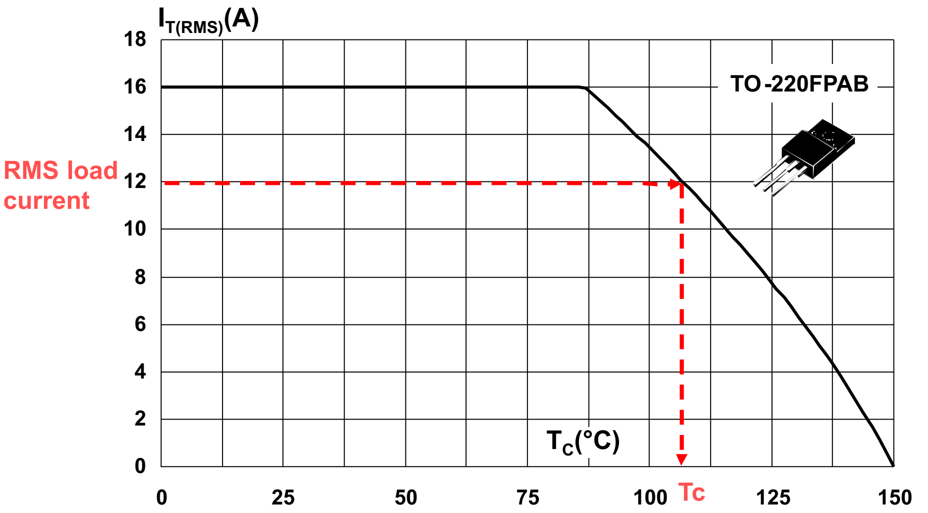
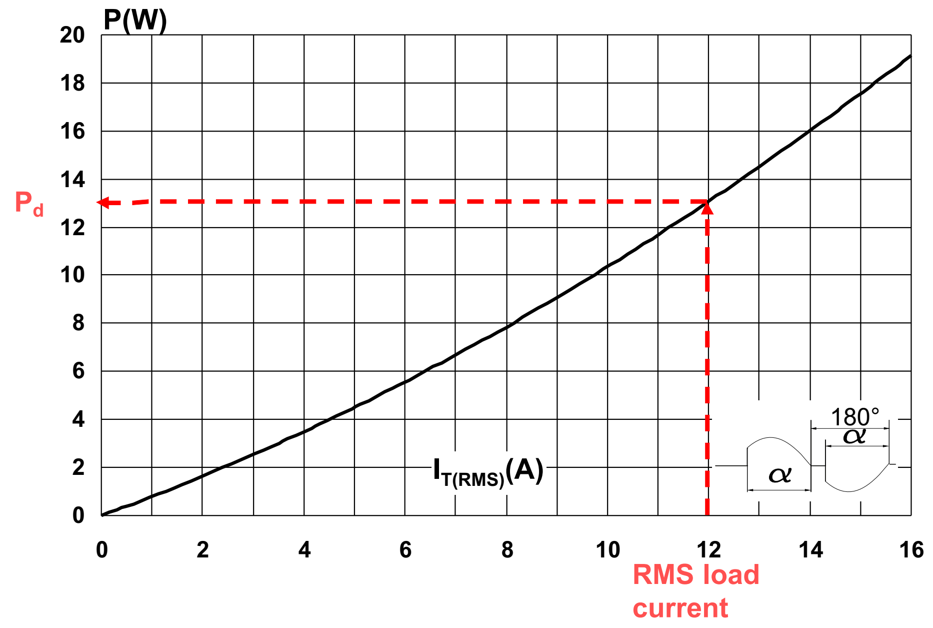


Figure 3. Maximum power dissipation versus rms on-state current for a T1635T-8FP



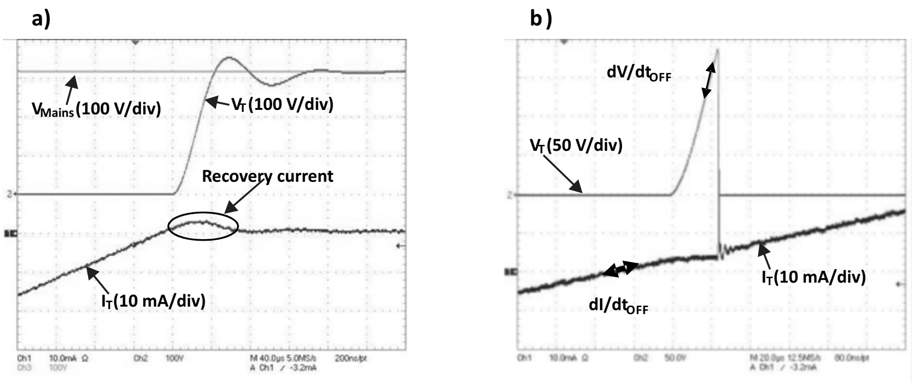
1.2 Turn-off limitation for specific applications

One particularity of an AC switch is that it may remain ON when the gate current is removed, even after that the current has reached zero. This kind of behavior could only occur if the Triac operates with conditions beyond its datasheet guaranteed operation, and particularly when the rate of load current decrease, or the rate of reapplied voltage after turn-off are higher than the specified (dI/dt)c and (dV/dt)c rates.

An AC switch can be compared to two Thyristors mounted back-to-back and coupled with a single control area. To trigger the two Thyristors, the control area overlaps the two conduction areas.

During the conduction time, a certain quantity of charge is injected into the structure. This charge disappears by recombination during the current decrease and by extraction after the turn-off with the reverse recovery current (refer to *Figure 4*.a). Nonetheless, if an excess of charge remains, particularly in the neighboring regions of the gate, this can induce the triggering of the other conduction area when the mains voltage is reapplied across the Triac (refer to Figure *Figure 4*.b).

Figure 4. Triac turn-off (inductive load), suitable turn-off (a) or missed turn-off (b)



To avoid such unwanted retriggering, ensure that the rate of decrease of the load current (dI/dt$_{OFF}$) and the rate of increase of the reapplied voltage (dV/dt$_{OFF}$) are both lower than the device specified minimum (dI/dt)c and (dV/dt)c parameters.

Note for Snubberless, ACS, and ACST devices, only the (dI/dt)$_{OFF}$ has to be checked as turn-off is guaranteed whatever the (dV/dt)$_{OFF}$ is.

Checking the (dI/dt)$_{OFF}$ of an application can be done easily as long as the current is sinusoidal. This parameter is the derivative of the current waveform. It is given by the following equations, according to the mains frequency (f) and the load peak or RMS currents (I_{PEAK}, I_{RMS}):

Equation 4

$$\frac{dI}{dt}_{OFF} = I_{PEAK} \cdot 2\pi \cdot f$$

Then, for 50 Hz, and with appropriate units, *Equation 4* gives:

$$\frac{dI}{dt}_{OFF(A/ms)} = 0.44 \cdot I_{RMS(A)}$$

For 60 Hz, equation 2 gives:

$$\frac{dI}{dt}_{OFF(A/ms)} = 0.53 \cdot I_{RMS(A)}$$

Knowing the peak current gives then the (dI/dt)$_{OFF}$ rate and the right AC switch device has to be selected so that it features a higher (dI/dt)c than this calculated rate.

Usually, a Triac features a (dI/dt)c parameter which is 0.44 or 0.5 times higher than its $I_{T(RMS)}$. So using such a Triac for a load rms current lower than the guaranteed $I_{T(RMS)}$ will ensure a proper operation as the (dI/dt)$_{OFF}$ will then be automatically lower than the device (dI/dt)c as explained by *Equation 4*.

Particular care has to be taken with sensitive devices (with I_{gt} current lower than 10 mA) as the (dI/dt)c could be lower than half the $I_{T(RMS)}$.

The only applications where $(dI/dt)_{OFF}$ rate has to be carefully checked (and measured) in the application are:

- Universal motors: Due to the brush commutations, the rate of decrease of the current is higher than the one calculated from the rms current from the equations.Typically the rate can be three times higher.
- Loads (such as universal motor or valve) connected in a diode bridge (refer to STMicroelectronics Application note AN439): In this case, the rate of decrease of the Triac current is limited only by the mains inductance. This is the reason why an inductor has to be put in series with the Triac to reduce this rate of decrease.

1.3 Inrush current and stalled rotor operation

AC switches thanks to their N-P-N-P layer silicon structure feature the best overcurrent capability among semiconductor switches. For example, the maximum peak current an AC switch can withstand during a line cycle (10 ms for a 50 Hz frequency) is usually 6 or 10 times higher than its nominal rms current ($I_{T(RMS)}$).

For a 1 ms pulse length, the ratio can even reach 20 to 40.

In all AC switch datasheet, the overcurrent capability is given by both the I_{TSM} parameter and two curves giving the variation of this parameter according to the pulse duration. One I_{TSM} curve is given for pulse durations longer than a line cycle, and another curve is given for pulse durations shorter than 10 ms.

These two curves allow users to know if the selected device fits with their application requirements, particularly if overcurrent due to inrush currents or stalled rotor operation can occur.

These curves demonstrate that is not necessarily mandatory to over-rate an AC switch current rating for a motor control application.

2 Voltage rating selection

2.1 Peak line voltage

An AC switch is used in series with the load and the line voltage in most applications. This means that at the OFF state, the Triac has to withstand at least SQRT(2) times the peak line voltage.

For single phase voltages, the power grid with the highest rms level that can be encountered is 277 V. This leads to a 390 V peak voltage applied across the AC switch. If we even assume a 15% increase of the nominal grid voltage, the applied voltage will be still lower than 448 V. This is the reason why 600 V devices fit with most single-phase applications (except those listed in *Section 2.2: Motor control applications*).

For a 3-phase power grid, the line-to-line voltage is SQRT(3) times higher than the line-to-neutral voltage. Table 1 gives the standard values according to the different classic power grids.

Table 1. Nominal voltages for single and 3-phase grids

Single-Phase voltage V_{LN} (V)	Phase-to-Phase voltage U_{KL} (V)
220	380
230	400
240	415
277	480

Then, the maximum voltage applied across the switch will then depend on load configuration. As the switch is in series with the load, then the maximum applied voltage will be:

- For delta configuration (see *Figure 6*): V_T max = U_{Peak}
- For star configuration (see *Figure 5*): V_T max = $\frac{U_{Peak}\sqrt{3}}{2}$ (worst case for floating load neutral)

Figure 5. Star connection

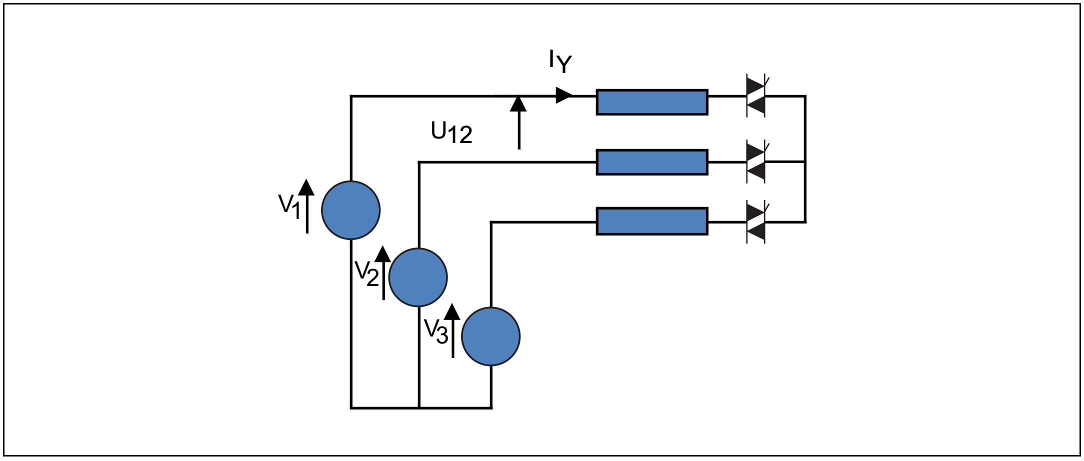
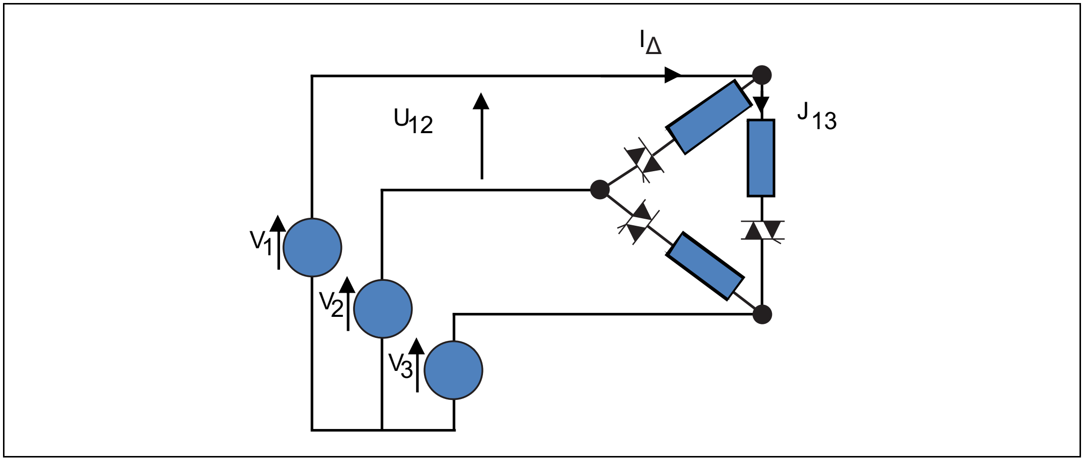


Figure 6. Delta connection



The highest voltage across the Triac is then: U_{Peak} (peak line-to-line voltage). This voltage, according to *Table 1* values, is very close or above 600 V. For such applications, AC switches able to withstand at least 800 V are then required. For motor control, due to the back electro-motive force (BEMF) that can be added to the voltage held by the AC switch at OFF state, 1000 V or 1200 V devices are preferred.

2.2 Motor control applications

A BEMF can be applied by a motor when the series AC switch is OFF. A motor can still be running due to inertia or if a mechanical torque is applied.

A BEMF will occur across a motor if it is turning and if an inductive field is applied. This is the reason why, such a BEMF does not occur with universal motors (as the exciting field applied by the rotor is switched off when the stator is turned off, as both windings are in series) and asynchronous induction motors (as the rotor field is generated by the stator field). A low-level BEMF could occur in case of permanent induction due to motor iron saturation but such a BEMF can usually be neglected.

A BEMF will actually appear at stator winding turn-off usually when permanent magnets are used. This is the case of permanent magnet synchronous motors (PMSM). Typically the BEMF could be between 30 to 50% of the line voltage. So a 50% margin on the AC switch voltage capability, versus the peak line voltage has to be taken into account.

There are also specific topologies where a capacitor can be used to control a motor. These two topologies are:

- Induction motors, with split-phase capacitors (see *Figure 8*): such motors are used for drum motor control (mainly in vertical axis washing machines), rolling shutters, garage-door openers, compressors, etc. The Triac voltage typically reaches 550-650 V at device turn-off for 230-240 V applications (see STMicroelectronics Application note AN2991).
- Motors used in a diode-bridge in series with an AC capacitor (used as a ballast to step-down the Line voltage, see *Figure 7*): such a topology is used to operate a low-voltage electronic load like a BLDC motor, directly from the mains. At turn-off, the voltage across the Triac reaches 2 times the line peak voltage due to the nearly perfect 180° phase-shift between line and capacitor voltages. This means 746 V can be applied for a 264 V line voltage (240 V + 10%).

Figure 7. BLDC low-voltage motor ON/OFF control with a Triac

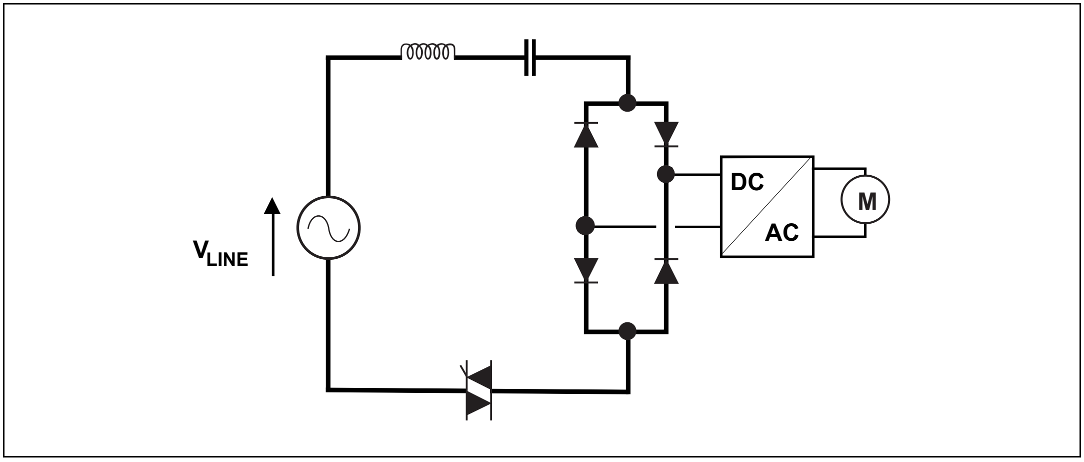
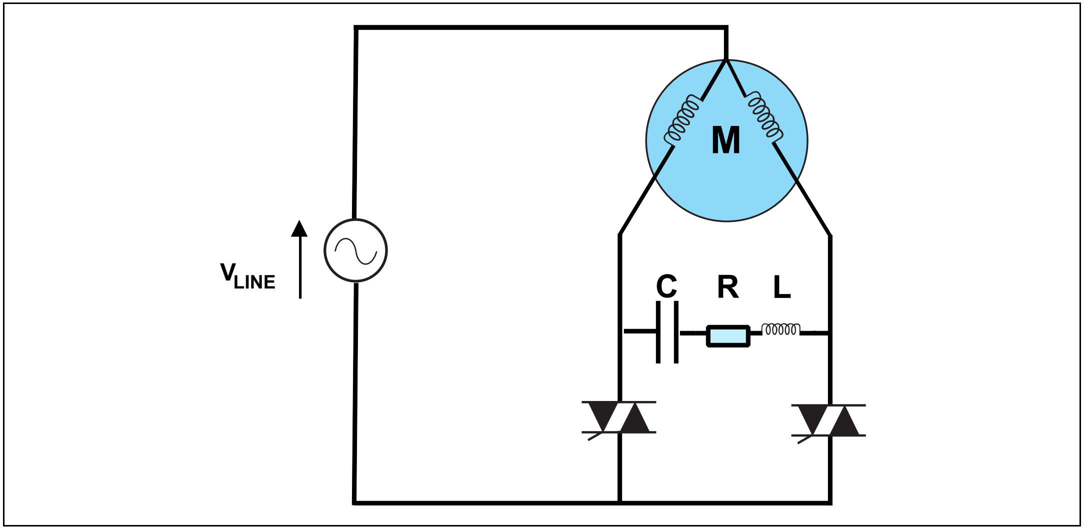


Figure 8. Split-phase induction motor ON/OFF control with two Triacs (double-direction)



2.3 Over-voltage protection

As an AC switch is mostly used in series with a load and the line voltage, any surge or transient voltage applied to the grid will be seen by the AC switch if it is in the OFF state.

ACS and ACST are a new AC switch family that is guaranteed to turn on safely by breakover as long as the applied current stress is within the guaranteed limits. So no overvoltage protection device is required in parallel to the device to protect it either from voltage surges coming from the mains or from an overvoltage generated at turn-off on inductive load (overvoltage could occur due to the holding current, refer to STMicroelectronics Application note AN1172).

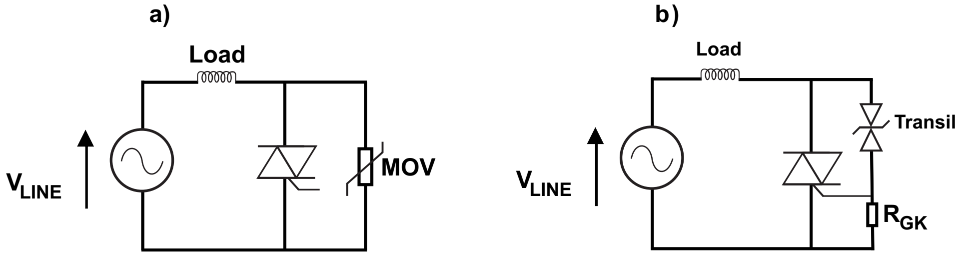
Any other device has to be protected from a voltage exceeding their maximum voltage capability (V_{DRM},V_{RRM} or V_{DSM},V_{RSM} parameters according to the technology). Two solutions are used to implement an overvoltage protection. The most common is to add a metal-oxide varistor (MOV) in parallel to the AC switch terminals (for example, A1 and A2 for a Triac).

It has to be noted that any MOV presents a series resistance that makes the voltage clamped by this device increase with the current created by the surge.

This current is limited by the load if the MOV is well placed in parallel with the Triac and not at the line input (see *Figure 9*a). This is the preferred position. But if the load power is high, this means the load impedance is low and the surge current, applied to the MOV, can be very high, leading to a high voltage applied across the AC switch.

One solution is then to use a Transil connected across Triac A2 and Gate terminals as shown in *Figure 9*b. This allows a crowbar protection to be implemented. This solution allows to more accurately control the maximum voltage applied to the Triac but it will lead to a spurious triggering of the device in case a surge is applied. More information on this solution can be found in STMicroelectronics Application note AN1966.

Figure 9. Triac overvoltage protection by MOV (a) or Transil (b)



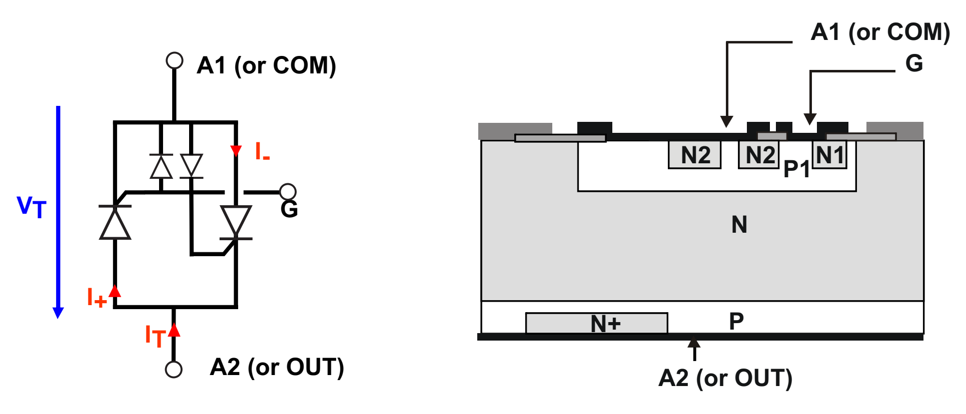
3 Gate current and triggering quadrants

3.1 Triac triggering quadrants

To switch-on an SCR, Triac, ACS or ACST, a gate current must be applied on its gate pin (G). The gate current flows between gate (G) and cathode (K) for SCR, or between gate and terminal A1 for Triac, or between gate and terminal COM for ACST and ACS.

For Triac and ACST, the gate current could be positive or negative. *Figure 10* illustrates the simplified schematic silicon structure of a Triac or an ACST and its associated equivalent diagram. As shown on this figure, a Triac or an ACST could be switched on either by a positive or a negative gate current thanks to the two diodes embedded back-to-back between G and A1. These 2 diodes are implemented by the P1-N1 and P1-N2 junctions.

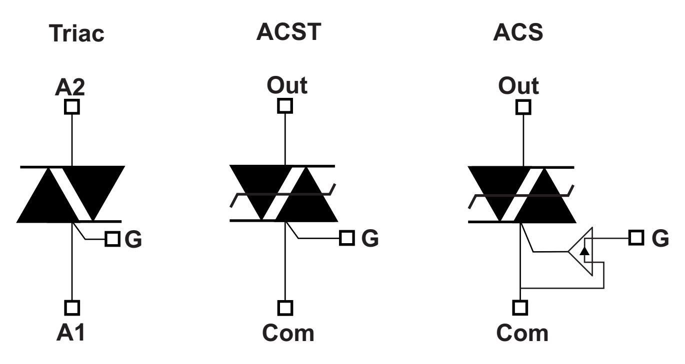
Figure 10. Triac simplified silicon structure



The silicon structure of an ACS is different from a Triac or an ACST. Here the gate is the emitter of a NPN bipolar transistor. So there is only one PN junction. The gate current can then only be sunk from the gate, and not sourced to it (refer to STMicroelectronics Application note AN3168)

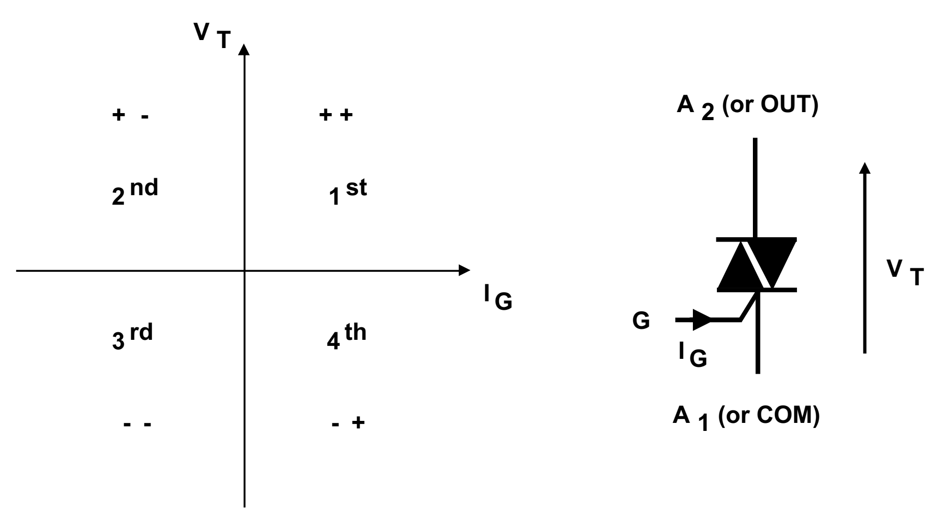
Figure 11 gives the symbol of a Triac, ACS or ACST. The symbol of the ACS illustrates the embedded gate driver that allows these devices to reach unbeatable immunity –sensitivity trade-offs. The crowbar symbol, for ACS and ACST, illustrates that these devices are overvoltage protected and can safely turn on by breakover.

Figure 11. AC switches symbols



Four triggering quadrants can be defined according to the polarity of the gate current and the polarity of the voltage applied across the device, as shown in *Figure 12*.

Figure 12. Triac triggering quadrants



For an SCR, only a positive gate current can switch-on the device. Thus, the triggering quadrants are not considered for SCR devices.

The usable triggering quadrants depend on the family and the class of the device used. The table 2 sums-up the triggering quadrants for STMicroelectronics devices.

Table 2. Usable triggering quadrants according to device family and class

Family	Class	Triggering quadrants			
		Q1	Q2	Q3	Q4
Triac	Standard	Yes	Yes	Yes	Yes
	Snubberless and logic level	Yes	Yes	Yes	NA
	Snubberless high temperature	Yes	Yes	Yes	NA
ACS / ACST	ACS	NA	Yes	Yes	NA
	ACST	Yes	Yes	Yes	NA

3.2 Operating quadrants or application

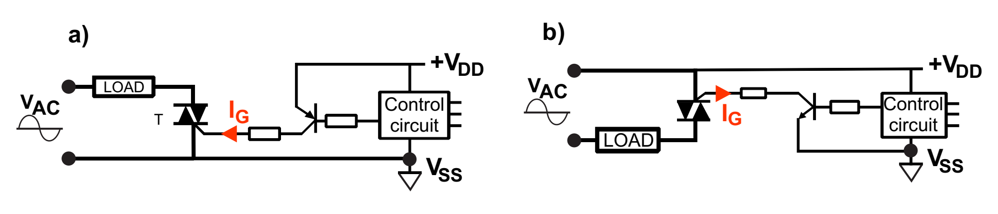
The choice of the triggering quadrants will depend only on the control circuit. Or vice-versa, the control circuit choice will depend on the operating quadrants of the selected AC switch.

The most common control circuit consists of controlling the AC switch gate directly by a low-voltage circuit which can be a microcontroller unit (MCU), ASIC, logic circuit, discrete low-voltage transistor or an opto-coupler.

Then there are two options in the way the drive reference of the AC switch (cathode K, for an SCR, terminal A1 for a Triac, terminal COM for an ACST or an ACS) is connected to the reference of the control circuit:

- Solution 1, called the “positive supply”, where the control circuit ground (V_{SS}) is connected to K or A1, as shown on *Figure 13*a.
- Solution 2, called the “negative supply”, where the control circuit voltage supply (V_{DD}) is connected to A1 or COM (see *Figure 13*b or refer to STMicroelectronics Application note AN3168 for more information on this solution).

Figure 13. Triac control with positive (a) or negative (b) power supply



In *Figure 13*, the Tb bipolar transistor is optional and the AC switch can be controlled directly by the logic circuit if its I/O pin can supply a current higher than the AC switch maximum I_{gt}.

For the “positive supply”, the current is always sourced to the gate (as it circulated from V_{DD} down to the ground through the gate). According to the line voltage polarity, the AC switch will then be triggered in quadrants Q1 or Q4. For such circuits, only standard Triacs and SCR can then be selected.

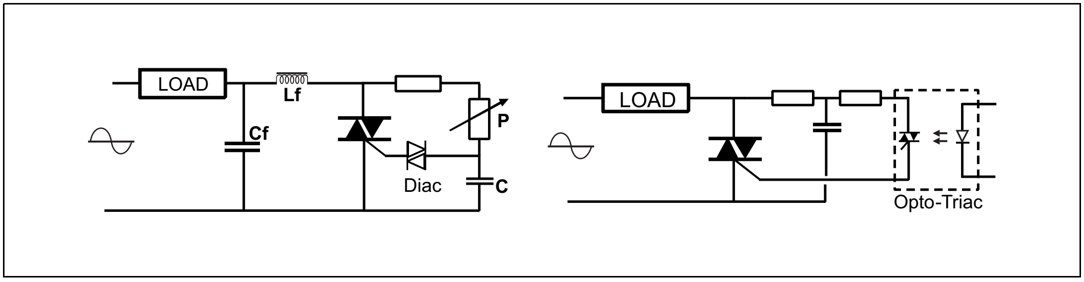
For the “negative supply”, the current is always sunk from the gate (as it circulated from V_{DD} through the gate, down to the ground). According to the line voltage polarity, the AC switch will then be triggered in quadrants Q2 or Q3.

For such circuits, all Triacs, ACS and ACST can then be selected. Only SCR cannot be controlled as they require a positive gate current. STMicroelectronics Application note AN3168 gives a circuit which can be implemented to trigger an SCR from a negative power supply.

Two other control circuits make the AC switch operate in quadrants Q1 and Q3. These circuits are those using a diac or an opto-Triac (refer respectively to *Figure 14*a and *Figure 14*b). For these two circuits, the gate current polarity is the same as the voltage polarity.

Such circuits can trigger any kind of Triac and ACST. SCR could be triggered at least for positive line cycles. But ACS devices, which require to be triggered in quadrants Q2 and Q3 can not operate with such circuits.

Figure 14. Triac control circuits operating in quadrants Q1 and Q3



4 Package selection

4.1 Surface mount device or through-hole packages

Through-hole packages are convenient for limiting the area used on the printed circuit board (PCB).

They are also the only solution when the device has to be connected to an external heatsink or to the appliance chassis.

Surface mount devices (SMD) are more often used in applications where devices are automatically mounted on the PCB. A heatsink, to limit the temperature of the device, can be implemented on the PCB by connecting a copper area on the device tab. Such solutions can be efficient for low load current (typically lower than 2 A).

4.2 Pin-out

The device pin-out can change between two technologies. This is mainly the case between ACS and Triac technologies. Two devices are then not pin-to-pin compatible.

Figure 15 gives an example of a PCB layout to allow a Z01xx Triac or an ACS108 device to be used on a same PCB. The selected device, at production step, is then soldered to the appropriate foot-print. A 180° rotation of the TO92 is enough for assembling compliance.

Figure 15. Triac and ACS pin-out compatibility (in TO92)

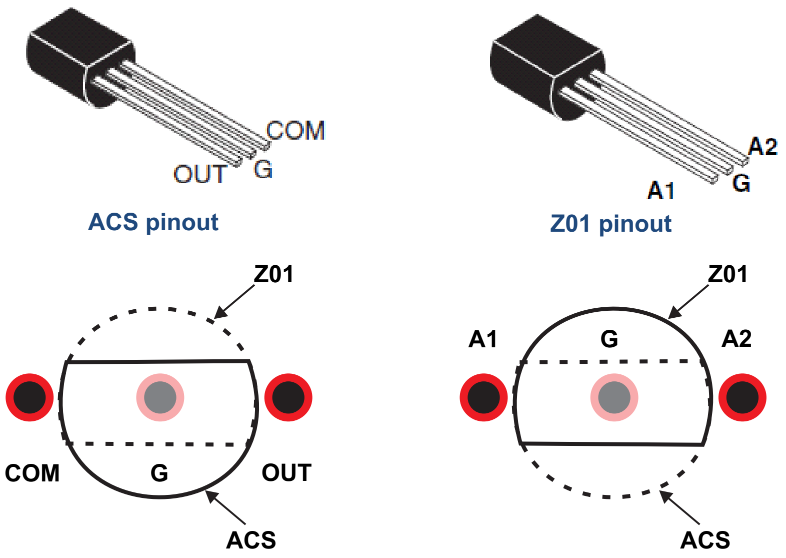
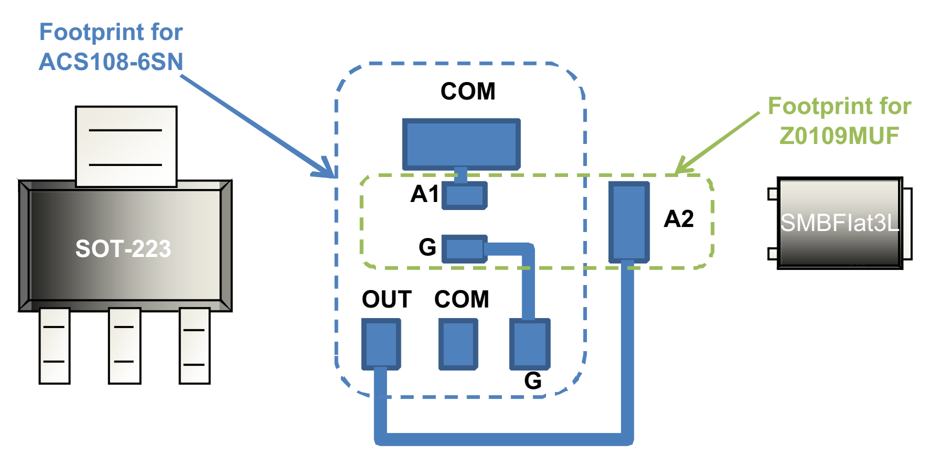


Figure 16 gives another example of PCB layout to allow production use of either an ACS108 or a Z01 Triac. These two devices do not offer the same pin-out when they are placed in a SOT-223 package. One measure could consist of using the Z01 in a SMBflat-3L package. As this package is around half the size of a SOT-223, it could use the SOT-223 footprint

while keeping a long enough creepage distance. And this is achieved with a very high density board.

Figure 16. Triac and ACS™ layout compatibility (in SOT223 and SMB-Flat)



5 Conclusion

We have seen in this paper the fundamentals of selecting an AC switch device:

- Current rating, which is mainly linked to the operating temperature and also to the device turn-off capability
- Voltage rating, according to the load to control and the mains voltage;
- Triggering quadrants and the I_{gt} which depend mainly on the application control circuit

Further information can be found in STMicroelectronics Application notes already listed in this document (AN439, AN533, AN1172, AN1966, AN3168) and in the following STMicroelectronics Application notes, which offer useful information for designers not fully familiar with these devices:

- AN2703: Definition of Triac, ACST, ACS, and SCR datasheet parameters
- AN302 and AN303: Details on the latching and holding current parameters
- AN392: Triac control with a microcontroller
- AN437: Designing a snubber circuit
- AN4030: Impacts of a capacitor connected between device gate and drive reference

6 Revision history

Table 3. Document revision history

Date	Revision	Changes
23-Jan-2014	1	Initial release.
24-Sep-2015	2	Updated two formulas in *Equation 4*.