# AN4564
# Application note

## Is a positive power supply mandatory for my application, or could a negative output work also?

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## Introduction

In this application note we explain the reasons why some appliance designers might choose a positive power supply. This selection is based mainly on the choice of switched mode power supply (SMPS). Some specific applications cases, which are detailed in *Section 3*, may also lead to the choice of a positive power supply.

Using a power supply with a positive output is not convenient for all applications. For example, as explained in *Section 1.2*, a negative supply is preferred to drive AC switches. We provide here an alternative solution which allows a negative output to be implemented whenever possible. Further, many solutions allow both a negative and a positive output (for the microcontroller) to be implemented, as shown in *Section 2*.

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# 1 Supply polarity definition and AC switch triggering quadrants

## 1.1 Positive and negative power supplies

To trigger an AC switch (i.e, Triac, ACST, ACS or SCR), a gate current has to be applied on the gate pin and circulates between the gate and AC switch reference terminals.

The AC switch reference terminal is called Cathode (K) for SCR, A1 for Triac, or COM for ACST and ACS.

This means that a non-insulated power supply is required to supply the gate, and this power supply has to be related to the AC switch drive reference (K, A1 or COM).

There are two ways to connect this drive reference to the non-insulated power supply:

- Solution 1: connect the control circuit ground (VSS) to drive reference (K or A1, as it works only for standard Triacs and SCRs).
- Solution 2: connect the control circuit voltage supply (VDD) to drive reference (A1 or COM, as it works only for Triacs and ACST/ACS devices).

Solution 1 is called a positive power supply. The voltage supply (VDD) is indeed above the drive reference (VSS) which is connected to the mains terminal (line or neutral), as shown in *Figure 1*. If the supply is a 5 V power supply, then VDD is 5 V above the mains reference.

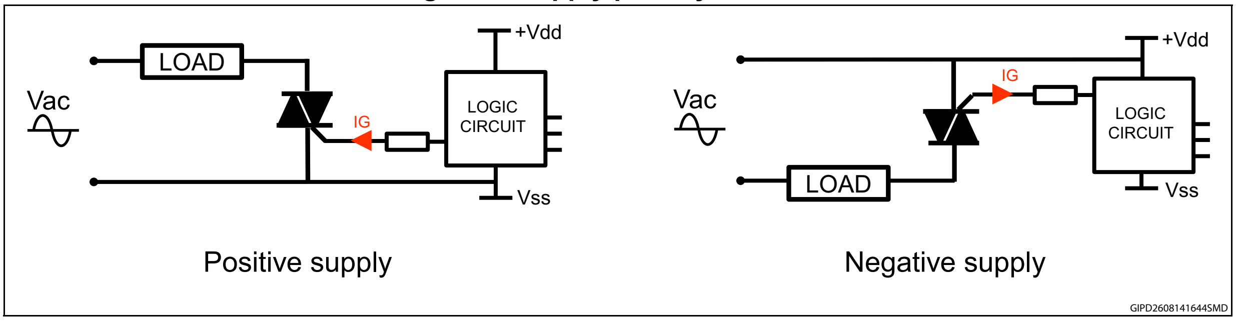
This topology can be used only with standard Triacs and SCR, not with non-standard Triacs, ACS and ACST, as explained below.

It should also be noted that a positive power supply is required when the control circuit has to drive a MOSFET with its drive reference (source) connected to the mains. Indeed, power MOSFETs are N-channel devices and need a gate-source positive bias to be turned on.

Solution 2 is called a negative power supply. The voltage supply reference (VSS) is indeed below A1 or COM, which is connected to the mains reference (line or neutral). If the supply is a 5 V power supply, then VSS is 5 V below the line reference.

This topology can be used with all Triacs, ACS and ACST, but not with SCR, as explained below.

**Figure 1. Supply polarity definition**



## 1.2 AC switch triggering quadrants

To switch on an AC switch, like any bipolar device, a gate current must be applied between its gate pin (G) and its drive reference terminal (refer also to AN3168).

Several cases occur:

- For an SCR, this gate current has to be positive (circulating from G to K).
- For a Triac and ACST, the gate current could be positive or negative (depending on the voltage applied to the device).
- For an ACS, the gate current has to be negative (circulating from COM to G).

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 on *Figure 2*.

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

**Figure 2. Triggering quadrants**

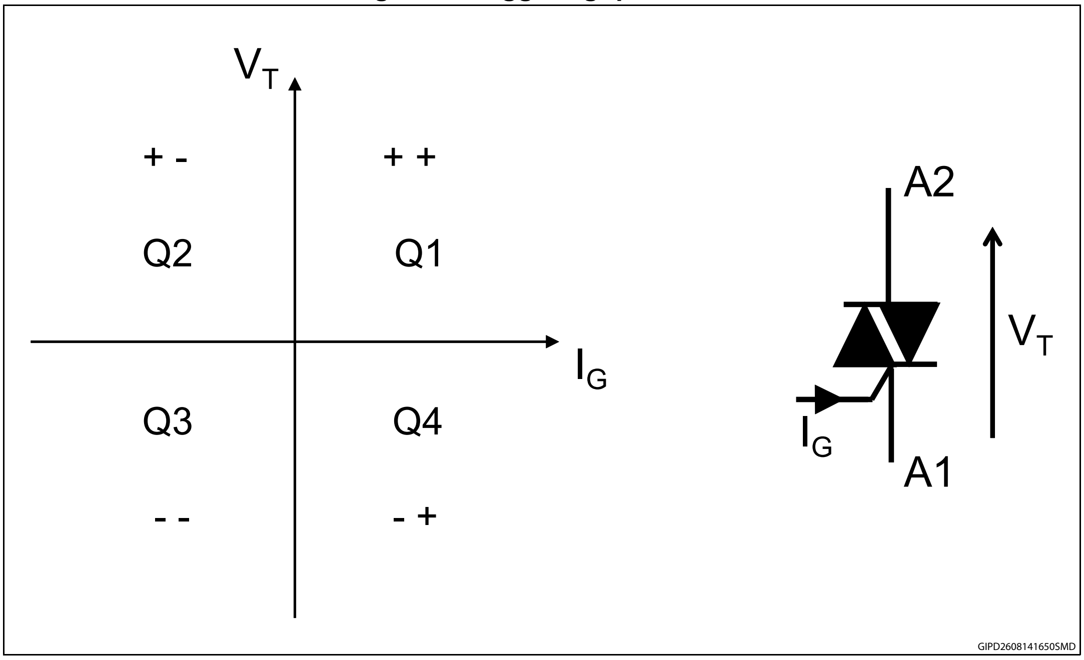



*Table 1* summarizes the triggering quadrants for each of STMicroelectronics' AC switch families.

**Table 1. Triggering quadrants for each AC switch family and class**

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

As the triggering quadrants Q2 and Q3 are common to all Triacs and ACS / ACST devices, the control mode in Q2 and Q3 is recommended. Indeed, the replacement of one device by another (for example, if an ACST is used in place of a standard Triac) is possible. Moreover, the triggering in Q4 is not advised because the triggering gate current is the highest. Also the dI/dt capability of Triacs is lower in Q4 compared to the other quadrants. Working in Q2 / Q3 quadrants is then advised, even for standard Triacs, to decrease board consumption and increase board reliability.

As Q2 and Q3 triggering means the current is sunk from the device gate, the power supply upper level has to be connected to the device drive reference (COM or A1). This means the control circuit must use a “negative power supply”.

# 2 Supply topology impact on polarity (negative/positive)

## 2.1 Buck or buck-boost converter

Such supplies are usually used for low output currents and when an insulated supply is not required.

Two different cases can occur based on whether or not the converter internal supply is used.

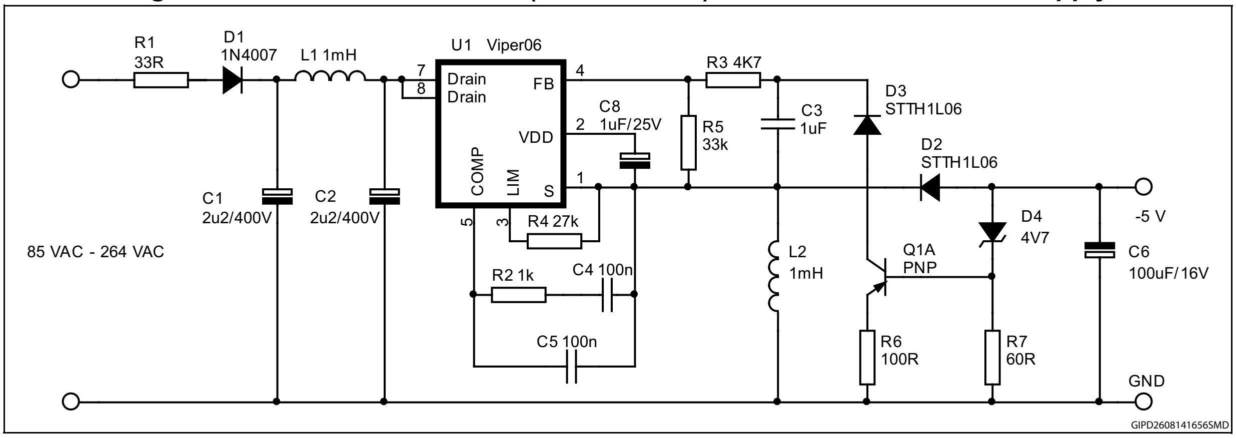
### 2.1.1 The SMPS converter IC uses its internal supply

As the supply converter already features the supply for its internal MOS (the source of which is connected back to the mains through the converter output capacitor), the designer does not need to implement it. So the designer has the freedom to choose either a positive or negative supply output according only to application requirements.

If a negative output is required, then a buck-boost can be implemented (see *Figure 3*). Good output voltage precision is achieved with a regulator that consists of Q1A, D4, R6 and R7. A buck-boost is as simple to implement as a buck, and offers better output voltage stability at low output power (refer to AN3168).

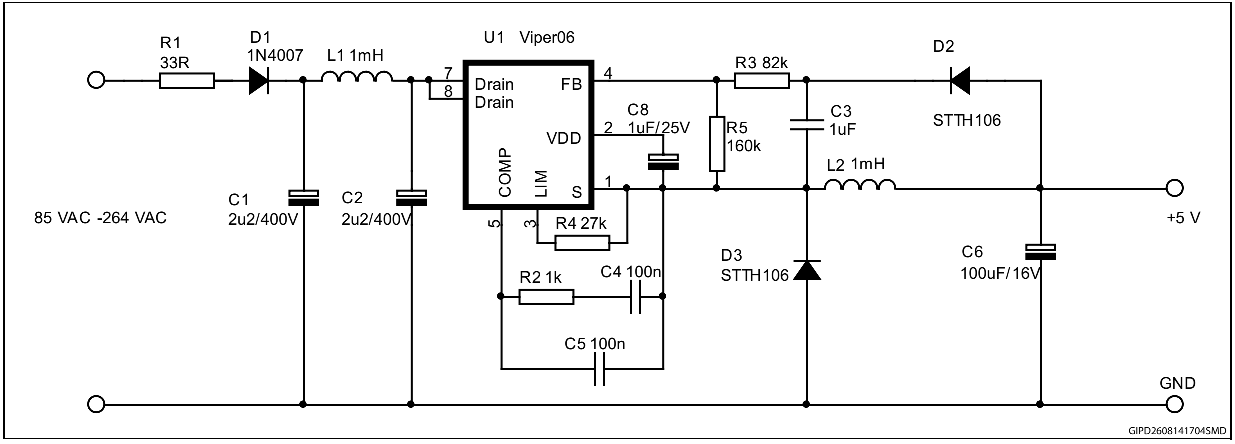
The schematic in *Figure 3* uses a VIPer06 converter from the VIPerPlus family. This device is available in a small SSO10 surface mount package.

**Figure 3. Buck-boost converter (-5 V / 120 mA) with use of internal self-supply**




It is clear that because a buck-boost allows only negative supply implementation, it can be used only if a positive supply is not mandatory for the application. If a positive supply is required (refer to *Section 3*), a buck converter must be implemented (*Figure 4*). In cases where +/- 20% output voltage precision is sufficient, the circuit in *Figure 4* can be used as shown. If greater precision is required, an output regulator similar to Q1A, D4, R6 and R7 in *Figure 3* must be used.

Figure 4. Buck converter (+5 V / 150 mA) with use of internal self-supply



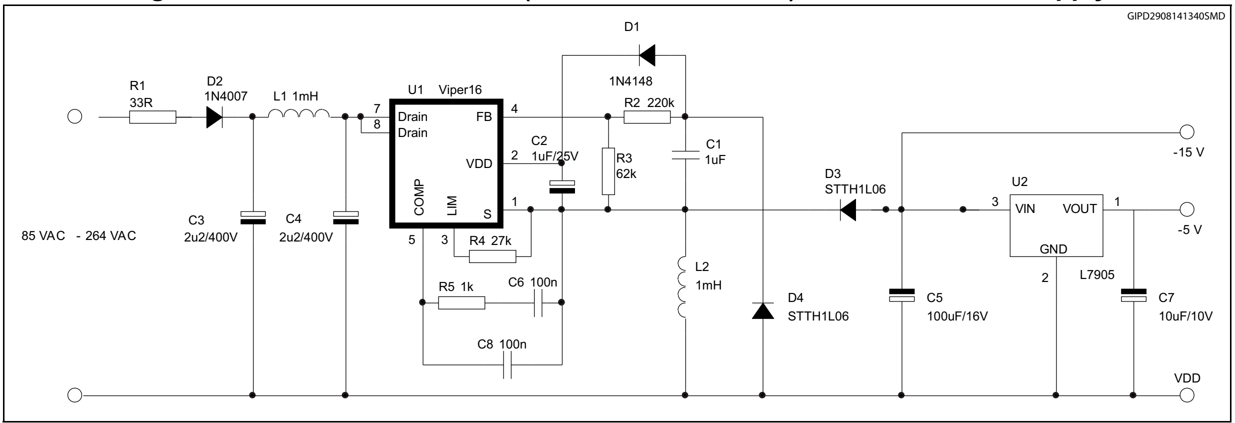

## 2.1.2 The SMPS converter IC is supplied from an external supply

Sometimes it could be decided not to use the converter IC internal supply for the sake of higher efficiency, especially for operation at very low power consumption in standby mode.

In this case, as explained in *Section 1.1*, a positive supply is required to supply the converter IC, as the VIPerPlus internal MOSFET has its source connected back to the mains through the SMPS output capacitor.

The classic choice for designers wishing to implement a positive power supply is to implement a buck converter. But a buck-boost converter can also work. Indeed, as shown in *Figure 5*, the freewheeling diode D3 allows capacitor C3 to be charged positively referred to the source. This enables the implementation of a positive supply for the Viper IC while a negative supply is implemented by the buck-boost converter.

Figure 5. Buck-boost converter (-5 V & -15 V / 150 mA) with external self-supply




## 2.2 Flyback converter

A flyback converter is required for higher output currents and/or when an insulated supply is required.

In this case two different scenarios can occur based on whether or not the SMPS IC uses its internal self-supply.

### 2.2.1 The SMPS converter IC uses its internal supply

If the SMPS IC controller uses its internal supply, and the MCU supply does not need to be insulated, a negative output could be implemented by the converter with a single secondary winding (see *Figure 6*), unless a positive supply is mandatory (refer to *Section 3*).

But if the MCU is referenced on the DC side, after a rectifier diode and before an inverter used for motor control, or if the MCU cannot be connected to the mains voltage for safety reasons (for example, if the MCU is connected to a sensor which could be touched by an end-user), then the MCU supply needs to be insulated. Two supplies can then be implemented with 2 secondary windings (each one insulated from the other): one is used to implement the insulated output for the MCU, and one is used to implement the negative output (connected to the AC side) as shown on *Figure 7*.

**Figure 6. Non-insulated single negative (-3.3 V) supply in flyback topology used for MCU and AC switch supply (IC supplied by its internal self-supply)**

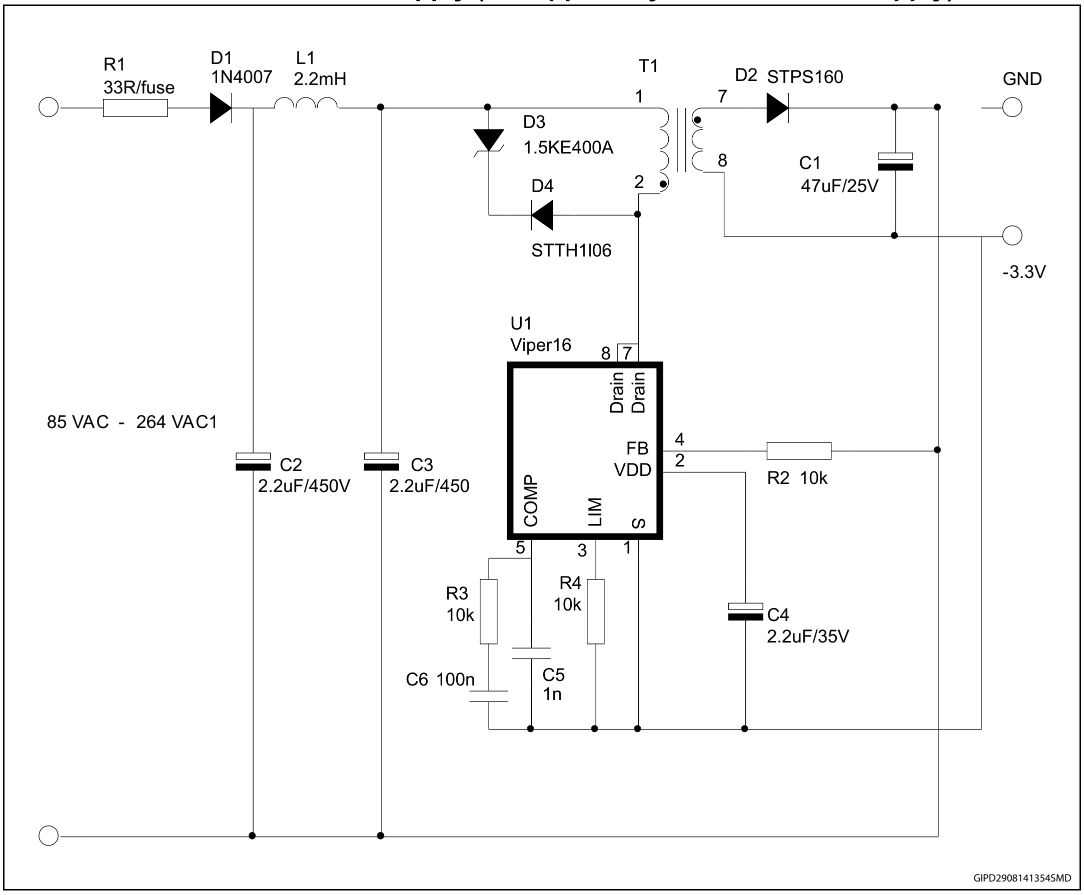
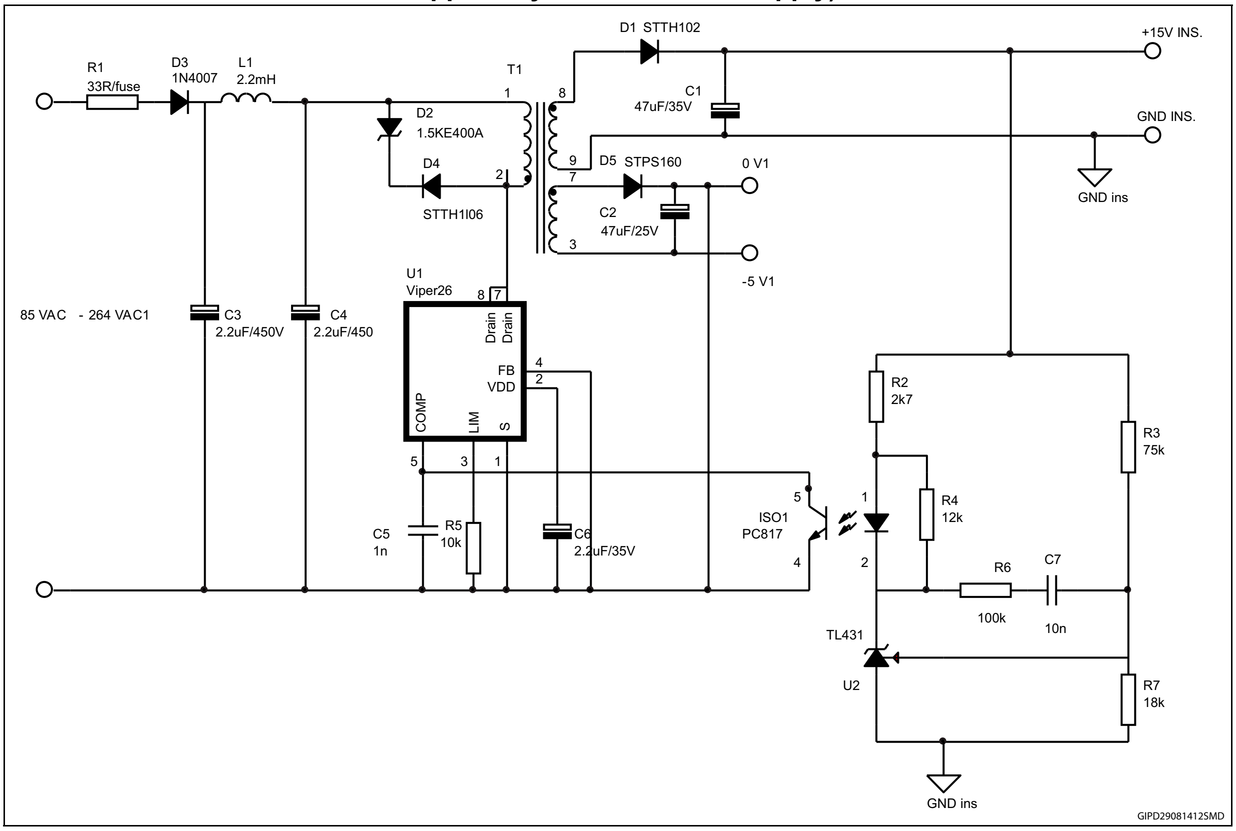


**Figure 7. Non-insulated negative supply and insulated positive supply in flyback topology (IC supplied by its internal self-supply)**




As shown in the schematic in *Figure 7*, as the negative output is not regulated by the feedback circuit, such a double-output supply has to be used only in applications where the current sunk from the regulated output (+15 V here) is always higher than the current sunk from the non-regulated output.

## 2.2.2 The SMPS converter IC is supplied from an external supply

If the IC converter is supplied externally, traditionally a designer's first choice is to implement a positive supply, as the MOSFET source is referenced back to the mains. But another solution is possible to supply both the IC with a positive supply and to implement a negative supply for other components like Triacs (also referenced to the mains). This solution consists in connecting the IC source back to the mains through its output bulk capacitor (refer to C5 in *Figure 8*). Then, as the IC VDD is connected to the mains, this allows a negative supply (*Section 1.1*) to be implemented.

In this solution, the VIPerPlus internal MOSFET current, which is flowing out from the source terminal, partially discharges C5. This is not a big concern as the MOSFET current is the transformer primary current, and so is much lower than the secondary current going out from terminal 4 of the secondary winding. So C5 is well charged and not discharged.

It should also be noted that, thanks to D6 diode, the VIPerPlus supply capacitor (C6) is not discharged by the MOSFET current.

Also, a second solution to implement a negative and a positive supply, both referenced on AC side, consists of using a 3-terminal secondary winding like the one shown in *Figure 9*. Here, as the negative output is not regulated by the feedback circuit, such a supply must be used only in applications where the current sunk from the regulated output is always higher than the current sunk from the non-regulated output. The VIPerPlus source could be connected to the -5 V level, as was done on *Figure 8*, in cases where both negative and positive supplies have to be monitored.

If an insulated supply is required for the MCU, then the solution in *Figure 10* can be implemented.

**Figure 8. Flyback with insulated positive supply (+15 V / +3.3 V) and non-insulated negative supply (-15 V) for SMPS IC and AC switches**

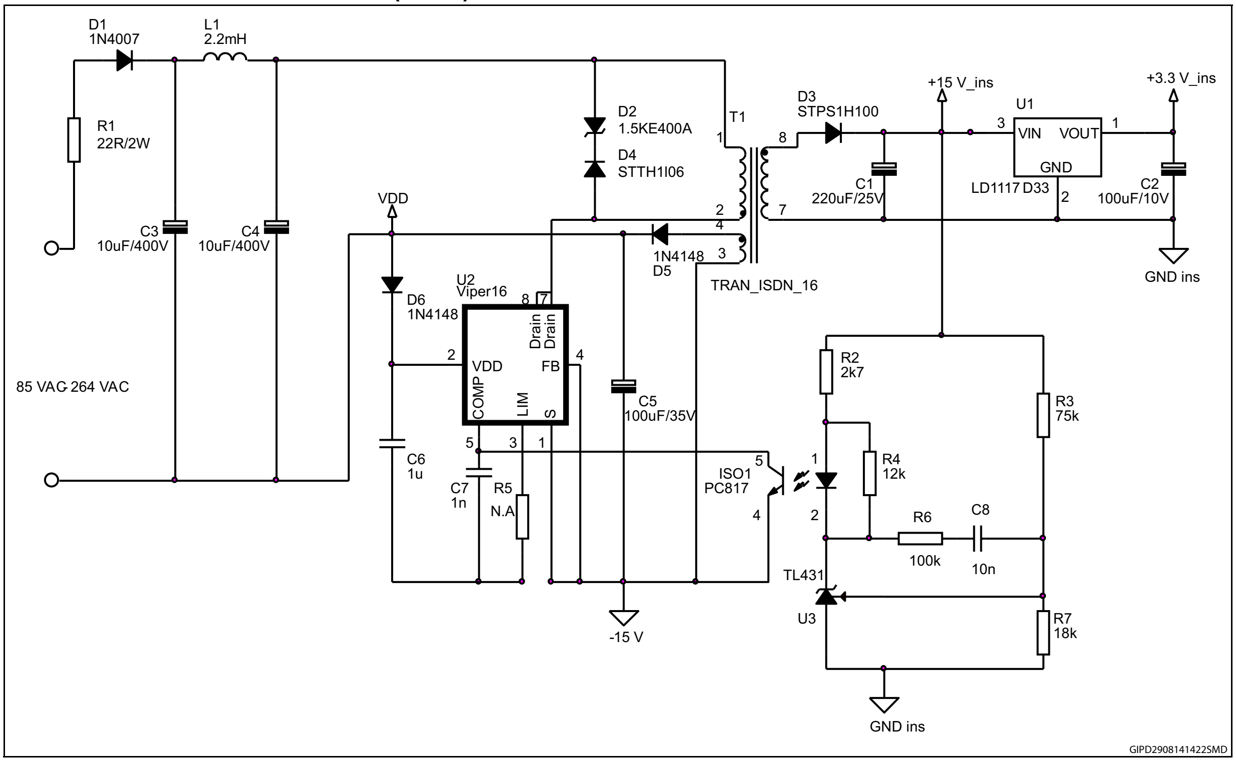


**Figure 9. Flyback with non-insulated (-5 V) negative & positive supplies (+15 V / +3.3 V) implemented with a 3-terminal winding**

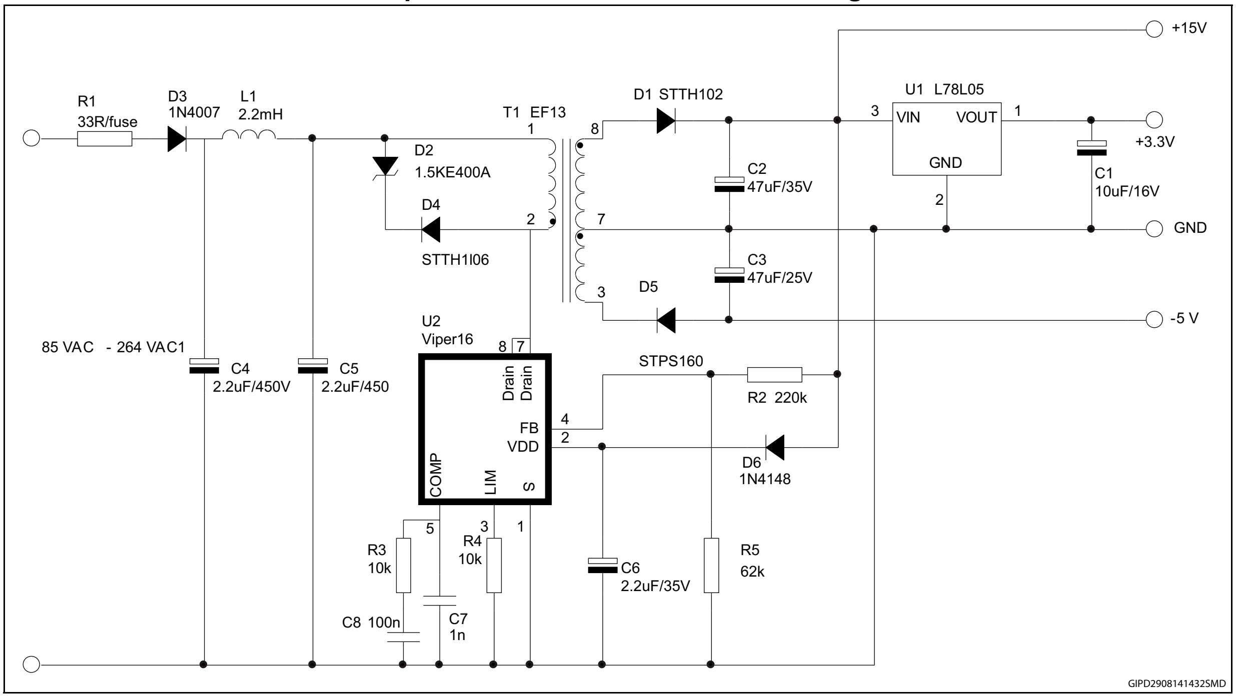
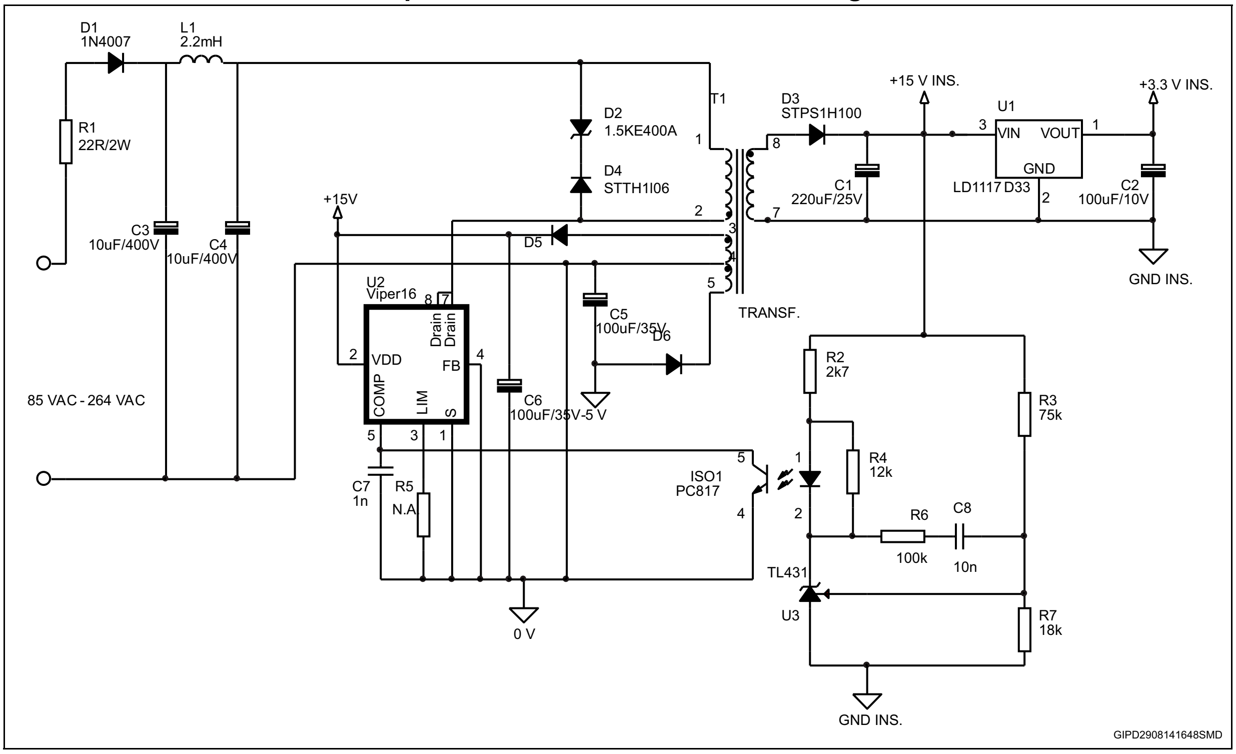



**Figure 10. Flyback with insulated supply and non-insulated negative & positive supplies implemented with a 3-terminal winding**



# 3 Other reasons a positive supply could be required and solutions to switch to a negative supply

We list here some reasons, apart from the choice of power supply topology, which could lead to the need for a positive power supply.

Again, as a negative supply is preferred to trigger AC switches, we explain how an alternative solution could be implemented, if possible, with a “negative-biased” circuit.

## 3.1 Power measurement circuits

There are several applications where a sensor is referenced to the mains. This is done, for example, to monitor certain electrical parameters. For example, for universal motor controls, a shunt resistor is often added in series with the AC switch to sense the load current and then implement a speed or torque closed-loop control, or just to protect the AC switch in case overcurrent is sensed (as shown on *Figure 11*). The shunt resistor R2 is then by definition referenced to the mains as the Triac drive reference. And so the MCU reference is also referenced to the mains.

Circuits are then traditionally implemented with a positive supply (see *Figure 11.a*) where the shunt resistor is connected to the supply GND. Indeed, it seems more logical to sense a voltage which increases when the shunt current increases also (as given in *Equation 1* below).

**Equation 1**

$$I_{Tpos} = \frac{V_{ADC}}{R_2}$$

If a negative supply is used, then the schematic is that shown on *Figure 11.b*. In this case, the R2 shunt is necessarily connected to the VDD of the supply. The MCU ADC input sees a voltage which decreases when the Triac current increases, as it follows *Equation 2* below. So, the logic of the MCU firmware has to be adapted to take into account this reversed measurement. But this is quite simple to implement.

**Equation 2**

$$I_{Tneg} = \frac{V_{DD} - V_{ADC}}{R_2}$$

Please also note that the circuits in *Figure 11* can only sense the current during half a cycle (circuit “a” allows positive current, going back to Neutral, to be sensed; circuit “b” allows the negative part of the same current to be sensed). To sense both polarities, a circuit with an offset has to be implemented (like that shown in *Figure 12* for the voltage sensor).

**Figure 11. Current sensor schematic with positive supply (a) or negative supply (b)**

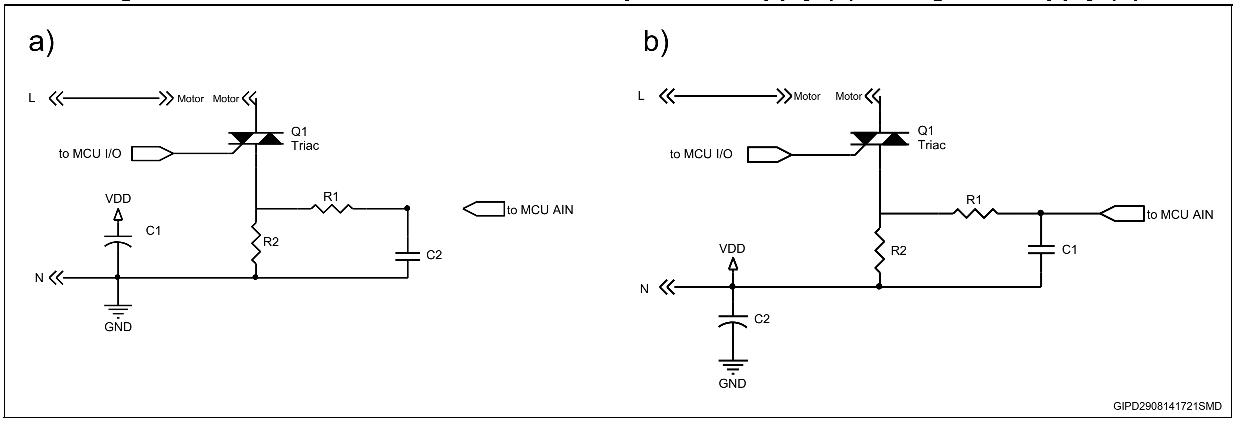
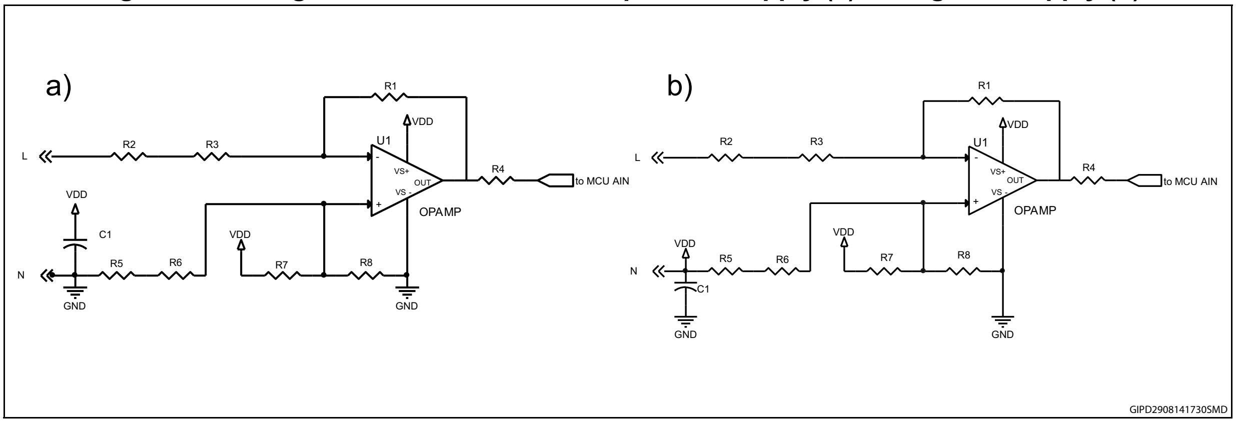



**Figure 12. Voltage sensor schematic with positive supply (a) or negative supply (b)**




In power metering applications, the mains voltage must be measured in order to calculate the energy sunk from the grid. Here also, traditionally, designers implement circuits using a positive supply (see *Figure 12.a*). But this schematic can also be adapted to a negative supply (see *Figure 12.b*). The amplifier is connected as a differential amplifier and the zero reference is shifted by the offset implemented with the R7-R8 divider. The voltage measurement is the same as for positive supply as long as R5 and R6 are much higher than R7 and R8, in order not to disturb the offset put on the non-inverting input of the operational amplifier. The formula is then:

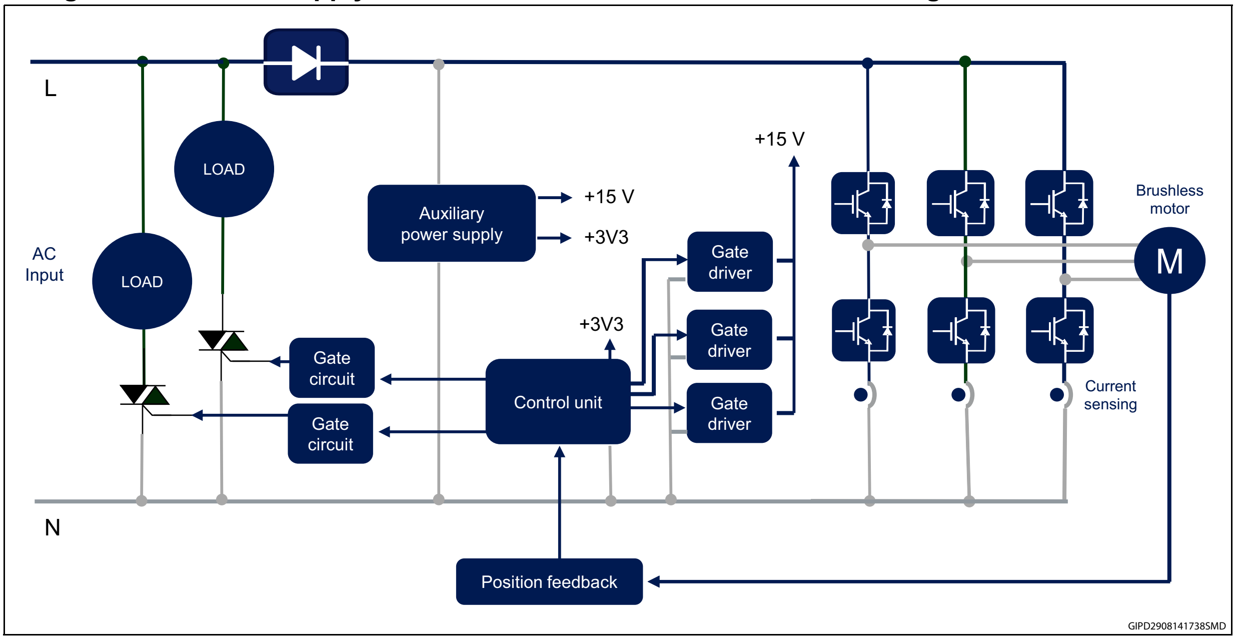
**Equation 3**

$$V_{out} = -V_{LN} \bullet \frac{R_1}{R_2 + R_3} + \frac{R_7}{R_8} \bullet V_{DD}$$

## 3.2 Control of BLDC motor

Another application where a positive power supply can be required is the case where a 3-phase inverter is used. Indeed, there are some topologies of motor control in the low power range which use a single diode, instead of a diode bridge, to rectify the line voltage. Then, as shown on *Figure 13*, the low-side IGBTs or MOSFETs of the inverter are referenced to the neutral (or the line). As these devices need a positive bias to be applied to their gate referred to their source, a positive supply has to be implemented. As Triacs are controlled by the same control circuit as the inverter legs, they are also triggered by a current sourced to their gate, i.e. in quadrants Q1 and Q4.

**Figure 13. Positive supply for both Triacs and inverter control with single-wave rectification**




## 3.3 Voltage regulator

*Figure 14* provides a reminder of negative and positive voltage regulators.

Positive regulators are used when the common point of both the +15 V and +5 V is the GND. This is the case when the GND of both positive power supplies has to be connected to the mains (neutral terminal in our case).

Negative regulators must be used when the common point of both the 15 V and 5 V supplies is the upper level. This is the case especially if the lower negative supply (5 V in our case) must be connected to the mains, which could be required if this supply is used to drive AC switches.

It should be noted that if the designer prefers to have the GND as the common point of the 15 V and the 3.3 V or 5 V supplies, a positive regulator can also be used for a negative supply (refer to *Figure 15*).

**Figure 14. Positive (a) and negative (b) voltage regulator classic circuits**

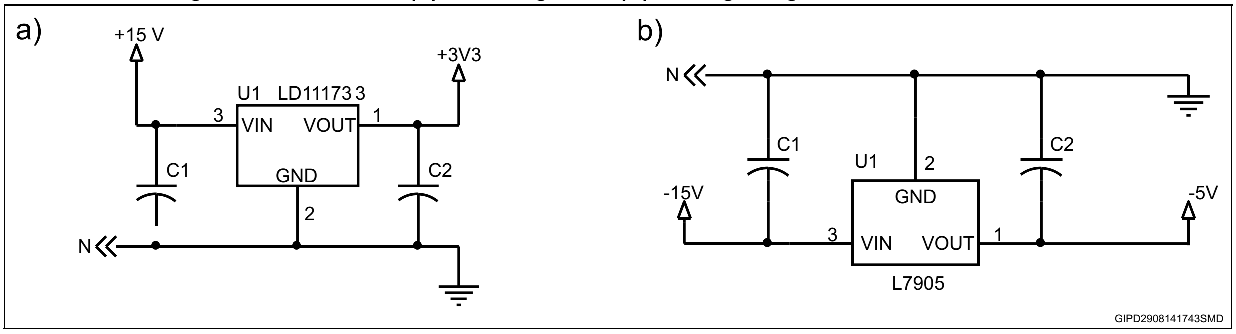
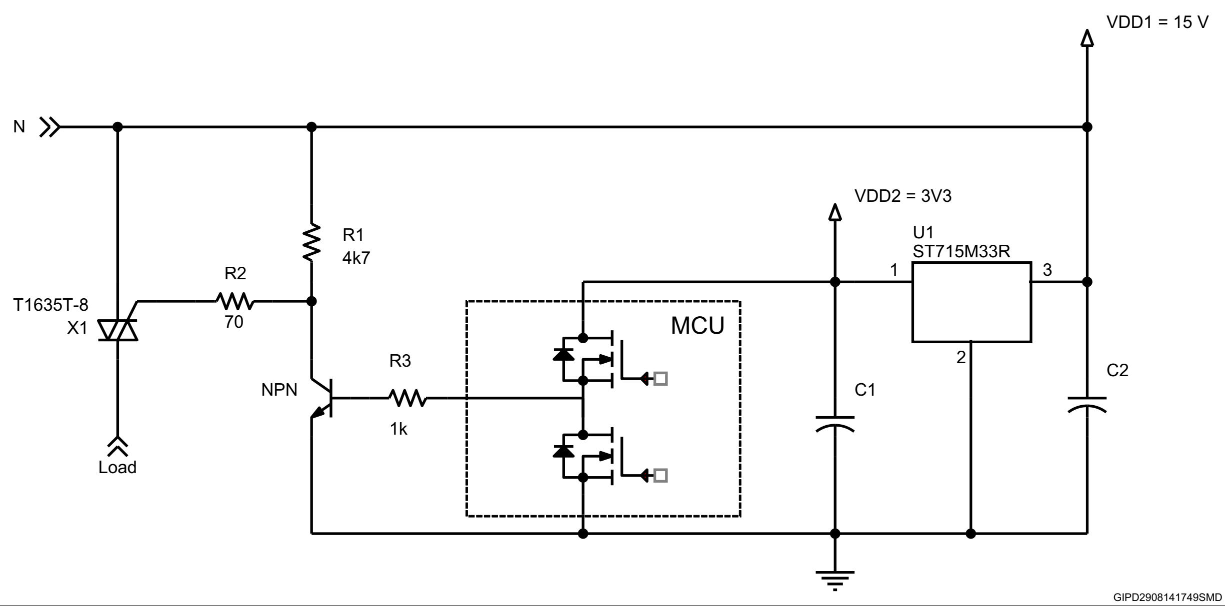


Figure 15. Positive regulator used for negative supply of Triac control circuit




Another reason why a positive power supply is used is because positive voltage regulators allow lower power consumption in standby mode. Indeed, positive linear voltage regulators can be found with internal consumption in the range of 50 µA, while the typical consumption of a negative voltage regulator is around 2 mA. This quiescent current significantly affects the standby consumption of the SMPS.

Another reason is that 3.3 V MCUs are promoted widely and it is very difficult to find accurate 3.3 V negative voltage regulators with low consumption.

For these reasons, the circuit in the *Figure 15* schematic could be implemented to combine both the advantages of a negative power supply and the advantages of a positive voltage regulator.

# 4 Conclusion

This application note has listed why, in some cases, a positive supply is required to simplify the SMPS or the sensor design. Although the positive topology is often chosen by habit, we have provided several examples where a negative supply output could also be implemented as easily as that of a positive one, and with the benefit of allowing AC switches to be driven in quadrants Q2 and Q3.

If a negative output can then be implemented for the MCU, as proposed in the various examples given, the AC switch driving circuits proposed in AN3168 could be used.

If a positive supply is really mandatory, application note AN440 explains how to implement an AC switch driving circuit according to the different AC switch technologies and the different application cases (one or two positive supplies, positive supply for MCU and negative supply available).

# 5 Revision history

**Table 2. Document revision history**

| Date | Revision | Changes |
|---|---|---|
| 11-Sep-2014 | 1 | Initial release. |