AN2859
Application note

Multiplexed diagnostics of AC switches using two STCC08s

Introduction

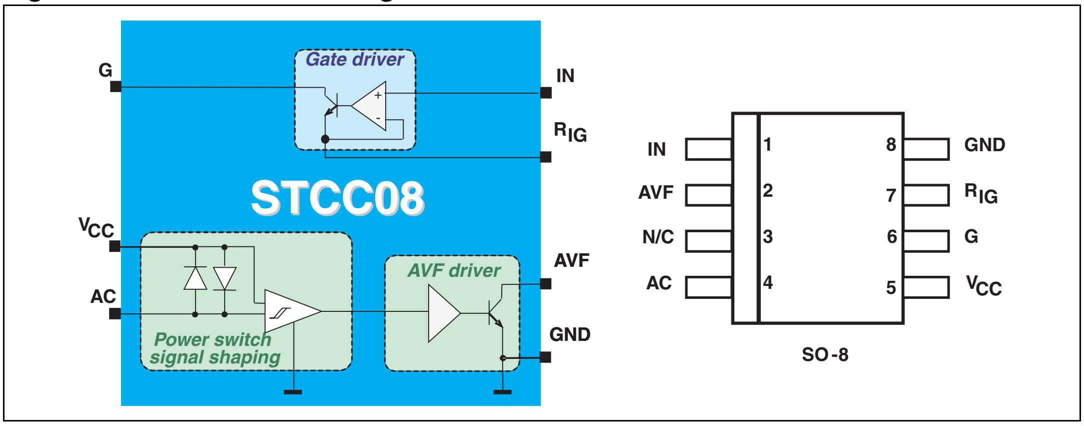
The aim of this application note is to present opportunities to reduce the number of input pins used on a microcontroller unit (MCU) to diagnose failures of several AC switches with the STCC08. This document deals with the multiplexed diagnostics of two STCC08 and gives technical recommendations on the implementation of this solution.

STCC08 overview

The STCC08 has been designed to improve home appliance safety. This new device can drive an AC switch (Triac, ACST and ACS) with a gate current I_{GT} up to 10 mA and to send back to the microcontroller unit a signal image of the voltage across the controlled AC switch (this signal defines the AC switch state). The STCC08 has three functional blocks (see *Figure 1*).

- A "gate driver" block used to drive an AC switch and to interface directly the STCC08 with the MCU (CMOS compatible)
- A "power switch signal shaping" block used to measure the AC switch voltage in both AC line cycles
- An "AVF driver" block used to give an image of the AC switch voltage to the MCU (digital information)

Figure 1. STCC08 block diagram



For more information about the STCC08, please refer to the ST Application note AN2716.

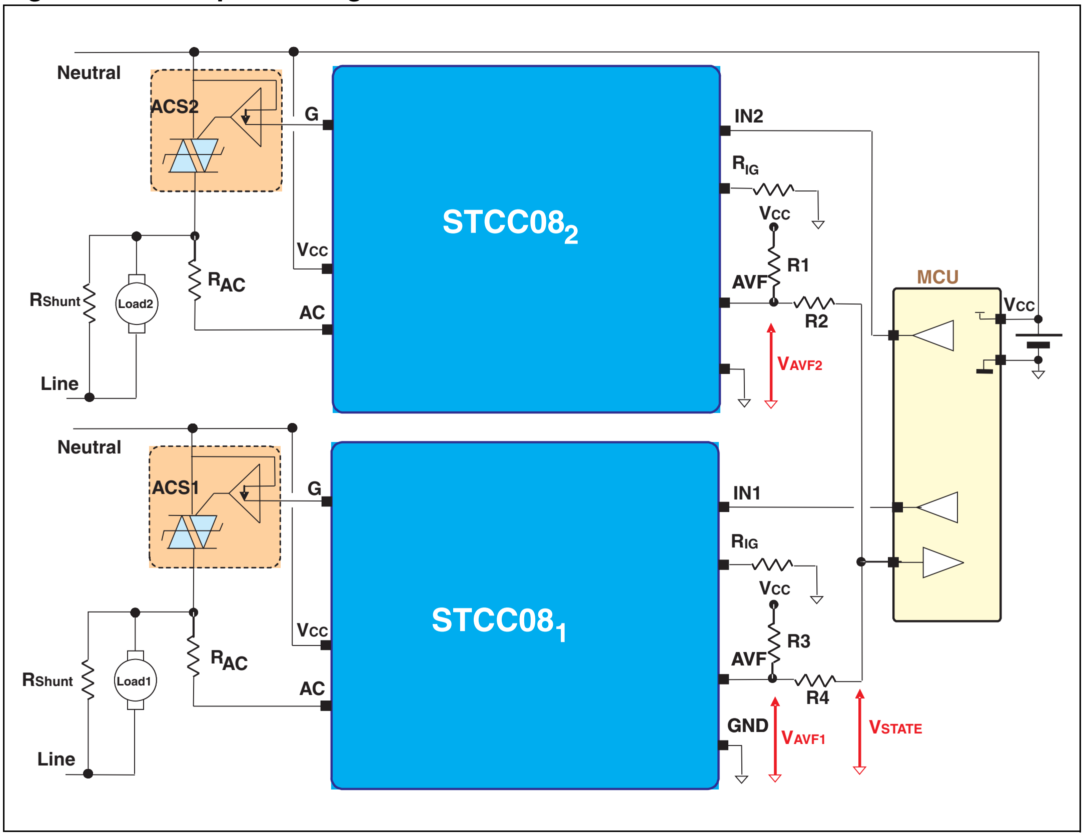
Contents

1 Multiplexed diagnostics

1.1 Principle

The multiplexed diagnostic allows the detection of the state of several AC switches independently using only one MCU input. In this case, an analog/digital converter input (ADC) of the MCU should be used and must be configured with no pull-up resistor. In this document, only the multiplexed diagnostic of two STCC08 ($STCC08_1$ and $STCC08_2$) is described (see *Figure 2*). Note that two output pins of an MCU should be used to control each STCC08 (IN1 and IN2).

Figure 2. Multiplexed diagnostic schematic of two STCC08



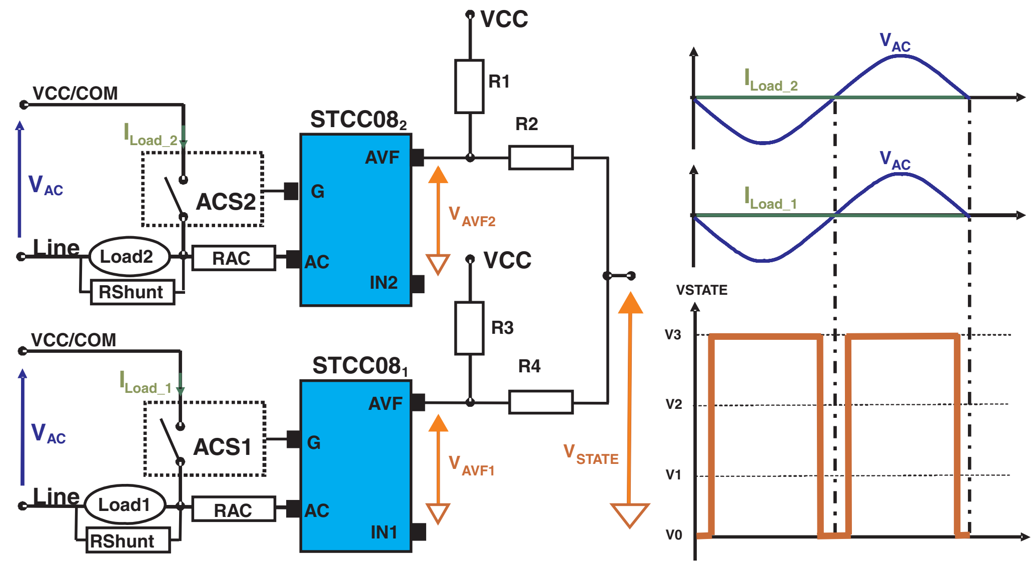
To distinguish the state of each AC switch (ACS1 and ACS2) a divider bridge is used. Resistors R_1, R_2, R_3 and R_4 are designed to convert the V_{AVF} digital signal given by each STCC08 (V_{AVF1} and V_{AVF2}) into an analog signal (V_{STATE}). Knowing the control state of each STCC08 (IN1 and IN2), the MCU is able to identify the state of each AC switch by analyzing the V_{STATE} signal (see *Section 1.2*).

Note: *The STCC08 AVF output is an open collector output. Resistors R_1 and R_3 bias the STCC08 AVF output and limit the collector current to 5 mA. For further information, and in particular, resistor values for R_{AC}, R_{shunt}, and R_{IG}, refer to the ST Application note AN2716.*

1.2 Failure mode detection of two AC switches

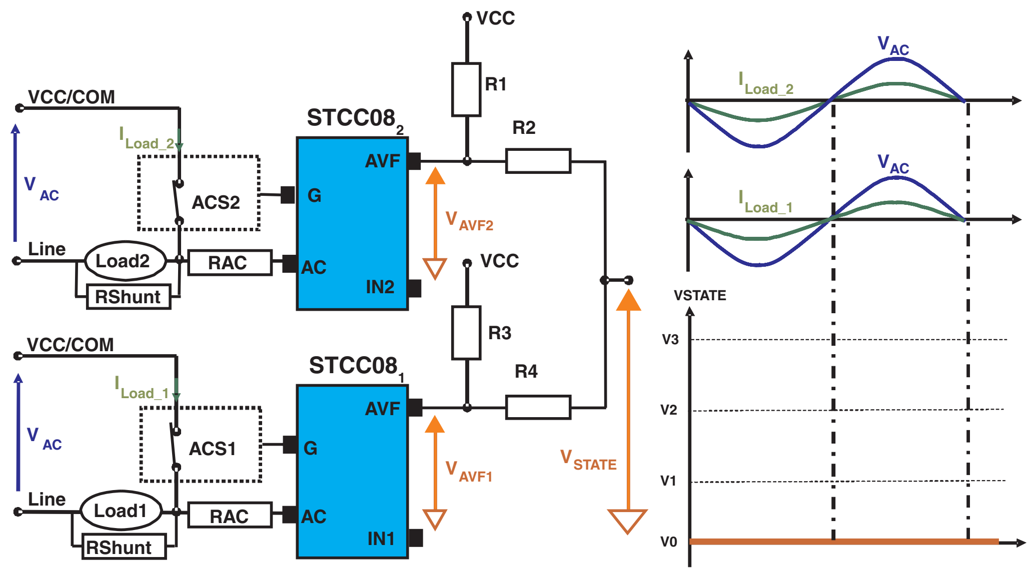
Figure 3 to *Figure 12* give the V_{STATE} signal level according to the state of each AC switch. V_0, V_1, V_2 and V_3 are levels reached by the parameter V_{STATE} and depends on R1, R2, R3, and R4 resitor values. *Table 1* shows that we only need four different levels to define the state of each AC switch.

Figure 3. Case 1: $V_{STATE} = V_3$ (except at each zero crossing of the AC line)



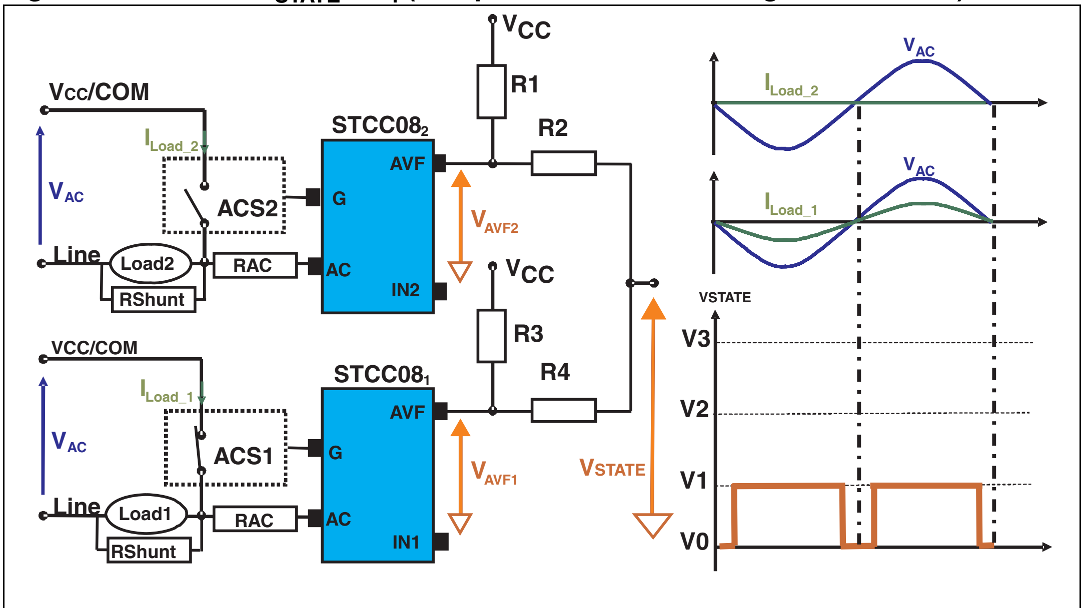
ACS1 and ACS2 are not in conducting state

Figure 4. Case 2: $V_{STATE} = V_0$



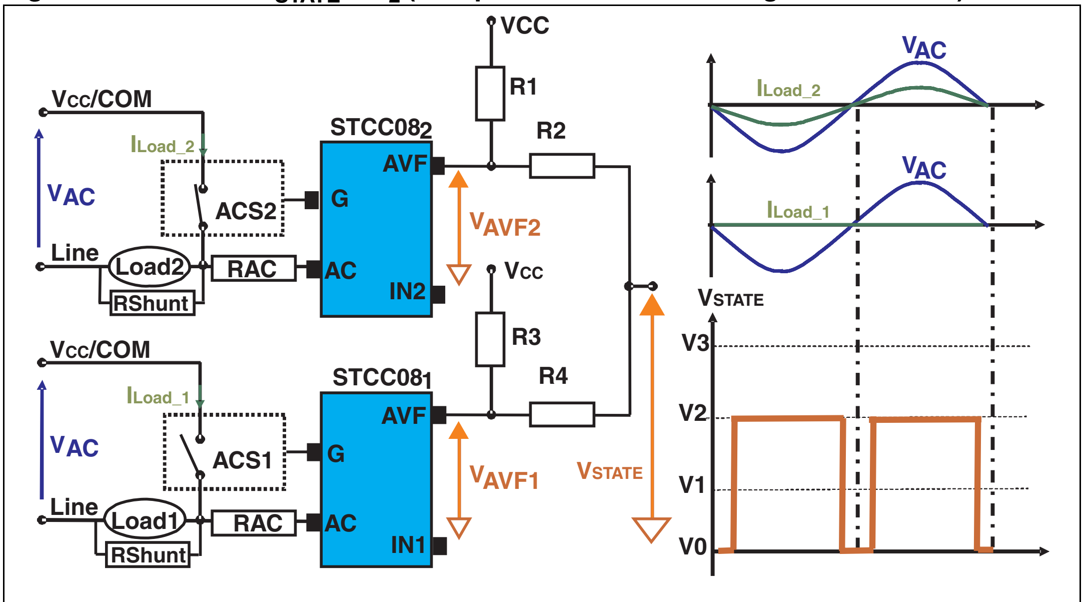
ACS1 and ACS2 are in conducting state

Figure 5. Case 3: $V_{STATE} = V_1$ (except at each zero crossing of the AC line)



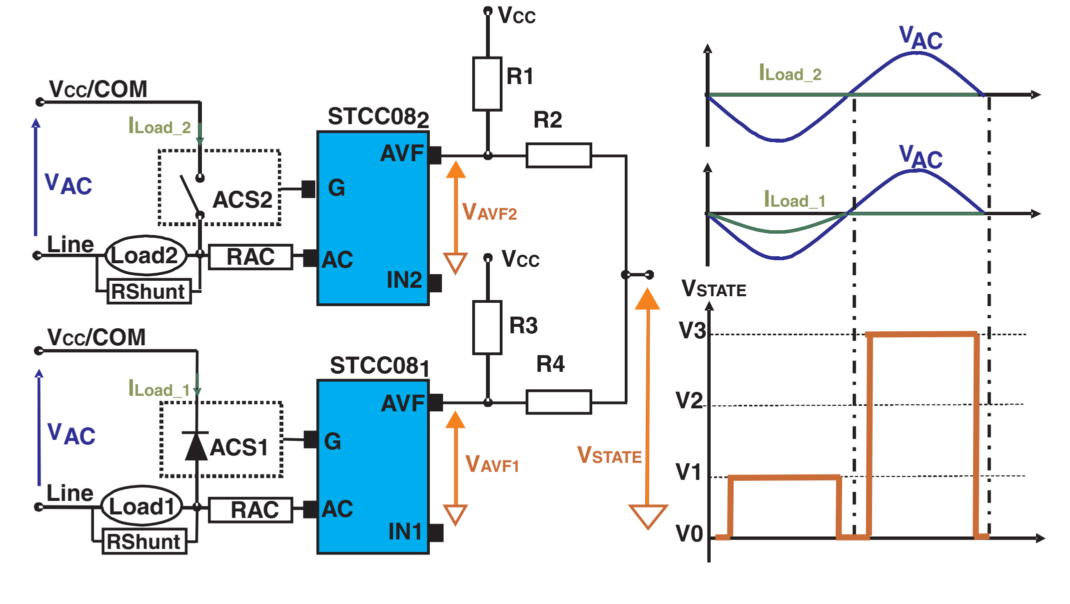
ACS1 is in conducting state and ACS2 is not in conducting state

Figure 6. Case 4: $V_{STATE} = V_2$ (except at each zero crossing of the AC line)



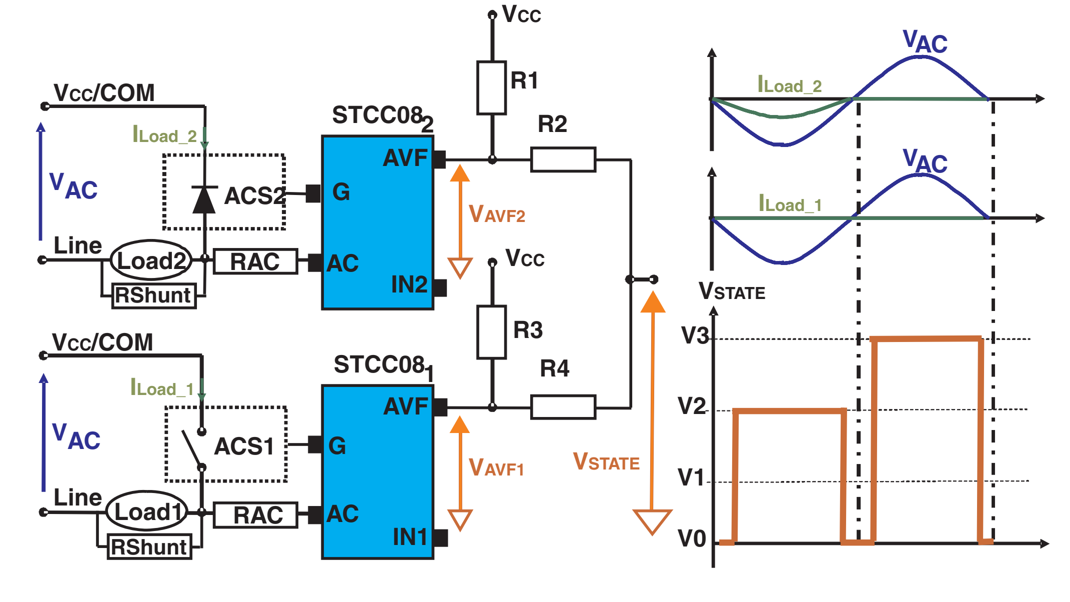
ACS1 is not in conducting state and ACS2 is in conducting state

Figure 7. Case 5: V_{STATE} toggles between V_1 and V_3 at each AC line cycle (except at each zero crossing of the AC line)



ACS1 is failed in diode mode and ACS2 is not in conducting state

Figure 8. Case 6: V_{STATE} toggles between V_2 and V_3 at each AC line cycle (except at each zero crossing of the AC line)



ACS1 is not in conducting state and ACS2 is failed in diode mode

Figure 9. Case 7: V_{STATE} toggles between V_1 and V_2 at each AC line cycle (except at each zero crossing of the AC line)

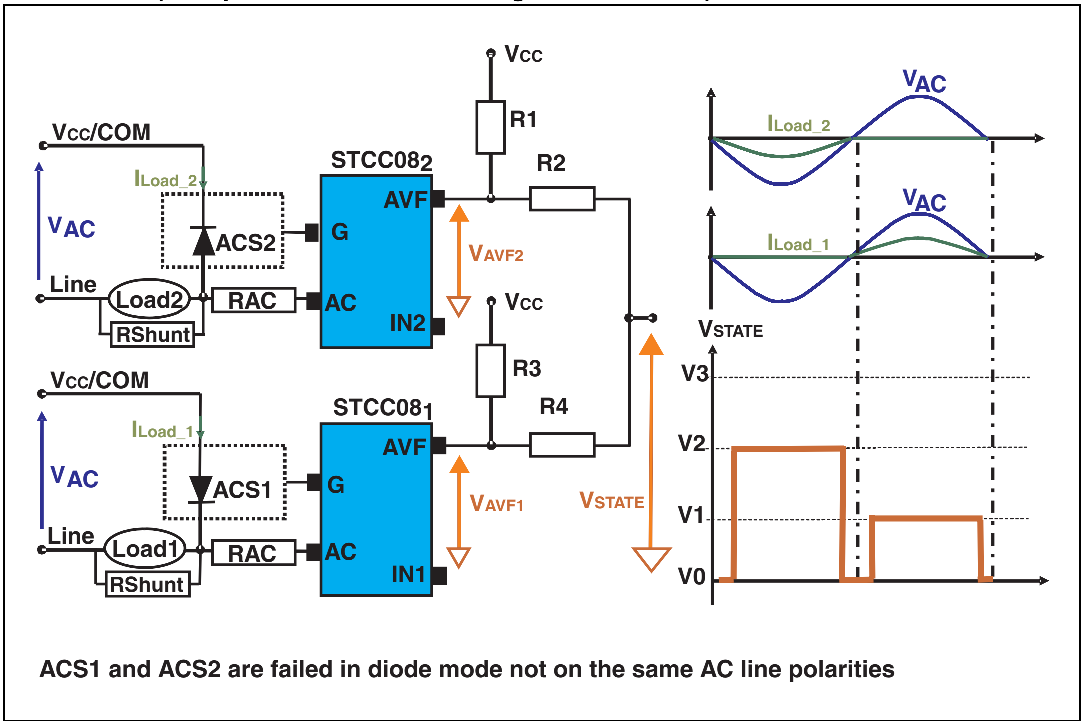


Figure 10. Case 8: V_{STATE} toggles between V_0 and V_3 at each AC line cycle (except at each zero crossing of the AC line)

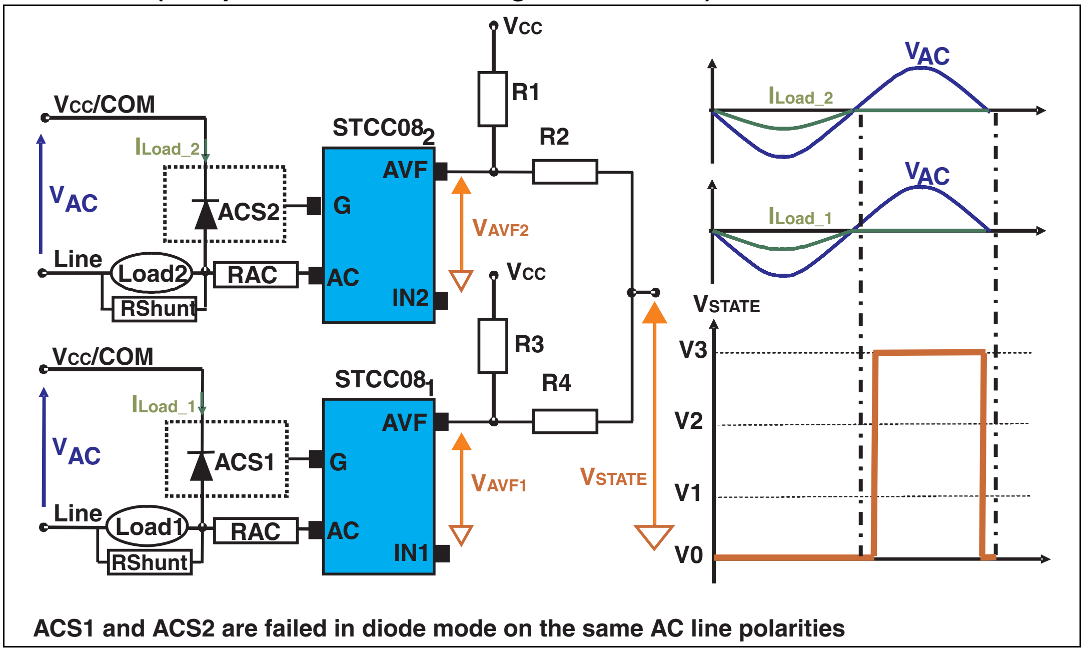
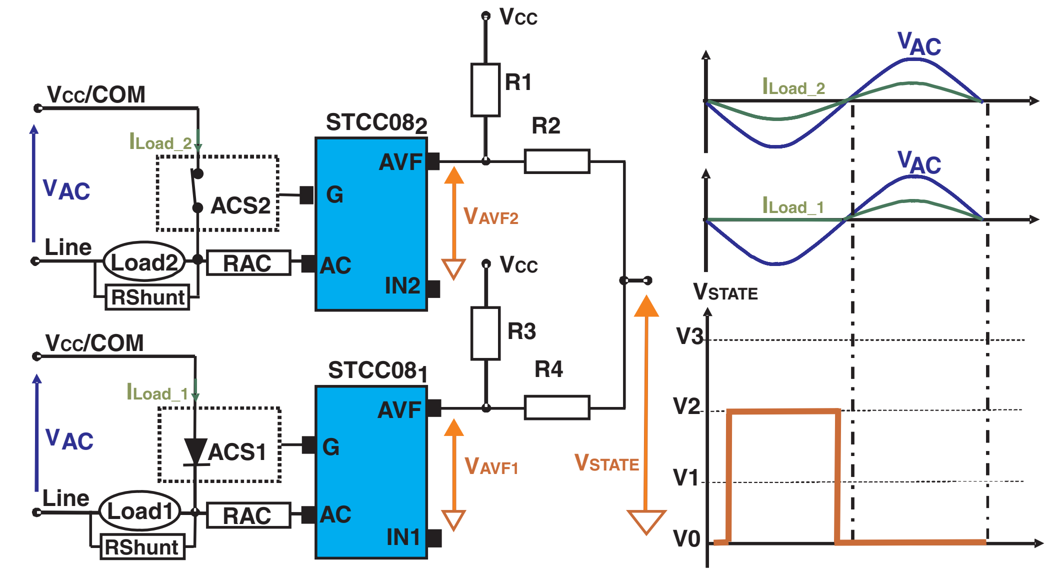
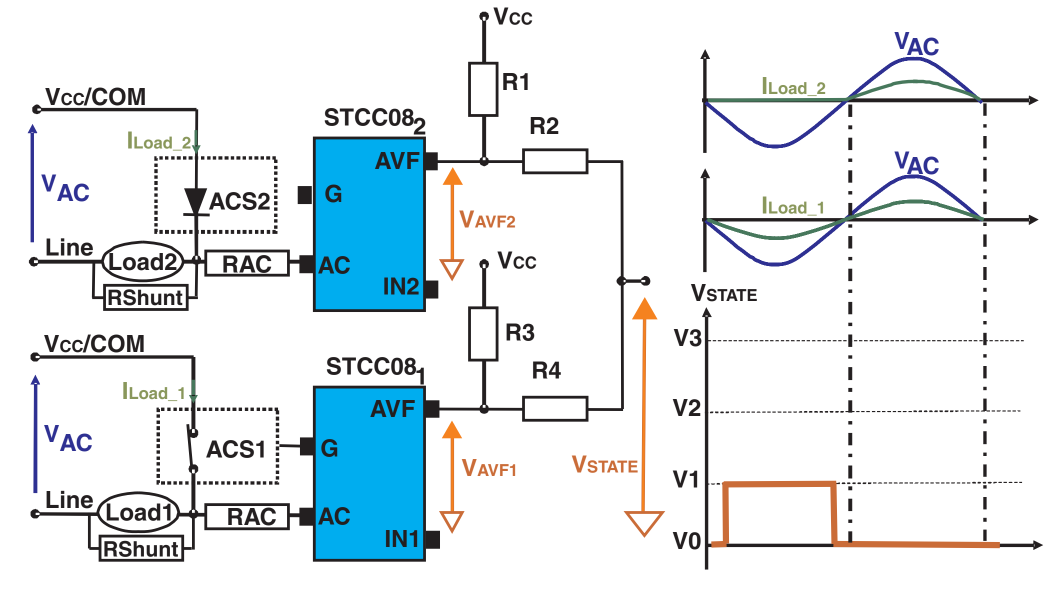


Figure 11. Case 9: V_{STATE} toggles between V_2 and V_0 at each AC line cycle



ACS1 is failed in diode mode and ACS2 is failed in short circuit

Figure 12. Case 10: V_{STATE} toggles between V1 and V0 at each AC line cycle



ACS1 is failed in shot circuit and ACS2 is failed in diode mode

Table 1. Variation of the V_{STATE} signal according to the AC switch states

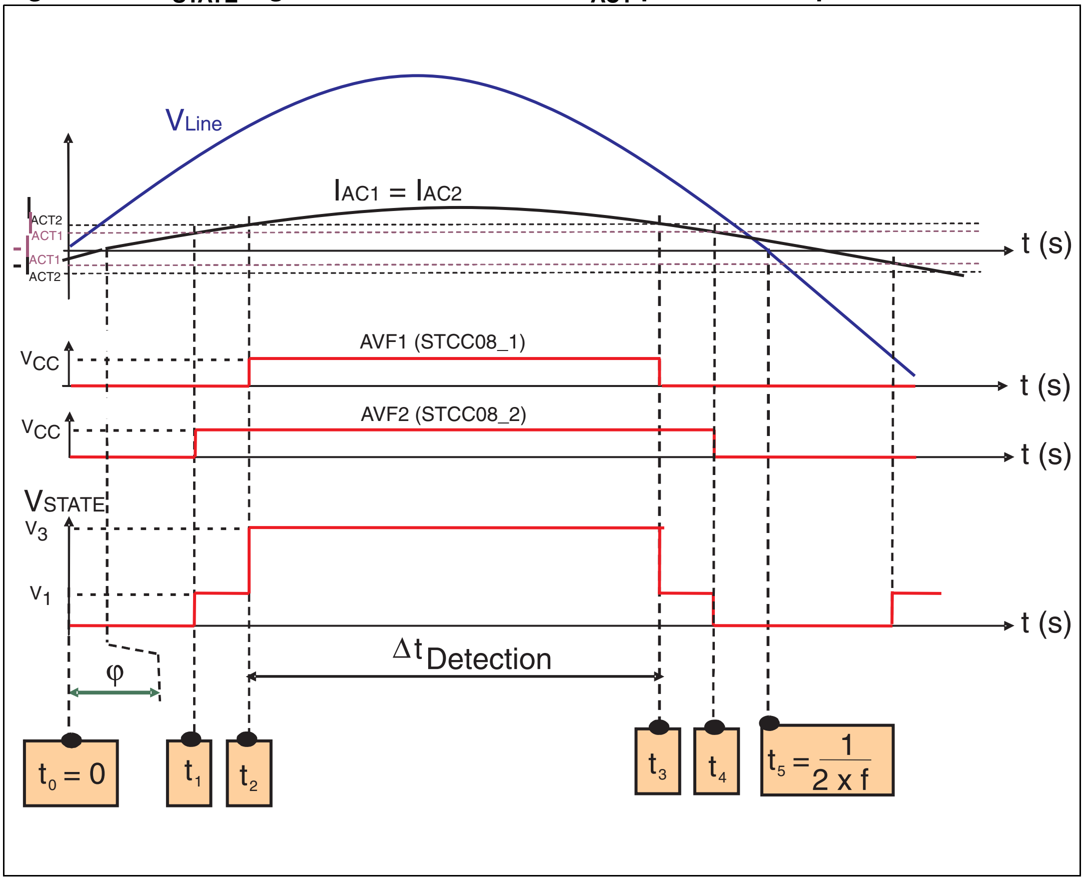
ACS1 state	ACS2 state	V_{STATE} status
ON	ON	$V_{STATE} = V_0$
ON	OFF	$V_{STATE} = V_1$
OFF	ON	$V_{STATE} = V_2$
OFF	OFF	$V_{STATE} = V_3$

Knowing the control state of each STCC08 (IN1 and IN2) and according to *Table 1*, the MCU is able to detect the AC switch state by analyzing V_{STATE} signal. *Appendix A* defines the states of each ACS according to the V_{STATE} signal level (V_0, V_1, V_2 and V_3) and the control state of each STCC08. In the case of failure of one of the AC switches, the MCU can place the application in a safe configuration by switching off an appliance front-end relay.

1.3 V_{AVF} signal reading synchronization

The STCC08 AVF output signal is an image of the AC switch voltage. This signal toggles between V_{CC} and zero level (GND) according to whether the STCC08 AC input current (I_{AC}) is higher or not than I_{ACT} (see AN2716). In case of multiplexed diagnostics the slight I_{ACT} electrical variation between ICs may result in the state of the AVF signal of each STCC08 (either V_{CC} or zero level) not changing at exactly the same time. This has an impact on the V_{STATE} signal and on the AC switches state detection (see *Figure 13*). Note that I_{ACT1} and I_{ACT2} define respectively the STTCO8 I_{AC} input current for $STCC08_1$ and $STCC08_2$ to allow V_{AVF} signal to toggle between VCC and GND. For example, if the two STCC08 are not controlled (IN1 = IN2 = 0) and AC1 and AC2 are not in conducting state the AC1 and AC2 can be interpreted (see *Table 1*) as failed in short circuit if V_{STATE} is read between t_0 and t_1 ($V_{STATE} = V_0$).

Figure 13. V_{STATE} signal variation due to the I_{ACT} parameter dispersion



The V_{STATE} should be read between times t_2 and t_3. To simplify the AC switches detection, it is advised to read the V_{AVF} signal around the AC line peak voltage to avoid any inappropriate interpretation of the AC switches state. Note that when the IN1 and/or IN2 signals are removed, a parasitic detection of the AC switch state exists up to the next AC load current zero crossing (see AN2716). Anyway to ensure a reliable detection of the AC switch state when the IN1 and/or IN2 control is removed, the AVF reading should be read 10 ms after the IN1 and/or IN2 control has been removed and at the next peak mains voltage.

Note: *It is recommended that the AVF signal be read during several AC line cycles around the AC line peak voltage.*

2 V_{STATE} level definition

According to the state of each AC switch, V_0, V_1, V_2 and V_3 levels are defined by equations 1, 2, 3 and 4 (see also Appendix B). In this document V_{AVF1_L} and V_{AVF2_L} are respectively the STCCO8$_1$ and STCCO8$_2$ AVF output at the low level. The minimum and maximum values of AVF at low level are respectively 0 V and 1 V.

Equation 1

ACS1 and ACS2 are on

$$V_0 = \frac{(V_{AVF1\_L} \cdot R_2 + V_{AVF2\_L} \cdot R_4)}{R_2 + R_4}$$

Equation 2

ACS1 is on and ACS2 is off

$$V_1 = \frac{V_{CC} \cdot R_4 + V_{AVF1\_L} \cdot (R_1 + R_2)}{R_1 + R_2 + R_4}$$

Equation 3

ACS2 is on and ACS1 is off

$$V_2 = \frac{V_{CC} \cdot R_2 + V_{AVF2\_L} \cdot (R_3 + R_4)}{R_2 + R_3 + R_4}$$

Equation 4

ACS1 and ACS2 are off

$$V_3 = V_{CC}$$

The tolerance of the resistors (R_1, R_2, R_3 and R_4), the STCC08 output AVF signal electrical dispersion and the DC power supply characteristics induce a dispersion on V_0, V_1, V_2 and V_3 levels (see Table 2).

Table 2. Variation of the V_{STATE} signal according to the AC switch states

ACS1 state	ACS2 state	V_{STATE} status
ON	ON	$V_{0\_Min} < V_{STATE} < V_{0\_Max}$
ON	OFF	$V_{1\_Min} < V_{STATE} < V_{1\_Max}$
OFF	ON	$V_{2\_Min} < V_{STATE} < V_{2\_Max}$
OFF	OFF	$V_{3\_Max} > V_{STATE} > V_{3\_Min}$

Knowing the previous equations 1, 2, 3 and 4, the resistors standard value and the tolerance of the resistors, V_{x_Max} and V_{x_Min} (x = 0, 1, 2, or 3) values are defined respectively by equations 5, 6, 7, 8, 9, 10, 11 and 12.

V_{CC_Min} and V_{CC_Max} are respectively the minimum and maximum power supply voltage of the application. X_{R_Max} and X_{R_Min} are the tolerances of the resistors. For example, with 5% resistor tolerance X_{R_Max} and X_{R_Min} are respectively 1.05 and 0.95. $V_{AVF\_L\_Max}$ and $V_{AVF\_L\_Min}$ values are fixed by the STCC08 AVF output electrical dispersion at low level with:

$V_{AVF\_L\_Max} = V_{AVF1\_L\_Max} = V_{AVF2\_L\_Max} = 1\ V$

and

$V_{AVF\_L\_Min} = V_{AVF1\_L\_Min} = V_{AVF2\_L\_Min} = 0\ V$

Equation 5

ASC1 is on and ACS2 is on.

$$V_{0\_Max} = V_{AVF\_L\_Max} \cdot \frac{(R_2 + R_4) \cdot X_{R\_Max}}{(R_2 + R_4) \cdot X_{R\_Min}} = V_{AVF\_L\_Max} \cdot \frac{X_{R\_Max}}{X_{R\_Min}}$$

Equation 6

ASC1 is on and ACS2 is on.

$$V_{0\_Min} = V_{AVF\_L\_Min} \cdot \frac{(R_2 + R_4) \cdot X_{R\_Min}}{(R_2 + R_4) \cdot X_{R\_Max}} = 0\ \ V$$

Equation 7

ASC1 is on and ACS2 is off.

$$V_{1\_Max} = \frac{V_{CC\_Max} \cdot R_4 \cdot X_{R\_Max} + V_{AVF\_L\_Max} \cdot (R_1 + R_2) \cdot X_{R\_Max}}{(R_1 + R_2 + R_4) \cdot X_{R\_Min}}$$

Equation 8

ASC1 is on and ACS2 is off.

$$V_{1\_Min} = \frac{V_{CC\_Min} \cdot R_4 \cdot X_{R\_Min} + V_{AVF\_L\_Min} \cdot (R_1 + R_2) \cdot X_{R\_Min}}{(R_1 + R_2 + R_4) \cdot X_{R\_Max}}$$

Equation 9

ASC1 is off and ACS2 is on.

$$V_{2\_Max} = \frac{V_{CC\_Max} \cdot R_2 . X_{R\_Max} + V_{AVF\_L\_Max} \cdot (R_3 + R_4) \cdot X_{R\_Max}}{(R_2 + R_3 + R_4) \cdot X_{R\_Min}}$$

Equation 10

ASC1 is off and ACS2 is on.

$$V_{2\_Min} = \frac{V_{CC\_Min} \cdot R_2 \cdot X_{R\_Min} + V_{AVF\_L\_Min} \cdot \left(R_3 + R_4\right) \cdot X_{R\_Min}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Max}}$$

Equation 11

ASC1 is off and ACS2 is off.

$$V_{3\_Max} = V_{CC\_Max}$$

Equation 12

ASC1 is off and ACS2 is off.

$$V_{3\_Min} = V_{CC\_Min}$$

3 Resistance settings

Equation 13 shows how to select values for R_1 and R_3 resistances. $I_{\text{AVF\_Max}}$ is the maximum current sunk by the STCC08 AVF pin and should be lower than 5 mA.

Equation 13

$$R_1 = R_3 = R \geq \frac{2 \cdot V_{\text{CC\_Max}}}{I_{\text{AVF\_Max}}}$$

Knowing the R_1 and R_3 resistor standard values, the tolerance of the resistors, the STCC08 AVF output electrical dispersion and the DC power supply characteristic, R_2 and R_4 resistances value should be chosen by using equations *14* , *15* , and *16* (see also *Appendix C*).

Equation 14

$$\begin{cases} \Rightarrow \; V_{\text{1\_Min}} > V_{\text{0\_Max}} \\ \Rightarrow \; R_4 > \dfrac{(R + R_2) \cdot \left[V_{\text{AVF\_L\_Max}} \cdot \left(\dfrac{X_{\text{R\_Max}}}{X_{\text{R\_Min}}} \right)^2 - V_{\text{AVF\_L\_Min}} \right]}{V_{\text{CC\_Min}} - V_{\text{AVF\_L\_Max}} \cdot \left(\dfrac{X_{\text{R\_Max}}}{X_{\text{R\_Min}}} \right)^2} \end{cases}$$

Equation 15

$$\begin{cases} \Rightarrow \; V_{\text{2\_Min}} > V_{\text{1\_Max}} \\ \Rightarrow \; R_4 < \dfrac{R_2 \cdot \left[V_{\text{CC\_Min}} - V_{\text{AVF\_L\_Max}} \left(\dfrac{X_{\text{R\_Max}}}{X_{\text{R\_Min}}} \right)^2 \right] - R \cdot \left[V_{\text{AVF\_L\_Max}} \cdot \left(\dfrac{X_{\text{R\_Max}}}{X_{\text{R\_Min}}} \right)^2 - V_{\text{AVF\_L\_Min}} \right]}{V_{\text{CC\_Max}} \cdot \left(\dfrac{X_{\text{R\_Max}}}{X_{\text{R\_Min}}} \right)^2 - V_{\text{AVF\_L\_Min}}} \end{cases}$$

Equation 16

$$\begin{cases} \Rightarrow \; V_{\text{3\_Min}} > V_{\text{2\_Max}} \\ \Rightarrow \; R_4 > \dfrac{R_2 \cdot \left[V_{\text{CC\_Max}} - V_{\text{CC\_Min}} \cdot \dfrac{X_{\text{R\_Min}}}{X_{\text{R\_Max}}} \right]}{V_{\text{CC\_Min}} \cdot \dfrac{X_{\text{R\_Min}}}{X_{\text{R\_Max}}} - V_{\text{AVF\_L\_Max}}} - R \end{cases}$$

4 Detection windows digital value setting

To detect the state of both AC switches, an MCU analog/digital converter input (ADC) should be used. The conversion result (N_{ADC}) of the V_{STATE} signal depends on the ADC size (N) and of the MCU voltage reference (V_{Ref}). Note that the ADC transfer function is considered as ideal (see *Equation 17*).

Equation 17

$$N_{ADC} = \frac{V_{STATE}}{V_{Ref}} \cdot 2^N$$

According to the state of the AC switches, the V_{STATE} signal is not directly dependent on the value of V_{CC} (see equations *1*, *2* and *3*). This has an impact on the conversion result if the voltage reference of the ADC transfer function depends directly on V_{CC}. In this case, the detection levels to implement in the MCU firmware should be determined by taking into account the DC power supply variation with $V_{REF} = V_{CC}$ (see equations *18*, *19*, *20*, *21*, *22*, *23* and *24*).

Equation 18

ASC1 is on and ACS2 is on.

$$\begin{cases} \Rightarrow N_0 = \dfrac{V_{AVF\_L}}{V_{CC}} \cdot \dfrac{(R_2 + R_4)}{(R_2 + R_4)} \cdot 2^N \\ \Rightarrow N_{0\_Max} = \dfrac{V_{AVF\_L\_Max}}{V_{CC\_Min}} \cdot \dfrac{(R_2 + R_4) \cdot X_{R\_Max}}{(R_2 + R_4) \cdot X_{R\_Min}} \cdot 2^N = \dfrac{V_{AVF\_L\_Max}}{V_{CC\_Min}} \cdot \dfrac{X_{R\_Max}}{X_{R\_Min}} \cdot 2^N \end{cases}$$

Equation 19

ASC1 is on and ACS2 is on.

$$N_{0\_Min} = 0$$

Equation 20

ASC1 is on and ACS2 is off.

$$\begin{cases} \Rightarrow N_1 = \left[\dfrac{R_4 \cdot V_{CC} + V_{AVF\_L} \cdot (R_1 + R_2)}{V_{CC} \cdot (R_1 + R_2 + R_4)}\right] \cdot 2^N \\ \Rightarrow N_{1\_Max} = \left[R_4 + \dfrac{V_{AVF\_L\_Max} \cdot (R_1 + R_2)}{V_{CC\_Min}}\right] \cdot \dfrac{2^N \cdot X_{R\_Max}}{(R_1 + R_2 + R_4) \cdot X_{R\_Min}} \end{cases}$$

Equation 21

ASC1 is on and ACS2 is off.

$$\begin{cases} \Rightarrow N_1 = \left[\dfrac{R_4 \cdot V_{CC} + V_{AVF\_L} \cdot \left(R_1 + R_2\right)}{V_{CC} \cdot \left(R_1 + R_2 + R_4\right)}\right] \cdot 2^N \\ \Rightarrow N_{1\_Min} = \left[R_4 + \dfrac{V_{AVF\_L\_Min} \cdot \left(R_1 + R_2\right)}{V_{CC\_Max}}\right] \cdot \dfrac{2^N \cdot X_{R\_Min}}{\left(R_1 + R_2 + R_4\right) \cdot X_{R\_Max}} \end{cases}$$

Equation 22

ASC1 is off and ACS2 is on.

$$\begin{cases} \Rightarrow N_2 = \left[\dfrac{R_2 \cdot V_{CC} + V_{AVF\_L} \cdot \left(R_3 + R_4\right)}{V_{CC} \cdot \left(R_2 + R_3 + R_4\right)}\right] \cdot 2^N \\ \Rightarrow N_{2\_Max} = \left[R_2 + \dfrac{V_{AVF\_L\_Max} \cdot \left(R_3 + R_4\right)}{V_{CC\_Min}}\right] \cdot \dfrac{2^N \cdot X_{R\_Max}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Min}} \end{cases}$$

Equation 23

ASC1 is off and ACS2 is on.

$$\begin{cases} \Rightarrow N_2 = \left[\dfrac{R_2 \cdot V_{CC} + V_{AVF\_L} \cdot \left(R_3 + R_4\right)}{V_{CC} \cdot \left(R_2 + R_3 + R_4\right)}\right] \cdot 2^N \\ \Rightarrow N_{1\_Min} = \left[R_2 + \dfrac{V_{AVF\_L\_Min} \cdot \left(R_3 + R_4\right)}{V_{CC\_Max}}\right] \cdot \dfrac{2^N \cdot X_{R\_Min}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Max}} \end{cases}$$

Equation 24

ASC1 is off and ACS2 is off.

$$N_{3\_Max} = N_{3\_Min} > N_{2\_Max}$$

5 Application example

Table 3. Defined values of the application

Symbol	Value	Unit
I_{AVF_Max}	5	mA
V_{CC_Min}	4.5	V
V_{CC_Max}	5.5	V
$V_{AVF\_L\_Min}$	0	V
$V_{AVF\_L\_Max}$	1	V
N (MCU ADC resolution)	10	bits

The first step is to calculate R_1 and R_3 resistor values using *Equation 13*. The second step is to choose the R_2 and R_4 resistor values to fulfil equations *14* and *15* (see also *Table 4*).

Table 4. R_1, R_2, R_3 and R_4 resistor values

Resistor settings	Standard value (5% tolerance)
$R_1 = R_3 > 1.1$ kΩ	2.2 kΩ
R_2	15 kΩ
R_4	6.8 kΩ

The third step is to calculate the window detection levels (see *Table 5*) according to equations *5*, *6*, *7*, *8*, *9*, *10*, *11*, *18*, *19*, *20*, *21*, *22*, *23* and *24*. The window detection digital levels will be stored in the MCU firmware to distinguish the state of each AC switch.

Table 5. Detection window values

Windows detection level	Analog values (Volts)		Equivalent digital values	
	Max.	Min.	Max.	Min.
V_0	1.105	0	252	0
V_1	2.514	1.154	501	262
V_2	4.214	2.545	802	579
V_3	5.5	4.5	1024	> 802

6 Conclusion

This application note illustrates how designers can diagnose the state of two AC switches with only one single microcontroller ADC input. The way to implement this solution in the application and the external resistor choice is described in this document.

This solution is used to detect the failure modes of two AC switches and to inform the MCU so that appropriate actions to put the system into a safe state can be taken. This function improves the system safety by detecting "diode mode" in both polarities of the AC mains, "short circuit" and "open circuit" of each AC switch independently.

The main benefit of this solution is to reduce the cost of the microcontroller when a platform needs to monitor several AC switches because it requires one less pin.

Appendix A AC switch state deduction

Table 6. AC switch states when IN1 = IN2 = 0

IN1	IN2	V_{STATE} value	ACS1 diagnostic	ACS2 diagnostic
0	0	V_0	Shorted circuit	Shorted circuit
0	0	V_1	Shorted circuit	OFF
0	0	V_2	OFF	Shorted circuit
0	0	V_3	OFF	OFF
0	0	Toggle between V_3 and V_2	OFF	Diode mode
0	0	Toggle between V_3 and V_1	Diode mode	OFF
0	0	Toggle between V_3 and V_0	Diode mode	Diode mode
0	0	Toggle between V_2 and V_1	Diode mode	Diode mode
0	0	Toggle between V_2 and V_0	Diode mode	Shorted circuit
0	0	Toggle between V_1 and V_0	Shorted circuit	Diode mode

Table 7. AC switch states when IN1 = 0 and IN2 = 1

IN1	IN2	V_{STATE} value	ACS1 diagnostic	ACS2 diagnostic
0	1	V_0	Shorted circuit	ON
0	1	V_1	Shorted circuit	OPEN circuit
0	1	V_2	OFF	ON
0	1	V_3	OFF	OPEN circuit
0	1	Toggle between V_3 and V_2	OFF	NA
0	1	Toggle between V_3 and V_1	Diode mode	OPEN circuit
0	1	Toggle between V_3 and V_0	Diode mode	NA
0	1	Toggle between V_2 and V_1	Diode mode	NA
0	1	Toggle between V_2 and V_0	Diode mode	ON
0	1	Toggle between V_1 and V_0	Shorted circuit	NA

Table 8. AC switch states when IN1 = 1 and IN2 = 0

IN1	IN2	V_{STATE} value	ACS1 diagnostic	ACS2 diagnostic
1	0	V_0	ON	Shorted circuited
1	0	V_1	ON	OFF
1	0	V_2	Open circuit	Shorted circuited
1	0	V_3	Open circuit	OFF
1	0	Toggle between V_3 and V_2	Open circuit	Diode mode
1	0	Toggle between V_3 and V_1	NA	OFF
1	0	Toggle between V_3 and V_0	NA	Diode mode
1	0	Toggle between V_2 and V_1	NA	Diode mode
1	0	Toggle between V_2 and V_0	NA	Shorted circuit
1	0	Toggle between V_1 and V_0	ON	Diode mode

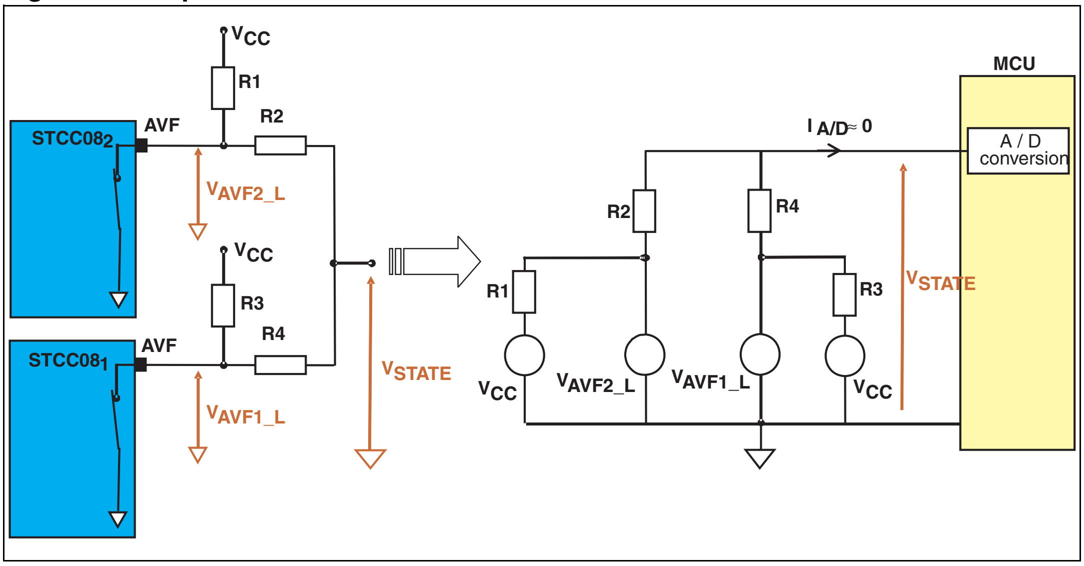
Table 9. AC switch states when IN1 = IN2 = 1

IN1	IN2	V_{STATE} value	ACS1 diagnostic	ACS2 diagnostic
1	1	V_0	ON	ON
1	1	V_1	ON	OPEN circuit
1	1	V_2	Open circuit	ON
1	1	V_3	Open circuit	OPEN circuit
1	1	Toggle between V_3 and V_2	Open circuit	NA
1	1	Toggle between V_3 and V_1	NA	OPEN circuit
1	1	Toggle between V_3 and V_0	NA	NA
1	1	Toggle between V_2 and V_1	NA	NA
1	1	Toggle between V_2 and V_0	NA	ON
1	1	Toggle between V_1 and V_0	ON	NA

Appendix B V_{STATE} signal voltage definition

The V_{STATE} voltage is defined according to the theorem of superposition applied on the linear circuits defined on Figures 14, 15, 16 and 17 (according to the state of each AC switch). The voltage resulting (V_{STATE}) from each source is calculated separately, and the results are added algebraically. The input current of the MCU A/D conversion block ($I_{A/D}$) is neglected.

Figure 14. Equivalent circuit ACS1 and ACS2 are on



Equation 25

$$V_{STATE} = V_0 = V_{AVF1\_L} \cdot V_{AVF2\_L} \cdot \frac{R_4}{R_4 + R_2}$$

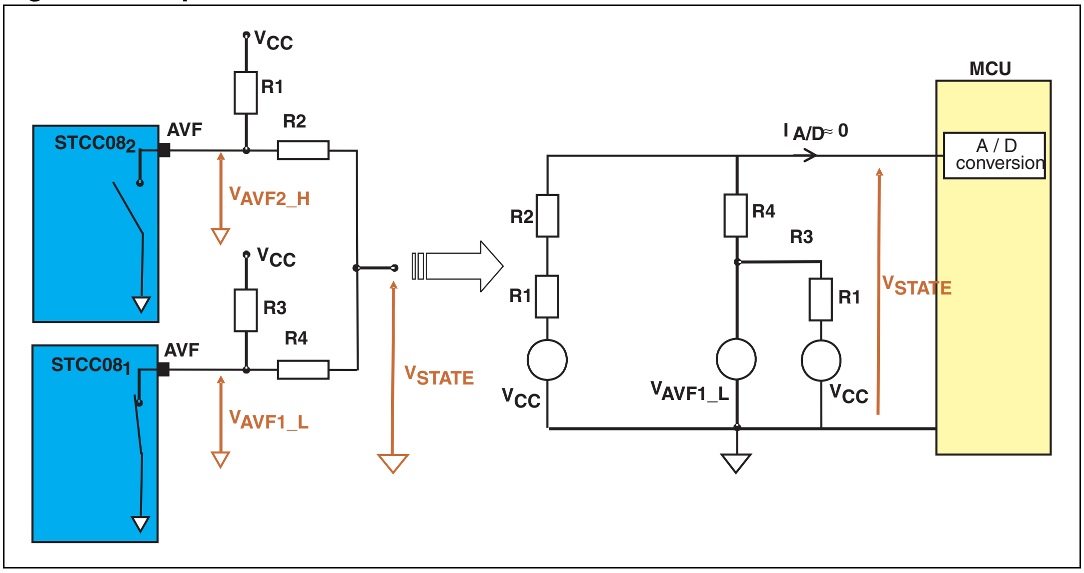
Equation 26

$$V_{0\_Max} = V_{AVF\_L\_Max} \cdot \frac{(R_2 + R_4) \cdot X_{R\_Max}}{(R_2 + R_4) \cdot X_{R\_Min}}$$

Equation 27

$$V_{0\_Min} = V_{AVF\_L\_Min} \cdot \frac{(R_2 + R_4) \cdot X_{R\_Min}}{(R_2 + R_4) \cdot X_{R\_Max}} = 0$$

Figure 15. Equivalent circuit ACS1 is on and ACS2 is off



Equation 28

$$V_{STATE} = V_1 = \frac{R_4}{R_4 + R_2 + R_1} \cdot V_{CC} + \frac{R_1 + R_2}{R_1 + R_2 + R_4} \cdot V_{AVF1\_L}$$

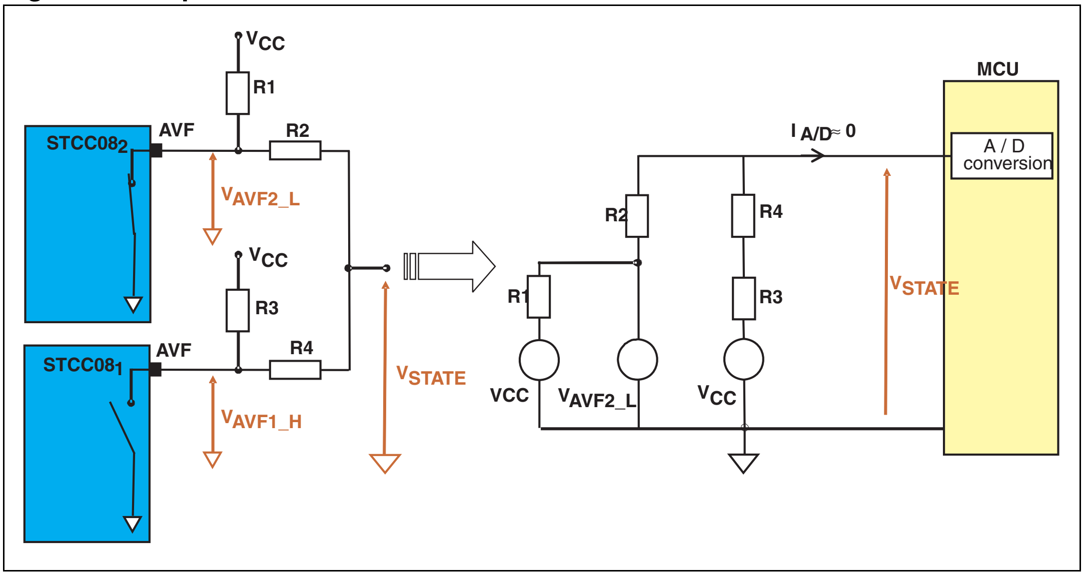
Equation 29

$$V_{1\_Max} = \frac{V_{CC\_Max} \cdot R_4 \cdot X_{R\_Max} + V_{AVF\_L\_Max} \cdot \left(R_1 + R_2\right) \cdot X_{R\_Max}}{\left(R_1 + R_2 + R_4\right) \cdot X_{R\_Min}}$$

Equation 30

$$V_{1\_Min} = \frac{V_{CC\_Min} \cdot R_4 \cdot X_{R\_Min} + V_{AVF\_L\_Min} \cdot \left(R_1 + R_2\right) \cdot X_{R\_Min}}{\left(R_1 + R_2 + R_4\right) \cdot X_{R\_Max}}$$

Figure 16. Equivalent circuit ACS2 is on and ACS1 is off



Equation 31

$$V_{STATE} = V_2 = \frac{R_2}{R_2 + R_4 + R_3} \cdot V_{CC} + \frac{R_3 + R_4}{R_3 + R_4 + R_2} \cdot V_{AVF2\_L}$$

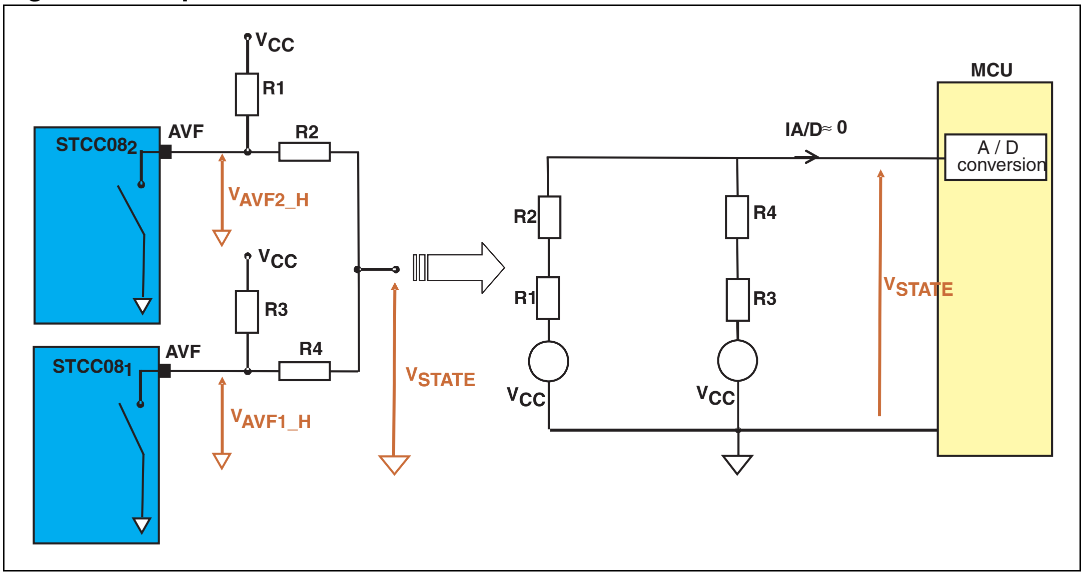
Equation 32

$$V_{2\_Max} = \frac{V_{CC\_Max} \cdot R_2 \cdot X_{R\_Max} + V_{AVF\_L\_Max} \cdot \left(R_3 + R_4\right) \cdot X_{R\_Max}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Min}}$$

Equation 33

$$V_{2\_Min} = \frac{V_{CC\_Min} \cdot R_2 \cdot X_{R\_Min} + V_{AVF\_L\_Min} \cdot \left(R_3 + R_4\right) \cdot X_{R\_Min}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Max}}$$

Figure 17. Equivalent circuit ACS1 and ACS2 are off



Equation 34

$$V_{STATE} = V_3 = V_{CC} \cdot \frac{R_3 + R_4}{R_1 + R_2 + R_3 + R_4} + V_{CC} \cdot \frac{R_1 + R_2}{R_1 + R_2 + R_3 + R_4} = V_{CC}$$

Equation 35

$$V_{3\_Max} = V_{CC\_Max}$$

Equation 36

$$V_{3\_Min} = V_{CC\_Min}$$

Appendix C Resistor settings

Figure 15, and equations *37*, *38* and*39* define conditions to identify the state of each AC switch.

Equation 37

$$V_{1\_Min} > V_{0\_Max}$$

Equation 38

$$V_{2\_Min} > V_{1\_Max}$$

Equation 39

$$V_{2\_Max} < V_{3\_Min}$$

C.1 First case: $V_{1\_Min} > V_{0\_Max}$

Equations *26* and *30* define respectively V_{0_Max} and V_{1_Min} (see *Appendix A*). To take into account R_1 resistor's standardized values (see *Equation 13*), the resistor's tolerance (X_R), the STCC08 AVF output electrical dispersion and the DC power supply characteristic, the condition on R_2 and R_4 resistors is defined in *Equation 42*.

Equation 40

$$V_{1\_Min} > V_{0\_Max}$$

Equation 41

$$\frac{V_{CC\_Min} \cdot R_4 \cdot X_{R\_Min} + V_{AVF\_L\_Min} \cdot \left(R_1 + R_2\right) \cdot X_{R\_Min}}{\left(R_1 + R_2 + R_4\right) \cdot X_{R\_Max}} > V_{AVF\_L\_Max}$$

Equation 42

$$R_4 > \frac{\left(R_1 + R_2\right) \cdot \left[V_{AVF\_L\_Max} \cdot \left(\frac{X_{R\_Max}}{X_{R\_Min}}\right) - V_{AVF\_L\_Min}\right]}{V_{CC\_Min} - V_{AVF\_L\_Max} \cdot \left(\frac{X_{R\_Max}}{X_{R\_Min}}\right)}$$

C.2 Second case: $V_{2\_Min} > V_{1\_Max}$

Equations *29* and *33* define respectively V_{1_Max} and V_{2_Min} (see *Appendix A*). To take into account R_3 resistor's standardized values, the resistor's tolerance (X_R), the STCC08 AVF output electrical dispersion and the DC power supply characteristic, the condition on R_2 and R_4 resistors is defined by *Equation 46*.

Equation 43

$$V_{2\_Min} > V_{1\_Max}$$

Equation 44

$$V_{2\_Min} = \frac{V_{CC\_Min} \cdot R_2 \cdot X_{R\_Min} + V_{AVF\_L\_Min} \cdot \left(R + R_4\right) \cdot X_{R\_Min}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Max}}$$

Equation 45

$$V_{1\_Max} = \frac{V_{CC\_Max} \cdot R_4 \cdot X_{R\_Max} + V_{AVF\_L\_Max} \cdot \left(R_1 + R_2\right) \cdot X_{R\_Max}}{\left(R_1 + R_2 + R_4\right) \cdot X_{R\_Min}}$$

Equation 46

$$R_4 < \frac{R_2 \cdot \left[V_{CC\_Min} - V_{AVF\_L\_Max}\left(\frac{X_{R\_Max}}{X_{R\_Min}}\right)^2\right] - R_3 \cdot \left[V_{AVF\_L\_Max} \cdot \left(\frac{X_{R\_Max}}{X_{R\_Min}}\right)^2 - V_{AVF\_L\_Min}\right]}{V_{CC\_Max} \cdot \left(\frac{X_{R\_Max}}{X_{R\_Min}}\right)^2 - V_{AVF\_L\_Min}}$$

C.3 Third case: $V_{2\_Max} < V_{3\_Min}$

Equations *32* and *36* define respectively V_{2_Max} and V_{3_Min} (see *Appendix A*). To take into account R_3 resistor's standardized values, the resistors' tolerance (X_R), the STCC08 AVF output electrical dispersion and the DC power supply characteristic, the condition on R_2 and R_4 resistors is defined in *Equation 49*.

Equation 47

$$V_{2\_Max} < V_{3\_Min}$$

Equation 48

$$\frac{V_{CC\_Max} \cdot R_2 \cdot X_{R\_Max} + V_{AVF\_L\_Max} \cdot \left(R_3 + R_4\right) \cdot X_{R\_Max}}{\left(R_2 + R_3 + R_4\right) \cdot X_{R\_Min}} < V_{CC\_Min}$$

Equation 49

$$R_4 > \frac{R_2 \cdot \left[V_{CC\_Max} - V_{CC\_Min} \cdot \frac{X_{R\_Min}}{X_{R\_Max}}\right]}{V_{CC\_Min} \cdot \frac{X_{R\_Min}}{X_{R\_Max}} - V_{AVF\_L\_Max}} - R_3$$

Revision history

Table 10. Document revision history

Date	Revision	Changes
08-Dec-2009	1	Initial release.