1.4 kW digital power factor corrector based on the STM32F103ZE

Introduction

This system has been designed to evaluate the capabilities of the high-density STM32F103ZE microcontroller to perform a digital power factor corrector. An application example is provided for easy evaluation of the system's features and performance. The system is intended for demonstration purposes to evaluate the potentiality of the STM32 to control a high power PFC with performances comparable to a standard continuous mode PFC monolithic IC, while assigning enough micro resources (such as program memory and CPU computational capabilities) to other complex operations (such as driving 3ph motors in scalar or field-oriented control). The system described in this document has been designed to offer high performances in terms of PF, THD and DC output voltage ripple. According to less demanding performances, power components (such as the inductor) present in the PFC power board can be downsized to obtain a cost-effective solution. As opposed to monolithic ICs, this digital approach enables a sophisticated control algorithm to be applied and system parameters to be adjusted to meet customer requirements. The STM32 digital PFC hardware system is composed of two boards: a PFC power stage (STEVAL-ISF002V1) and a dual motor control stage (STEVAL-IHM022V1) based on the STM32F103ZE microcontroller. Thanks to an MC connector on the PFC power board, this latter can be interfaced to several ST MCU-based boards, especially those developed for motor control. On-board OFF-line SMPS based on a VIPER12 is used to generate the 15 VDC voltages necessary to supply the drivers inside the power board. Additionally, this board provides 5 volts for supplying any control stage supplied via the MC connector.

Note: Read Section 1 prior to using the system.

- Main system features
  - Maximum output power: 1400 W
  - Input voltage range: 185 - 230Vac, 50/60 Hz
  - Output voltage: 415VDC, 5% ripple
  - PF up to 0.998 (at nominal rated power)
  - THD between 0.9% and 9% over entire operating range
  - Hardware overcurrent protection
  - Software current limitation
  - Software overvoltage protection
  - Software voltage limitation
  - Regulated DC output voltage with zero load
  - Adjustable target value of output DC voltage
  - Embedded UI for adjusting real-time PIs parameters for voltage and current
  - Available demo for dual FOC motor control drive

Contents

List of tables

List of figures

1 Safety and operating instructions

1.1 General

During assembly and operation, the PFC power board poses several inherent hazards, including bare wires, moving or rotating parts, and hot surfaces. Serious personal injury and damage to property may be caused if it is used or installed incorrectly.

All operations involving transportation, installation and use, as well as maintenance, should be carried out by skilled technical personnel (national accident prevention rules must be observed). For the purpose of these basic safety instructions, "skilled technical personnel" refers to suitably qualified people who are familiar with the installation, use and maintenance of power electronic systems.

Warning: Many sources of serious hazard are present on this board. The board operates directly from the mains, is not galvanic insulated, and provides high voltage DC levels at the output that can cause serious electric shocks, serious burns and death. Hot surfaces that can cause burns are present on the board.

This board must be used in a power laboratory only, and under protection, by engineers and technicians who are experienced in power electronics technology.

STMicroelectronics will not be held responsible for damage caused to objects or persons.

1.2 Intended use of the demonstration board

The entire system is designed for demonstration purposes only, and shall not be used for electrical installation or machinery. The technical data as well as information concerning the supply conditions shall be taken from the documentation and strictly observed.

1.3 Installation of the demonstration board

The installation and cooling of the whole system must be in accordance with the specifications and targeted application.

- Excessive strain on the board must be avoided. In particular, no components are to be bent, or isolating distances altered, during the course of transportation or handling.
- No contact must be made with electronic components and contacts.
- The boards contain electro-statically sensitive components that are prone to damage through improper use. The electrical components must not be mechanically damaged or destroyed (to avoid potential health risks).

1.4 Electronic connection

National accident prevention rules must be followed when working on the main power supply with the power supply or power board in general.

The electrical installation must be completed in accordance with the appropriate requirements (for example, cross-sectional areas of the conductors, fusing, PE connections).

1.5 Demonstration board operation

An AC insulated and protected against overload and short-circuits is preferable during the evaluation tests of the system (that is, in compliance with technical equipment and accident prevention rules).

A proper load, able to dissipate – or in any case, absorb and reuse – the power delivered by the system, must be used. In case of resistive and dissipative dummy loads, particular attention should be paid to the temperature that the load may reach. Provide the needed equipment to avoid hot surfaces and risk of fire during the tests (fan, water cooled load, etc).

Note: Do not touch the board and its components after disconnection from the voltage supply as several parts and power terminals containing possibly energized capacitors must be given time to discharge.

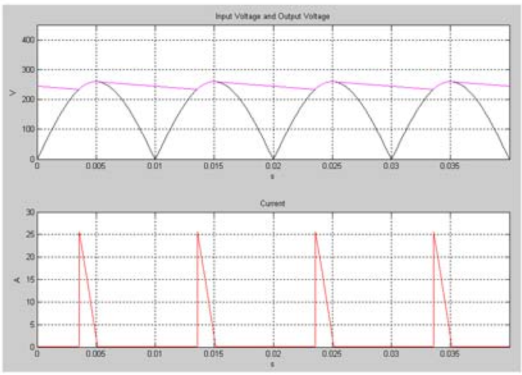
2 PFC basics and operating principles

2.1 Introduction

Most of the power conversion applications consist of an AC to DC conversion stage immediately following the AC source. The DC output obtained after rectification is subsequently used for further stages.

Since many applications demand a DC voltage source, a rectifier with a capacitive filter is necessary. However, current pulses with high peak amplitudes are drawn from a rectified voltage source with sine wave input and capacitive filtering. The current drawn is discontinuous and of a short duration irrespective of the load connected to the system. When this type of current is drawn from the mains supply, the resulting network losses, the total harmonic content and the radiated emissions become significantly higher. At power levels of more than 500 W, these problems become more pronounced.

Figure 1. Typical AC to DC rectification without PFC



Two factors that provide a quantitative measure of the power quality in an electrical system are the power factor (PF) and total harmonic distortion (THD). The amount of useful power being consumed by an electrical system is predominantly decided by the PF of the system.

- Benefits from improvement of power factor include:
  - lower energy and distribution costs,
  - reduced losses in the electrical system during distribution,
  - better voltage regulation,
  - increased capacity to serve power requirements.

Most often, the core of a power factor correction (PFC) is an AC to DC boost converter (see *Figure 2*). For power typically above 600 W, the switching of the power MOSFET (T) is modulated so that the inductor current is in continuous conduction mode (CCM), as shown in *Figure 3*.

Figure 2. Scheme of AC to DC boost converter topology

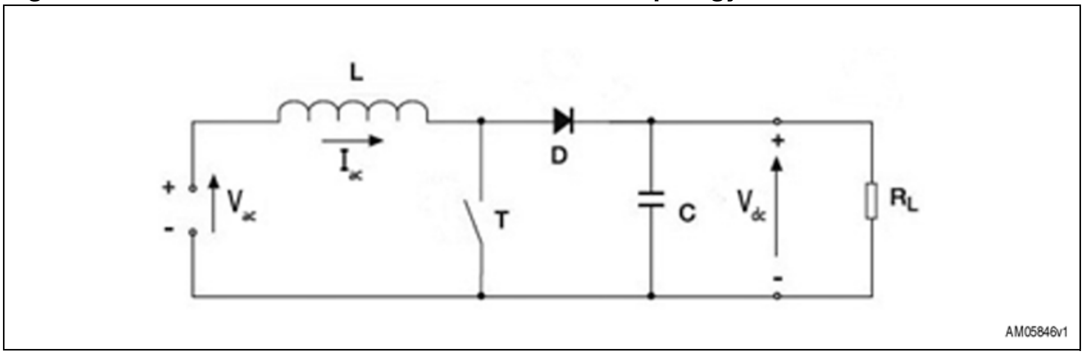


Figure 3. AC to DC boost converter signals with CCM PFC - output VDC, input Vac and inductor current (time scale = 5 ms)

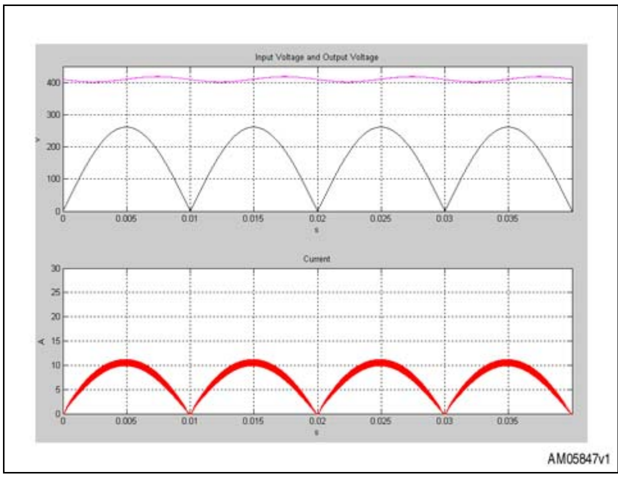
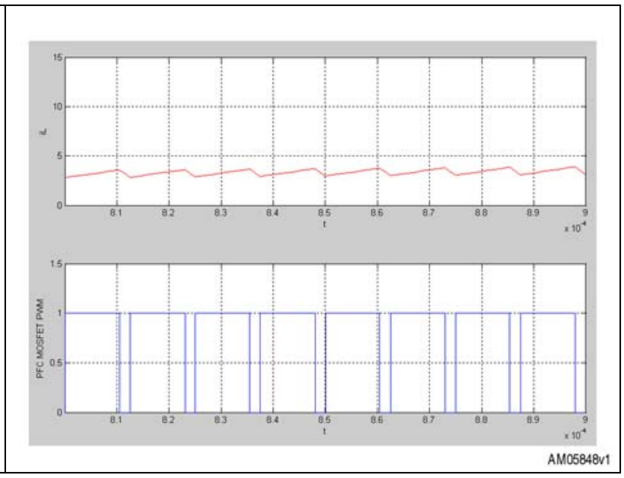


Figure 4. AC to DC boost converter signals with CCM PFC - inductor current and power MOSFET gate command (time scale = 10 µs)



2.2 PFC with digital approach

- A digital implementation for a PFC gives some advantages.
  - Easy implementation of sophisticated control algorithms.
  - Quick software modifications to meet specific requirements.
  - Simple integration with other applications.

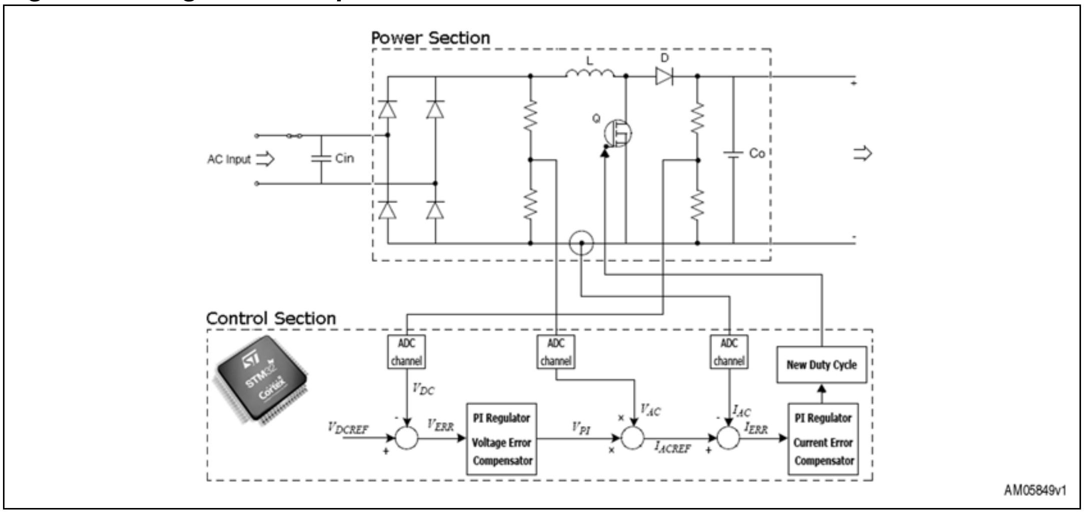
From a theoretical point of view, it could be possible to replace an existing analog solution made up of discrete components with ST's digital solution, in which case, other than the PFC control, the same MCU would also manage the main application.

To perform a digital power factor corrector, a microcontroller needs to have information about three main system parameters. These are the output DC voltage, the input AC voltage and the inductor current.

These parameters, appropriately scaled down, are managed by the microcontroller that modulates the switching of the MOSFET to have the input current in phase with the input AC voltage while keeping the output DC voltage to a fixed and stable value.

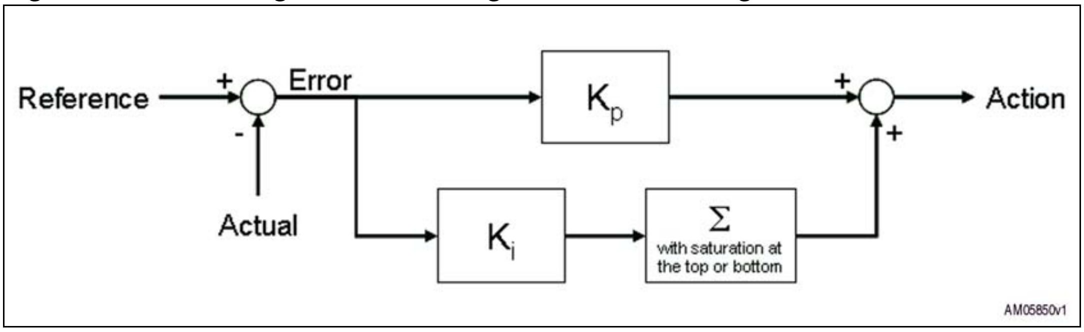
A generic implementation scheme for a digital PFC is shown in *Figure 5*.

Figure 5. Digital PFC implementation scheme



Note: The power section is composed of the STEVAL-ISF002V1 (covered in this user manual). The control section is composed of the STEVAL-IHM022V1 (covered in UM0686).

Figure 6. Block diagram of the voltage and current PI regulator



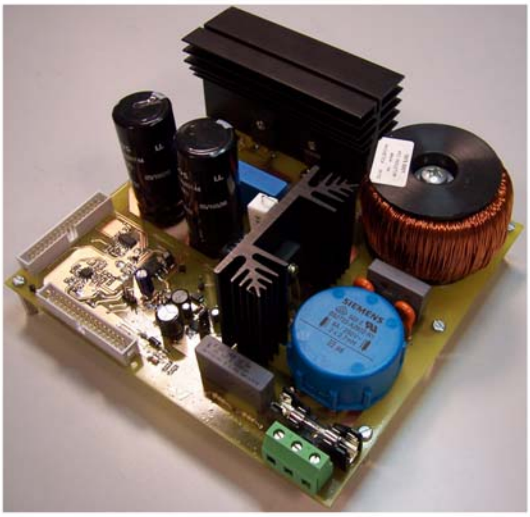
By means of a "voltage error compensator" it is possible to follow the target of the output voltage. Moreover, its output is used as a scaling factor for the Vac, the latter used as the current reference input for the "current error compensator". The output of this last PI is the actual duty cycle of the PFC power MOSFET.

3 STEVAL-ISF002V1 hardware description

3.1 Electrical characteristics

- Voltage input range: 185 ÷ 265 Vrms at 50/60 Hz.
- Output voltage (for power section): 415 Vdc (ripple lower than 5%)
- Output voltage (for digital section): 15 Vdc and 5 Vdc
- Target output power: 1400 W
- Power factor: > 0.99 at 1400 W
- Total harmonic distortion: < 3%
- DC to DC converter: boost topology
- PFC mode: continuous conduction mode
- Switching frequency: 80 kHz
- Control loop frequency: 40 kHz
- Hardware protection against PFC overcurrent: 14.3 A

Figure 7. STEVAL-ISF002V1



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3.2 Target applications

This demonstration board is intended for motor control applications involved in domestic appliances, HVAC (heating, ventilating and air conditioning) appliances, blowers and fans.

AN3165 describes how to merge the digital PFC firmware with the one developed for the STM32 dual FOC motor control demonstrator.

3.3 Dimensioning the power components

This section describes how to dimension the power components relating to the power section shown in *Figure 5* and the electrical characteristics shown in *Section 3.1*.

3.3.1 Preliminary definition

Based on the electrical characteristics listed in *Section 3.1*, the following maximum values are calculated.

Equation 1

$$I_{in(rms)} = \frac{P_{out}}{\eta \cdot V_{in(min)} \cdot PF} = \frac{1400}{0.95 \cdot 185 \cdot 0.99} A = 8.05 A$$

Equation 2

$$I_{in(pk)} = I_{in(rms)} \cdot \sqrt{2} = 11.38 A$$

Equation 3

$$I_{in(avg)} = \frac{2 \cdot I_{in(pk)} \cdot \sqrt{2}}{\pi} = 7.24 A$$

3.3.2 Rectifier

The following equation is a calculation of the power rate for the bridge rectifier.

Equation 4

$$P_{Bridge} = 2 \cdot V_F \cdot I_{in(avg)} = (2 \cdot 0.8 \cdot 7.24) W = 11.6 W$$

3.3.3 Input capacitor

A ripple of 20% has been chosen for the inductor current I_L and it is assumed that the Vin ripple is 6%.

Therefore:

Equation 5

$$I_{ripple} = 0.2 \cdot I_{in(pk)} = 2.28 A$$

Equation 6

$$V_{in(ripple)} = 0.06 \cdot V_{in(pk)_{max}} = \left(0.06 \cdot 265 \cdot \sqrt{2}\right) V = 22.49 V$$

Equation 7

$$C_{in} = \frac{I_{ripple}}{8 \cdot f_{sw} \cdot V_{in(ripple)}} = \frac{2.28}{8 \cdot 80 \cdot 10^3 \cdot 22.49} \mu F = 0.158 \mu F$$

This capacitor has to be in class X2 so its value must be 0.22 µF.

3.3.4 Boost inductor for CCM

The inductance value is calculated by taking into account the inductor's continuous conduction mode.

Equation 8

$$I_{L(pk)} = I_{in(pk)} + \frac{I_{ripple}}{2} = \left(11.38 + \frac{2.28}{2}\right) A = 12.52\ A$$

Equation 9

$$I_{L(avg)} = \frac{2 \cdot I_{L(pk)}}{\pi} \cong 8\ A$$

Equation 10

$$L_{min} \geq \frac{V_{out} \cdot \delta_{max} \cdot (1 - \delta_{max})}{f_{sw} \cdot I_{ripple}} = \frac{V_{out} \cdot \frac{V_{out} - V_{in(pk)_{min}}}{V_{out}} \cdot \left(1 - \frac{V_{out} - V_{in(pk)_{min}}}{V_{out}}\right)}{f_{sw} \cdot I_{ripple}}$$

Equation 11

$$L_{min} \geq \frac{\left(V_{out} - V_{in(pk)_{min}}\right) \cdot \left(\frac{V_{out} - \left(V_{out} - V_{in(pk)_{min}}\right)}{V_{out}}\right)}{f_{sw} \cdot I_{ripple}}$$

Equation 12

$$L_{min} \geq \frac{\left(V_{out} - V_{in(pk)_{min}}\right) \cdot V_{in(pk)_{min}}}{V_{out} \cdot f_{sw} \cdot I_{ripple}} = \frac{\left(415 - 185 \cdot \sqrt{2}\right) \cdot 185 \cdot \sqrt{2}}{415 \cdot 80 \cdot 10^3 \cdot 2.28} H$$

Equation 13

$$L_{min} \geq 0.530\ mH$$

The inductor shown in *Section A.2* is manufactured with this inductance value at normal operating conditions.

3.3.5 Output capacitor

Assuming that $V_{out(ripple)} \leq 5\%$, the value of the output capacitor is calculated.

Equation 14

$$C_{out} \geq \frac{I_{out(max)}}{\pi \cdot 2 \cdot f_{mains} \cdot V_{out(ripple)}} = \frac{\frac{1400}{415}}{\pi \cdot 2 \cdot 50 \cdot \frac{415 \cdot 5}{100}} F \cong 520\ \mu F$$

Two capacitors in parallel have been selected. Their values are 330 µF at 450 V.

3.3.6 Power MOSFET

The maximum current that can pass into the power MOSFET is given by *Equation 15*.

Equation 15

$$I_{MOSFET(rms)} = \frac{P_{out}}{V_{in(pk)_{min}}} \cdot \sqrt{2 - \frac{16 \cdot V_{in(pk)_{min}}}{3 \cdot \pi \cdot V_{out}}} = \left(\frac{1400}{185 \cdot \sqrt{2}} \cdot \sqrt{2 - \frac{16 \cdot 185 \cdot \sqrt{2}}{3 \cdot \pi \cdot 415}} \right) A$$

Equation 16

$$I_{MOSFET(rms)} = 5.16 \text{ A}$$

The selected power MOSFET is the STW23NM60N. Its $R_{DS(on)}$ is 0.180 Ω for a T_{case} of 25°C.

Considering a factor of 1.5 due to the temperature of 80°C, $R_{DS(on)}$ = 0.270 Ω. Its maximum power rate is calculated as follows.

Equation 17

$$P_{MOSFET(conduction)} = I_{MOSFET(rms)}{}^{2} \cdot R_{DS(on)} = \left(5.16^{2} \cdot 0.270\right) W \cong 7.2 \text{ W}$$

Equation 18

$$P_{MOSFET(switching)} = f_{sw} \cdot \left(t_r \cdot V_{out} \cdot I_{in(pk)} + \frac{1}{2} \cdot C_{oss} \cdot V_{out}{}^{2} \right)$$

Now for the STW23NM60N:

Equation 19

$$C_{oss} = 140 \text{ pF}$$

Equation 20

$$t_r = 15 \text{ ns}$$

Equation 21

$$P_{MOSFET(switching)} = \left[80 \cdot 10^{3} \cdot \left(15 \cdot 10^{-9} \cdot 415 \cdot 11.38 + \frac{1}{2} \cdot 140 \cdot 10^{-12} \cdot 415^{2} \right) \right] W$$

Equation 22

$$P_{MOSFET(switching)} = 6.63 \text{ W}$$

Equation 23

$$P_{MOSFET(tot)} = P_{MOSFET(conduction)} + P_{MOSFET(switching)} = (7.2 + 6.63) W \cong 14 \text{ W}$$

3.3.7 Boost diode

The maximum current that can pass into the boost diode is:

Equation 24

$$I_{Diode(rms)} = \frac{P_{out}}{V_{in(pk)_{min}}} \cdot \sqrt{\frac{16 \cdot V_{in(pk)_{min}}}{3 \cdot \pi \cdot V_{out}}} = \left(\frac{1400}{185 \cdot \sqrt{2}} \cdot \sqrt{\frac{16 \cdot 185 \cdot \sqrt{2}}{3 \cdot \pi \cdot 415}} \right) A$$

Equation 25

$$I_{Diode(rms)} = 5.54\ A$$

The selected boost diode is the STTH12S06.

Equation 26

$$I_{avg} = \frac{P_{out}}{V_{out}} = \frac{1400}{415} A = 3.37\ A$$

Equation 27

$$P_{Diode(conduction)} = V_F \cdot I_{avg} = (1.5 \cdot 3.37)\, W \cong 5\ W$$

Equation 28

$$P_{Diode(switching)} = \frac{1}{2} \cdot f_{sw} \cdot V_{out} \cdot Q_{rr}$$

Now for the STTH12S06:

Equation 29

$$Q_{rr} = 0.160\ nC$$

Equation 30

$$P_{Diode(switching)} = \left(\frac{1}{2} \cdot 80 \cdot 10^3 \cdot 415 \cdot 160 \cdot 10^{-9} \right) W \cong 2.65\ W$$

Equation 31

$$P_{Diode(tot)} = P_{Diode(conduction)} + P_{Diode(switching)} = (5 + 2.65)\, W \cong 8\ W$$

Equation 32

$$P_{PFC(tot)} \cong P_{Bridge(tot)} + P_{MOSFET(tot)} + P_{Diode(tot)} = (11.6 + 14 + 8)\ W \cong 34\ W$$

3.4 Connectors

The STEVAL-ISF002V1 has five connectors (see *Section A.1*).

- J7 for V_{in}
- J8 for V_{in}
- J10 to provide 15 Vdc if the VIPER12 is bypassed
- J15 for connection with the control board (MC + PFC connector)
- J16 for connection with a 3-ph inverter board (MC connector only)

3.4.1 Vin connector

Refer to J7 of *Figure 43*.

Figure 8. Vin connector

3.4.2 Vout connector

Refer to J8 of *Figure 44*.

Figure 9. Vout connector

3.4.3 15 V connector

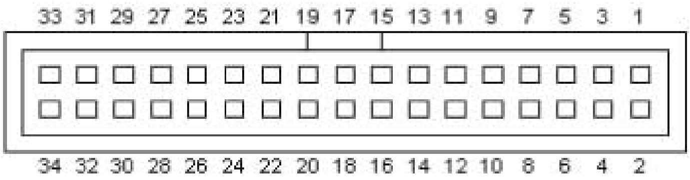
Refer to J10 of *Figure 44*.

This connector can be used to provide 15 V to the STEVAL-ISF002V1 if the VIPER12 is bypassed. For correct polarity, follow the board's serigraphy.

3.4.4 MC + PFC connector

Refer to J15 of *Figure 44*.

Figure 10. MC + PFC connector



1	EMERGENCY STOP	2	PFC OCP
3	MC_UH	4	GND
5	MC_UL	6	GND
7	MC_VH	8	GND
9	MC_VL	10	GND
11	MC_WH	12	GND
13	MC_WL	14	BUS VOLTAGE
15	CURRENT A	16	GND
17	CURRENT B	18	GND
19	CURRENT C	20	GND
21	NTC BYPASS RELAY	22	PFC Vac SENSE
23	DISSIPATIV BRAKE	24	PFC Iac SENSE
25	5V POWER	26	HEAT SINK TEMP
27	PFC SYNC	28	3.3V POWER
29	PFC PWM	30	GND
31	ENCODER A	32	GND
33	ENCODER B	34	ENCODER INDEX

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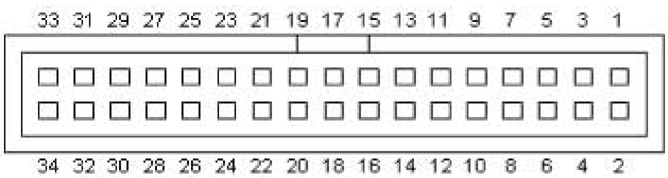
3.4.5 MC connector only

Refer to J16 of *Figure 44*.

Figure 11. MC connector only



1	EMERGENCY STOP	2	GND
3	MC_UH	4	GND
5	MC_UL	6	GND
7	MC_VH	8	GND
9	MC_VL	10	GND
11	MC_WH	12	GND
13	MC_WL	14	BUS VOLTAGE
15	CURRENT A	16	GND
17	CURRENT B	18	GND
19	CURRENT C	20	GND
21	NTC BYPASS RELAY	22	N.C.
23	DISSIPATIV BRAKE	24	N.C.
25	5V POWER	26	HEAT SINK TEMP
27	N.C.	28	3.3V POWER
29	N.C.	30	GND
31	ENCODER A	32	GND
33	ENCODER B	34	ENCODER INDEX

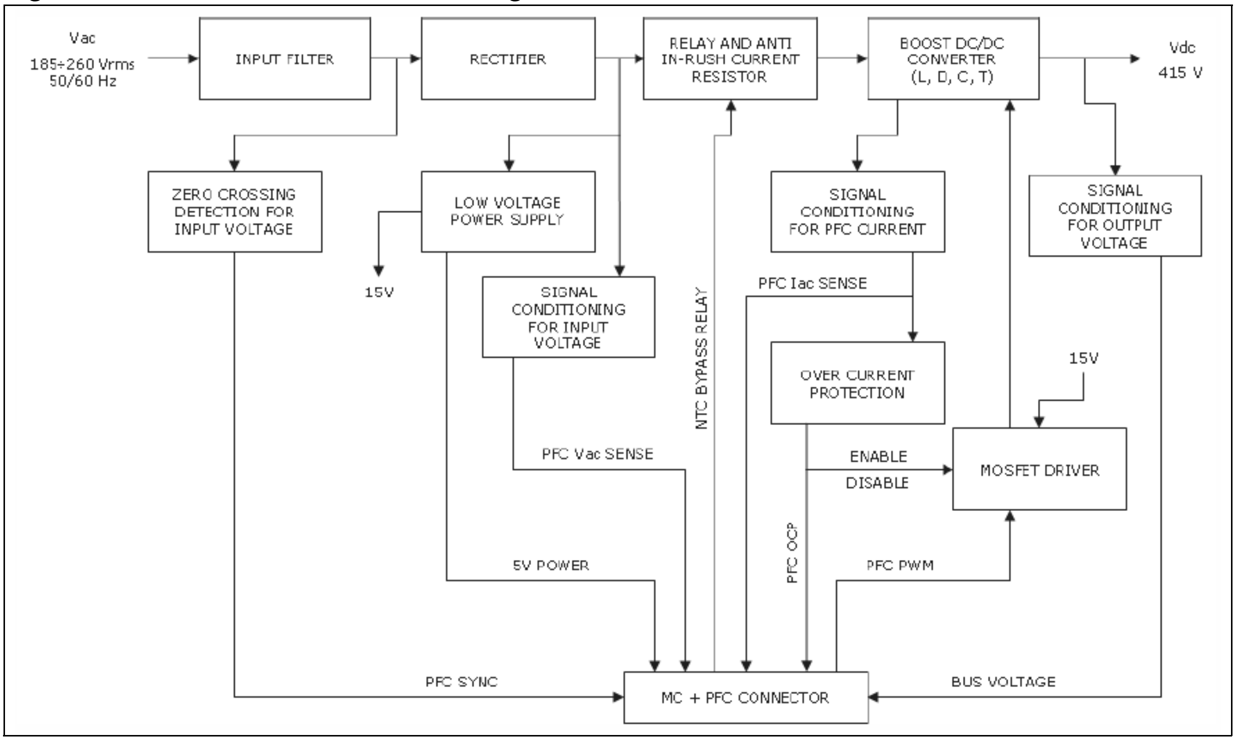
AM05855v1

3.5 STEVAL-ISF002V1 block diagram

Figure 12 shows the principal blocks of the STEVAL-ISF002V1 and their interconnections.

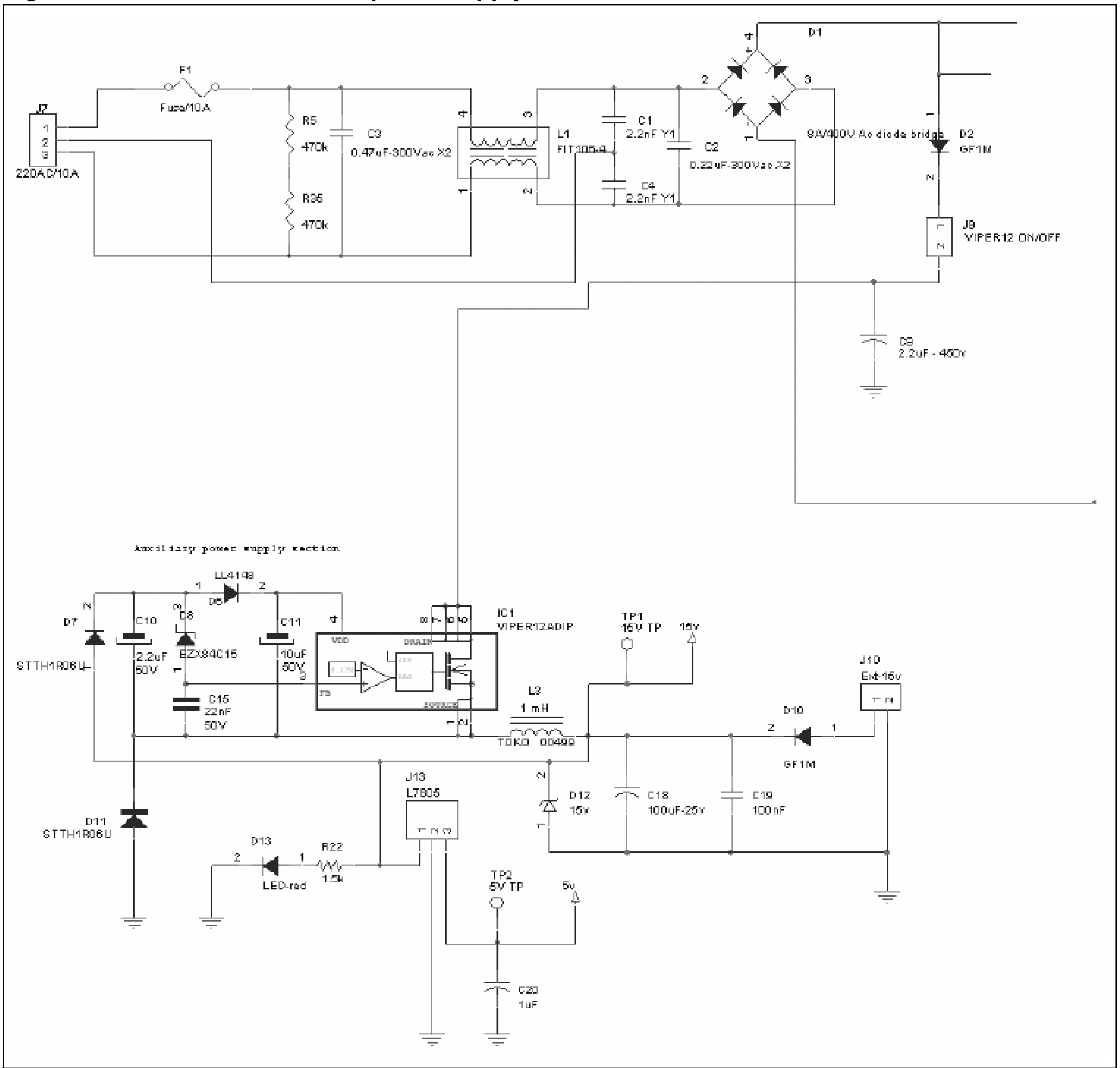
Each block is described in the following sections.

Figure 12. STEVAL-ISF001V1 block diagram



3.5.1 Power supply

Figure 13. STEVAL-ISF002V1 - power supply section



The mains has to be provided by pins 1 and 3 of the J7 connector (pin 2 can be linked up to earth). The voltage input range must be within 185 ÷ 265 Vrms at 50 Hz.

The digital section is provided by means of a circuit based on the VIPER12 to obtain 15 Vdc and a positive voltage regulator L7805 to obtain 5 Vdc.

The VIPER12 can be left out by removing J9. In this case, 15 Vdc have to be provided on J10 (positive on pin 1).

3.5.2 Signal conditioning for input voltage

Figure 14. STEVAL-ISF002V1 - input voltage sensing section

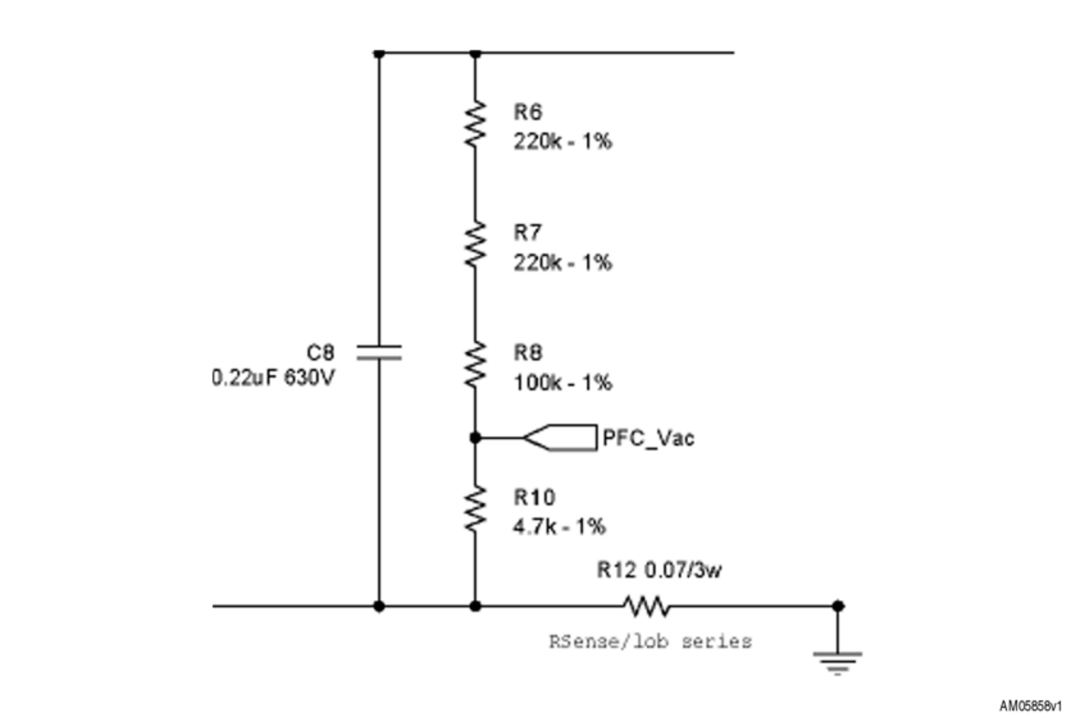
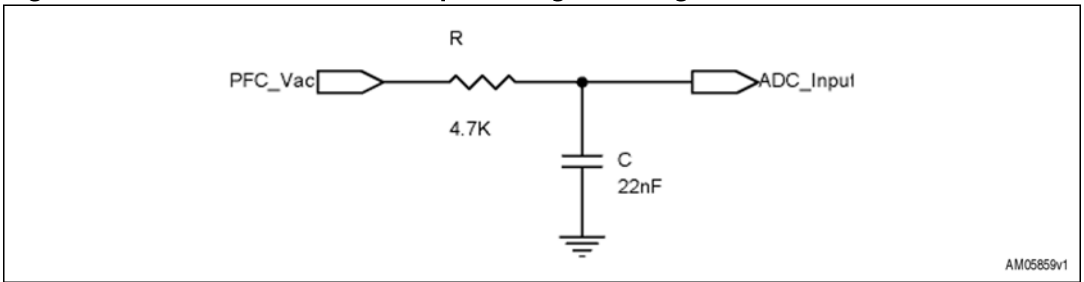


Figure 15. STEVAL-IHM022V1 - input voltage sensing section



The conversion ratio is given by *Equation 33*.

Equation 33

$$\frac{R10}{R6+R7+R8+R10} = \frac{4.7 \cdot 10^3}{(220+220+100+4.7) \cdot 10^3} = 0.008629$$

The input voltage scaled by this conversion ratio will be read by the MCU's ADC.

3.5.3 Signal conditioning for output voltage

Figure 16. STEVAL-ISF002V1 - output voltage sensing section

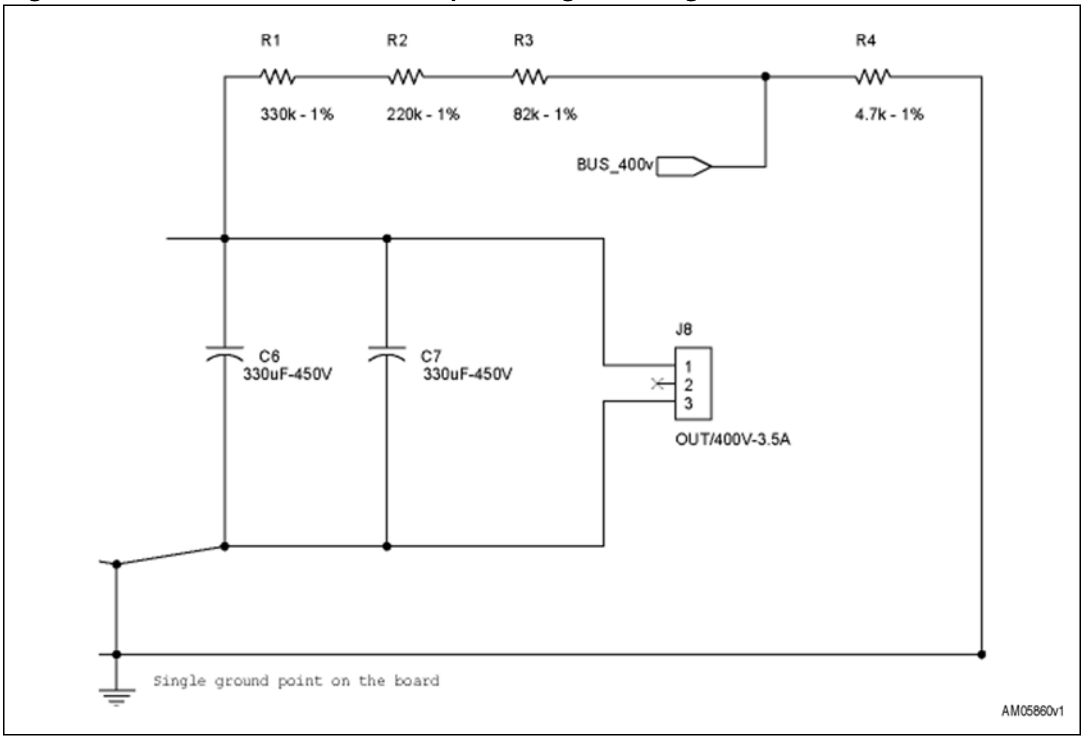
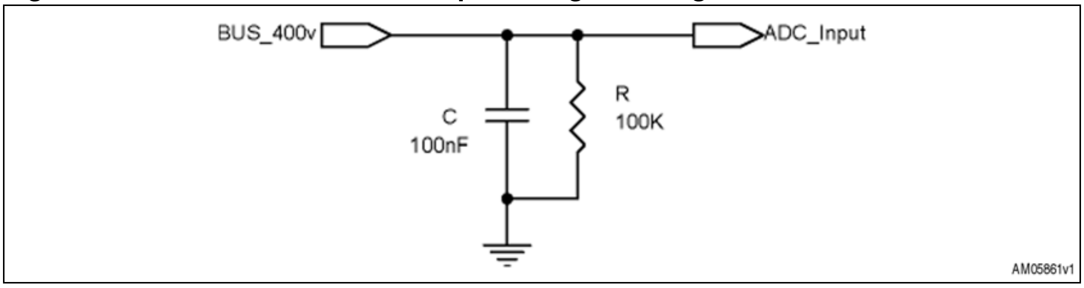


Figure 17. STEVAL-IHM022V1 - output voltage sensing section



The conversion ratio is given by:

Equation 34

$$\frac{\frac{R4 \cdot R}{R4 + R}}{(R1 + R2 + R3) + \frac{R4 \cdot R}{R4 + R}}$$

That is:

Equation 35

$$\frac{\frac{4.7\cdot 10^3\cdot 100\cdot 10^3}{(4.7+100)\cdot 10^3}}{(330+220+82)\cdot 10^3+\frac{4.7\cdot 10^3\cdot 100\cdot 10^3}{(4.7+100)\cdot 10^3}}=0.007053$$

The output voltage scaled by this conversion ratio will be read by the MCU's ADC.

3.5.4 Signal conditioning for PFC current

Figure 18. STEVAL-ISF002V1 - PFC current sensing section

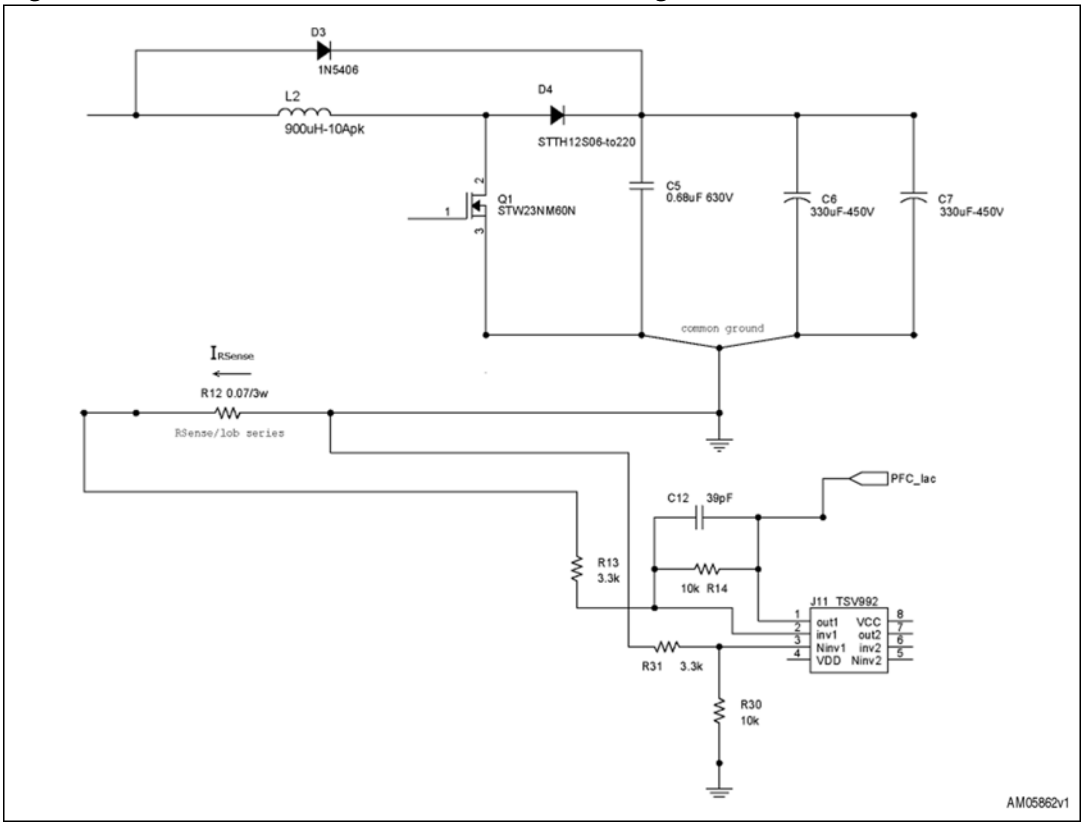
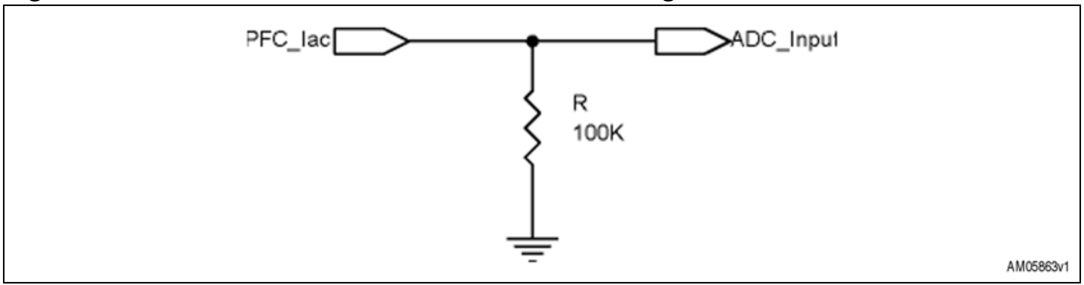


Figure 19. STEVAL-IHM022V1 - PFC current sensing section



Equation 36

$$PFC\_Iac = I_{RSense} \cdot R12 \cdot \frac{R14}{R13} = I_{RSense} \cdot 0.07 \cdot \frac{10 \cdot 10^3}{3.3 \cdot 10^3}$$

Equation 37

$$PFC\_Iac = I_{RSense} \cdot 0.212121$$

Conversion ratio:

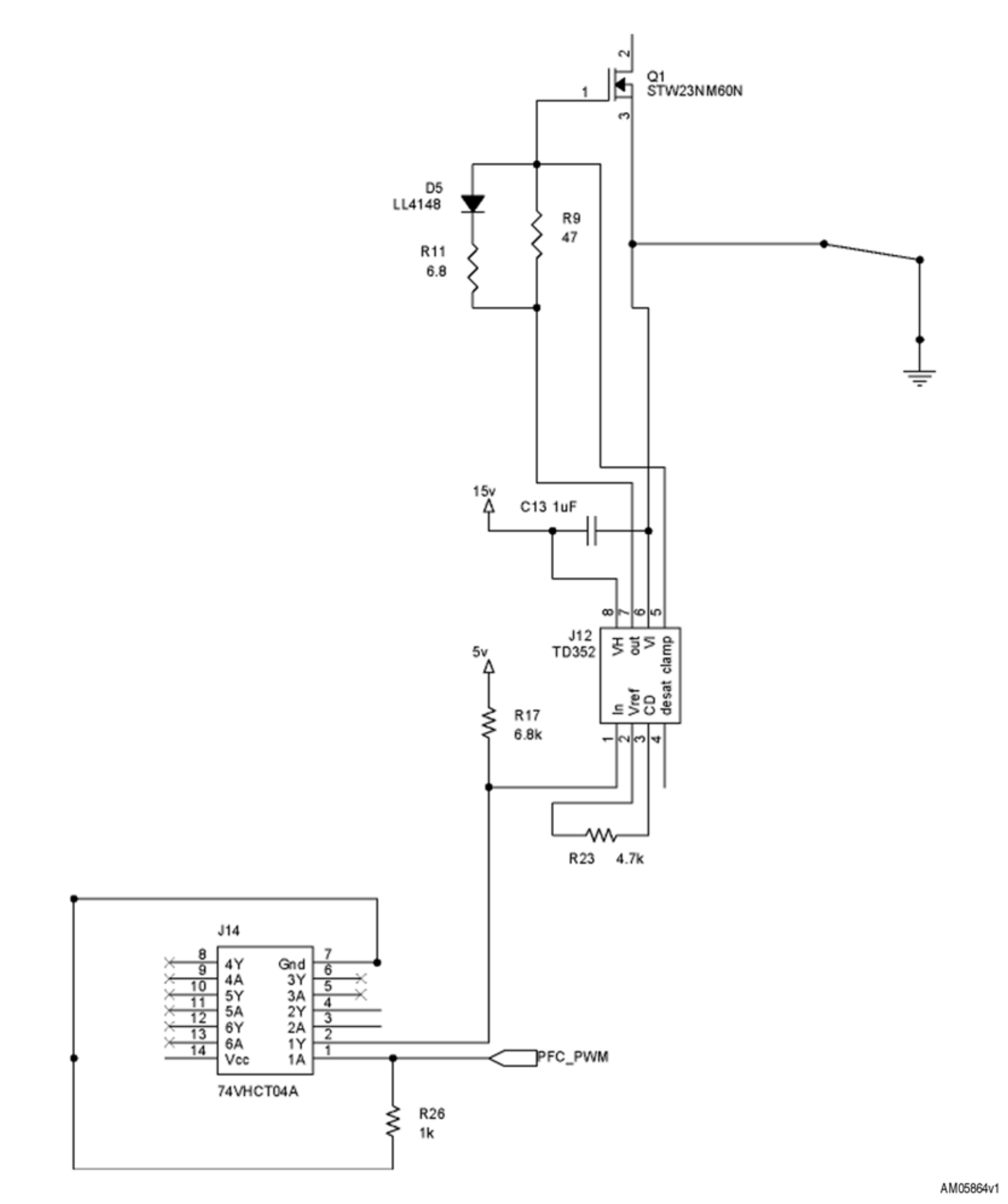
Equation 38

$$0.212121 \frac{V}{A}$$

The PFC current scaled by this conversion ratio will be read by the MCU's ADC.

3.5.5 Driving the PFC power MOSFET

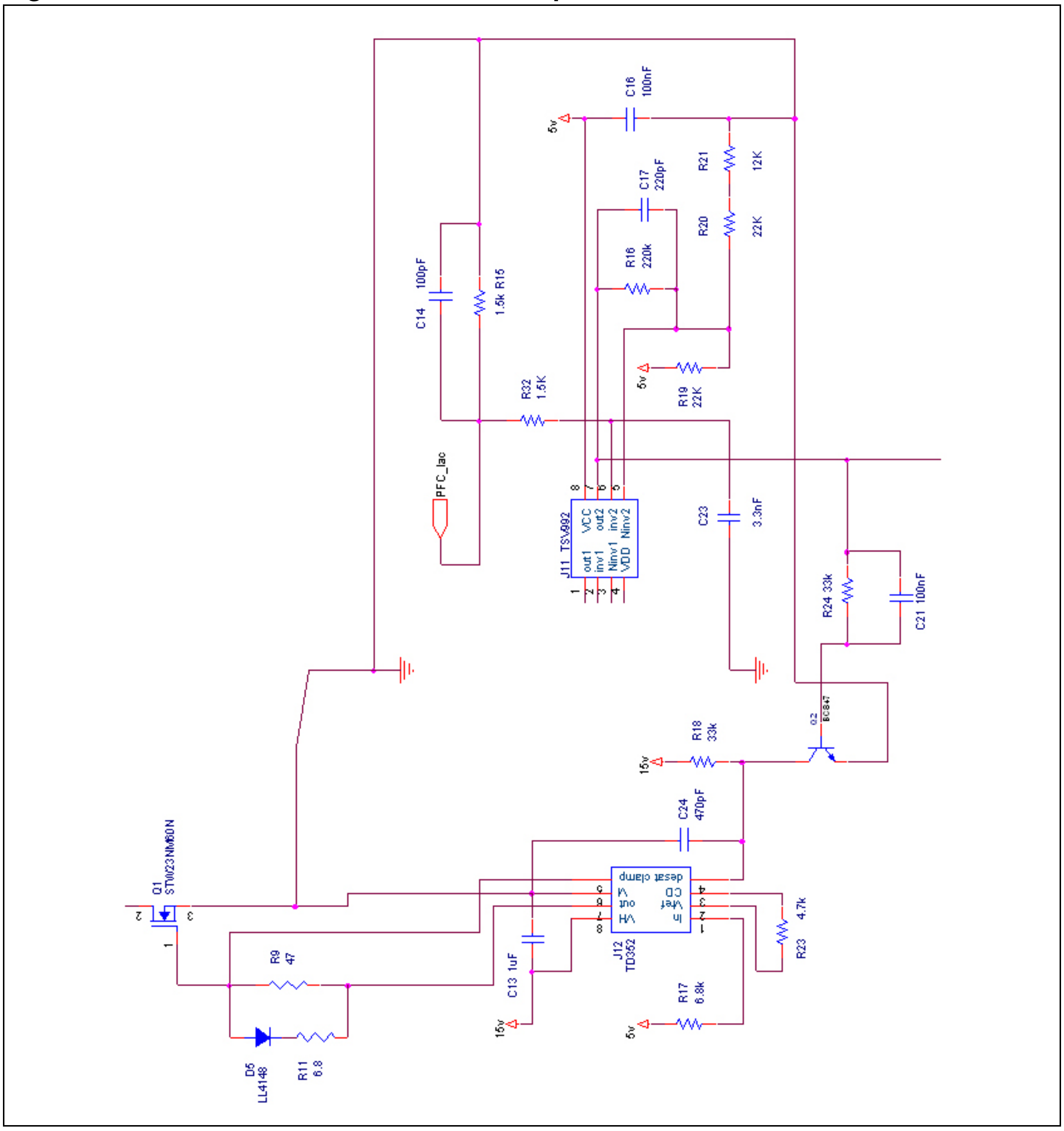
Figure 20. STEVAL-ISF002V1 - PFC power MOSFET driving section



The PFC_PWM provided by the MCU is inverted and sent to the MOSFET driver TD352.

3.5.6 Overcurrent protection

Figure 21. STEVAL-ISF002V1 - overcurrent protection section



This hardware protection unit uses a feature of the TD352. The output is fixed to zero as soon as a high level is detected on its "desat" pin (pin 4).

While the Q2 NPN transistor is in saturation, the voltage on the "desat" pin is zero. Otherwise the voltage on the "desat" pin is 15 V and the output of the TD352 is fixed to zero.

Q2 remains saturated until I_{RSense} goes below 14.3 V.

In fact, the second operational amplifier inside the TSV992 is used as a comparator and its output is high if the following conditions are met.

Equation 39

$$PFC\_Iac < \frac{R20 + R21}{R19 + R20 + R21} \cdot 5\,V$$

From *Equation 4* and *Equation 7*, out2 of the TSV992 is high if:

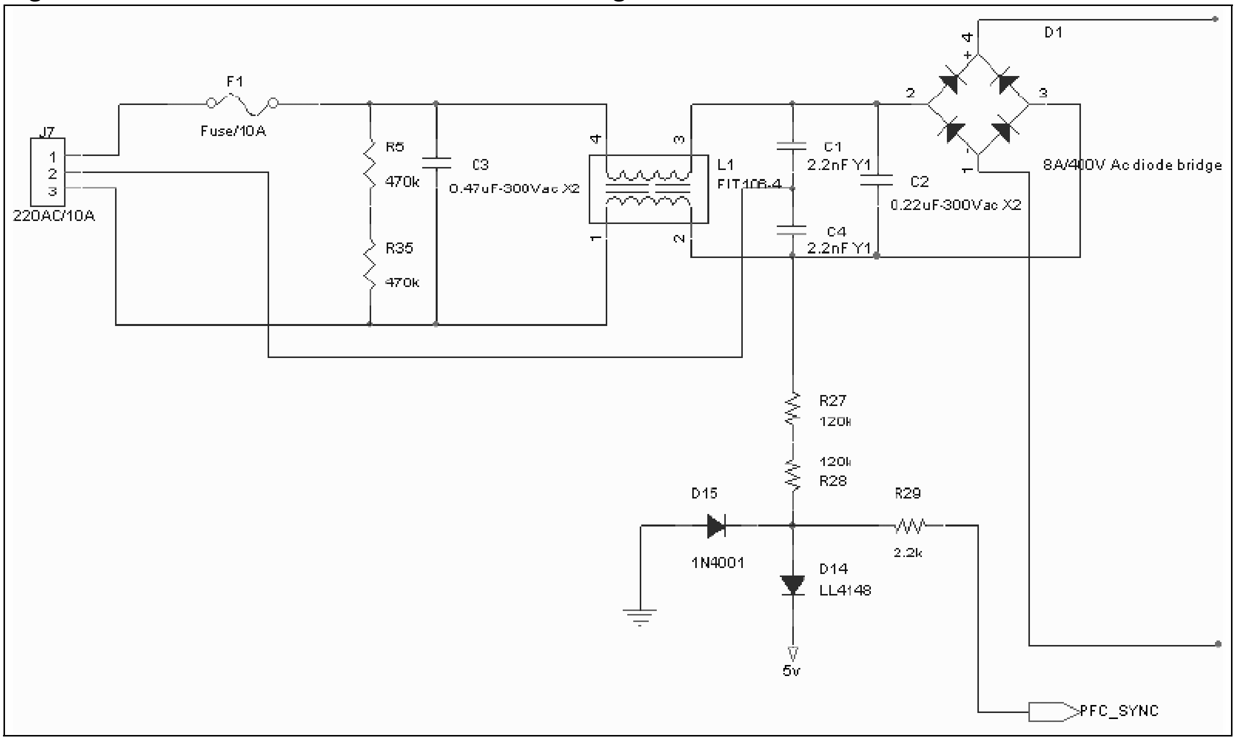
Equation 40

$$I_{RSense} < \frac{3.035714}{0.212121} A = 14.31\,A$$

Furthermore, out2 of the TSV992 is connected to the MCU that can have information about the PCF overcurrent occurrence (see *Figure 43*).

3.5.7 Zero crossing detection of input voltage

Figure 22. STEVAL-ISF002V1 - vin zero crossing detection section



From PFC_SYNC, information can be obtained on the zero crossing of the input voltage as shown in *Figure 23*.

Figure 23. Vin zero crossing detection (without load)

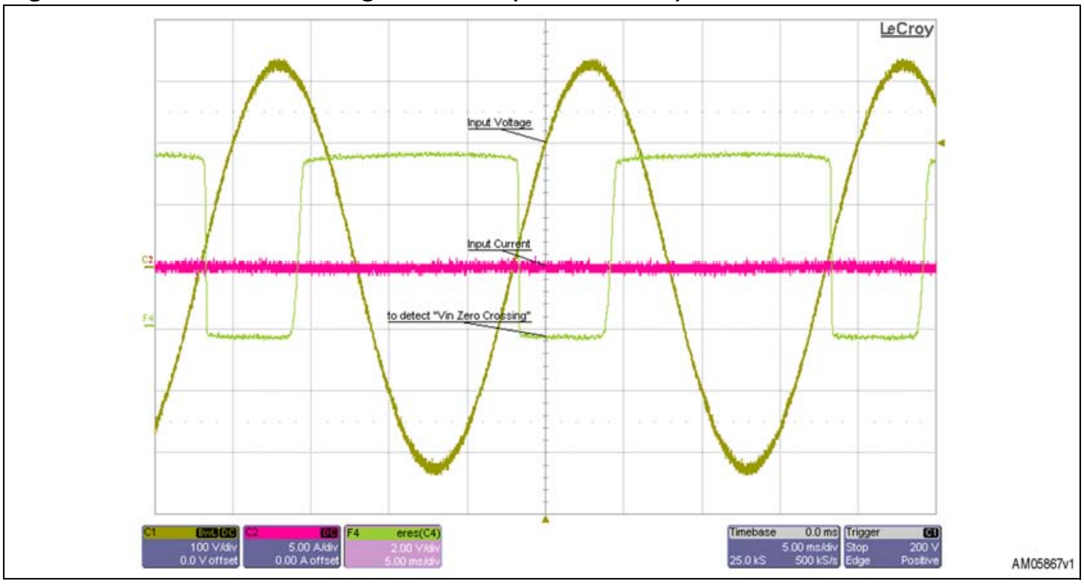
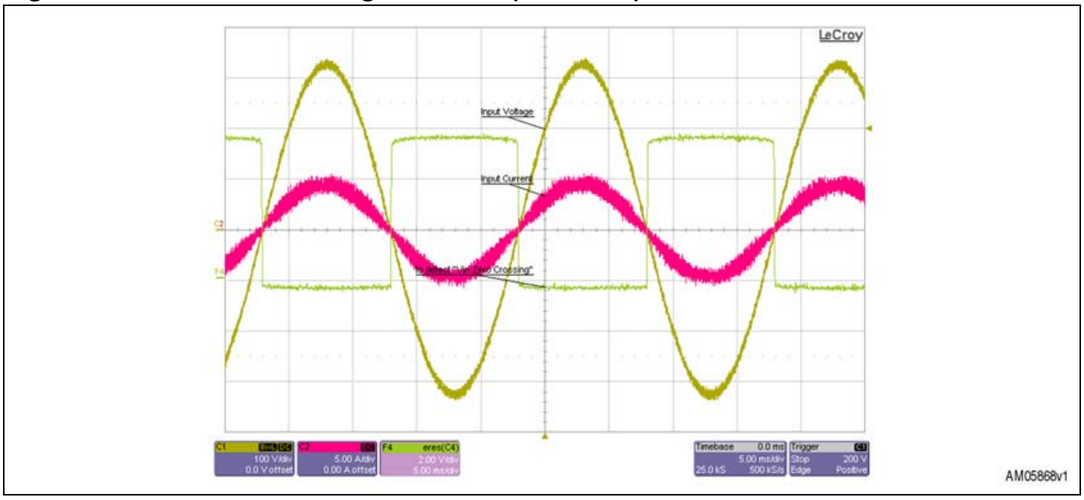


Figure 24. Vin zero crossing detection (with load)



Then for each mains period on PFC_SYNC, a transition high/zero occurs as soon as the mains crosses zero.

Note: This circuitry, combined with a timer, is also used to measure the frequency of V_{in}.

4 Current and voltage protections

The digital PFC demonstrator includes the following.

- A hardware protection against PFC overcurrent (14.3 A). The PFC is stopped when the value of the inductor current goes above the value fixed by the hardware, in this case 14.3 A (see *Section 3.5.6*).
- A software limitation for a maximum PFC current (13 A). Each control loop PFC is momentarily stopped if the inductor current rises above PFC_MAX_IL (13 A) and restarts when the inductor current goes below PFC_MAX_HYS_IL (95% of PFC_MAX_IL).
- A software protection against output overvoltages (460 V). Each control loop PFC is stopped if the DC voltage rises above PFC_MAX_THRESHOLD_VDC (460 V).
- A software limitation for a maximum output voltage (435 V). Each control loop PFC is momentarily stopped if the DC voltage rises above PFC_MAX_VDC (105% of PFC_REFERENCE_VDC) and restarts when the DC voltage goes below PFC_MAX_HYS_VDC (98.75% of PFC_REFERENCE_VDC). PFC_REFERENCE_VDC is 415 V.

Note: With the exception of the hardware protection, all values that take part in the software protection or limitation can be modified in the "PFC.h" file (see Section 6.3.2).

5 STEVAL-IHM022V1 demonstration board

The STM32F103ZE's demonstration board STEVAL-IHM022V1 is designed as a dual and triple motor control development platform for STMicroelectronics' ARM Cortex-M3 core-based STM32F103ZE microcontroller.

Figure 25. STEVAL-IHM022V1

For more information refer to the user manual of the STEVAL-IHM022V1[a].

a. UM0688: Quick reference guide for the STEVAL-IHM022V1 STM32™ dual motor drive demonstration board and software application, available for download from www.st.com.

6 Digital PFC firmware

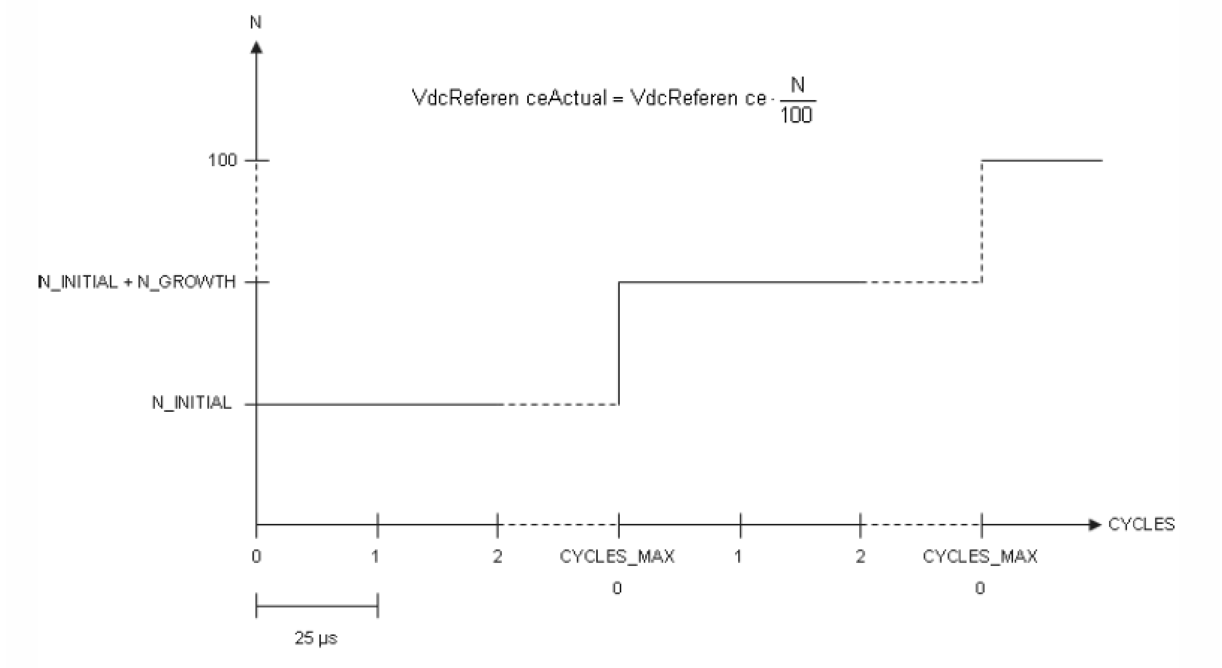
This chapter describes and explains how to implement the digital PFC software.

6.1 Firmware architecture

The execution of the PFC firmware is based on the implementation of a state machine. It is basically made up of four states.

- PFC_WAITING: after initialization, the system waits for the AC mains insertion, triggered by a falling edge of the zero-crossing detector shown in *Figure 22*. After this time, the new state assumed is PFC_STARTING.
- PFC_STARTING: the mains frequency is measured and if it is outside the range of 45 ÷ 66 Hz, the new state becomes PFC STOPPED. If the mains frequency is within this range, the relay against in-rush current is closed and protections are enabled. To avoid current peaks, the VDC setpoint for the voltage PI is not immediately fixed to the final target. The actual VDC reference is gradually increased to reach the final target voltage of 415 V. The growth of this reference is shown in *Figure 26* and it is managed by the PFC_ROUTINE function (part of the "PFC.c" file) every 25 µs. This method of gradually incrementing to reach the target output voltage reference is called *soft-start*.

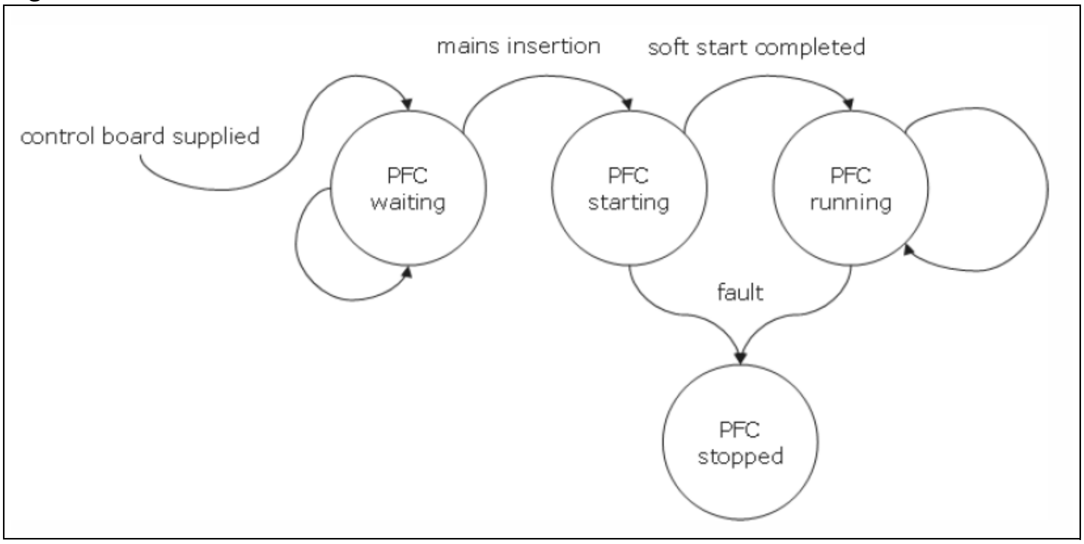
Figure 26. Output voltage soft-start methodology



- PFC_RUNNING: this is the steady state of the PFC. The PFC routine is performed with a loop frequency of 40 kHz, half of the switching frequency of the MOSFET. This routine controls the digital PFC and performs the following.
  - Software protections and limitations
  - Voltage PI
  - Current PI
  - Updating of the PFC MOSFET duty cycle
- PFC STOPPED: the PFC is in this state after any fault condition. The MOSFET is switched off and it is not possible to exit from this state.

Figure 27 summarizes the states and transition events of the state machine.

Figure 27. PFC states



6.2 STM32 peripherals for digital PFC

Some STM2 peripherals are used to perform the digital PFC.

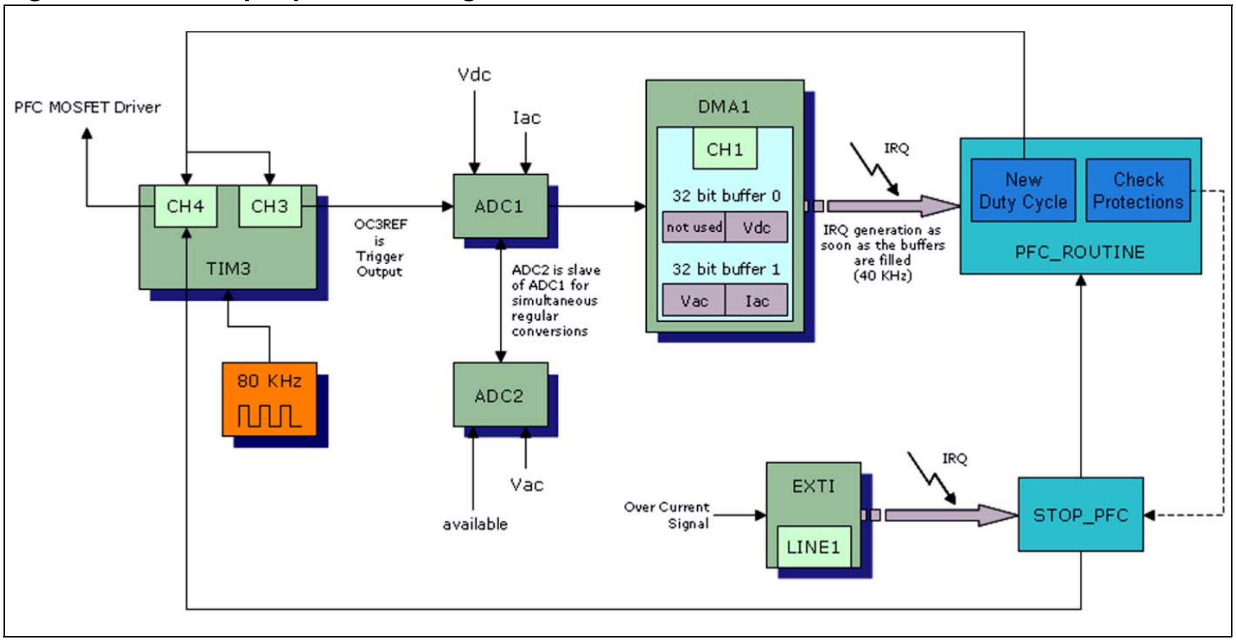
Table 1. Peripherals and pins of the STM32F103ZE used for the digital PFC

Peripheral	Description	MCU pin	MC + PFC connector
ADC1 Ch.3 (regular channel)	Output DC voltage	PA.03	14
ADC1 Ch.4 (regular channel)	PFC current	PA.04	24
ADC2 Ch.5 (regular channel)	Input AC voltage	PA.05	22
TIM3 Ch.4 (80 kHz) Duty cycle changes every two periods	Drives the PFC power MOSFET	PC.09	29
TIM3 Ch.3 (80 kHz) This duty cycle is half of the TIM3 Ch.4 duty cycle, but never lower than 8% (1 µs) to avoid any bad effects caused by the power MOSFET's commutation	Triggers the ADC: – 1st trigger to convert ADC1 Ch.3 (one channel is available) – 2nd trigger to convert ADC1 Ch4 and ADC2 Ch.5		
DMA Ch.1	Stores the converted values coming from ADCs. Its IRQ calls the PFC routine after 2nd couple of ADC conversions		
Input	V_{in} zero crossing detection	PD.02	27
Output	Drives the relay for bypassing the resistor when there is in-rush current	PD.10	21
EXTI line 1	PFC hardware overcurrent detection	PE.01	2
System timer (SYSTICK)	Internal timer for other features		

Table 2. Used interrupts and their priority

Peripheral	IRQ Use	Pre-emption priority	Sub priority
EXTI Line1	Overcurrent protection (PE.01)	0	0
EXTI Line2	Mains frequency detection (PD.02)	0	1
DMA1 channel1	PFC routine	1	0
System timer (SYSTICK)	Timer for delays	2	0

Figure 28. Use of peripherals for digital PFC



6.3 Main files for digital PFC

This firmware is structured in such a way as to allow easy integration with other existing applications.

The software for the digital PFC is composed of two files. The first, "PFC.c", contains all the functions, while the second, "PFC.h", contains the definitions of the system parameters (other than constants used internally by the main file).

Obviously, with an existing (host) application, some additional steps must be accomplished to integrate the PFC software. Assuming that the host application has the minimum necessary resources available (in terms of embedded peripherals, CPU load and code memory), it is basically sufficient to include these two files in the host application firmware and to appropriately call a function that initializes and starts the digital PFC.

6.3.1 PFC.c file

The "PFC.c" file contains the following functions.

- PFC_ CONFIGURATION
  - Sets the PFC status to PFC_WAITING.
  - Performs I/O configuration for ADCs, timer, PFC synchronization, PFC overcurrent protection and relay driving against in-rush current.
  - Timer3 configuration (CH. 3 for ADC trigger and CH. 4 for driving PFC power MOSFET).
  - ADC1 configuration: converts Vdc and Iac. ADC1 and ADC2 convert their channels simultaneously.
  - ADC2 configuration: converts a dummy channel and Vac. This dummy channel is not used by the digital PFC standalone.
  - DMA1 CH. 1 configuration: has two buffers of 32 bits each. Each buffer contains the converted value of the simultaneous conversion of ADC1 and ADC2 (see *Figure 28*).
  - DMA1 CH. 1 IRQ configuration: this interrupt will be generated as soon as the two buffers are filled.
  - EXTI Line 1 IRQ configuration.
- WAIT_FOR_Vin_ZERO
  - Waits until Vin gets zero within one mains period.
- ENABLE_PROTECTIONS
  - Enables check for hardware protection against PFC overcurrent.
  - Enables check for software protections.
- DISABLE_PROTECTIONS
  - Disables check for hardware protection against PFC overcurrent.
  - Disables check for software protections.
- STOP_PFC
  - Calls DISABLE_PROTECTIONS.
  - Sets to zero the TIM3 CH. 4 output (PFC power MOSFET will be open from this point on).
  - Changes the PFC status in PFC_STOPPED.
- CHECK_PROTECTIONS
  - Checks protections against overvoltages and undervoltages.
  - Calls STOP_PFC if any protections are triggered.
- PFC_INIT
  - Calls PFC_CONFIGURATION.
  - Uses WAIT_FOR_Vin_ZERO as timer to wait for charging output capacitors.
  - Enables the TIM3 counter.
  - Bypasses resistor when there is in-rush current.
  - Uses WAIT_FOR_Vin_ZERO as timer to wait for change relay status.
  - Calls ENABLE_PROTECTIONS.
  - Sets the PFC status as PFC_STARTING.

- PFC_ROUTINE
  - This routine is called by the IRQ of DMA1_CH_1 that is generated after two completed ADC conversions (see *Figure 30*).
  - Calculates mean of Vdc.
  - Performs a soft-start if the PFC status is PFC_STARTING or a software limitation if an overcurrent or overvoltage incident occurs. After this, the PFC status switches to PFC_RUNNING.
  - Manages the software limitation against overcurrent.
  - Manages the software limitation against overvoltage.
  - Performs a voltage PI every 400 cycles.
  - Performs a current PI every cycle.
  - Updates the duty cycle of TIM3 CH.4 and CH.3.
  - Calls CHECK_PROTECTIONS.
- ACTUAL_PFC_FLAG
  - Returns the value of PFC_STATUS_FLAG.
- DC_BUS_Value
  - Returns the value in volts of the DC bus voltage.
- Get_Vac
  - Returns the ADC's converted value of Vac.
- Get_Iac
  - Returns the ADC's converted value of Iac.
- Get_Vdc_main
  - Returns the ADC's converted value of Vdc.

6.3.2 PFC.h

The "PFC.h" file contains the definitions of constants used to perform the digital PFC as well as prototypes of functions.

Some of its parameters can be changed.

- TIM3 frequency

```
#define TIM3FREQ        80000 // in Hz
```

- ADC channel mapping

```
/* ADC1 and ADC2
************************************************************ */

#define Vdc_main_Channel ADC_Channel_3

#define Vdc_sub_Channel ADC_Channel_14

#define Iac_Channel ADC_Channel_4

#define Vac_Channel ADC_Channel_5

/* ************************************************************ */
```

- Conversion ratios (see *Section 3.5.2*, *3.5.3* and *3.5.4*)

```
/* Conversion Ratios
******************************************************** */
```

```
#define CONV_RATIO_VAC  0.008629 // net ratio
#define CONV_RATIO_VDC  0.007053 // net ratio
#define CONV_RATIO_IL   0.212121 // net ratio
```

- Thresholds for software protections and limitations (see *Chapter 4*)

```
/* Thresholds for SW Protections and Limiters
****************************** */
#define PFC_REFERENCE_VDC        415 // in Volt
#define PFC_MAX_VDC              (PFC_REFERENCE_VDC * 1.05)  //435V
#define PFC_MAX_HYS_VDC          (PFC_REFERENCE_VDC * 0.9875)  //410V
#define PFC_MAX_THRESHOLD_VDC    460
#define PFC_MIN_THRESHOLD_VDC    225 // in volt
#define PFC_MAX_IL               13  // in ampere
#define PFC_MAX_HYS_IL           PFC_MAX_IL * 0.95
/* ************************************************************ */
```

- Parameters of voltage PI

```
/* Voltage PI Regulator
***************************************************** */
/* divided by 1024
************************************************************/
#define kpv_init  (u16)1700
#define kiv_init  (u8)213
/* ************************************************************ */
```

- Parameters of current PI

```
/* Current PI Regulator
***************************************************** */
/* divided by 1024
************************************************************/
#define kpi_init  (u16)230
#define kii_init  (u8)56
/* ************************************************************ */
```

- Parameters of soft restart (see *Figure 26*)

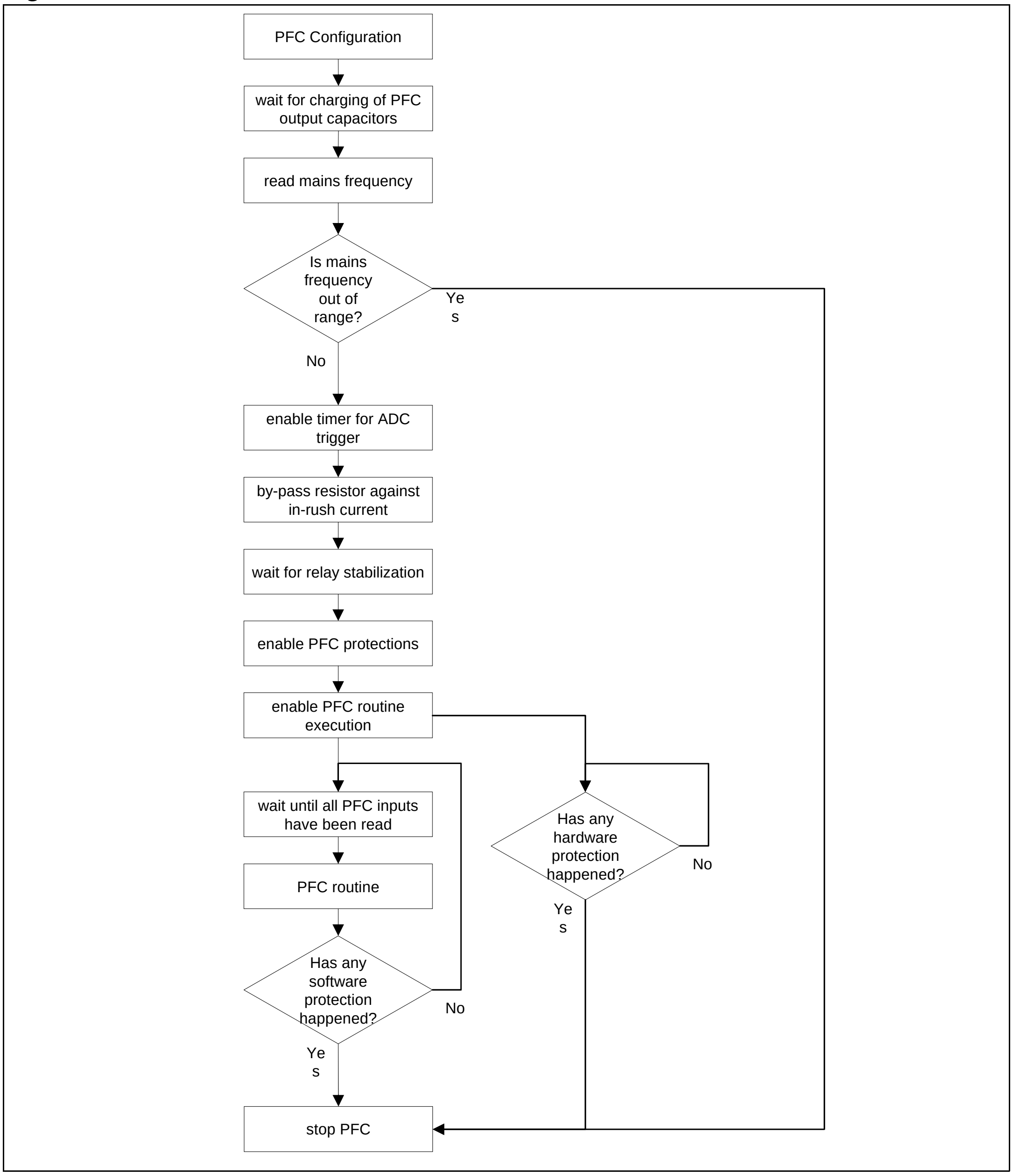
```
/* for soft restart
********************************************************* */
/* Three particular points are located (at startup, after OC and
after OV     */
/* N (in percentage) is the part of VdcRef used by voltage PI
*/
/* N will be increased by N_GROWTH as soon as CYCLES reaches
CYCLES_MAX       */
```

```
/* CYCLES is increase by 1 every 25us that is at 40kHz
*/
/* example:
*/
/* for CYCLE_MAX = CYCLE_MAX_STARTUP = 1600
*/
/* then N will be increased after 1600 x 25us = 40ms
*/
/* ************************************************************ */
#define CYCLES_MAX_STARTUP      1600
#define CYCLES_MAX_OVERCURRENT  3200
#define CYCLES_MAX_OVERVOLTAGE  3200
#define N_INITIAL_STARTUP       68
#define N_INITIAL_OVERCURRENT   97
#define N_INITIAL_OVERVOLTAGE   98
#define N_GROWTH_STARTUP        4
#define N_GROWTH_OVERCURRENT    1
#define N_GROWTH_OVERVOLTAGE    1
/* ************************************************************ */
```

6.4 Digital PFC firmware execution

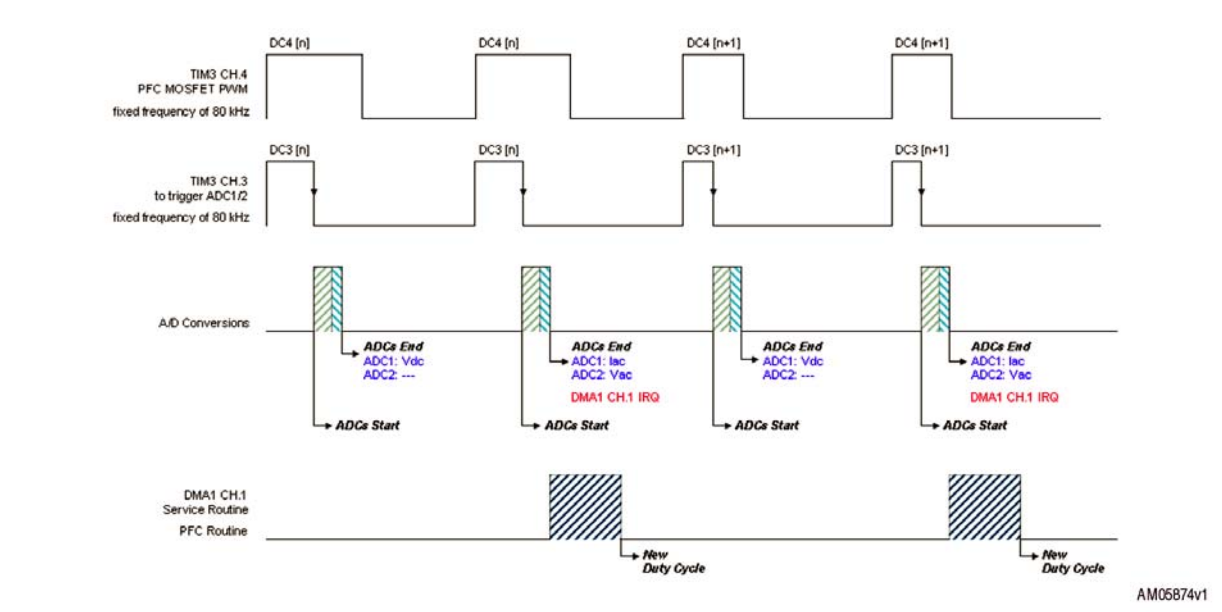
Figure 29 shows the sequence of events for the digital PFC firmware.

Figure 29. PFC firmware flowchart



The timing of the PFC is explained in *Figure 30*.

Figure 30. Digital PFC timing



The frequency of TIM3 is fixed at 80 kHz while the duty cycle varies according to the digital PFC control. TIM3/CH.4 is used to drive the PFC power MOSFET. TIM3/CH.3 is used to trigger the ADC. The ADC conversion starts at the end of the TIM3/CH.3 duty cycle. The TIM3/CH.3 duty cycle is equal to half of the TIM3/CH.4 duty cycle, but never lower than 1 µs to avoid invalidating the conversion with noise coming from the switching of the power MOSFET. For the STM32 ADC the total conversion time is calculated as follows.

Equation 41

$$T_{ADC\,conv} = SamplingTime + 12.5\ cycles$$

For design purposes, the following values have been selected.

Equation 42

$$SamplingTime = 7.5\ cycles$$

Equation 43

$$ADC_{clock} = 12\,MHz$$

Thus yielding:

Equation 44

$$T_{ADC\,conv} = \frac{SamplingTime + 12.5}{ADC_{clock}} = \frac{(7.5 + 12.5)}{12\,MHz} = (0.625 + 1.041)\,\mu s = 1.666\,\mu s$$

Through experimental measurements, the CPU performs a "PFC routine" for a time of 4.27 µs every control loop, then the CPU's load for the PFC routine

becomes: $\frac{4.27\,\mu s}{25\,\mu s} \cong 17\%$

7 Starting the PFC application

This chapter explains how to configure the demonstrator.

7.1 Hardware requirements

- STEVAL-ISF002V1 PFC power board
- 34-pin flat cable
- AC power source able to supply the appropriate voltage and current
- DC electronic load able to provide the appropriate load
- STEVAL-IHM022V1 dual motor control demonstration board
- 5 V / 2 A DC power supply to supply the STEVAL-IHM022V1
- J-Link-ARM-KS
- USB cable (A and B type plug)
- 20-pin flat cable
- PC

7.2 Software requirements

- IAR embedded workbench for ARM 5.20
- IAR project for digital PFC based on the STM32F103ZE microcontroller

The software demonstration source code is provided by STMicroelectronics free of charge (after acceptance of the license agreement during the installation procedure).

The firmware can be customized with your own preferred development tool and downloaded into the internal Flash memory of the STM32 through a JTAG interface present on the STEVAL-IHM022V1.

7.3 Jumper settings

Table 3 and *Table 4* show the jumper settings for the STEVAL-ISF002V1 power board and STEVAL-IHM022V1 demonstration board respectively. Note that *Table 4* only describes the jumpers used from the digital PFC; all other jumper settings must be left as default.

Table 3. PFC power board STEVAL-ISF002V1 jumper settings

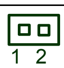
Name	Selection	Description
JP9		VIPER12 is enabled. J10 connector must be open.
		VIPER12 is disabled. 15 V must be provided by J10 connector.

Table 3. PFC power board STEVAL-ISF002V1 jumper settings (continued)

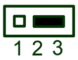
Name	Selection	Description
J18		Control board is not supplied from power board.
		Control board is supplied with 5 Vdc provided by power board.
		Control board is supplied with 5 Vdc provided by a power stage connected to the power board by means of an MC connector J16.

Table 4. Control demonstration board STEVAL-IHM022V1 jumper settings

Name	Selection	Description
JMP6		To connect *MC_Main PFC_Iac* with PA4
JP13		To connect *MC_Main PFC_Vac* with PA5

Note: MC_Main_Bus_Voltage is connected directly to PA3. For any other jumpers, refer to the default settings of the STEVAL-IHM022V1 as described in UM0688.

7.4 Downloading the firmware

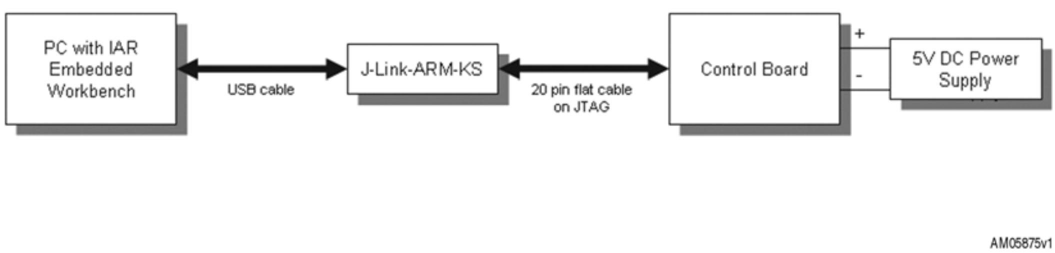
The firmware package is a workspace written for IAR/EWARM version 5.20 and must be downloaded into the STM32 program memory before using the digital PFC.

The firmware is ready to be used at first power ON or immediately after a board reset event (after the system's hardware configuration has been completed).

If a different parameter needs to be modified before the demo board is run, you should refer to the "PFC.h" file. Once the modifications have been applied, the firmware must be re-built and downloaded into the STM32 microcontroller using your own development tool. In any case, you can change the parameters of two PIs while the firmware is running.

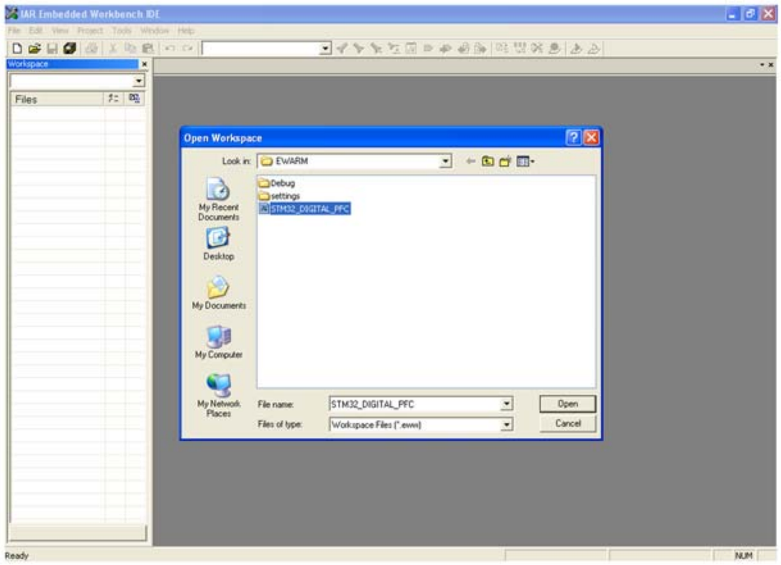
Connect the components as shown in *Figure 31* to download the firmware into the STM32.

Figure 31. Hardware connections for firmware downloading



With the IAR "embedded workbench IDE" open the workspace file *STM32_DIGITAL_PFC\EWARM\STM32_DIGITAL_PFC.eww*.

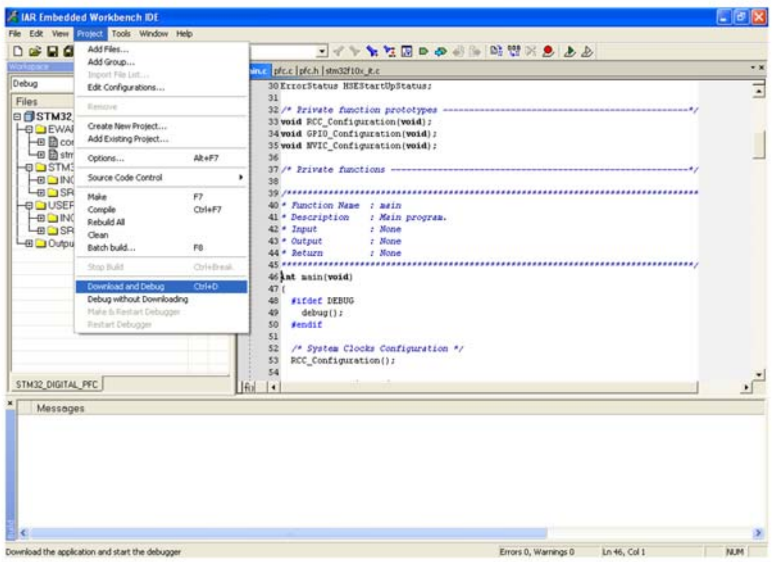
Figure 32. Opening the workspace file



AM05876v1

Download the code into the STM32 as shown.

Figure 33. Downloading and debugging the firmware



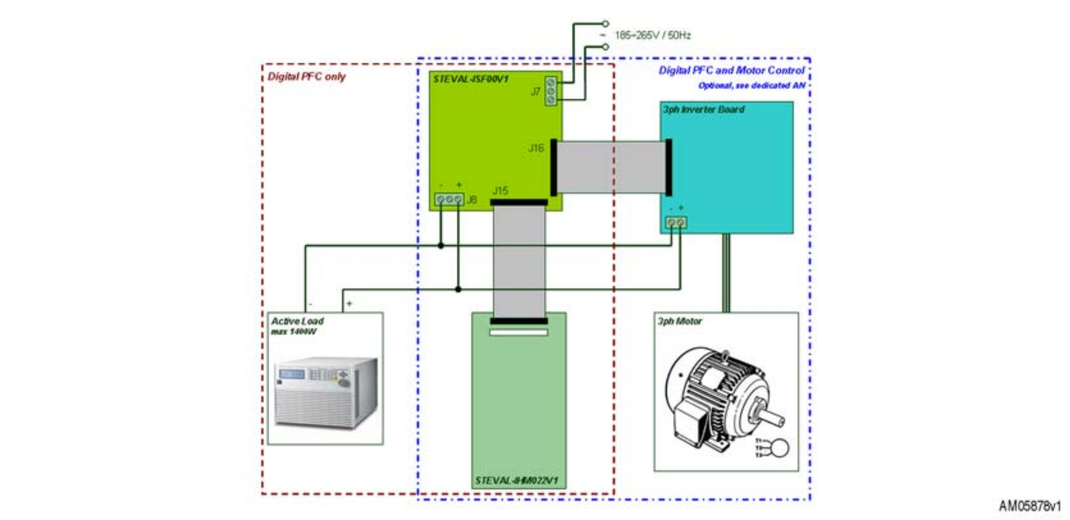
AM05877v1

As soon as the download is complete you can unplug the J-LINK probe. Once you have reset the STM32, the control board will be ready for you to try out the demonstrator.

7.5 Getting started with the system

The next step is to interconnect the parts to assemble the digital PFC demonstrator.

Figure 34. Connecting the various system components



1. Connect the AC power source to pins 1 and 3 of the J7 connector of the STEVAL-ISF002V1.
2. Connect an active DC load to pins 1 and 3 of the J8 connector of the STEVAL-ISF002V1.
3. Connect a 34-pin flat cable between J15 of the STEVAL-ISF002V1 and the main MC connector of the STEVAL-IHM022V1.
4. Connect a 3-ph inverter board if required (optional).
5. Supply the control board STEVAL-IHM022V1 with either a 5 V DC power supply or by means of the PFC power board STEVAL-ISF002V1 (refer to J18 in *Table 3*).

8 Running the demonstrator

8.1 Navigating in the system menu

The system's user interface is comprised of four basic hardware elements.

- A 320 x 240 TFT LCD display
- Four LEDs (red, orange, blue and green)
- A 5-way joystick (UP, DOWN, RIGHT, LEFT, SELECTION)
- One push button (KEY)

Figure 35. Hardware elements of the control board

AM05879v1

The four LEDs are used to obtain information on the actual state of the digital PFC.

Table 5. LED description for digital PFC

LED color	Description
Red	PFC stopped
Orange	PFC waiting
Blue	PFC starting
Green	PFC running

As shown in *Figure 5 on page 10*, two PI regulators are used to implement a digital PFC.

The parameters of these PIs can be changed by either modifying the "PFC.h" file or by changing the parameters of the PIs while the firmware is running by means of the joystick and KEY push button.

- Use UP or DOWN of joystick to select the PI parameter.
- Use RIGHT of joystick to increase the selected PI parameter.
- Use LEFT of joystick to decrease the selected PI parameter.
- Use KEY push button to restore the selected PI parameter.

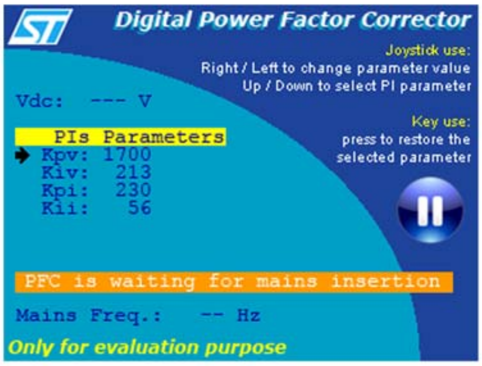
Table 6. Default values of PI regulators

	Kp	Ki
Voltage PI	$\frac{1700}{1024}$	$\frac{213}{1024}$
Current PI	$\frac{230}{1024}$	$\frac{56}{1024}$

8.2 Digital PFC at work

Once the board has been reset, and if the firmware is correctly loaded into the Flash memory and the PFC power board is waiting for a mains insertion, the LCD display should show the following.

Figure 36. LCD after startup



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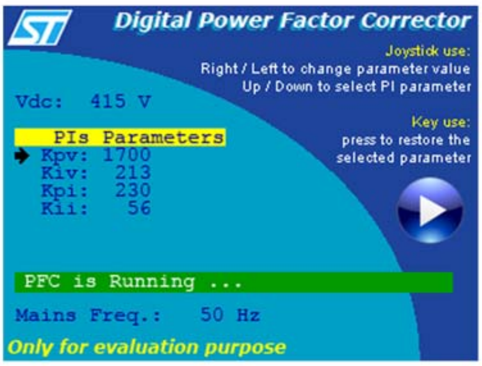
If after the reset the screen is blank, this means that the firmware has not been correctly downloaded into the memory or that the microcontroller has been kept in a halt state by the dongle. First check if the microcontroller is in a halt state. Remove the JTAG dongle from the connector and press the reset button. If the screen is still blank, you will have to compile and download the firmware again. If the system has been connected correctly, after the mains has been inserted the MCU will detect this condition and will launch the digital PFC and protections.

The LCD display should now show the following.

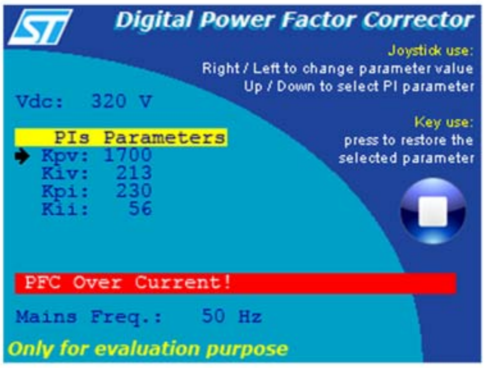
Figure 37. LCD during running of the digital PFC



AM05881v1

If any errors occur, the MCU will stop the digital PFC and the LCD will display the following.

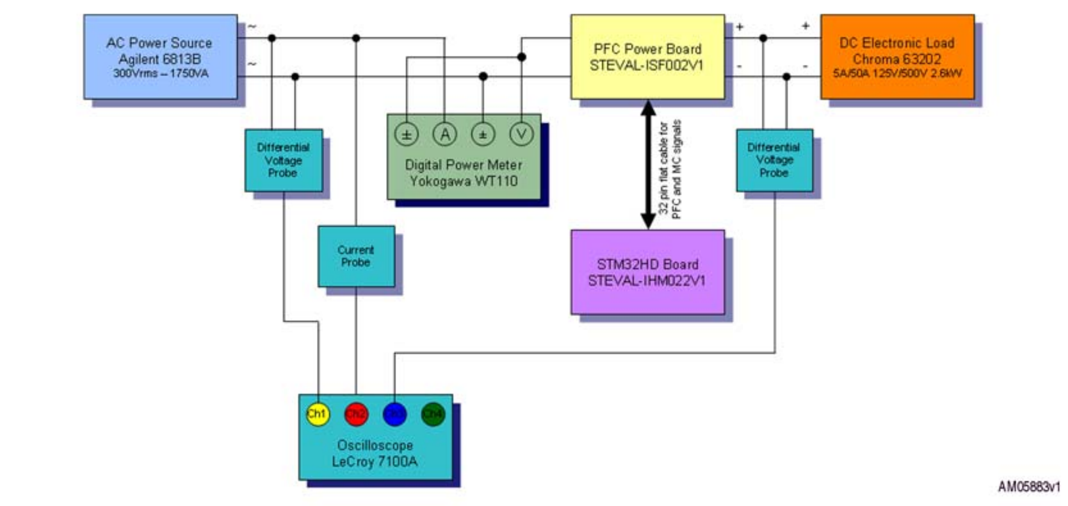
Figure 38. LCD after an overcurrent



9 Performance of the digital PFC

The following connections have been used to test the system.

Figure 39. Test setup block diagram

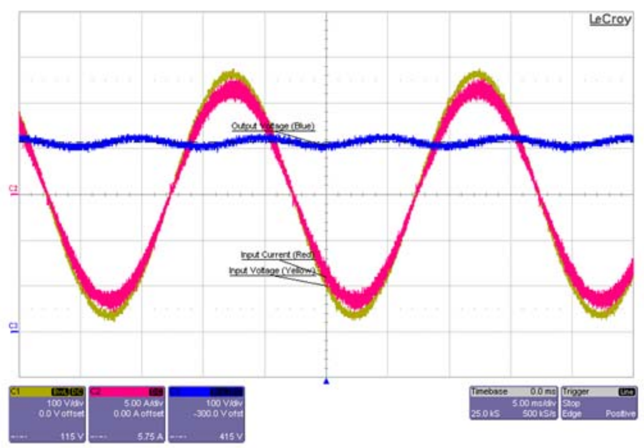


AM05883v1

9.1 Steady state

The following figures show the behavior of the digital PFC when it is supplying a load of 1400 W while the input voltage is 185 V/50 Hz, 230 V/50 Hz and 265 V/50 Hz.

Figure 40. 185 Vrms at 50 Hz as input - 1400 W as output load



AM05884v1

Figure 41. 230 Vrms at 50 Hz as input - 1400 W as output load

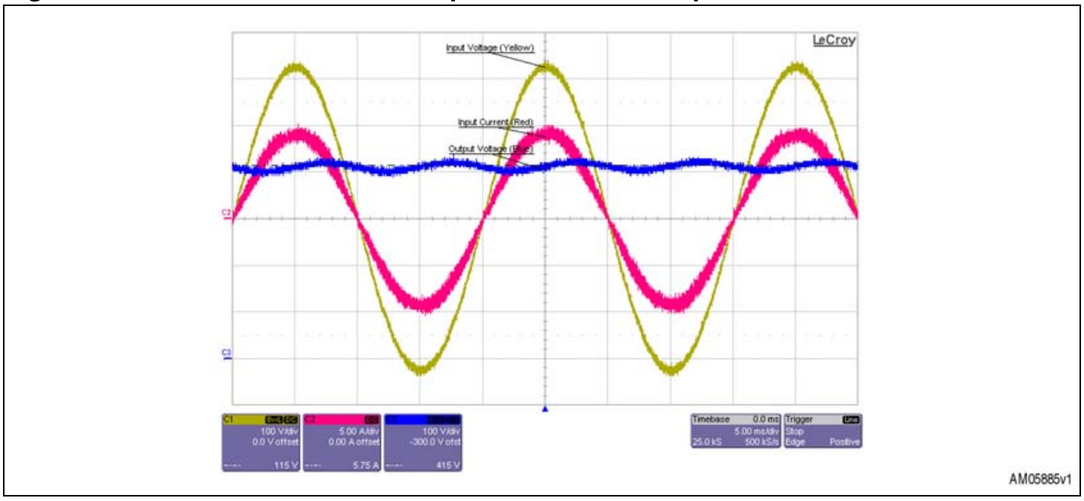
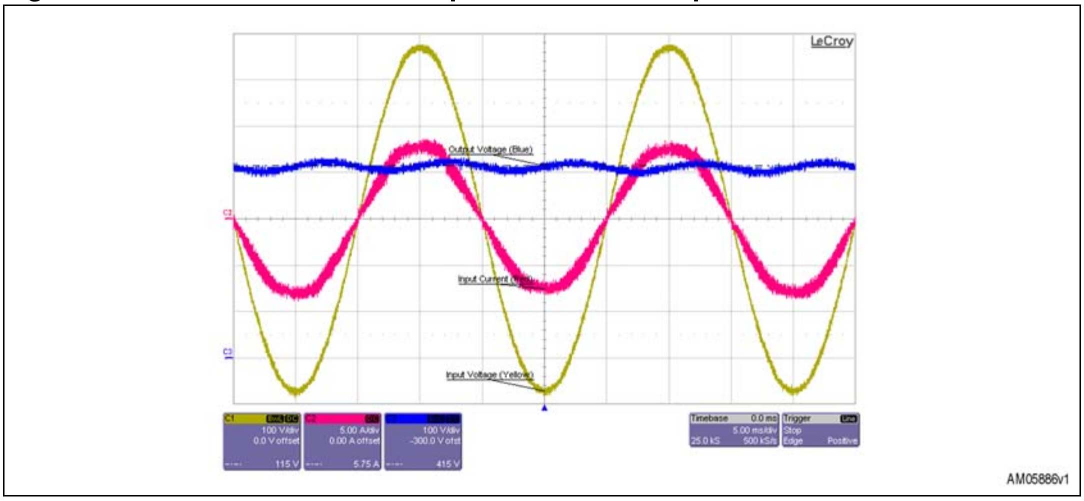


Figure 42. 265 Vrms at 50 Hz as input - 1400 W as output load



9.2 Efficiency measurement

The following tables provide information on the efficiency of the digital PFC.

Table 7. Efficiency with 185 Vrms at 50 Hz

Input voltage	Percentage of target power	Nominal output power [W]	Input power [kW][1]	Output voltage [V] [3]	Output power [kW] [3]	Eff.	PF[1]	THD [%][2]
185 Vrms at 50 Hz	25.00%	350	0.37	410.9	0.36	97.3%	0.978	3.6
	50.00%	700	0.73	410.0	0.71	97.3%	0.995	1.5
	75.00%	1050	1.10	410.5	1.06	96.4%	0.997	1.1
	100.00%	1400	1.47	413.5	1.41	95.9%	0.998	0.9
	105.00%	1470	1.55	416.9	1.48	95.5%	0.998	0.9

Table 8. Efficiency with 230 Vrms at 50 Hz

Input voltage	Percentage of target power	Nominal output power [W]	Input power [kW](1)	Output voltage [V] (3)	Output power [kW](3)	Eff.	PF(1)	THD [%](2)
230 Vrms at 50 Hz	25.00%	350	0.37	410.5	0.36	97.3%	0.966	5.0
	50.00%	700	0.72	410.0	0.70	97.2%	0.992	2.1
	75.00%	1050	1.09	412.4	1.06	97.2%	0.996	1.7
	100.00%	1400	1.45	414.9	1.41	97.2%	0.998	1.6
	105.00%	1470	1.52	415.2	1.47	96.7%	0.998	1.6

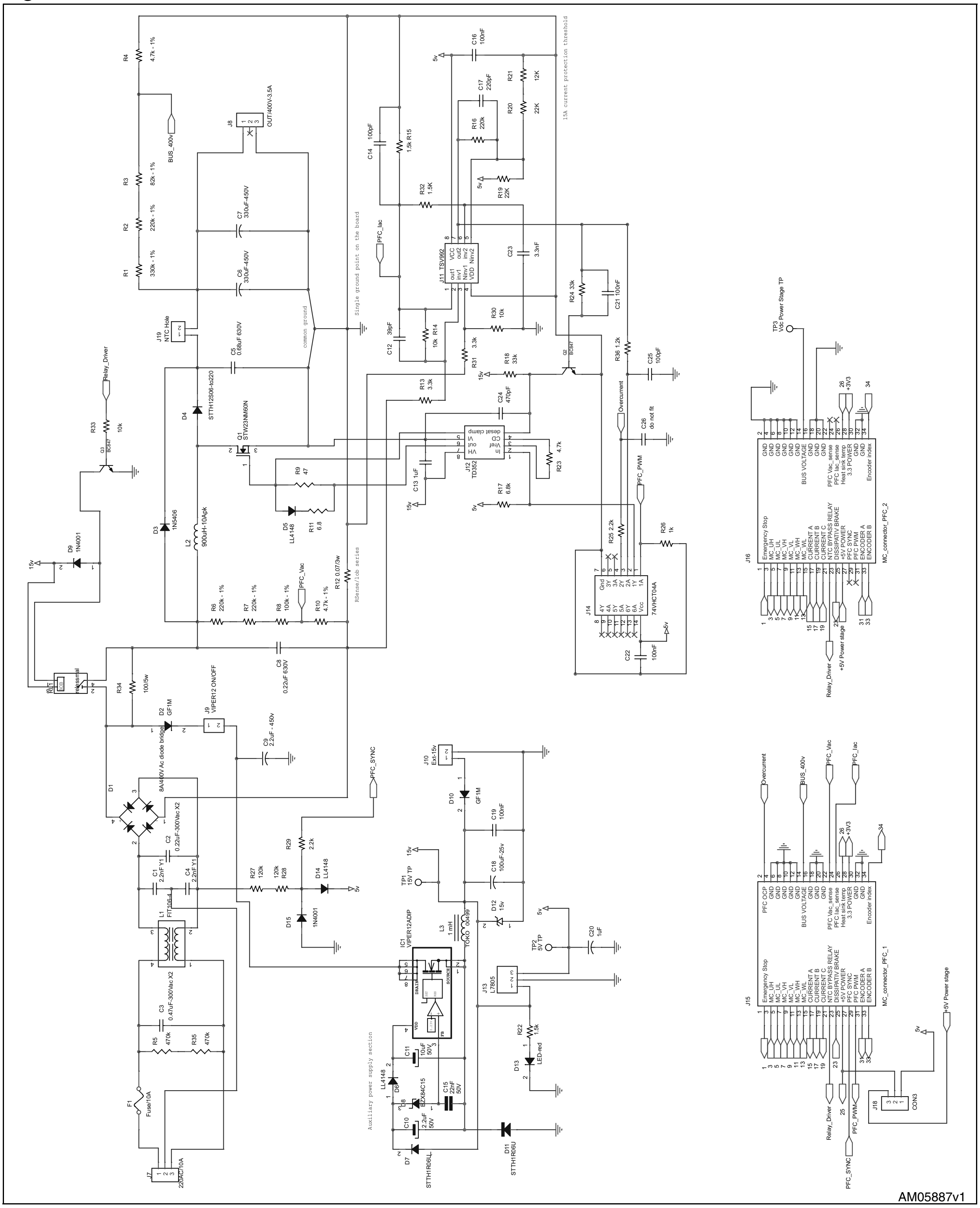
Table 9. Efficiency with 265 Vrms at 50 Hz

Input voltage	Percentage of target power	Nominal output power [W]	Input power [kW](1)	Output voltage [V](3)	Output power [kW](2)	Eff.	PF(1)	THD [%](3)
265 Vrms at 50 Hz	25.00%	350	0.37	410.7	0.36	97.3%	0.955	9.0
	50.00%	700	0.72	410.5	0.70	97.2%	0.990	3.7
	75.00%	1050	1.09	411.9	1.06	97.2%	0.996	3.2
	100.00%	1400	1.45	415.0	1.41	97.2%	0.998	2.7
	105.00%	1470	1.52	415.0	1.47	96.7%	0.998	2.7

1. By means of digital power meter Yokogawa WT110.
2. By means of AC power source/analyzer Agilent 6813B.
3. By means of DC electronic load Chroma 63202.

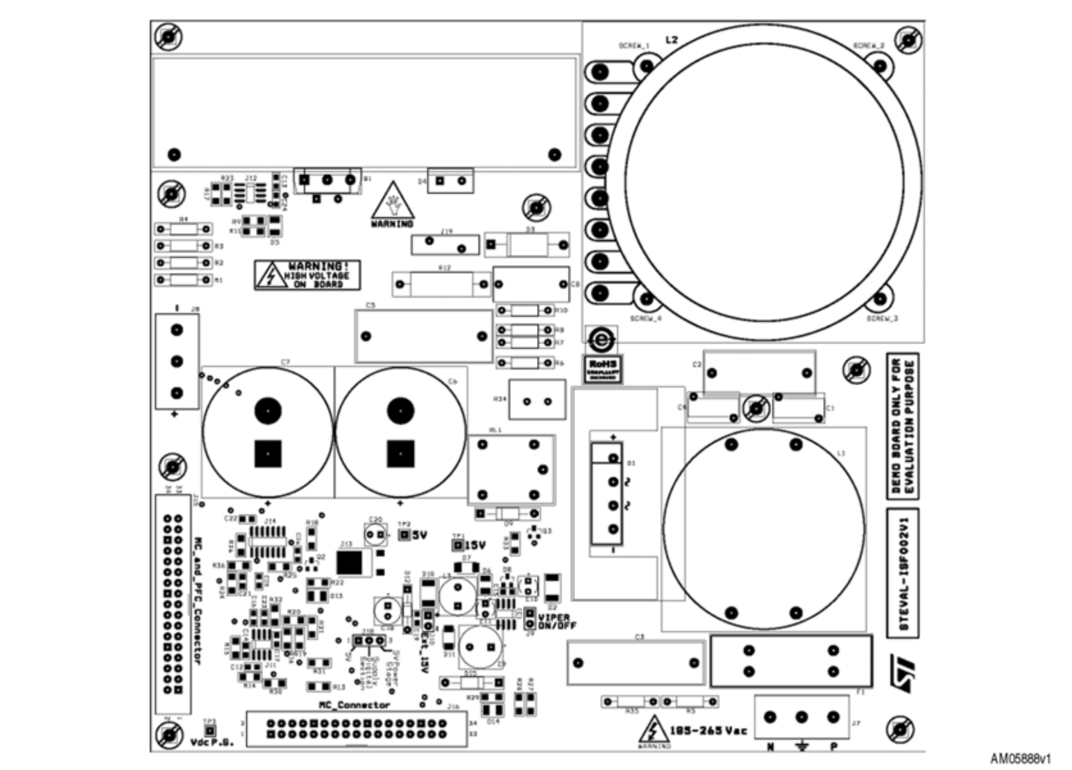
Appendix A Schematic and bill of materials

Figure 43. STEVAL-ISF00V1 schematic



A.1 Layout

Figure 44. STEVAL-ISF002V1 layout



- D1: rectifier bridge
- D4: PFC diode (STTH12S06)
- C6: DC output voltage capacitor
- C7: DC output voltage capacitor
- IC1: VIPER12
- J7: AC input voltage connector (185 ÷ 265 V at 50 Hz)
- J8: DC output voltage connector (400 Vdc)
- J9: jumper to remove low voltage supply (VIPER12)
- J10: 15 Vdc input connector
- J1: operational amplifiers (TSV992)
- J12: advanced MOSFET driver (TD352)
- J14: hex inverters (74VHCU04)
- J15: MC and PFC connector to interface with digital board
- J16: MC connector to drive 3 ph inverter board
- J18: jumper to supply digital board with 5 Vdc
- L1: EMI filter
- L2: PFC inductor
- Q1: PFC power MOSFET (STW23NM60N)
- R34: resistor to avoid in-rush current at start-up
- RL1: relay to bypass the R34 resistor

Table 10. STEVAL-ISF00V1 BOM

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
C1, C4	2.2 nF Y1	+/-20%	400 V		Y1 ceramic capacitor	Through hole	Any		RS code: 214-5903	
C2	0.22 µF	+/-20%	300 V		X2 capacitor	Through hole	Any		RS code: 208-6882	
C3	0.47 µF	+/-10%	300 V		X2 capacitor	Through hole	Any		RS code: 441-9694	
C5	0.68 µF	+/-10%	630 V		Radial polyprop cap	Through hole	Any		RS code: 190-8438	
C6, C7	330 µF	+/-20%	450 V		Electrolytic capacitor	Through hole	Phycomp	LH450M03 30BPF-3050	RS code: 440-6711	
C8	0.22 µF	+/-10%	630 V		Polyester capacitor	Through hole	Any		Distrelec code: 823778	
C9	2.2 µF	+/-20%	450 V		Electrolytic capacitor	Through hole	Any		RS code: 193-7256	
C10	2.2 µF	+/-20%	50 V		Electrolytic capacitor	Through hole	Any		RS code: 117-007A	
C11	10 µF	+/-20%	50 V		Electrolytic capacitor	Through hole	Any		RS code: 365-4240	
C12	3 9 pF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C13	1 µF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C14, C25	100 pF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C15	2 2 nF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C16, C19, C21, C22	100 nF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				

Table 10. STEVAL-ISF00V1 BOM (continued)

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
C17	220 pF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C18	100 µF	+/-20%	25 V		Electrolytic capacitor	Through hole	Any		RS code: 365-4127	
C20	1 µF	+/-20%	50 V		Electrolytic capacitor	Through hole	Any		RS code: 365-4199	
C23	3.3 nF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C24	470 pF	+/-10%	50 V		Ceramic capacitor X7R	SMD 0805				
C26	Do not fit	Do not fit	Do not fit	Do not fit	Do not fit	Do not fit	Do not fit	Do not fit	Do not fit	Do not fit
D1	8 A/400 V Ac diode bridge		400 V/ 8 A		Single-Phase Bridge Rectifier	Through hole	Vishay	KBU8G-E4	RS code: 634-9288	
Heat-sink for D1	Heatsink for D1				Heatsink for D1		Aavid Thermalloy	S055/B/10 0	RS code: 4907208	
D2, D10	GF1M		1000 V/ 1 A		Rectifier diode	DO214BA	Vishay	GF1M	RS code: 269-451	
D3	1N5406		600 V/ 3 A		Rectifier diode	DO201AD	Any		RS code: 262-343	
D4	STTH12S06				Turbo 2 ultrafast high voltage rectifier	TO-220	ST Microelectronics	STTH12S0 6FP		
D5, D6, D14	LL4148				Switching diode_	SOD-80	Any		Distrelec code: 601496	
D7, D11	STTH1R06				Turbo 2 ultrafast high voltage rectifier	SMB	ST Microelectronics	STTH1R06 U		

Table 10. STEVAL-ISF00V1 BOM (continued)

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
D8	BZX84C15		15 V		Zener diode	SOT-23	NXP	BZX84-C15	RS code: 436-8186	
D9, D15	1N4001		50 V/1 A		Rectifier diode	DO204AL	Vishay	1N4001	RS code: 261-148	
D12	15 V		15 V	0.5 W	Zener diode	DO-34	Any		Distrelec code: 601542	
D13	LED-red				Red CHIPLED	SMD 1206	Any		RS code: 654-5694	
F1	Fuse		250 V/ 10 A		Time lag fuse	-	RS		RS code: 488-8567	
Socket for F1	Socket for F1				SOCKET for F1	Through hole	Schurter	31.8231	RS code: 336-7851	
IC1	VIPER12A-E				Low-power OFF line SMPS primary switcher	SO-8	ST Microelectronics	VIPER12A S-E		
J7	220AC/16 A				3-way PCB mount screw terminal, 7.62 mm	Through hole	Phoenix Contact	1731734	RS code: 189-5972	
J8	OUT/400 V - 3.5 A				3-way PCB mount screw terminal, 7.62 mm	Through hole	Phoenix Contact	1731734	RS code: 189-5972	
J9	VIPER12 ON/OFF				2-way single row strip line connector (male connector) 2.54 mm pitch	Vertical through hole	Any		RS code: 495-8470	

Table 10. STEVAL-ISF00V1 BOM (continued)

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
J10	External, 15 V				2-way single row strip line connector (male connector) 2.54 mm pitch	Vertical through hole	Any		RS code: 495-8470	
J11	TSV992				Rail-to-rail input/output 20 MHz GBP operational amplifiers	SO-8	ST Microelectronics	TSV992ID		
J12	TD352				Advanced IGBT/MOSFET driver	SO-8	ST Microelectronics	TD352ID		
J13	L7805C				Positive voltage regulators	DPAK	ST Microelectronics	L7805CDT-TR		
J14	74VHCU04				HEX INVERTER	SO-14	ST Microelectronics	74VHCU04 MTR		
J15	MC_connector_PFC_1				34-way IDC low profile boxed header 2.54 mm pitch	Vertical through hole	Any		RS code: 461792	
J16	MC_connector_PFC_2				34-way IDC low profile boxed header 2.54 mm pitch	Vertical through hole	Any		RS code: 461792	
J18	CON3				3-way single row strip line connector (male connector) 2.54 mm pitch	Vertical through hole	Any		RS code: 495-8470	

Table 10. STEVAL-ISF00V1 BOM (continued)

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
L1	B82725A2802N1				Power line choke	Vertical through hole	Epcos	B82725A2 802N1	Distrelec code: 351190	
L2	900 µH-10 Apk									
L3	1 mH	+/-10%	290 mA		Radial inductor	Through Hole	Wurth Elektronik	744741102	RS code: 488-9964	
Q1	STW23NM60N				N-channel 600 V - 0.150 Ω - 19 A, second generation MDmesh™ power MOSFET	TO-247	ST Microelectronics	STW23NM 60N		
Heat-sink for Q1 and D4	Heatsink for Q1 and D4				Heatsink for STW23NM60N and STTH12S06 (100,00 mm)		Aavid Thermalloy	78075		
Q2,Q3	BC847				NPN transistor	SOT23	NXP	BC847	RS code: 436-7953	
RL1	Small relay		12 V/ 10 A		Mini power PCB relay	Through hole	Tyco Electronics	T7SS5E6-12	RS code: 616-8714	
R1	330 kΩ	+/-1%		0.6 W	Resistor	Through hole			RS code: 149-105	
R2,R6, R7	220 kΩ	+/-1%		0.6 W	Resistor	Through hole			RS code: 149-060	
R3	82 kΩ	+/-1%		0.6 W	Resistor	Through hole			RS code: 148-950	
R4, R10	4.7 kΩ	+/-1%		0.6 W	Resistor	Through hole			RS code: 148-663	
R5, R35	470 kΩ	+/-5%		1/4 W	Resistor	Through hole				
R8	100 kΩ	+/-1%		1/4 W	Resistor	Through hole			RS code: 148-972	
R9	47 Ω	+/-5%		1/4 W	Resistor	SMD 1206				

Table 10. STEVAL-ISF00V1 BOM (continued)

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
R11	6.8 Ω	+/-5%		1/4 W	Resistor	SMD 1206				
R12	0.07 Ω	+/-3%		3 W	Non-inductive resistor LOB3 type	Through Hole	IRC		Distrelec: 710516	
R13, R31	3.3 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R14, R30, R33	10 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R15, R22	1.5 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R16	220 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R17	6.8 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R18, R24	33 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R19, R20	22 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R21	12 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R23	4.7 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R25, R29	2.2 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R26	1 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R27, R28	120 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R32	1.5 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				
R34	100 Ω	+/-5%		5 W	Resistor	Through hole	Any		RS code: 199-7769	
R36	1.2 kΩ	+/-5%		1/4 W	Resistor	SMD 1206				

Table 10. STEVAL-ISF00V1 BOM (continued)

Ref.	Part/value	Toll.%	Voltage/ current	Watt	Technology information	Package	Manufacturer	Manuf. code	RS/distrelec/other code	More info
TP1	15 V TP				1-way single row strip line connector (male connector) 2.54 mm pitch	Vertical through hole	Any		RS code: 495-8470	
TP2	5 V TP				1-way single row strip line connector (male connector) 2.54mm pitch	Vertical Through hole	Any		RS code: 495-8470	
TP3	Vdc power stage TP				1-way single row strip line connector (male connector) 2.54 mm pitch	Vertical Through hole	Any		RS code: 495-8470	
Metal spacer	Metal spacer				Metal spacer M3x10mm		Any		RS code: 222-395	
Metal screw	Metal screw				Metal screw M3x6mm		Any		RS code: 560-580	
Metal screw	Metal screw				Metal screw M3x10mm		Any		RS code: 560-596	
Metal washer	Metal washer				Metal washer M3		Any		RS code: 560-338	
Metal shake-proof washer	Metal shakeproof washer				Metal washer M3		Any		RS code: 526-574	

A.2 Customized inductor by MAGNETICA

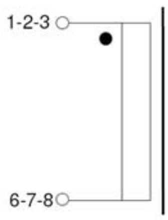
Figure 45. Technical sheet of PFC inductor - page 1 of 2

STP 04	Product Technical Specification	*Code :* **1856.0002**
Product: **PFC Inductor 900uH 10A**		
Customer: **STMicroelectronics**		*Customer Code:*
Date : 30/06/09	*Revision:* 0	Page 1 of 2

TYPICAL APPLICATION

INDUCTOR FOR BUCK, BOOST AND BUCK-BOOST DC/DC CONVERTER, SUITABLE ALSO IN HALF-BRIDGE, PUSH-PULL AND FULL-BRIDGE APPLICATIONS

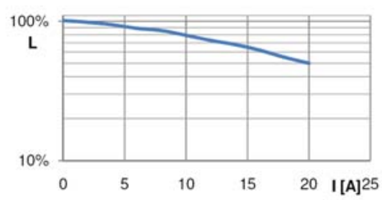
CIRCUIT DIAGRAM



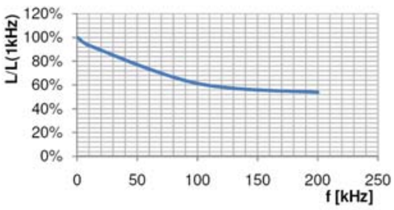
TECHNICAL DATA

INDUCTANCE *(MEASURE 1KHz, TA 20°C)* PIN 1,2,3-6,7,8	900uH ±15%
RESISTANCE *(DC MEASURE, TA 20°C)* PIN 1,2,3-6,7,8	100mΩ MAX
OPERATING CURRENT *(DC MEASURE , TA 20°C)*	10A MAX
OPERATING VOLTAGE *(F 80KHz, IR 10A , TA 20°C)*	500V MAX
SATURATION CURRENT *(DC MEASURE, L ≥ 50%NOM, TA 20°C)*	20A MAX
RESONANCE FREQUENCY *(TA 20°C)*	286KHz NOM
OPERATING AMBIENT TEMPERATURE *(IR 10A MAX)*	-10°C÷+45°C
MAXIMUM DIMENSIONS	75x80 H48mm
WEIGHT	550g APPROX

INDUCTANCE VS CURRENT



INDUCTANCE VS FREQUENCY



PIN DESCRIPTION

PIN (*)	*FUNCTION*	*PIN (*)*	*FUNCTION*
1_A	PFC BOBBIN START	5	NOT USED
2_A	PFC BOBBIN START	6_B	PFC BOBBIN END
3_A	PFC BOBBIN START	7_B	PFC BOBBIN END
4	NOT USED	8_B	PFC BOBBIN END

(*)PIN WITH THE SAME SUBSCRIPT MUST BE CONNECTED TOGETHER ON PCB

MOR&D0014-00 Rev.00 02/09/08

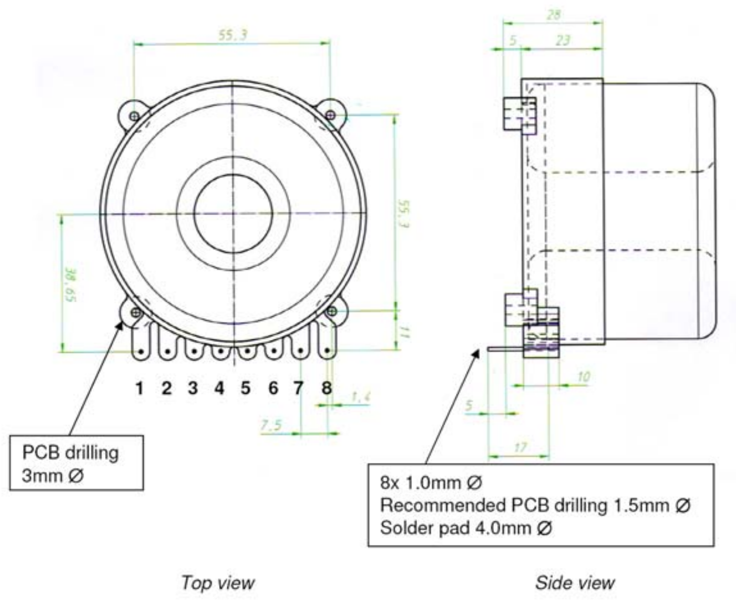
MAGNETICA

AM05889v1

Figure 46. Technical sheet of PFC inductor - page 2 of 2

STP 04	Product Technical Specification	*Code* : **1856.0002**
Product: **PFC Inductor 900uH 10A**		
Customer: **STMicroelectronics**		*Customer Code:*
Date : 30/06/09 *Revision:* 0		Page 2 of 2

DIMENSIONAL DRAWING DIMENSIONS IN MILLIMETERS, DRAWING NOT IN SCALE



MOR&D0014-00 Rev.00 02/09/08

MAGNETICA

AM05890v1

Revision history

Table 11. Document revision history

Date	Revision	Changes
23-Apr-2010	1	Initial release.

Please Read Carefully: