Control Integrated POwer System (CIPOS™)

PFC Integrated IPM (IFCMxxS(P)60yz) Reference Board

About this document

Scope and Purpose

The scope of this application note is to describe the product reference board-type1 of the CIPOS™ Mini PFC integrated IPM and the basic requirements for operating the product in a recommended mode.

Environmental conditions were considered in the design of the reference board. The design was tested as described in this document but not qualified regarding safety requirements or manufacturing and operation over the whole operating temperature range or lifetime. The boards provided by Infineon are subject to functional testing only.

Reference boards are not subject to the same procedures as regular products regarding Returned Material Analysis (RMA), Process Change notification (PCN) and Product Discontinuation (PD). Reference boards are intended to be used under laboratory conditions by specialists only.

When handling or operating the board, all necessary safety precautions must be observed. The board operates at high voltages and may become hot.

Intended Audience

Power electronics engineers who want to evaluate the CIPOS™ Mini PFC integrated IPM.

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1 Introduction

This reference board-type1 is composed of the IFCMxxy60GD, IRS44273L (Gate driver for PFC IGBT), ICE2PCS05G (CCM PFC controller), minimum peripheral components and two current sensing resistors. It is designed for customers to evaluate the performance of the CIPOS™ Mini PFC integrated IPM with simple connections of 3-phase inverter control signals, PFC IGBT control signal and power wires. Figure 1 shows the external view of the reference board.

This application note also describes how to design key parameters and PCB layout.

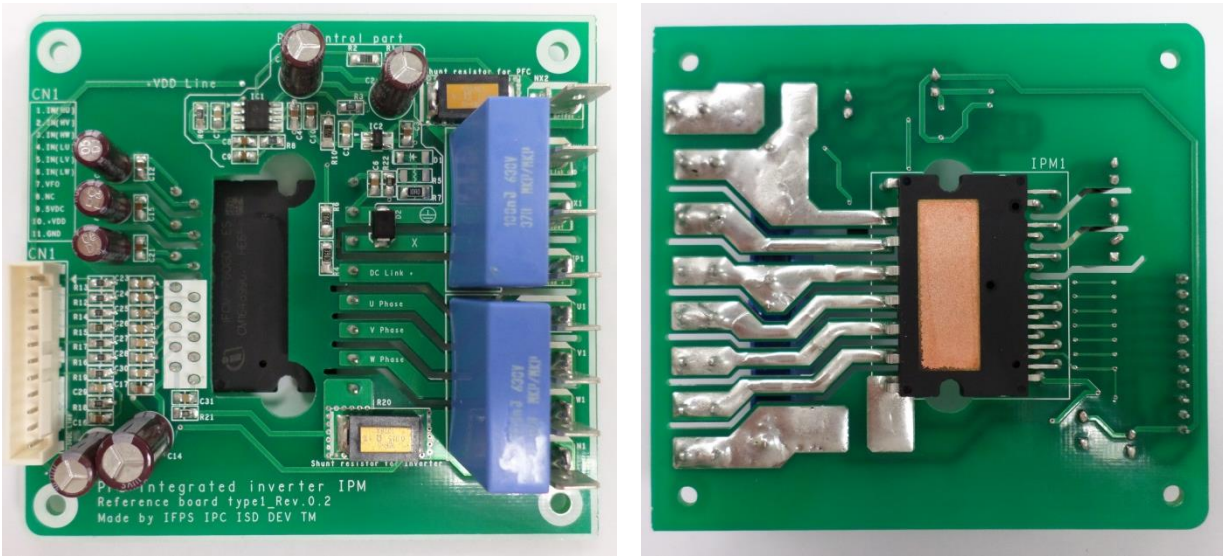


Figure 1 Reference board pictures

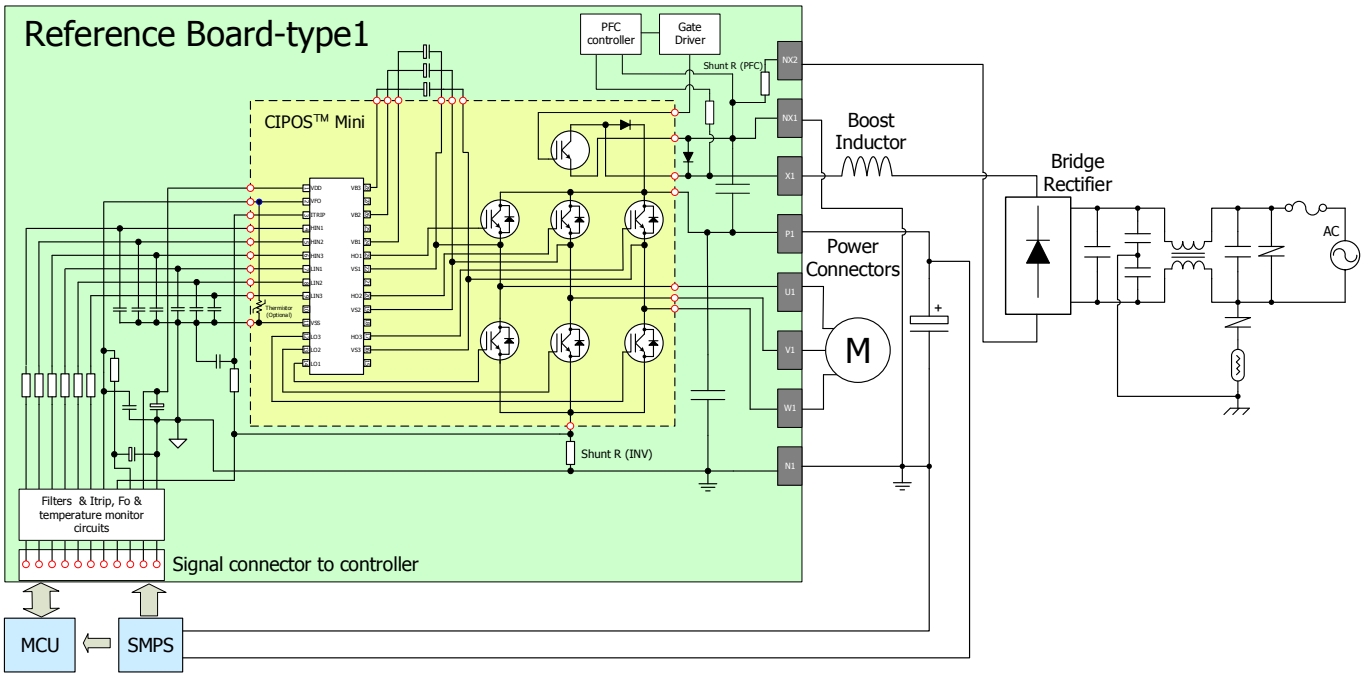


Figure 2 Application example

2 Schematic

Figure 3 shows a circuitry of the reference board-type1.

The reference board consists of interface circuit, bootstrap circuit, snubber capacitors, Short Circuit (SC) protection circuit, fault output circuit, current sensing resistors, PFC gate driver and passive parts etc.

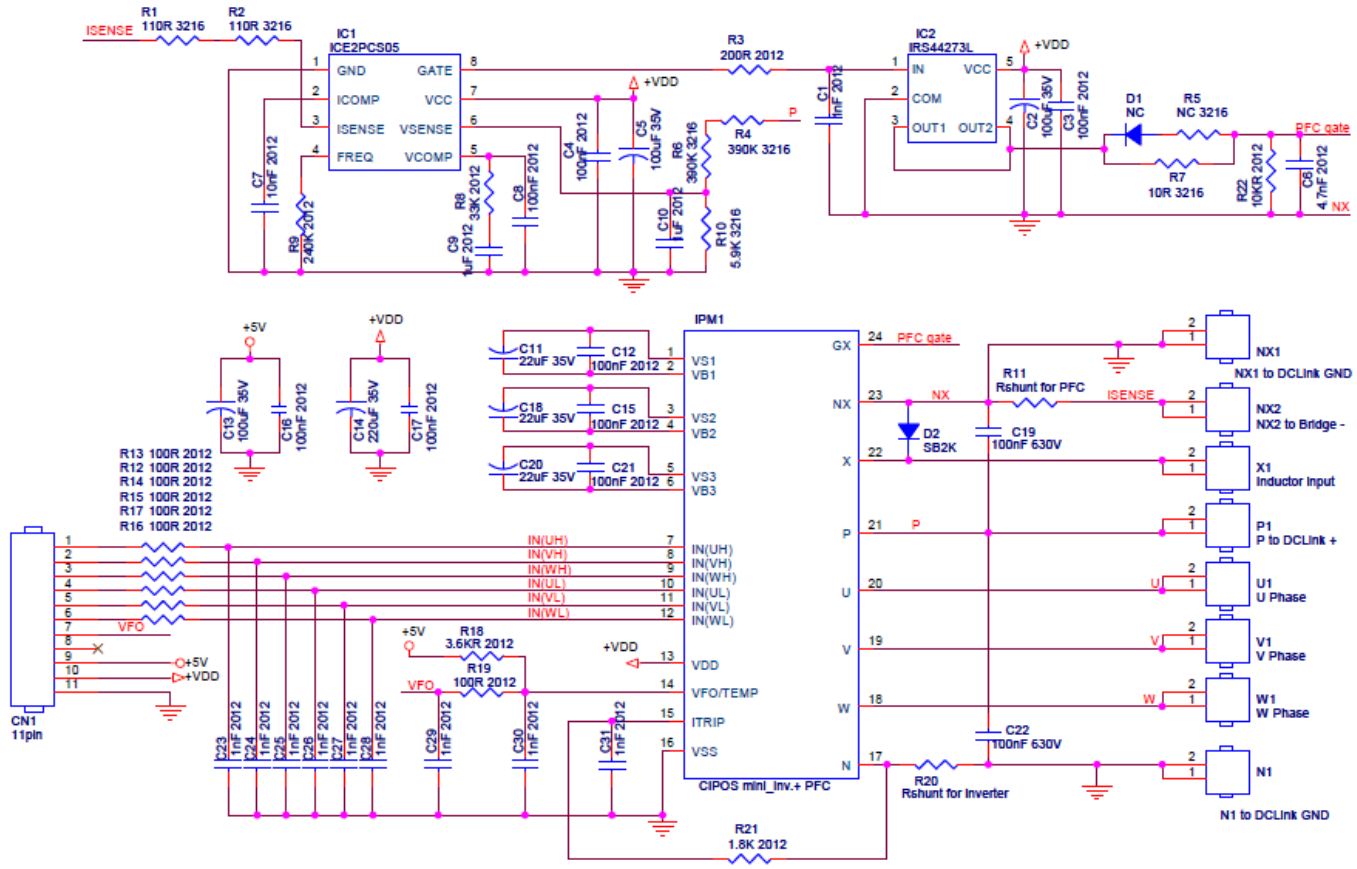


Figure 3 Circuit of the reference board

Note: The "+5V" on the CN1 HEADER 11 pin 9 denotes the control signal supply voltage such as 5V or 3.3V

3 External Connection

3.1 Signal Connector

Table 1 Pin description of the signal connector (CN1 HEADER 11, 11-pin, 2.5mm pin pitch)

Pin No.	Name	Description
1	IN(UH)	Control signal input for phase U upper side IGBT
2	IN(VH)	Control signal input for phase V upper side IGBT
3	IN(WH)	Control signal input for phase W upper side IGBT
4	IN(UL)	Control signal input for phase U lower side IGBT
5	IN(VL)	Control signal input for phase V lower side IGBT
6	IN(WL)	Control signal input for phase W lower side IGBT
7	VFO	Fault output signal
8	NC	No connection
9	+5V	External 5V or 3.3V supply for control signal
10	VDD	External 15V supply for module and PFC controller power
11	GND	Ground

3.2 Power Terminals

Table 2 Pin description of power terminals

Terminal No.	Name	Desctiption
NX1	NX1	Ground for DC capacitor
NX2	NX2	Ground to Bridge Diode
X1	X	Inductor Input
P1	P	Positive node of DC link voltage
U1	U	Output node of U phase
V1	V	Output node of V phase
W1	W	Output node of W phase
N1	N	Power Ground

4 Key Parameter Setting

4.1 Circuit of Input Signals (IN(xH), IN(xL))

The input signals can be supplied by either TTL- or CMOS-compatible. The logic level can go down to 3.3V. The maximum input voltage of the input signal pin is 10.5V clamped by the internal Zener diode. However the recommended voltage range of input voltage is up to 5V. Those control pins of input signal IN(xH) and IN(xL) are active high.

They have an internal pull-down structure with a pull-down resistor, which is nominal 5kΩ. The input noise filter inside the CIPOS™ Mini PFC integrated IPM suppresses short pulses and prevents a false IGBT driving from an unintentional operation. The input noise filter time (t_{FLIN}) is typically 270ns. This means that the input signal must stay on more than 270ns so that the driver IC detects the normal PWM input for a correct IGBT driving. CIPOS™ Mini PFC integrated IPM can be connected directly to the controller without an external input RC filter due to internal pull down resistor and input noise filter, as shown in Figure 4.

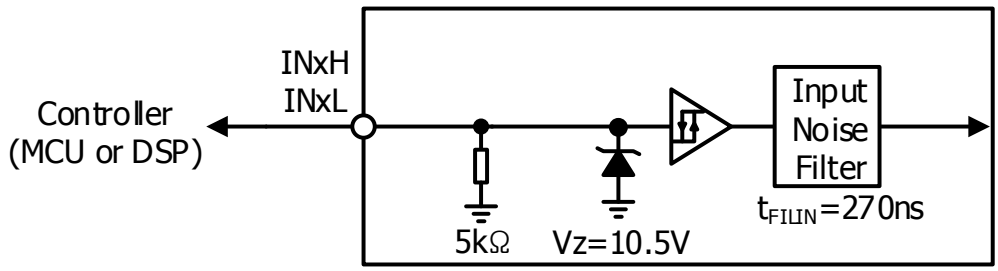


Figure 4 Internal pull-down resistor and input noise filter on input signal pin

4.2 Bootstrap Capacitor

Bootstrapping is a common method of the charge pumping from a low potential to a higher one. With this technique a supply voltage can be easily established for a floated high side section of the gate driver. Figure 5 below shows a simple bootstrap circuit diagram. It represents only one-phase effective circuit from a three-phase half bridge inverter. The bootstrap functionality is composed internally to limit current. Please refer to datasheet and application note for the bootstrapping method in detail.

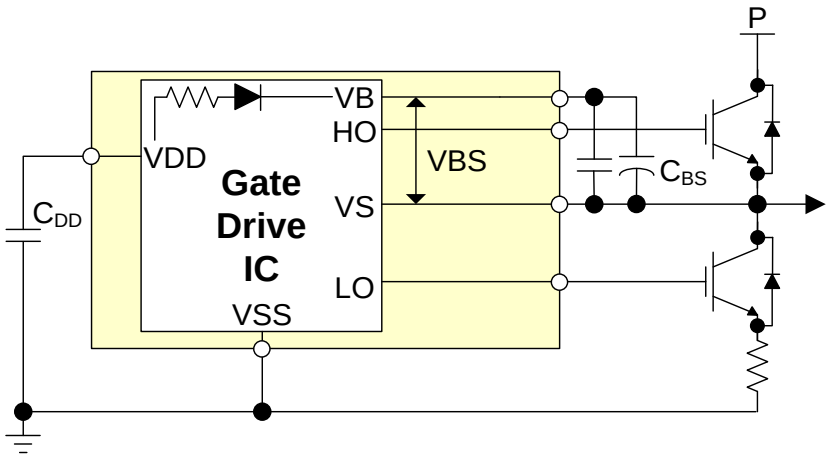


Figure 5 Bootstrap circuit for the supply of the high side gate drive

Key Parameter Setting

A low leakage current of the high side section is very important in order to keep the bootstrap capacitor small. The bootstrap capacitor (C_{BS}) is discharged mainly by the following mechanisms:

- Quiescent current to the high side circuit in IC
- Gate charge for turning high side IGBT on
- Level-shift charge required by level shifters in IC
- Bootstrap capacitor leakage current (can be ignored for a non-electrolytic capacitor)
- Bootstrap diode leakage current
- Bootstrap diode reverse recovery charge

The calculation of the bootstrap capacitor results in the following equation.

$$C_{BS} = \frac{I_{leak} \times t_P}{\Delta V_{BS}}$$

Where,

- C_{BS} : bootstrap capacitor value
- I_{leak} : maximum discharge current of the C_{BS}
- t_P : maximum on pulse width of the high side IGBT
- ΔV_{BS} : voltage drop at the bootstrap capacitor within a switching period

A practical leakage current level (I_{leak}) of the CIPOS™ Mini PFC integrated IPM is max. 1mA for 1 cycle turn on of the HS IGBT. Figure 6 shows the curve corresponding to the C_{BS} equation above for a continuous sinusoidal modulation when the voltage ripple (ΔV_{BS}) is 0.1V. The recommended bootstrap capacitance for a continuous sinusoidal modulation method is therefore in the range up to 4.7µF for 2~20kHz switching frequencies. In other PWM method case like a discontinuous sinusoidal modulation, the t_P must be set to the longest period of the low side IGBT off.

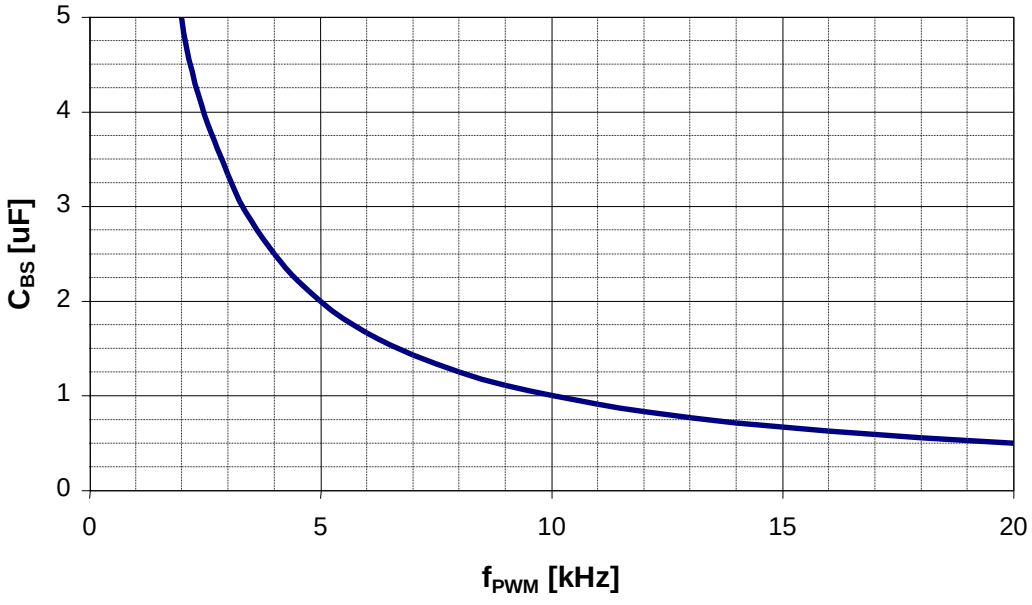


Figure 6 Value of the bootstrap capacitor as a function of the switching frequency, f_{PWM}

4.3 Internal Bootstrap Circuit Characteristics

CIPOS™ Mini module includes three bootstrap circuits in the internal drive IC, which consist of three diodes and three resistors, as shown in Figure 5. A typical value of the internal bootstrap resistor is 40Ω. For more information, please refer to the below Table 3. Note that R_{BS2} and R_{BS3} have the same value with the R_{BS1}.

Table 3 Internal bootstrap circuit characteristics

Description	Condition	Symbol	Min.	Typ.	Max.	Unit
Repetitive peak reverse voltage		V_{RRM}	600			V
Bootstrap resistance of U-phase	VS2 or VS3=300V, T_J=25°C VS2 and VS3=0V, T_J=25°C VS2 or VS3=300V, T_J=125°C VS2 and VS3=0V, T_J=125°C	R_{BS1}		35 40 50 65		Ω
Reverse recovery time	I_F=0.6A, di/dt=80A/µs	t_{rr_BS}		50		ns
Forward voltage drop	I_F=20mA, VS2 and VS3=0V	V_{F_BS}		2.6		V

4.4 Over Current Protection

Over Current (OC) protection level is decided by ITRIP positive going threshold voltage ($V_{IT,TH+}$) and current sensing resistance. When the ITRIP voltage exceeds $V_{IT,TH+}$, the module turns off 6 IGBTs and the fault flag is activated during fault-output duration time, typically 65µs.

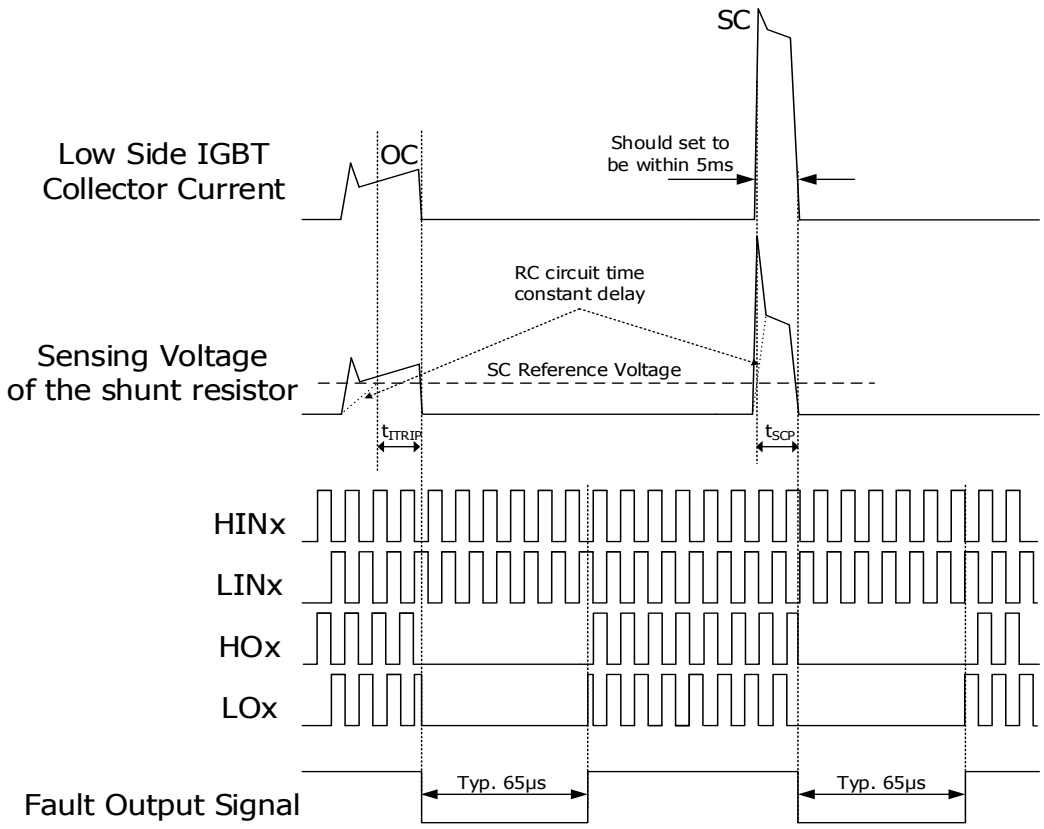


Figure 7 Timing chart of OC protection

4.4.1 Current Sensing Resistor Selection

The value of the current sensing resistor (R20) can be calculated with the following equation.

$$R_{SH} = \frac{V_{IT,\,TH+}}{I_{OC}}$$

Where,

- R_{SH} : current sensing resistor value
- $V_{IT,TH+}$: ITRIP positive going threshold voltage, typ. 0.47V
- I_{OC} : over current level

A maximum value of the OC protection level should be set less than the maximum peak output current in the datasheet absolute maximium ratings under considering the tolerance of the current sensing resistor.

For example, the maximum peak output current of the IFCM15P60GD is $30A_{peak}$,

$$R_{SH(min)} = \frac{0.47V}{30A} = 0.016\Omega$$

So the recommended value of the current sensing resistor should be higher than 16mΩ for IFCM15P60GD.

In order to calculate the power rating of the current sensing resistor, below items have to be taken into account.

- Maximum load current of inverter (I_{RMS})
- Shunt resistor value at T_C=25°C (R_{SH})
- Power derating ratio of the current sensing resistor at T_{SH}=100°C according to manufacturer's datasheet
- Safety margin

And the power rating can be calculated with the equation below.

$$P_{SH} = \frac{I_{RMS}{}^2 \times R_{SH} \times \text{Safety margin}}{\text{Derating ratio}}$$

For example, in case of IFCM15P60GD and R_{SH}=16mΩ,

- Max. load current of inverter (I_{RMS}) : $10A_{RMS}$
- Power derating ratio of shunt resistor at T_{SH}=100°C : 80%
- Safety margin : 30%

$$P_{SH} = \frac{10A^2 \times 0.016\Omega \times 130\%}{80\%} = 2.6W$$

So the proper power rating of the current sensing resistor is recommended as over than 3W.

Based on the equation, condition and calculation method above, some example values of minimum current sensing resistance and required resistor power rating are introduced as shown in below Table 4 for CIPOS™ Mini PFC integrated IPM product. When choosing a proper current sensing resistance and its power rating, an accurate OC protection level in the application set should be taken into account for a correct over current detection.

Key Parameter Setting

Table 4 Maximum peak current, shunt resistor(R20) value and required power rating

Product	Max. Peak Current	Min. Shunt Resistance, R_{SH}	Min. Shunt Resistance Power, P_{SH}
IFCM10P60zD	20A	24mΩ	1.5W
IFCM10S60zD	20A	24mΩ	1.5W
IFCM15P60zD	30A	16mΩ	3W
IFCM15S60zD	30A	16mΩ	3W

4.4.2 Delay Time

RC filter should be necessary in an OC sensing circuit to prevent a false OC protection caused by noise interference. The time constant of the RC filter should be determined with considering noise period and IGBT withstanding time against the OC event. When the current flows through the current sensing resistor, the induced voltage drop on the current sensing resistor is supplied to the ITRIP pin of the CIPOS™ Mini PFC integrated IPM through the RC filter. While the ITRIP pin voltage is rising to the ITRIP positive threshold voltage ($V_{IT,TH+}$ = typ. 0.47V), the filter delay time (t_{Filter}) is created by below equation (1), (2).

$$V_{IT,TH+} = R_{SH} \cdot I_C \cdot \left(1 - \frac{1}{e^{\frac{t_{Filter}}{\tau}}}\right) \quad (1)$$

$$t_{Filter} = -\tau \cdot \ln\left(1 - \frac{V_{IT,TH+}}{R_{SH} \cdot I_C}\right) \quad (2)$$

Where, $V_{IT,TH+}$ is the ITRIP pin input voltage, I_C is the peak current, R_{SH} is the shunt resistor value and τ is the RC time constant. In addition there is a shutdown propagation delay on ITRIP (t_{ITRIP}) as shown in the Table 5 below.

Table 5 Shut down propagation delay

Item		Condition	Min.	Typ.	Max.	Unit
Shut down propagation delay (t_{ITRIP})	IFCM10P60zD	I_{out} =6A, from $V_{IT,TH+}$to 10% I_{out}	-	1290	-	ns
	IFCM10S60zD					
	IFCM15P60zD	I_{out} =10A, from $V_{IT,TH+}$to 10% I_{out}	-	1330	-	
	IFCM15S60zD					

Therefore, the total delay time from the occurrence of the OC event to the shut-down of the IGBT gate becomes

$$t_{total} = t_{Filter} + t_{ITRIP}$$

The shut down propagation delay is in inverse proportion to the current range. Therefore the t_{ITRIP} will be shorter with a higher current condition, comparing to the current condition in the Table 5. The total delay must be less than 5µs of the short circuit withstand time (t_{SC}), which is specified in the datasheet. Thus, the RC time constant should be set in the range of 1~2µs. A recommended RC filter values are 1.8kΩ R21 and 1nF C31.

4.5 Temperature Monitor and Thermal Protection

In case of the CIPOS™ Mini PFC integrated IPM, a built-in thermistor (85kΩ at 25°C) is connected between VFO and VSS pins. The typical application circuit looks like Figure 8 where the VFO pin is used for both thermistor temperature sensing and fault flag. The voltage of the VFO pin decreases as the thermistor temperature increases because the thermistor is a NTC (Negative Temperature Coefficient) type and it is connected to the external pull-up resistor. Note that the voltage variation of the VFO pin, which is generated by the thermistor temperature change, should be always higher than the fault detection level of the micro controller. In this reference board, the pull-up resistor is set to 3.6kΩ so that the VFO voltage becomes 2.95V and 1.95V

respectively for 5V and 3.3V control voltage (Vctr) when the thermistor temperature is 100°C, as shown in Figure 9.

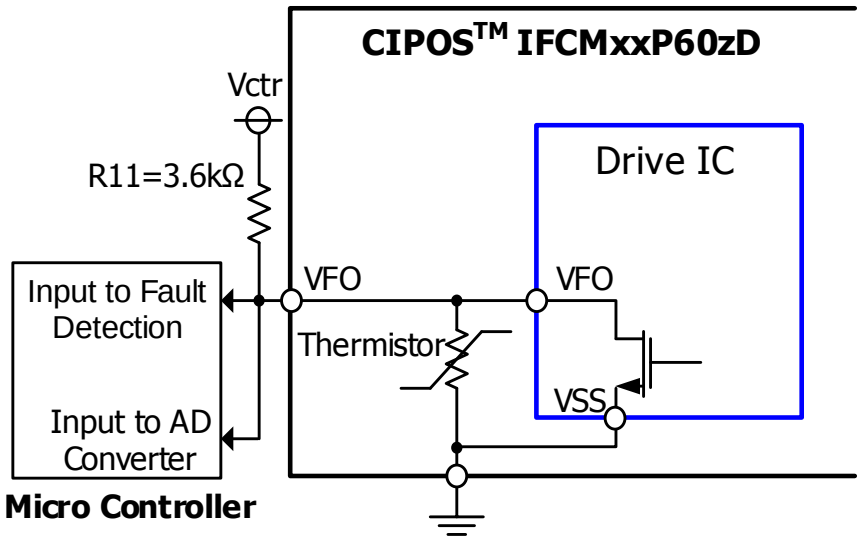


Figure 8 **Temperature monitor with built in thermistor and pull up resistor**

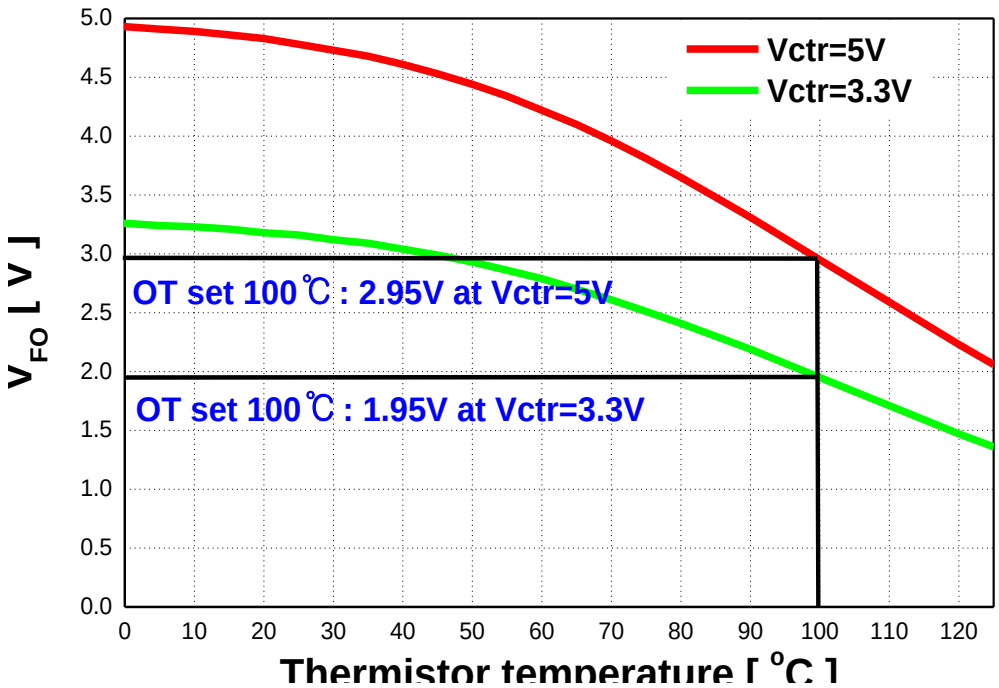


Figure 9 **Voltage variation of the VFO along with the NTC thermistor temperature change**

5 PFC Control Circuit Setting

5.1 PFC Control Circuit in the Reference Board

The reference board consists of two sections for PFC integrated IPM and PFC control circuit. The PFC IGBT inside IPM needs gate drive IC for switching operation. Figure 10 shows the board configuration diagram for PFC integorated IPM and PFC control circuit section.

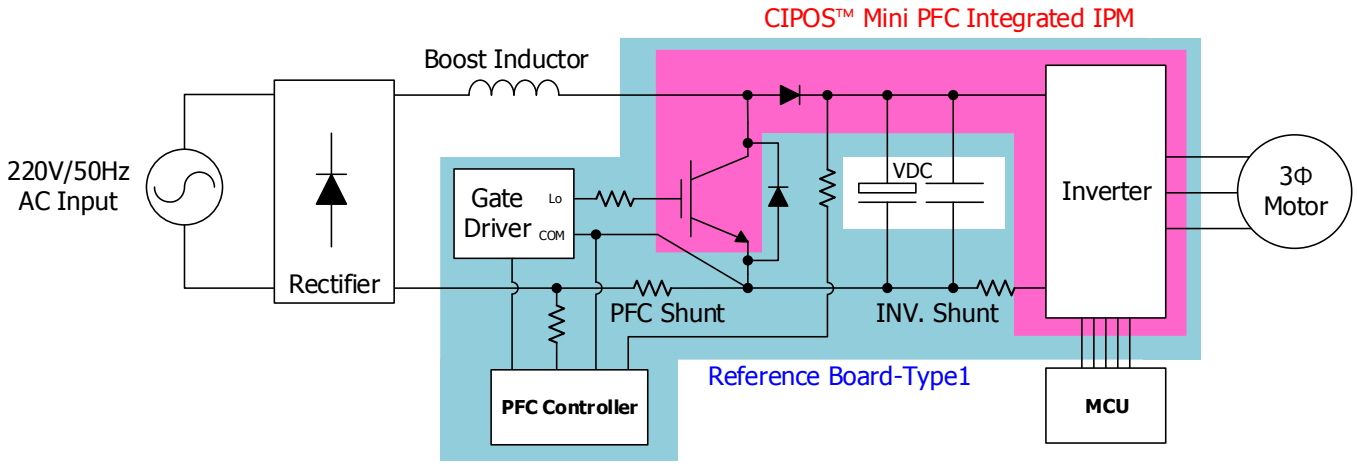


Figure 10 Reference board configuration diagram

Figure 11 below shows the detailed schematic of the PFC gate drive and PFC control circuit in the reference board. Infineon IRS44273L is used for the PFC gate drive and Infineon ICE2PCS05 is used for the PFC controller.

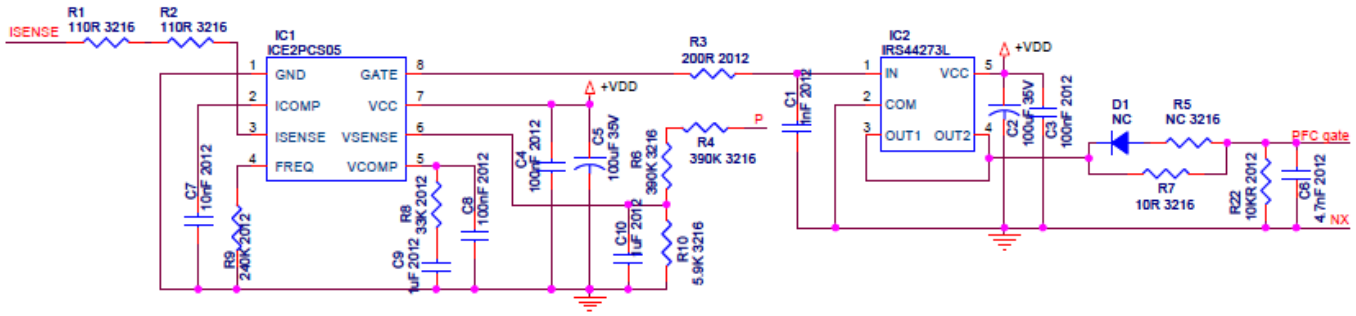


Figure 11 PFC controller and gate drive circuit for PFC IGBT

5.2 Anti-parallel diode between collector and emitter of IGBT

In this reference board, anti-parallel diode is embedded between collector and emitter of IGBT as Figure 12. The standard conventional boost power factor correction (PFC) circuit needs this anti-parallel diode between collector and emitter of IGBT in order to prevent IGBT random failure.

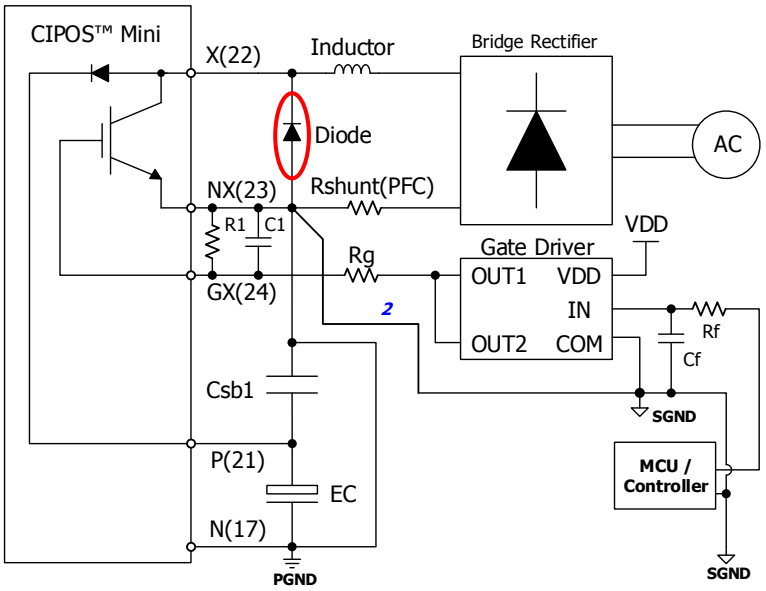


Figure 12 Anit-parallel diode for PFC IGBT

During startup, shutdown and under fault conditions power circuits often pass through operating modes that are not readily apparent from normal operation analysis. A PFC circuit may be designed to operate its boost inductor in the continuous current mode (CCM) during normal load operation. However, under light load, the boost inductor may go into discontinuous current mode (DCM) conduction. Discontinous operation may also occur near the AC mains zero voltage crossing even under full load conditions. Operation in DCM may require the PFC powerswitching device to conduct in the reverse direction. If an alternate current path is not provided for this switch current reversal, the IGBT may be reverse avalanched. In most cases low energy reverse avalanche is not harmful to IGBTs but it will cause additional heating. However, under specific circumstances gradual degradation and failure is possible. If the energy associated with this current reversal is minimal the failure mode may not be immediate but appear as gradual device degradation and random device failures. For detailed information, please refer to [2].

5.3 PFC Control Key Parameter Setting

5.3.1 Gate Drive IC

In order to drive the PFC (Power Factor Correction) IGBT, we strongly recommend using a gate driver IC such as IRS44273L which is a single low side driver IC. Features of IRS44273L are as below,

Features

- CMOS Schmitt-triggered input
- Under voltage lockout
- 3.3V logic compatible
- 1.5A Sinking / Sourcing current (typical)
- 50nsec Turn-on/off propagation delay (typical)

5.3.2 PFC Controller

In order to control PFC, we recommend using a single PFC controller such as ICE2PCS05G [3] which is standalone PFC controller in CCM. Features of ICE2PCS05G are as below. For detail information about ICE2PCS05G, please refer to reference [3].

Features

- Ease of Use with few External Components
- Average Current Control
- External Current and Voltage Loop Compensation for Greater User Flexibility
- Programmable Operating/Switching Frequency (20kHz ~ 250kHz)
- Trimmed Internal Reference Voltage (3V±2% at 25°C)
- VCC under-Voltage Lockout,
- Cycle by Cycle Peak Current Limiting
- Output Over-Voltage Protection
- Open Loop Detection
- Short Startup(SoftStart) Duration
- Fulfills Class D Requirements of IEC 61000-3-2
- Soft Overcurrent Protection

5.3.3 Output Bus Voltage (DC Link Voltage)

The VSENSE pin of the PFC controller ICE2PCS05 is used for sensing the output bus voltage in order to setup the DC link voltage level. The voltage divider composed of R12~R14 senses the output bus voltage and scales it down. The scale-downed voltage by R12~R14 is supplied to the VSENSE pin. The reference voltage of the VSENSE pin is typ. 3V. The equation below shows the relationship among Vout, Vref and R12~R14..

$$\frac{R10}{R4+R6+R10}=\frac{Vref}{Vout}$$

Where,

- R10 : lower resistor of the voltage divider between output bus and VSENSE pin
- R4+R6 : upper resistor of the voltage divider between output bus and VSENSE pin
- Vref : reference voltage of the VSENSE pin, typ. 3.0V
- Vout : output bus voltage (DC link voltage)

The equation above can be rearranged as below for R4+R6 calculation.

$$R4+R6=\frac{Vout-Vref}{Vref}\times R10$$

Table 1 below shows some example of R4, R6 and R10 calculation for various DC link voltages. Note that each value of R4 and R6 are a standard value based on the 5% tolerance resistors to obtain an accurate R13+R14 value.

PFC Control Circuit Setting

Table 1 Resistor value example for various DC link voltage setup

DC Link Voltage	R10	R4+R6	R4	R6	Note
380V	5.9kΩ	740kΩ	180kΩ	560kΩ	
390V	5.9kΩ	760kΩ	330kΩ	430kΩ	
400V	5.9kΩ	780kΩ	390kΩ	390kΩ	Default setting
410V	5.9kΩ	800kΩ	180kΩ	620kΩ	
420V	5.9kΩ	820kΩ	200kΩ	620kΩ	

5.3.4 PFC Switching Frequency

The FREQ pin is used for setting up the PFC switching frequency. A resistor value of the R9 on the FREQ pin defines the PFC switching frequency as shown in the Table 2 below. Yellow cells show default setting.

Table 2 Resistor value on FREQ pin vs. PFC switching frequency

R9 [kΩ]	Fsw [kHz]	R9 [kΩ]	Fsw [kHz]	R9 [kΩ]	Fsw [kHz]	R9 [kΩ]	Fsw [kHz]
15	281	60	76	100	46	210	22.7
20	216	63	72	110	42	221	21.6
30	147	70	65	120	39	232	20.6
33	134	80	58	150	31.3	240	19.9
40	112	83	56	169	27.9	249	19.2
50	90	90	51	191	24.8		

5.3.5 Over Current Protection

The PFC controller ICE2PCS05 has two OC protection features such as SOC (Soft Over Current Control) and PCL (Peak Current Limit).

The PFC controller IC is designed not to support any output power that corresponds to a voltage lower than typ. -0.68V at the ISENSE pin. A further increase in the inductor current, which results in a lower ISENSE voltage, will activate the SOC. It is a soft control as it does not directly switch off the gate drive. It acts on the nonlinear gain block to result in a reduced PWM duty cycle.

The PCL feature provides a cycle by cycle peak current limitation during switching. It is acvated when the voltage at ISENSE pin is lower than typ. -1.04V.

Table 3 below shows some example for setting up the OCP level with different shunt resistor values. The 30mΩ is a default shunt resistor value for PFC output current of 22.7A typ. by SOC and 34.7A typ. by PCL.

Table 3 Shunt resistor vs. OCP level for PFC control circuit

Shunt resistor R11	OCP level by SOC [A]			OCP level by PCL [A]			Note
	Min.	Typ.	Max.	Min.	Typ.	Max.	
30mΩ	20.3	22.7	25.0	31.7	34.7	38.7	Default setting
40mΩ	15.3	17.0	18.8	23.8	26.0	29.0	
50mΩ	12.2	13.6	15.0	19.0	20.8	23.2	

The two 110Ω resistors in series (R1 and R2) are recommended in order to limit an inrush current flowing into the ISENSE pin during the power up period.

5.3.6 Gate Resistance & Capacitance for PFC IGBT

In order to achieve low switching loss and low EMI effect, a gate resistor, R7 in the Figure 11 between gate drive IC and PFC IGBT can be used to control IGBT turn on and off speed. When decreasing the gate resistance, IGBT turn on and off speed will be getting faster and the IGBT switchinig loss will be smaller, but the EMI will be increasing by the fast dv/dt. On the contrary, increasing the gate resistance will create higher switching loss and lesser EMI. In addition, in order to prevent gate oscillation due to fast turn-on di/dt of IGBT at small Rg conditions, gate-emitter capacitance, C6 in Figure 11 between gate and emitter of IGBT is needed. A recommended gate resistance and capacitance is shown in the Table 4 below.

Table 4 Switching characteristics at recommended gate drive parameters(V_{DC}=400V, V_{GE}=15V, I_C=15A, T_J=25°C)

Product	R7 [Ω]	C6 [nF]	E_{ON} [µJ]	On dv/dt [kV/µs]	On di/dt [A/µs]	E_{OFF} [µJ]	Off dv/dt [kV/µs]	Off di/dt [A/µs]
IFCM15P60zD	10	4.7	368	8.1	368	99	17.9	664
IFCM15S60zD	10	4.7	570	5.7	249	212	8.9	525

6 Boost PFC Circuit Setting

6.1 Target Specification

Table 5 below shows a target specification example for the CIPOS™ Mini PFC integrated IPM reference board.

Table 5 Design parameters for the proposed target specification

Design parameter	Parameter name	Value
Minimum input voltage	Vin_min	85VAC
Maximum input voltage	Vin_max	265VAC
Line frequency	f_L	60Hz
Output voltage	Vout	400VDC
Minimum output voltage	Vout_min	250VDC
Output current	Iout	5.128A
Output power	Pout	2000W
Efficiency	η	>90% at full load
PFC switching frequency	f_{SW}	20kHz
Maximum ambient temperature around PFC	T_{Amax}	70°C

6.2 Boost Inductor

The maximum input RMS current, I_{in_RMS}, is needed to obtain 2000W output power P_{out} with 85V minimum AC input voltage V_{in_min}. The equation below shows the calculation example for a maximum input RMS current.

$$I_{in_RMS} = \frac{P_{out}}{V_{in_min} \times \eta} = \frac{2000W}{85V \times 90\%} = 26.14A$$

The sinusoidal peak value of AC current, I_{in_pk}, is calculated as below.

$$I_{in_pk} = \sqrt{2} \times I_{in_RMS} = \sqrt{2} \times 26.14A = 36.97A$$

The I_{HF} represents a high frequency ripple current peak to peak on the boost inductor. It is related to maximum input power and minimum input voltage as below.

$$I_{HF} = k \times \sqrt{2} \times \frac{P_{in_max}}{V_{in_min}}$$

$$P_{in_max} = \frac{P_{out_max}}{\eta}$$

The "k" is a ratio of inductor ripple current based on the inductor average current. It must be kept reasonably small, and it is usually optimized in the range of 15% to 25% for cost effective design based on the current magnetic component status. For example, if k=22%, then,

$$I_{HF} = k \times \sqrt{2} \times \frac{P_{in_max}}{V_{in_min}} = 22\% \times \sqrt{2} \times \frac{2000W}{90\%} \times \frac{1}{85V} = 8.13A$$

Boost PFC Circuit Setting

The peak current passing through the inductor is,

$$I_{L_pk} = I_{in_peak} + \frac{I_{HF}}{2} = 36.97A + \frac{8.13A}{2} = 41.04A$$

The on-duty of the transistor switch in a boost converter operating under CCM at minimum AC input RMS voltage is,

$$D_{on} = 1 - \frac{\sqrt{2} \times V_{in_min}}{V_{out}} = 1 - \frac{\sqrt{2} \times 85V}{390V} = 0.692$$

The boost inductor value is,

$$L_{boost} \geq \frac{Don \times (1 - Don) \times V_{out}}{I_{HF} \times f_{SW}}$$

The value of Don=0.5 will generate the maximum L_{boost} value, so the L_{boost} should be selected with higher value than below.

$$L_{boost} \geq \frac{Don \times (1 - Don) \times V_{out}}{I_{HF} \times f_{SW}} = \frac{0.5 \times (1 - 0.5) \times 400V}{8.13A \times 20kHz} = 600\mu H$$

However, designer have to consider various AC input voltage conditions. For higher AC input voltage conditions as evaluation example in chapter7, we need to select bigger boost inductor value than 0.6mH@Vin=85Vac such as 2~3mH@Vin=220Vac.

The core material of the boost inductor can be either magnetic power or ferrite. For further detailed design of boost inductor, please refer to the PFC controller related or appropriate application note.[3]

6.3 Output Capacitor

An output bulk capacitor has to meet the requirement for output double line frequency ripple limit as the equation below. The Vout_ripple is normally defined as lower than 10% of Vout. For example, 3% of 400VDC Vout is around 12V of Vout_ripple. The equation below shows a calculation example of minimum output capacitance.

$$C_{OUT} \geq \frac{I_{OUT}}{2\pi \times f_L \times V_{out_ripple}} = \frac{5.128A}{2\pi \times 60Hz \times 12V} = 1134\mu F$$

The output capacitor of PFC circuit also has to supply enough energy to the next stage during hold-up time. The 16.7ms hold-up time is based on the line frequency of 60Hz. The output capacitor value should be higher than the result of the equation below for hold-up time requirement.

$$C_{OUT} \geq \frac{2 \times P_{OUT} \times t_{holdup}}{V_{out}^2 - V_{out_min}^2} = \frac{2 \times 2000W \times 16.7ms}{400V^2 - 250V^2} = 684\mu F$$

Comparing with two output capacitor calculation values above, the 1134µF capacitor can be chosen, but a max. 20% capacitance tolerance should be considered. So, approximately 1400µF capacitor is finally recommended for the output capacitor.

7 Evaluation Example of Reference Board

7.1 Evaluation Results

Table 6 Evaluation Setup [DUT: IFCM15S60GD, PFC Controller: ICE2PCS05G]

Parameter		Parameter name	Value
PFC Part	Input Voltage	V_{in}	220 [Vac]
	Line frequency	f_L	60 [Hz]
	PFC Switching Frequency	F_{SW}	20.0 [kHz]
	Output Voltage	V_{out}	400 [V]
	Gate Resistance	R_g	10 [Ω]
	Gate-Emitter Capacitance	C_{ge}	4.7 [nF]
	Boost Inductor	L_B	3.0 [mH]
Inverter Part	DC Link Voltage	V_{DC}	400 [V]
	Control Supply Voltage	V_{DD}	15 [V]
	Switching Frequency	FSW	5 [kHz]
	Power Factor	P.F.	0.99
	Modulation Index	M.I.	0.70
	Output Current	IO	7.0 [Arms]

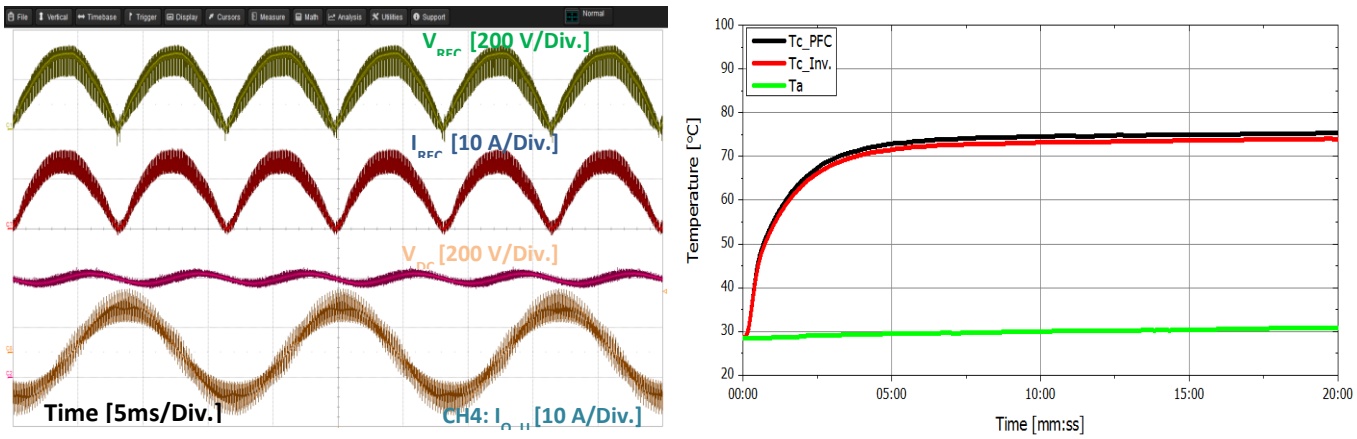


Figure 13 Operating waveform (CH1: input voltage, CH2: input current, CH3: output voltage, CH4: motor output current) and Case Temperature (T_C)

Input Voltage [Vac]/Frequency [Hz]	PFC Input Current [Arms]	Input Power [kW]	Inverter Output Current [Arms]	Power Factor	THD [%]	Case Temperature [°C]	
						PFC IGBT	Inverter IGBT
220/60	9.0	2.0	7.0	0.99	9.1	62.8	63.7

8 Part List

Table 7 Part list (Only for reference. Supplier can be changed)

Symbol	Part description	Description	Part number	Supplier
R1, R2,	N/A (1206)	Voltage divide resistor for ISENSE on PFC control(Option)	N/A	N/A
R3	200Ω 5% 0805	Filter resistor for PFC gate drive IC signal input	WR08X201J	Walsin
R4	10kΩ 5% 0805	Pull down resistor for PFC IGBT gate to emitter	WR08X103J	Walsin
R5	N/A (1206)	Gate resistor for PFC IGBT(Option)	N/A	N/A
R6, R8	390kΩ 1% 1206	Voltage divide resistor for VSENSE on PFC control(Option)	WR12X3903F	Walsin
R7	10Ω 5% 1206	Gate resistor for PFC IGBT	WR12X100J	Walsin
R8	33kΩ 1% 0805	Comp. network resistor for VCOMP on PFC controller	WR08X3302F	Walsin
R9	240kΩ 1% 0805	Switching frequency setting resistor for PFC controller	WR08X2403F	Walsin
R10	5.9kΩ 1% 1206	Pull-down resistor for VSENSE on PFC controller	WR12X5901F	Walsin
R11	0.03 1% 5W	Shunt resistor for PFC current sensing	WSR5R0300F	Vishay
R12~R17, R19	100Ω 5% 0805	Filter resistors for IN(xH), IN(xL), and VFO signal input	WR08X101J	Walsin
R18	0.03 1% 5W	Shunt resistor for PFC current sensing	WSR5R0300F	Vishay
R20	Refer to 4.4.1	Shunt resistor for inverter current sensing	N/A	Vishay
R21	1.8kΩ 1% 0805	Filter resistor for current sensing signal input	WR08X1801J	Walsin
C1	1nF 50V X7R 10%	Filter capacitors for PFC gate drive IC signal input	0805B101K500	Walsin
C2	100μF 35V	Electrolytic capacitor for 15V(VDD) supply voltage of PFC gate drive IC	100μF 35V	Samyoung
C3	100nF 50V X7R 10%	Decoupling capacitor for PFC gate drive IC	0805B104K500	Walsin
C4	100nF 50V X7R 10%	Decoupling capacitor for PFC controller	0805B104K500	Walsin
C5	100μF 35V	Electrolytic capacitor for 15V(VDD) supply voltage of PFC controller	100μF 35V	Samyoung
C6	4.7nF 50V X7R 10%	Filter capacitor for PFC IGBT gate to emitter	0805B471K500	Walsin
C7	10nF 50V X7R 10%	Comparator network capacitor for ICOMP on PFC controller	0805B102K500	Walsin
C8	100nF 50V X7R 10%	Comparator network capacitor for VCOMP on PFC controller	0805B104K500	Walsin
C9	1μF 50V X7R 10%	Comparator network capacitor for VCOMP on PFC controller	0805B105K500	Walsin
C10	1μF 50V X7R 10%	Filter capacitor for VSENSE on PFC controller	0805B105K500	Walsin
C11,C18,C20	22uF 35V	Bootstrap capacitors for xH IGBT	22μF 35V	Samyoung

Part List

Symbol	Part description	Description	Part number	Supplier
C13	100µF 35V	Electrolytic capacitor for 5V supply voltage	100µF 35V	Samyoung
C14	220µF 35V	Electrolytic capacitor for 15V supply voltage	220µF 35V	Samyoung
C16	100nF 50V X7R 10%	Decoupling capacitor for 5V supply voltage	0805B104K500	Walsin
C17	100nF 50V X7R 10%	Decoupling capacitor for 15V supply voltage	0805B104K500	Walsin
C19	100nF 630V 5%	Snubber capacitor on inverter to reduce voltage spike	PCMP 378 J62 104	Pilkor
C22	100nF 630V 5%	Snubber capacitor on inverter to reduce voltage spike	PCMP 378 J62 104	Pilkor
C23 ~ C28	1nF 50V X7R 10%	Filter capacitors for IN(xH) and IN(xL) signal input	0805B101K500	Walsin
C29	1nF 50V X7R 10%	Filter capacitors for VFO signal	0805B101K500	Walsin
C30	1nF 50V X7R 10%	Decoupling capacitors for VFO signal	0805B101K500	Walsin
C31	1nF 50V X7R 10%	Filter capacitors for ITRIP signal	0805B101K500	Walsin
C12,C15,C21	100nF 50V X7R 10%	Bootstrap capacitors for xH IGBT	0805B104K500	Walsin
D1	1N4148	Series diode for gate drive IC	1N4148	Vishay
D2	SB2K	Anti-parallel diode for boost PFC	SB2K	Vishay
CN1, CN2	SMW250-11P	11-pin connector for signal and power supply	SMW250-11P	Yeonho
NX1,NX2, X1, P1,U1,V1,W1, N1	Fasten Tap	Power terminals	GP881181-2	KET
IC2	IRS44273L	Gate Drive IC for PFC IGBT	IRS44273L	Infineon
IPM1	N/A	CIPOS™ Mini PFC integrated IPM	IFCM10P60xD IFCM10S60xD IFCM15P60xD IFCM15S60xD	Infineon

9 PCB Design Guide

In general, there are a lot of issues to be considered when designing a 3-phase motor drives application.

- Low stray inductive connection
- Isolation distance
- Component placement

This chapter will explain about the items above and come up with the solutions for the better layout design.

9.1 Layout of Reference Board

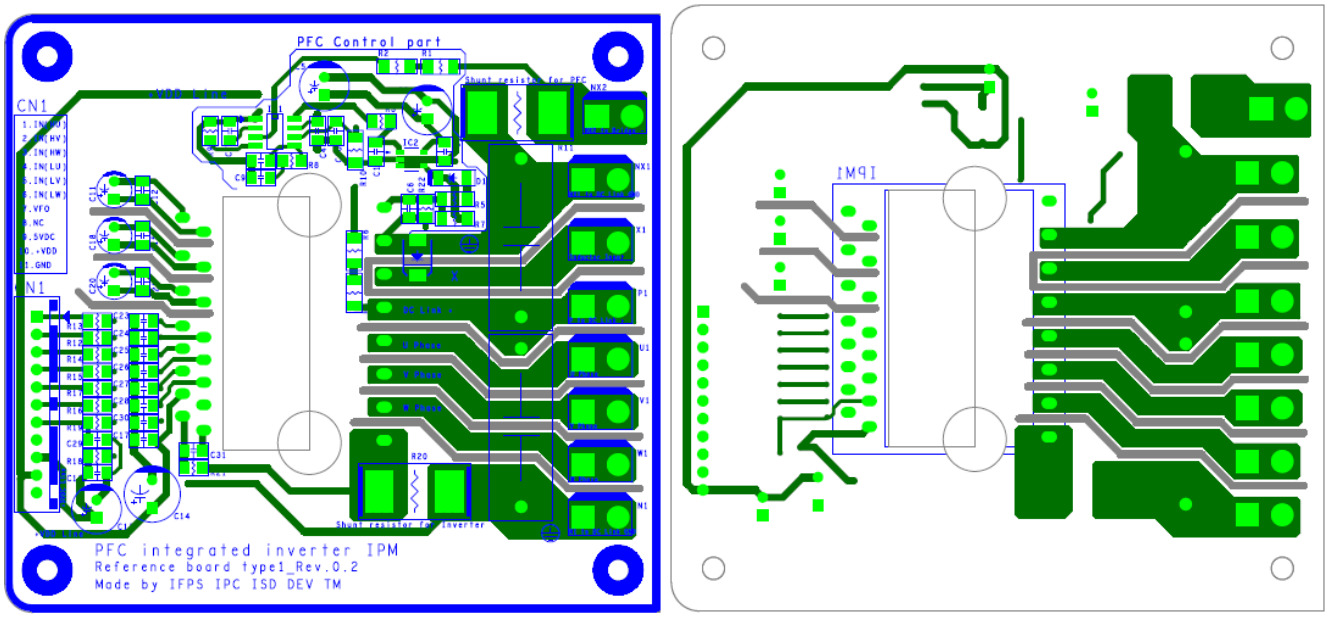


Figure 14 Layout of reference board type-1

1. *The connection between emitters of CIPOS ™ Mini PFC integrated IPM (N and NX) and current sensing resistors should be as short and as wide as possible.*
2. *It is recommended that the ground pin of the micro-controller should be directly connected to the VSS pin. Signal ground and power ground should be as short as possible and connected at only one point via the VDD capacitor (C14).*
3. *All of the bypass capacitors should be placed as close to the pins of CIPOS ™ Mini PFC integrated IPM as possible.*
4. *The capacitor (C31) for voltage sensing of the current sensing resistor should be placed as close to ITRIP and VSS pins as possible.*
5. *In order to accurately detect the voltage of the current sensing resistor, both sensing and ground patterns should be connected at the pins of the current sensing resistor and should not be overlapped with any patterns for the load current, as shown in Figure 14.*
6. *The snubber capacitors (C19, C22) should be placed as close to the power terminals as possible.*
7. *The PCB routings for power pins such as P, U, V, W, X, N and NX should be placed on both top and bottom layers with vias to allow high current flowing. They have to keep the minimum isolation distance among the power patterns. The distance should be at least over than 2.54mm.*
8. *Note that there are milling profiles in blue lines on the board to keep the isolation distance.*
9. *Make the one point connection between gate driver ground and power ground for PFC part.*

10 Reference

[1] CIPOS™ Mini PFC Integrated IPM; IFCM15P60GD Datasheet

[2] AN2017-12; CIPOS Mini PFC integrated IPM technical description_V1.0_EN

[3] Design Guide for Boost Type CCM PFC with ICE2PCSxx, 2008

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