

15 W 5 V charger reference design with 700 V CoolMOS™ P7

EVAL_15W_5V_FLYB_P7 using IPS70R1K4P7S, ICE2QS03G, BSC067N06LS3 G

About this document

Scope and purpose

This document introduces a 15 W high efficiency USB charger reference design with a 5 V output voltage using the QR PWM IC <u>ICE2QS03G</u> with CoolMOS[™] <u>IPS70R1K4P7S</u> (IPAK SL) and a secondary side synchronous rectification IC with OptiMOS[™] <u>BSC067N06LS3 G</u> (SuperSO8) in a small form factor, high efficiency and various protections for a highly reliable system.

Additionally, it will show the benefits <u>700 V CoolMOS[™] P7</u> can offer in charger designs in comparison to the existing <u>650 V CoolMOS[™] CE</u> technology, leading to higher efficiency and lower mold compound temperature.

This document will start by describing the general structure of the 15 W charger and will conclude by benchmarking the difference. It can be viewd as an update to the existing application note AN_201411_PL21_002 and therefore only describes the controller, OptiMOS[™] and reference board sections in general and will concentrate on the performance advantage of 700 V CoolMOS[™] P7 in this design.

Intended audience

This document is intended for designers and engineers who wish to design a high efficiency, very small form factor universal 15 W 5 V AC-DC adapter with Infineon CoolMOS[™] P7 series, OptiMOS[™], QR PWM IC ICE2QS03G and synchronous rectification.



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Reference board

1 Reference board

This document contains a list of features, power supply specifications, schematic, Bill of Materials (BOM) (component list) and transformer construction documentation. Furthermore, operating characteristics such as the performance curve of IPS70R1K4P7S compared to IPS65R1K5CE are included.

1.1 Pictures and outer dimensions



Figure 1 Demoboard perspective view EVAL_15W_5V_FLYB_P7



Figure 2 Demoboard top and bottom view EVAL_15W_5V_FLYB_P7



Reference board

Specifications 1.2

Specifications of EVAL_15W_5V_FLYB_P7 Table 1

•				
85 VAC ~ 265 VAC				
50 ~ 60 Hz				
5 V				
3 A				
15 W				
55 – 110 kHz				
> 89% at 115 VACand 230 VAC(@ full load)				



1.3 Circuit diagram



Figure 3 Schematic of EVAL_15W_5V_FLYB_P7





1.4 PCB layout





Top side copper (upper picture) and bottom side copper (lower picture)



Reference board

1.5 BOM

I BR1 2 C12 3 C13,C 4 C15 5 C16 6 C17 7 C18, C 8 C19 9 C21 10 C22 11 C24 12 C25 13 C27 14 D11 15 D12, C 16 D21 17 F1 18 FB21 19 IC11 20 IC12 21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R	C13A C26 D13	22μF/35V 100nF/50V 1nF/50V 47pF/50V 560pF/100V 820μF/6.3V 470μF/6.3V 220nF/25V 1μF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A	Footprint SOP-4 MKT2/13/10_0M8 RB10H(10x16) 0805 1206 0402 0403 SDBSMA SOD323 DO-221AC (slim SMA) AXIAL0.4_V 3mm SO-8 optocoupler half pitch mini flat package	GRM155R71H102KA01D GRM1555C1H470JA01D GRM1885C2A561JA01D RL80J821MDN1KX A750EK477M0JAAE018 GRM155C81E224KE01D GRM155R61E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	SHINDENGEN MURATA RUBYCON MURATA MURATA MURATA MURATA MURATA NICHICON KEMET MURATA MURATA INFINEON INFINEON	Quantity 1 1 1 1 1 1 1 1 1 1 1 1 1
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3 C13,C1 4 C15 5 C16 6 C17 7 C18, C 8 C19 9 C21 10 C22 11 C24 12 C25 13 C27 14 D11 15 D12, C 16 D21 17 F1 18 FB21 19 IC11 20 IC12 21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B	C26	15μF/400V 1nF/1000V 22μF/35V 100nF/50V 1nF/50V 47pF/50V 560pF/100V 820μF/6.3V 470μF/6.3V 220nF/25V 1μF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A FAIR RITE ICE2QS03G TCMT1103	RB10H(10x16) 0805 1206 0402 0402 0402 0402 0603 8.0mm diameter 6.3mm diameter 0402 0403 0402 0403 0404 050323 00-221AC (slim SMA) AXIAL0.4_V 3mm SO-8	400AX15M10X16 C0805X102KDRACTU C3216X5R1V226M GRM155R71H104KE14D GRM155R71H102KA01D GRM155SC1H470JA01D GRM1885C2A561JA01D RL80J821MDN1KX A750EK477M0JAAE018 GRM155C81E224KE01D GRM155C81E224KE01D GRM155C81E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	RUBYCON MURATA MURATA MURATA MURATA NICHICON KEMET MURATA MURATA	2 1 1 2 1 1 1 1 1 1 1 2 1 1 2 1
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6 C17 7 C18, C 8 C19 9 C21 10 C22 11 C24 12 C25 13 C27 14 D11 15 D12, D 16 D21 17 F1 18 F821 19 IC11 20 IC12 21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B	C26	100nF/50V 1nF/50V 47pF/50V 560pF/100V 820μF/6.3V 470μF/6.3V 220nF/25V 1μF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A FAIR RITE ICE2QS03G TCMT1103	0402 0402 0402 0603 8.0mm diameter 6.3mm diameter 0402 0402 0402 Sub SMA SOD323 DO-221AC (slim SMA) AXIAL0.4_V 3mm AXIAL0.4_V 3mm SO-8	GRM155R71H104KE14D GRM155R71H102KA01D GRM155SC1H470JA01D GRM1885C2A561JA01D RL80J821MDN1KX A750EK477M0JAAE018 GRM155C81E224KE01D GRM155R61E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	MURATA MURATA MURATA NICHICON KEMET MURATA MURATA	1 2 1 1 1 1 1 1 2 1
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9 C21 10 C22 11 C24 12 C25 13 C27 14 D11 15 D12, E 16 D21 17 F1 18 FB21 19 IC11 20 IC22 21 IC21 22 IC22 23 L 24 I.11 25 N 26 Q.11 27 Q.21 28 R.11, R 29 R.12, R 30 R.12A, 31 R.12B	D13	47pF/50V 560pF/100V 820μF/6.3V 470μF/6.3V 220nF/25V 1μF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A FAIR RITE ICE2QS03G TCMT1103	0603 8.0mm diameter 6.3mm diameter 0402 0402 Sub SMA SOD323 DO-221AC (slim SMA) AXIAL0.4_V 3mm AXIAL0.4_V 3mm SO-8	GRM1885C2A561JA01D RL80J821MDN1KX A750EK477M0JAAE018 GRM155C81E224KE01D GRM155R61E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	MURATA NICHICON KEMET MURATA MURATA	1 1 1 1 1 2 1
10 C22 11 C24 12 C25 13 C27 14 D11 15 D12, E 16 D21 17 F1 18 FB21 19 IC11 20 IC22 21 IC21 22 IC22 23 L 24 I11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B	D13	820μF/6.3V 470μF/6.3V 220nF/25V 1μF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A FAIR RITE ICE2QS03G TCMT1103	8.0mm diameter 6.3mm diameter 0402 0402 Sub SMA SOD323 DO-221AC (slim SMA) AXIAL0.4_V 3mm AXIAL0.4_V 3mm SO-8	RL80J821MDN1KX A750EK477M0JAAE018 GRM155C81E224KE01D GRM155R61E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	NICHICON KEMET MURATA MURATA	1 1 1 1 2 1
11 C24 12 C25 13 C27 14 D11 15 D12, E 16 D21 17 F1 18 FB21 19 IC11 20 IC22 21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B	D13	820μF/6.3V 470μF/6.3V 220nF/25V 1μF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A FAIR RITE ICE2QS03G TCMT1103	6.3mm diameter 0402 0402 Sub SMA SOD323 DO-221AC (slim SMA) AXIAL0.4_V 3mm AXIAL0.4_V 3mm SO-8	A750EK477M0JAAE018 GRM155C81E224KE01D GRM155R61E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	KEMET MURATA MURATA	1 1 1 2 1
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12 C25 13 C27 14 D11 15 D12, C 16 D21 17 F1 18 FB21 19 IC11 20 IC22 21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B	D13	220nF/25V 1µF/25V 600V/1A 200V/0.25A 45V/5A 250V/1A FAIR RITE ICE2Q\$03G TCMT1103	0402 Sub SMA SOD323 DO-221AC (slim SMA) AXIAL0.4_V 3mm AXIAL0.4_V 3mm SO-8	GRM155C81E224KE01D GRM155R61E105KA12D ES1JL BAS21-03W VSSAF5L45-M3/6A 0263001.HAT1L 2743002112	MURATA MURATA	रूम रूम 2
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19 IC11 20 IC12 21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B		ICE2QS03G TCMT1103	SO-8			1
20 IC12 21 IC21 22 IC22 23 L 24 I11 25 N 26 Q11 27 Q21 28 R11, R 29 R12A, R 30 R12A, 31 R12B		TCMT1103		ICE2QS03G	INFINEON	1
21 IC21 22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12A, R 30 R12A, 31 R12B				TCMT1103		1
22 IC22 23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B			SOT-23	TL431BFDT		1
23 L 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B		UCC24610	SO-8	UCC24610		1
 24 L11 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B 		connector	Connector	5000RED		1
 25 N 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B 		1mH/0.5A	CH8	768772102	WURTH ELECTRONICS	1
 26 Q11 27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B 		Connector N(2.5)	Connector(2.5)	5001BLACK		1
27 Q21 28 R11, R 29 R12, R 30 R12A, 31 R12B		650V/1R	TO251(IPAK)	IPS70R1K4P7S	INFINEON	1
28 R11, R 29 R12, R 30 R12A, 31 R12B		60V/6.7mR	INF-PG-TDSON81	BSC067N06LS3G	INFINEÓN	1
29 R12, R 30 R12A, 31 R12B		200k/400V/0.5W	0805	ERJ-P06F2003V		2
30 R12A, 31 R12B			0402			2
31 R12B	, R13, R14B		0402			3
			0402			1
. SZ IKIZU		10k/1%	0402			1
33 R14, R		2R/0.33W/1%	1206	ERJ8BQF2R0V		2
34 R18			0402			1
35 R21		47R/0.5W	0805	ERJP6WF47R0V		1
36 R22			0402			1
37 R23			0402			1
38 R24			0402			1
39 R25, R			0402			2
40 R27			0402			1
41 R28			0402			1
42 R29			0402			1
43 R30			0402			1
44 R31, R			0402			1
45 R32			0402			1
46 TR1	R33		TR_RM6_THT6Pin			1
47 USB P	R33	/18uH(66:5:16): RIVI6(1P4A) 1	USB2 Short(Horizontal)	JL-CAF-001		1
48 ZD11	R33	718µH(66:5:16); RM6(TP4A) USBPORT		UDZS22B		1

1.6 Transformer construction

Core and material: RM6 TP4A

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Bobbin: RM6 with 3 pin
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Primary Inductance: Lp = 718 μ H (±10 %), measured between pin 2 and pin 6

Reference board



Figure 5 Transformer structure

1.7 Additional information related to components of the design

To understand the control approach and obtain additional information on the components used, refer to AN_201411_PL21_002. This application note contains a detailed circuit description, circuit operation and the protection features of the controller.

Infineon



Test results

2 Test results

This section of the application note will concentrate on benchmarking of the IPS70R1K4P7S against the IPS65R1K5CE that is the main focus of this document.

2.1 Efficiency

Measurement tolerance: 0.1%



Figure 6 Efficiency comparison

As clearly shown in Figure 6, the IPS70R1K4P7S outperforms the IPS65R1K5CE over the whole load range at 115 VAC and 230 VAC input voltage. This behavior also improves the relevant average efficiency of 100%, 75%, 50% and 25% load points leading to an increase of 0.3% at low input voltage and around 0.25% at higher line operation.

2.2 Thermals

Measurement tolerance: 1°C



Test results



Figure 7 Mold compound temperature comparison

One of the biggest challenges in low power charger/adapters is the thermal behavior of the high voltage MOSFET on the primary side. This benchmarking shows that IPS70R1K4P7s exhibit in both operating conditions (low line and high line) a dramatic reduction of mold compound temperature under the same test condition. These values are measured with a thermal camera at 25°C ambient temperature after 2 hours burn-in at full load operation. There is an advantage for the IPS70R1K4P7S of around 2°C at 115 V AC and around 4.5°C at 230 VAC input voltage.

It is shown that at 115 VAC input voltage the thermal benefit of 700 V CoolMOS[™] P7 is not as pronounced as at higher input voltage. This behavior is based on the E_{oss} differences between P7 and CE technology where the E_{oss} difference is more pronounced at higher drain source voltage. This will be described in the following chapter of this application note.



Performance increase due to 700 V CoolMOS[™] P7

Performance increase due to 700 V CoolMOS[™] P7 3

Now, the question may arise: "Why does 700 V CoolMOS[™] P7" outperform the competitor?" This section of the application note will concentrate on the most interesting value proposition besides higher efficiency and lower thermals but which is interlinked in order to achieve higher efficiency and introduce more safety in peak current controlled designs.

3.1 Energy stored in output capacitance (E_{oss})

E_{oss} is one of the main contributors to losses during the turn-on of the MOSFET. This is the energy which translates into losses during the turn-on at a certain V_{DS} voltage. In QR Flyback converters there are no E_{on} losses as there is no overlap between I_D and V_{DS} as the current throught the main transformer is 0 A. Nevertheless, additional losses are generated at every turn-on based on the amount of energy stored in the output capacitance.



Figure 8 E_{oss} comparison of 1400 m Ω devices

From the diagram it is seen that 700 V CoolMOS[™] P7 offers the lowest E_{oss} starting from 80 V V_{DS}. Typically it is not possible to have a real ZVS turn-on of the MOSFET as there would be a need to increase the reflected voltage from the secondary side to the primary side tremendously. This would also increase the bulk voltage and the drain source voltage peak during turn off. Therefore turn-on V_{DS} at low line is typically between 50 V and 150 V and at high line 200 V to 300 V, resulting in around 30% lower turn-on losses than for IPS65R1K5CE.

As these additional losses are present at every turn on, 700 V CoolMOS[™] P7 offers the opportunity to move to higher switching frequencies.

With respect to low line operation, the drawback of higher Eoss is reduced by the temperature dependency of the IPS70R1K4P7S which is due to the much reduced E_{off} losses and described in the next chapter.



Performance increase due to 700 V CoolMOS[™] P7

3.2 Temperature dependency of the on-state resistance

In the lower power market the conduction losses also have an influence on the efficiency and the thermal behavior of the overall system, especially at lower input voltages such as 90 VAC or 115 VAC. In this case, 700 V CoolMOS[™] P7 offers a significant value proposition. Due to the MOSFET structure, 700 V CoolMOS[™] P7 offers the lowest R_{DS(on)} change driven by increasing junction temperature. The following diagram illustrates this behavior.



Figure 9 R_{DS(on)} behavior over junction temperature

At 150°C junction temperature, the 700 V CoolMOS[™] P7 shows around 21% lower maximum R_{DS(on)} compared to Infineon's CoolMOS[™] CE family. This key parameter results in the reduction of the MOSFET conduction losses in any design.

3.3 Improved transfer characteristics

Around 95% of all Flyback converters use peak current control. This means that the controller sends the turnoff signal to the gate driver at a certain value of current running through primary inductance of main transformer and MOSFET. There is a well known failure mode in charger and adapter applications when the gate source voltage is dropping (for example during burst mode operation) and the MOSFET is not able to carry enough current to reach the peak current. In this case, the MOSFET is operating in the linear region and the MOSFET does not turn off resulting in destruction of the application. In addition, 700 V CoolMOS[™] P7 can offer a very narrow V_{GS(th)} (gate source threshold voltage) window from 2.5 V to 3.5 V with a typical value of 3.0 V.



Performance increase due to 700 V CoolMOS[™] P7



Transfer characteristics comparison of 1400 m Ω devices at 25°C Figure 10

700 V CoolMOS™ P7 shows the best in class transconductance behavior due to the unmatched current capability at low gate source voltage. This leads to the opportunity to reduce the gate source voltage intentionally in order to minimize the overall driving losses as well as the opportunity to meet new no load operation requirements.



4 Conclusion

700 V CoolMOS[™] P7 is an enabler for higher switching frequency applications in order to reduce the overall magnetic content of the applications, resulting in a smaller form factors and higher power densities.

700 V CoolMOS[™] P7 shows its best performance at high line operation due to the E_{oss} behavior, but shows also good performance during low line operation due to the temperature dependency of R_{DS(on)}.

Last but not least, the typical V_{GS(th)} and the slope of the transfer characteristics give 700 V CoolMOS[™] P7 one additional factor in order to reduce failures on peak current controlled designs.



Revision history

Revision history

Major changes since the last revision

Page or Reference	Description of change

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