Application Note

How to Implement Four-Phase Interleaving Buck With LM5137F-Q1

TEXAS INSTRUMENTS

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ABSTRACT

Automotive systems continue to integrate, this includes advanced driver assistance systems (ADAS). The result of system integration is the need for more power including the need for higher levels of functional safety. As power is consolidated into a single point of load meeting efficiency, thermal, ripple voltage and transient specifications become more challenging. Reference design PMP41158 is a four-phase interleaved buck using the LM5137F-Q1 which addresses the mentioned challenge. This application note reviews the reference design and features, in addition to key performance metrics.

The hardware presented herein can be modified for 48V input rail converting to a 12V output rail.

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1 Introduction

The reference design describes a four-phase interleaved buck converter which can be used in ADAS and IVI applications. As table 1 shows, the converter operates over a wide input voltage range of 6.5V to 36V to deliver a single 4.5V regulated output. The output tolerance has better than 1% steady state set-point accuracy at load currents up to 42A. The reference design also employs dynamic phase shedding to make sure excellent light load efficiencies, achieving as high as 81% efficiency at 15mA load current. With peak current mode control, the converter achieves ±8.3% output voltage perturbation, for a load step 21A to 86A at 65A/us. The LM5137F-Q1 is dual phase stackable controller, this reference design uses two LM5137F-Q1 to obtain a single output four-phase interleaved voltage regulator. One LM5137-Q1 is used as a primary controller and the second LM5137-Q1 is used as a secondary controller. In the stacked configuration, COMP1 and COMP2 of each controller are all connected together. Being a single output interleaved design, all outputs are connected together, with each phase being synchronized to a clock interleaving each phase, shifted 90 degrees apart. Four-phase interleaving effectively reduces ripple current compared to a single-phase design, thus reducing ripple voltage and RMS ripple currents on both the input and output capacitors.

Table 1-1. Key System Specifications

Parameter	Test Conditions	MIN	NOM	MAX	UNIT
Input Conditions					
Input voltage	/	6.5	13.5	36	Volt
Input current	/		14	26	Ampere
Output Conditions					
Output voltage	/		4.5		Volt
Output current	/			42	Ampere
Output voltage ripple	Full range Vin , full range load			40	mV
Output power				200	Watt
System Characteristics					
Efficiency (η)	Vin = 13.5V, Vout= 4.5V, Iout = 15mA		81.1		%
	Vin = 13.5V, Vout = 4.5V, Iout = 21A		95.5		%
	Vin = 13.5V, Vout = 4.5V, Iout = 40A		94.1		%
Load transient	21A-42A-56A-83A-21A, 1µs slew time 12 × 47µF/1210 output caps	-5.5		5.5	%
	21A-83A-56A-42A-21A, 1µs slew time 12 × 47µF/1210 output caps	-8.3		8.3	%
Operating ambient	Open frame	-25	25	85	°C
Switching frequency	/		400		kHz
Board form factor	FR4 material, 6-layer, 2-oz copper	126 × 87 × 35			mm3

2 Hardware Design with LM5137F-Q1

The LM5137F-Q1 is an 80V, dual-channel, buck controller offered from a family with three options for functional safety: Capable, ASIL B, or ASIL D. The device uses an interleaved, stackable, peak current mode architecture for easy loop compensation, fast transient response, excellent load and line regulation, and accurate current sharing with paralleled phases for high output current. A high-side switch minimum on-time of 22ns facilitates large step-down ratios, enabling the direct conversion from 12V, 24V, or 48V automotive inputs to low-voltage rails for reduced system design cost and complexity. The LM5137F-Q1 continues operating during input voltage dips as low as 4V, at 100% duty cycle if needed.

2.1 Schematic

Please refer to [PMP41158](link).
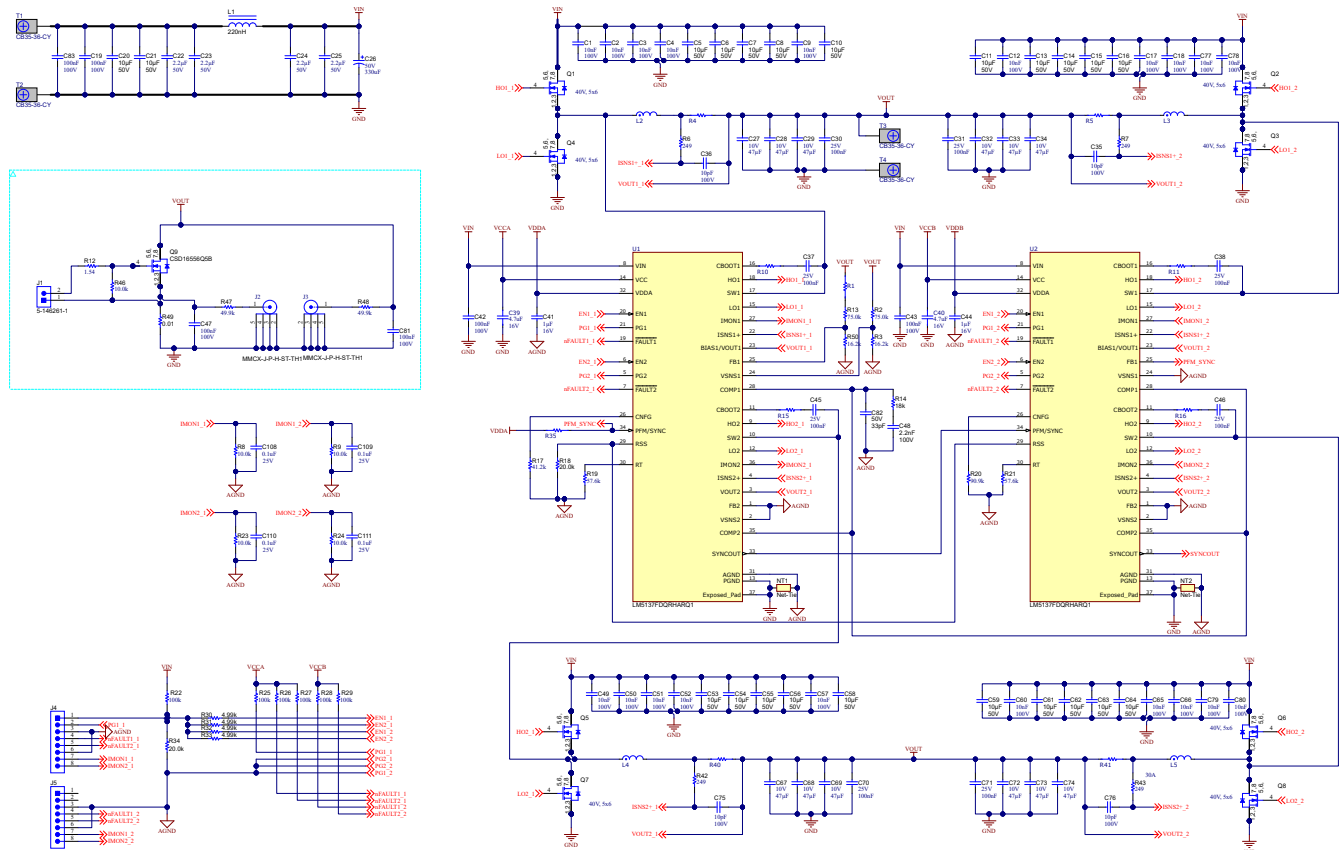
Figure 2-1. PMP41158 Schematic

3 PMP41158 Performance Curves

3.1 Four-Phase Interleaving

Figure 3-1 shows switch nodes 1 through four showing stable permanence at 45A load. As Figure 3-1 shows, Channel 1 and channel 2 are complementary, which is produced by primary controller. Channel 3 and channel 4 are complementary, which is produced by secondary controller. Each phase is shifted 90 degrees apart.
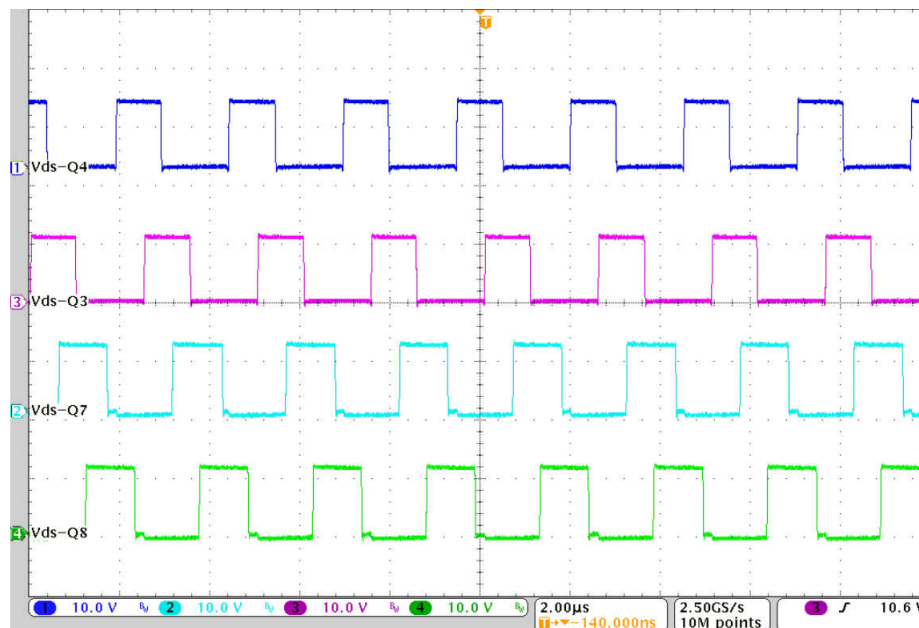

Figure 3-1. Switching Node Voltage Waveform

3.2 Thermal Performance

Both Figure 3-2 and Figure 3-3 show thermal performance of reference designs taken at a room temp of 25℃, open frame, no air flow. As you can see, when Iout is 21A, the max rising temperature is only about 25.5℃, while if Iout is 42A, the max rising temperature is about 73.4℃. So better to add a heatsink at the bottom side of conveter.
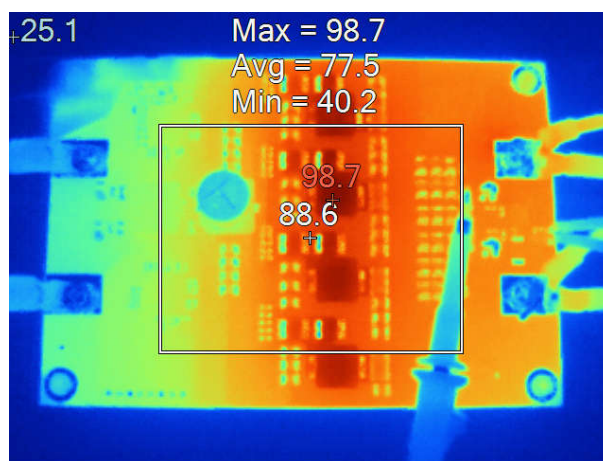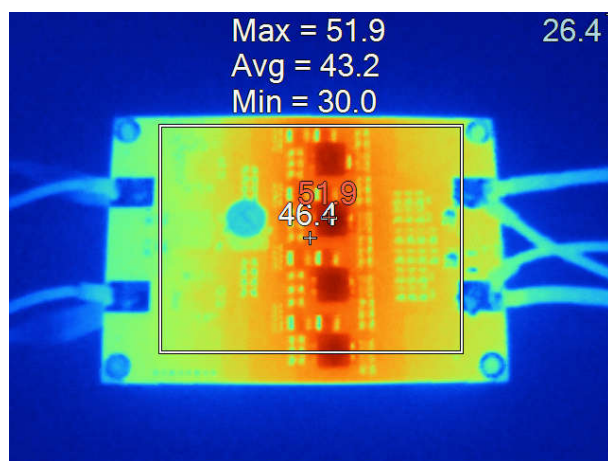
Figure 3-2. 13.5V in, 4.5V out at 21A Thermal Image

Figure 3-3. 13.5V in, 4.5V out at 42A Thermal Image

3.3 Load Transient

To achieve high slew rates of 62A/us for the load transient test, the reference design requires an onboard load stepper circuit, as Figure 3-4 shows. In theory, the MOSFET used in the load stepper works in linear region which is controlled by the gate to source voltage, VGS. By modulating the gate to source voltage, we adjust the current slew rate of the load step. The onboard load stepper is capable of achieving up to 100A/us load step slew rate.
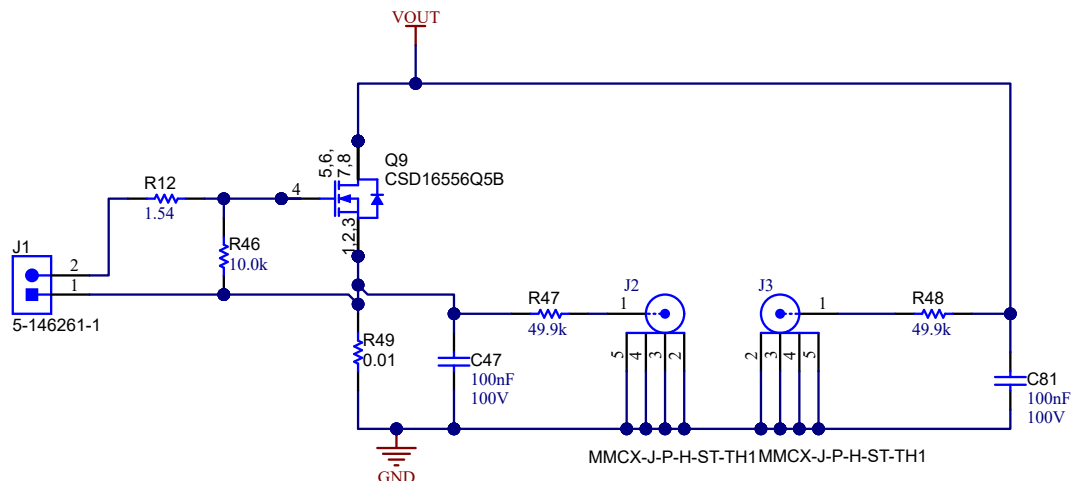

Figure 3-4. Onboard Load Stepper Circuit
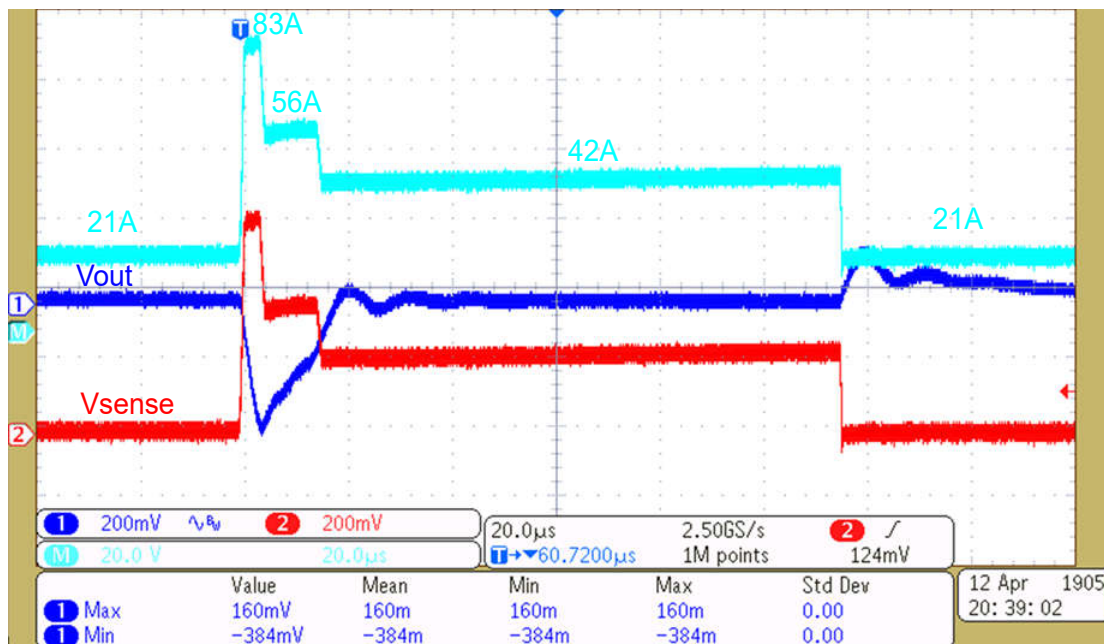
Figure 3-5. Load Transient Test

For load stepper set up details, please refer to *PMP41158: 450W Four-Phase Interleaved Buck Converter Reference Design*.

Note

Since different MOSFET has the different gate charge specifications, using different MOSFET can result in the need to tune the VGS voltage to attain the required load step slew rate.
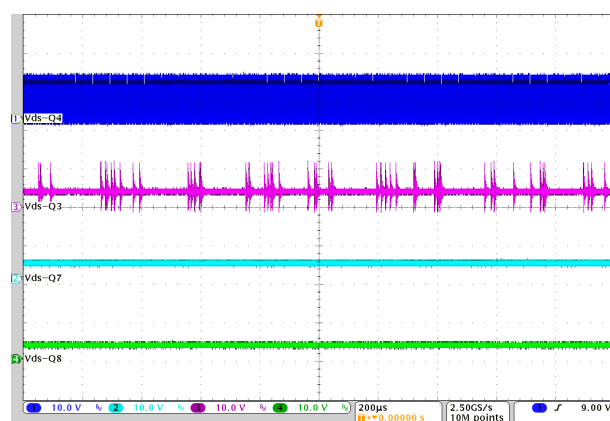

3.4 Light Load Efficiency

The switch node and output ripple voltage waveforms are shown in Figure 3-6 to Figure 3-10.
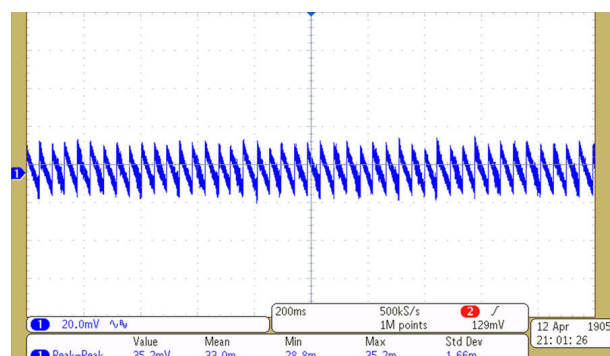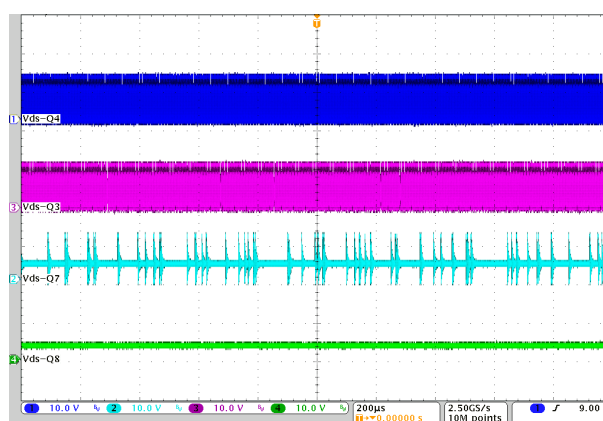

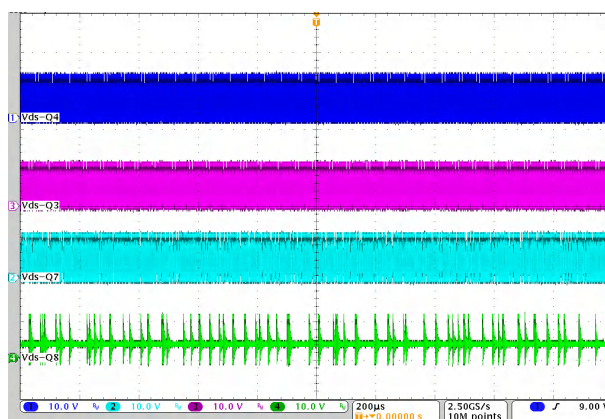**Figure 3-6. Ripple Voltage Waveform Under No Load**
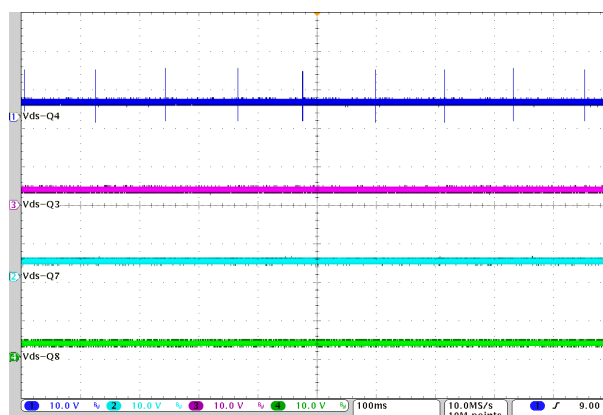
Figure 3-7. PFM + Phase Shedding, Switch Node at 0A Load

**Figure 3-8. PFM + Phase Shedding, Switch Node at 0.5A Load**

Figure 3-9. PFM + Phase Shedding, Switch Node at 0.8A Load

Figure 3-10. PFM + Phase Shedding, Switch Node at 1.2A Load

PMP41158 achieves excellent light load efficiency by shedding the phases at light load and minimizing current draw from the input supply. This results in only one phase operating under no load conditions, as Figure 3-7 shows. And as load increasing, the phase can start to work one by one, as Figure 3-8 to Figure 3-10 shows. In addition to phase shedding, the LM5137-Q1 operates in PFM mode. Refer to Figure 3-11 for light load efficiency performance.
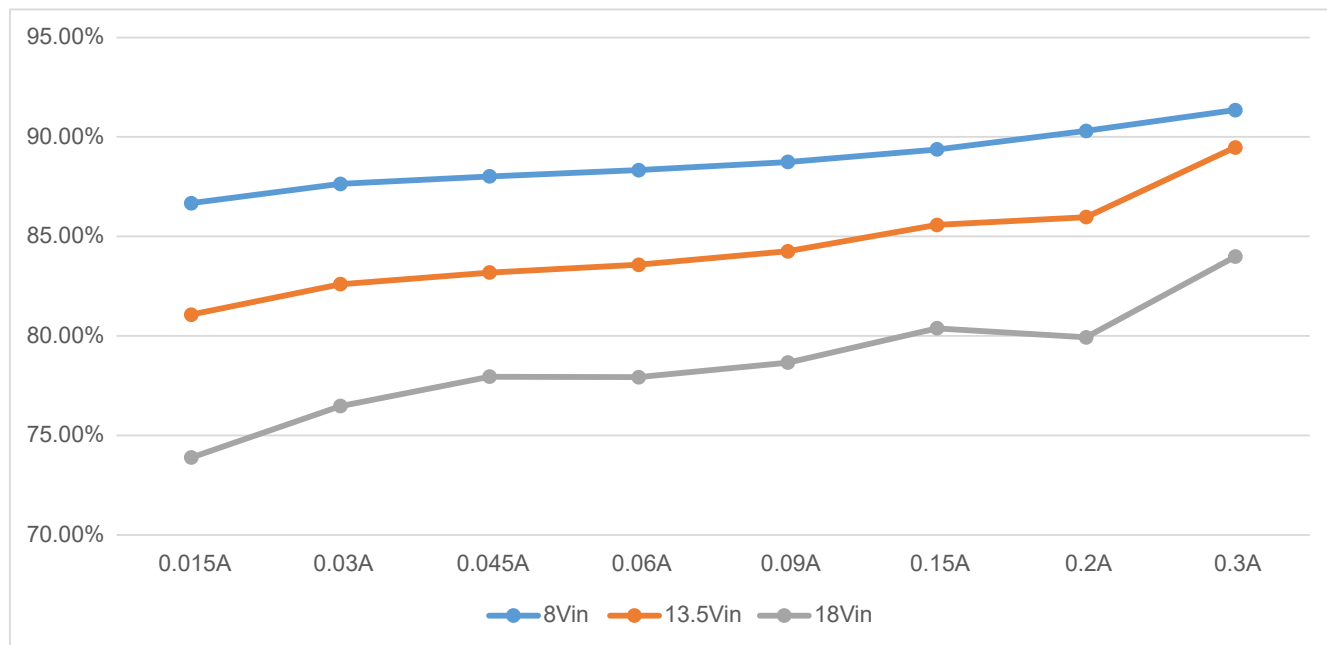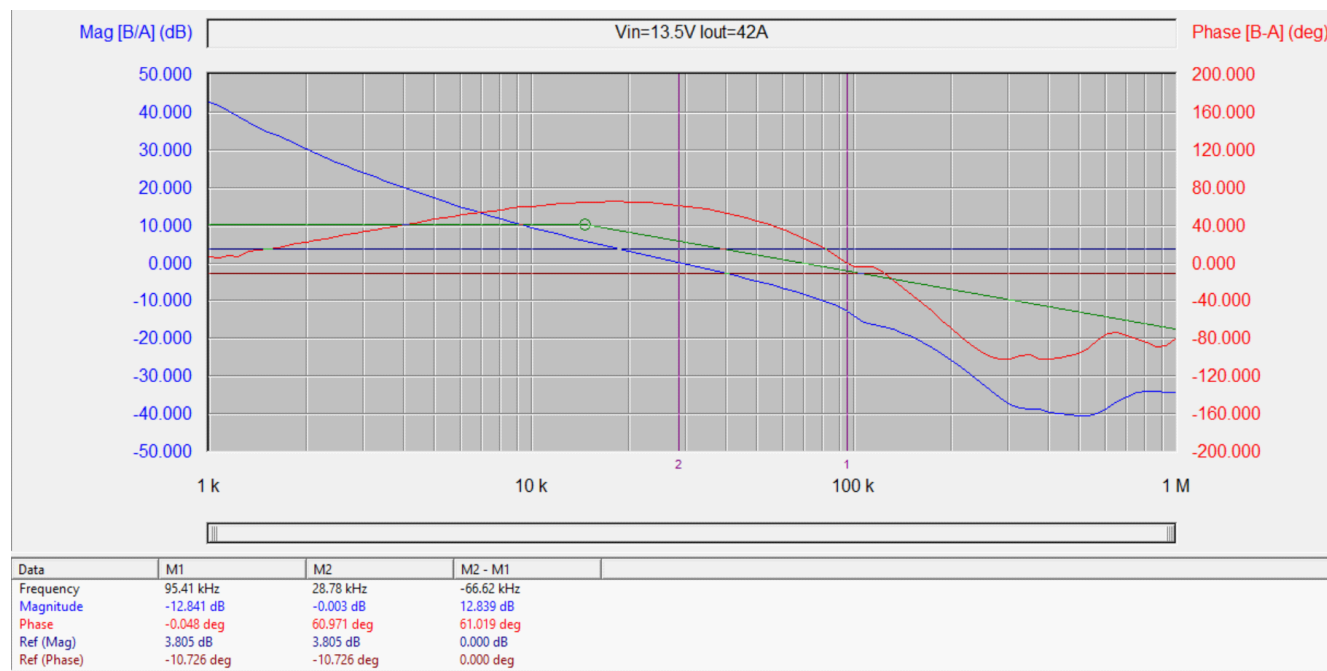
**Figure 3-11. Light Load Efficiency 15mA-300mA**

3.5 Bode Plot

Through optimized compensation circuit, PMP41158 can get good bode plot. Figure 3-12 is a bode plot of the reference design. Phase margin of 60° and gain margin is -12.8dB is achieved, making sure of stable operation.

Data	M1	M2	M2 - M1
Frequency	95.41 kHz	28.78 kHz	-66.62 kHz
Magnitude	-12.841 dB	-0.003 dB	12.839 dB
Phase	-0.048 deg	60.971 deg	61.019 deg
Ref (Mag)	3.805 dB	3.805 dB	0.000 dB
Ref (Phase)	-10.726 deg	-10.726 deg	0.000 deg

Figure 3-12. Bode Plot at 13.5Vin, 4.5Vout, 42Aout

4 Reference Design Modification Conversion From 48V to 12V

48V to 12V conversion is possible with this reference design, by making the following small modification to the board. Please refer to Figure 4-1 and Table 4-1 for modification required to obtain a 48V to 12V single output four phase buck converter.
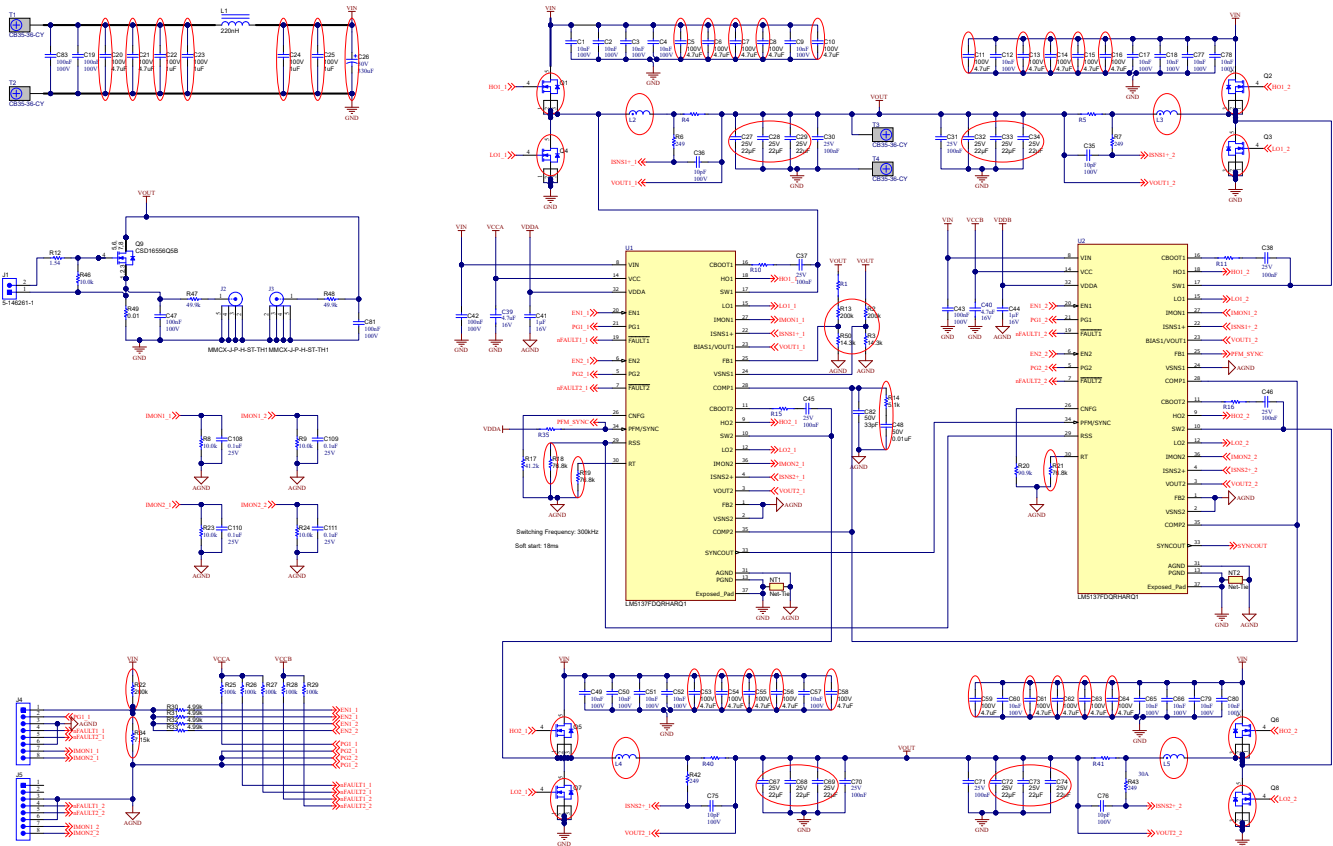
Figure 4-1. Schematic Detail Modification To Reference Design To Achieve 48V to 12V Conversion

Table 4-1. BOM List Changes to Reference Design to Achieve 48V to 12V Conversion

Position	Designator	PN	Remarks
Input filter	C22,C23,C24,C25	CGA4J3X7S2A105K125AB	1uF/100V, 0805
	C26	EEV-FK1K101Q	100uF/80V, H13
Input capacitor	C20,C21,C5,C6,C7,C8,C10,C11,C13,C14,C15,C16	CGA6M3X7S2A475K200	4.7uF/100V, 1210
FET	Q1,Q2,Q5,Q6	NVMFS6H852NLT1G	13.1mohm, 80V, QFN5*6
	Q3,Q4,Q7,Q8	NVMFS6H836NLT1G	6.2mohm, 80V, QFN5*6
Inductor	L2,L3,L4,L5	XGL1010-682MED	6.8uH
Output capacitor	C27,C28,C29,C32,C33,C34,C67,C68,C69,C72,C73,C74	GA6P3X7R1E226M250	22uF/25V, 1210
FB	R13,R2	CRCW0603200KFKEA	200kΩ, 0603
	R50,R3	CRCW060314K3FKEA	14.3kΩ, 0603
RT	R19,R21	CRCW060376K8FKEA	76.8kΩ, 0603
EN	R22	CRCW0603200KFKEA	200kΩ, 0603
	R34	CRCW06037K15FKEA	7.15kΩ, 0603

5 Summary

A four phase interleaved Buck converter with LM5137F-Q1 in ADAS application has been validated in the application note. The converter can achieve excellent light load efficiency by shedding the phases and reducing switching frequent at light load. This also can fulfill the high di/dt requirement in ADAS application.

If battery voltage is 12V, LM25137-Q1, which is a 42V, 100% duty-cycle capable dual-channel synchronous buck controller, is preferred. With updated BOM, the converter based on LM5137F-Q1 can also be used in 48V battery application. For more details on those applications, please refer to PMP41165.

6 References

- Texas Instruments, *LM5137F-Q1 Automotive, 80V,100% duty cycle, dual-channel functional safety synchronous buck controller*
- Texas Instruments, *LM25137F-Q1 Automotive, 80V,100% duty cycle, dual-channel functional safety synchronous buck controller*
- Texas Instruments, *PMP41158: 450W 12V to 4.5V Four-Phase Interleaved Buck Converter Reference Design*
- Texas Instruments, *PMP41165: 600W 48V to 12V Four-Phase Interleaved Buck Converter Reference Design*
- Texas Instruments, *Benefits of a Multiphase Buck Converter*, article
- EE Times, *Benefits Of Multiphasing Buck Converters Part 1*

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