

Ideal Diode Controllers for Active Rectification of AC Voltage Ripple for Automotive Applications: LM7480-Q1 and LM7481-Q1

Karikalan Selvaraj

ABSTRACT

Automotive electronic modules are required to work uninterrupted when AC ripple voltage is superimposed on the battery input line and AC ripple current flows into the modules. Reverse battery protection circuit contains components such as electrolytic capacitors, P-Channel MOSFETs or diodes. Reverse battery protection circuits using P-Channel MOSFETs does not rectify the AC ripple voltage due to lack of reverse current blocking and hence power dissipation in these components increases as the RMS value of the AC ripple current increases. It affects the overall system reliability and degrades the operating life time. Further, AC ripple frequency overlaps with the audio frequency and can cause interference in modules such as Audio Amplifiers which are sensitive to AC ripple voltage on its supply. The AC ripple voltage must be rectified and filtered to achieve superior audio performance. This application report discusses the key benefits of using TI’s Ideal Diode Controllers LM7480-Q1 and LM7481-Q1 for active rectification of the AC ripple voltage superimposed on the battery line

Contents

1	Introduction	2
2	Automotive Test Standards.....	2
3	Rectification of AC Ripple Voltage.....	3
4	Active Rectification using Ideal Diode Controllers.....	4
5	Charge Pump and MOSFET Gate Capacitance.....	6
6	Summary.....	9
7	References	9

List of Figures

1	AC Super Imposed Test	2
2	Reverse Battery Protection: Schottky Diode and P-Channel MOSFET	3
3	Response to AC Ripple Voltage: Diode and P-Channel MOSFET	3
4	Simplified Schematic of Ideal Diode Controller LM7480-Q1	4
5	LM7480-Q1 - Active Rectification of 2-V Peak-Peak 5 kHz AC Ripple.....	5
6	LM7480-Q1 - Active Rectification of 2-V Peak-Peak 30-kHz AC Ripple	6
7	Gate Charge Derating for Active Rectification	7
8	LM7481-Q1 Active Rectification at 100 kHz – BUK9J2R8-40H	8
9	LM7481-Q1 Active Rectification at 200 kHz – BUK7Y3R5-40H.....	8

List of Tables

1	Charge Pump Current and Gate Charge Limit.....	7
---	--	---

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

In systems powered by internal combustion engines, alternator provides power to the automotive electrical system by charging the battery during normal runtime of the vehicle. Rectified alternator output voltage contains AC voltage ripple superimposed on the battery voltage during entire life time of the vehicle depending on the operating conditions. The alternator output voltage is regulated by a voltage regulator by controlling the rotor field current and alternator output contains residual AC voltage ripple superimposed on the DC battery line due to variation in engine speed, regulator duty cycle with field current switching ON/OFF and electrical load variations.

In fully electric systems or semi-hybrid systems, the entire electrical load is fed through DC-DC converters. Output voltage of DC-DC converter contains AC voltage ripple superimposed on the DC battery voltage up to 200 kHz.

Hence most of the automotive ECUs are verified for uninterrupted and stable operation with AC voltage ripple superimposed on the battery supply line by testing its reverse battery protection circuit according to different automotive test standards.

2 Automotive Test Standards

AC superimposed tests are specified in various automotive test standards such as ISO 16750-2, LV124, other OEM standards and are intended to verify stable operation of various electronic modules. Typically the input protection circuit or the reverse battery protection circuit is verified for normal operation without much degradation in the operating life time of the modules.

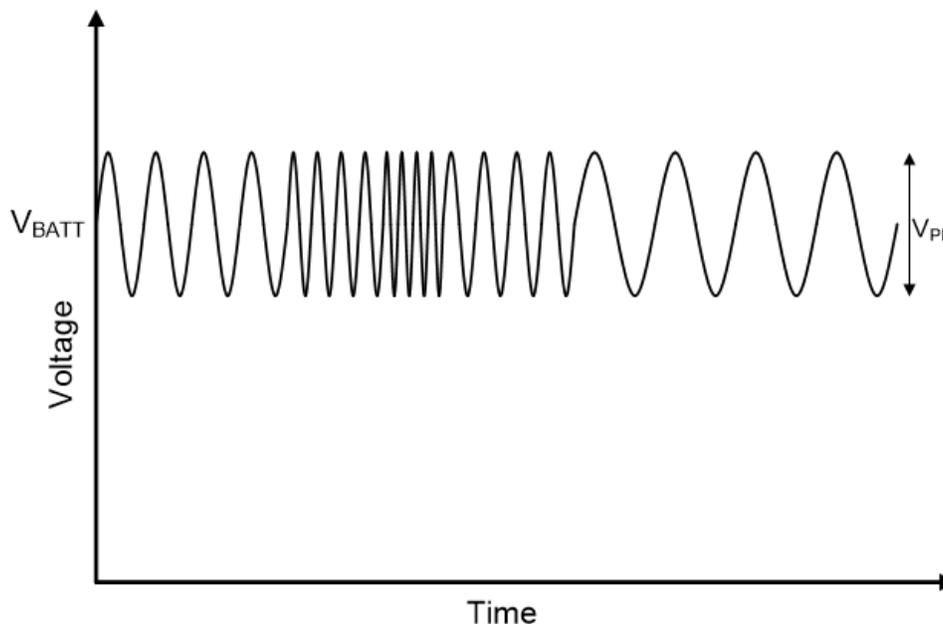


Figure 1. AC Super Imposed Test

For ECU modules operating in an alternator powered vehicle, ISO 16750-2 and LV124 E-06 specifies AC ripple of 2-V Peak-Peak on a 13.5-V DC battery voltage, swept from 15 Hz to 30 kHz and the test waveform is shown in [Figure 1](#). Other manufacturer specific requirements can vary and the frequency can go up to 100 kHz. Peak-Peak ripple amplitude varies from 2-V peak-peak to 6-V peak-peak, depending on the location of module with reference to Alternator and Battery. For ECU modules fed through a DC-DC converter, AC ripple frequency extends to 200 kHz.

3 Rectification of AC Ripple Voltage

Conventional input protection circuits use either a Schottky diode or P-Channel MOSFET to provide reverse battery protection. Figure 2 shows two reverse battery protection circuits, first one using a Schottky diode and second one using P-Channel MOSFET.

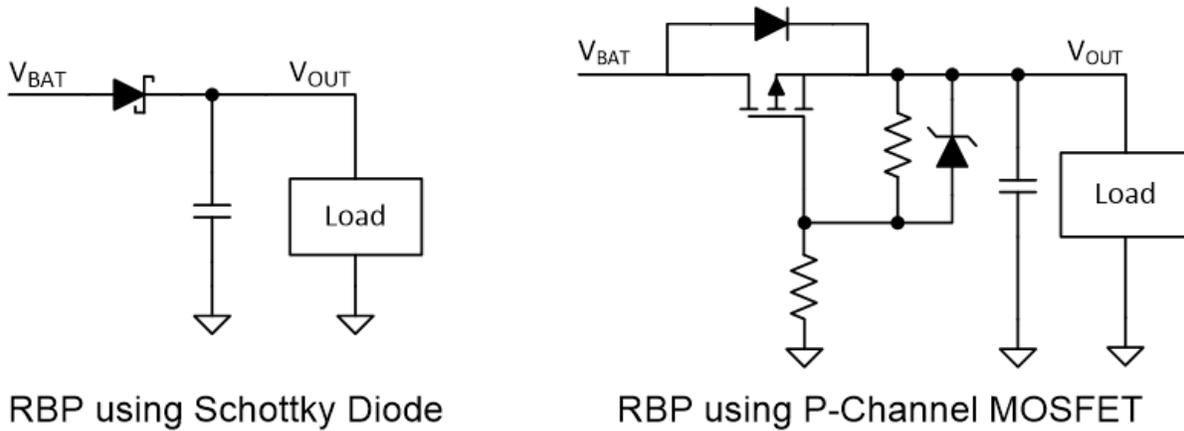
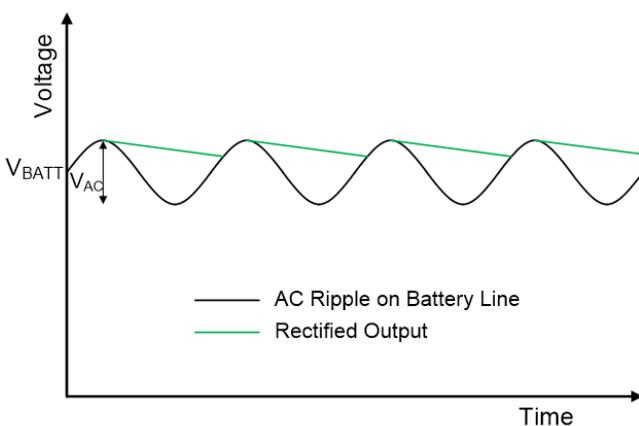


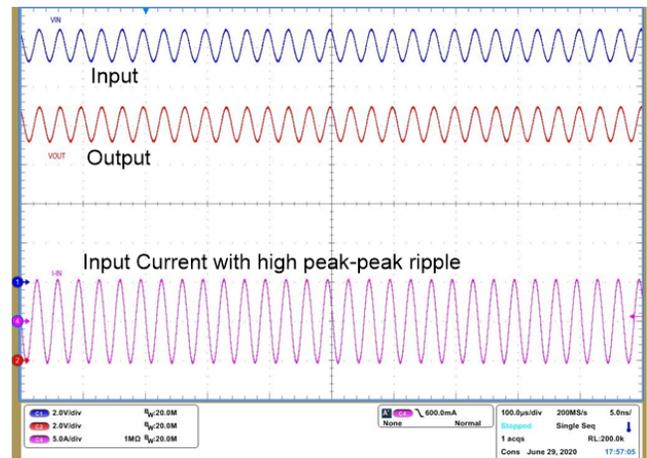
Figure 2. Reverse Battery Protection: Schottky Diode and P-Channel MOSFET

Schottky diode rectifies the AC ripple superimposed on the battery voltage effectively, except the high power dissipation due to high forward voltage drop. At every AC cycle of the ripple voltage, the input voltage swings lower than the output, Schottky diode is reverse biased and block reverse current flow from output. Until the next positive cycle, load current is supplied by the output electrolytic capacitor and capacitor is charged during the next cycle by the battery.

However, reverse battery protection circuit using a P-Channel MOSFET shown in Figure 2 does not block reverse current and hence the AC ripple voltage is not rectified. Figure 3 shows the response of P-Channel MOSFET based reverse battery protection circuit. Since AC ripple is not rectified, output voltage follows input voltage and AC ripple current swings negative leading to increase in peak-peak ripple current of 10A and RMS ripple current. The RMS ripple current through the output electrolytic capacitors increases the power dissipation as the ripple current increase and its needs to be limited to minimize power dissipation reduce aging effect and improve overall reliability.



Response to AC ripple: Diode



Response to AC ripple: P-Channel MOSFET

Figure 3. Response to AC Ripple Voltage: Diode and P-Channel MOSFET

4 Active Rectification using Ideal Diode Controllers

The LM7480x-Q1 ideal diode controller features a dual-gate drives topology to control two external back to back N-Channel MOSFETs. One of the MOSFET is controlled to emulate an ideal diode and another MOSFET for power path ON/OFF control, inrush current limiting and over voltage protection.

Ideal Diode Controller LM748x-Q1 family of devices features a very low forward drop to minimize power dissipation in the N-Channel MOSFET during normal operation. Fast reverse current blocking response, fast DGATE turn on and dual gate drive enables LM7481-Q1 to rectify AC ripple voltage up to 200 KHz.

During each cycle when the input voltage swings below the output, DGATE is turned off within $1\mu\text{s}$ to block reverse current from flowing back into the battery. In the next 'positive cycle', when the input voltage swings above the output, 'DGATE fast charge' allows DGATE to turn ON quickly within $2\mu\text{s}^*$, thereby reducing the power dissipation in the MOSFET. This enables LM748x-Q1 controller to do active rectification the AC voltage ripple.

Thus the key to uninterrupted cycle-cycle active rectification at 200 KHz is fast reverse recovery and fast forward turn ON.

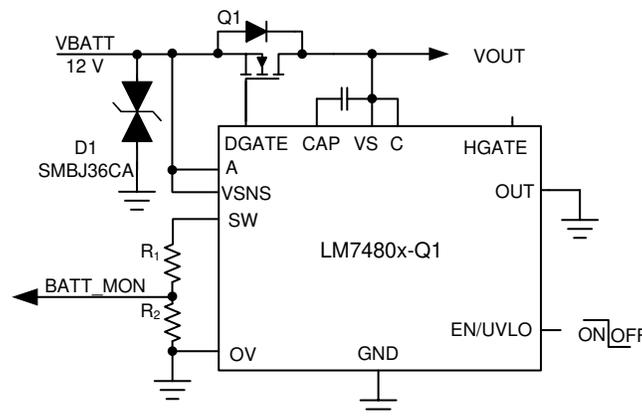


Figure 4. Simplified Schematic of Ideal Diode Controller LM7480-Q1

A simplified schematic showing ideal diode used for active rectification is shown in [Figure 4](#). For complete application circuit, refer to the LM7480-Q1 and LM7481-Q1 datasheet application section.

Active rectification of 2-V peak-peak 5 kHz and 30 kHz AC voltage ripple by LM7480-Q1 is captured in [Figure 5](#) and [Figure 6](#) respectively. During the positive cycle MOSFET is turned ON, output capacitor charges and output follows input until the current through the MOSFET reverses. As soon as reverse current is detected, LM748x-Q1 turns off the MOSFET within $1\mu\text{s}$, thereby blocking the reverse current completely. In the negative cycle, output capacitor discharges at a constant rate determined by the load current and amount of output capacitance.

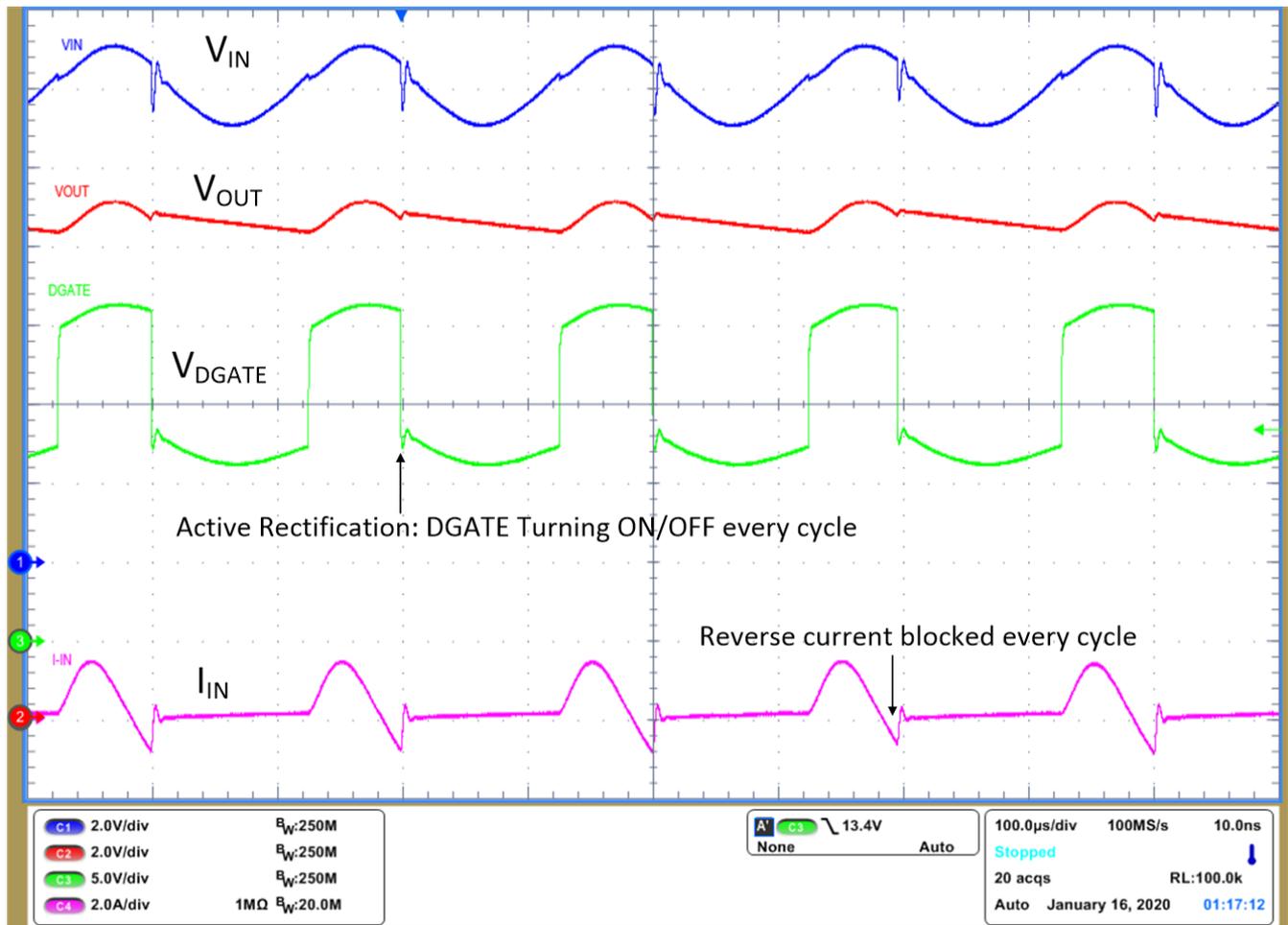


Figure 5. LM7480-Q1 - Active Rectification of 2-V Peak-Peak 5 kHz AC Ripple

Fast reverse current blocking minimizes the peak reverse current and completely block reverse current during the negative cycle. Thus AC ripple current RMS value is reduced by half which in-turn reduces the power dissipation in the output electrolytic capacitor ESR by half. Very low forward voltage drop and reduced RMS ripple current reduces the power dissipation in the MOSFET as well.

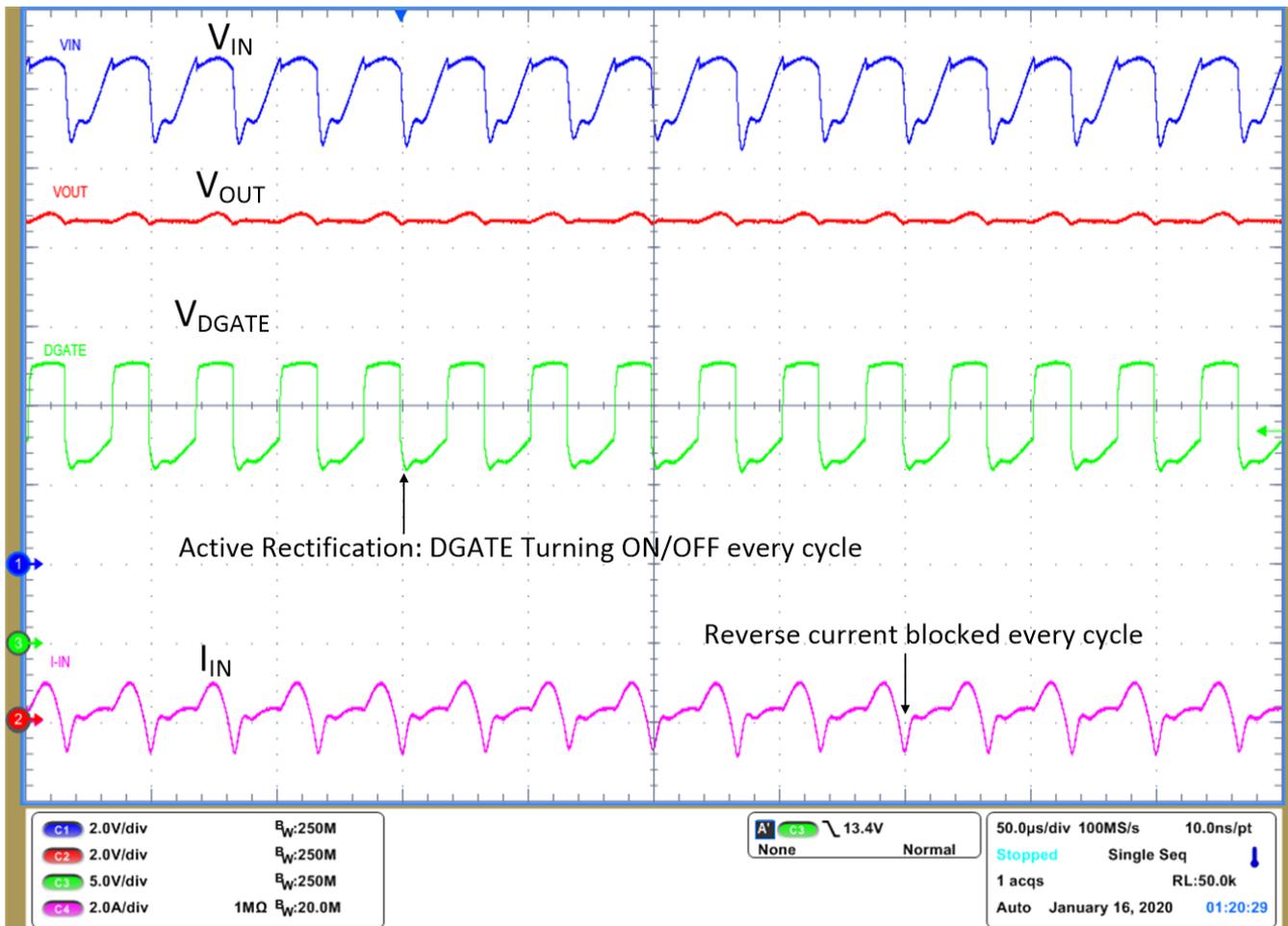


Figure 6. LM7480-Q1 - Active Rectification of 2-V Peak-Peak 30-kHz AC Ripple

5 Charge Pump and MOSFET Gate Capacitance

During the active rectification of AC voltage ripple, DGATE drive turns the MOSFET ON and OFF every cycle continuously and this result in increased loading on the charge pump depending on the MOSFET gate capacitance and frequency of the AC Voltage ripple. The charge pump loading is determined by

$$I_{CP} = Q_{GM} \times F_{AC} \quad (1)$$

Q_{GM} is the gate capacitance at V_{GS} 6 V, de-rated for miller charge and F_{AC} is the frequency of the AC voltage ripple.

MOSFET manufacturers usually specify the gate charge characteristics in three region: Gate-Source charge Q_{GS} determines the MOSFET turn ON, Gate-Drain charge Q_{GD} depends on the Drain-Source Voltage and $Q_{G(total)}$ the total gate charge. Due to the orientation of the MOSFET in an ideal diode application, maximum V_{DS} cannot be more than the maximum forward diode voltage and hence the gate charge Q_{GD} needs to be derated accordingly. Figure 7 shows derated Gate charge Q_{GM} at 6-V V_{GS} in dotted lines.

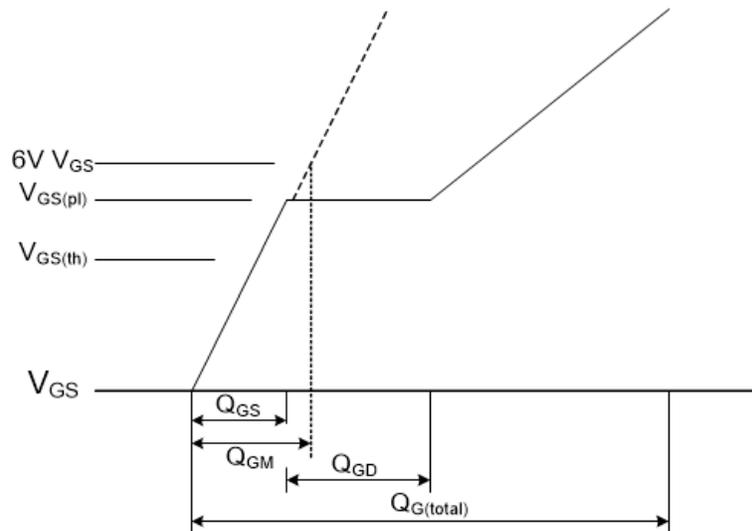


Figure 7. Gate Charge Derating for Active Rectification

For continuous cycle-cycle active rectification of AC superimposed ripple, higher charge pump capacity is required as the frequency increases. [Table 1](#) shows comparison of charge pump current for LM7480-Q1, LM7481-Q1 and LM74700-Q1 along with maximum gate charge Q_{GM} for continuous active rectification of AC ripple.

Table 1. Charge Pump Current and Gate Charge Limit

Parameter		LM74700-Q1	LM7480-Q1	LM7481-Q1
Charge Pump Current at $V_{CAP-VS} = 6V$		300 μA	600 μA	3000 μA
Maximum Gate Charge Q_{GM} at AC ripple frequency F_{AC}	30 kHz	10nC	20nC	100nC
	100 kHz	-	-	30nC
	200 kHz	-	-	15nC

LM7481-Q1 with higher charge pump current than LM7480-Q1 and LM74700-Q1 is recommended for higher power ECU applications and applications having AC ripple frequency 100 kHz or 200 kHz requirements. [Figure 8](#) shows the AC superimposed test run at 100 kHz on LM7481-Q1 driving MOSFET BUK9J2R8-40H. At 100 kHz maximum gate charge is 30nC and MOSFET BUK9J2R8-40H having 20nC gate charge Q_{GM} meets the requirements of maximum gate charge. [Figure 9](#) shows the 200 kHz AC superimposed test on LM7481-Q1 driving MOSFET BUK7Y3R5-40H with 12nC gate charge Q_{GM} . This meets the maximum gate charge Q_{GM} of 15nC at 200 kHz. Due its fast gate drive and fast reverse recovery response, LM7481-Q1 is able to drive the MOSFETs ON/OFF continuously at 100 kHz and 200 kHz.

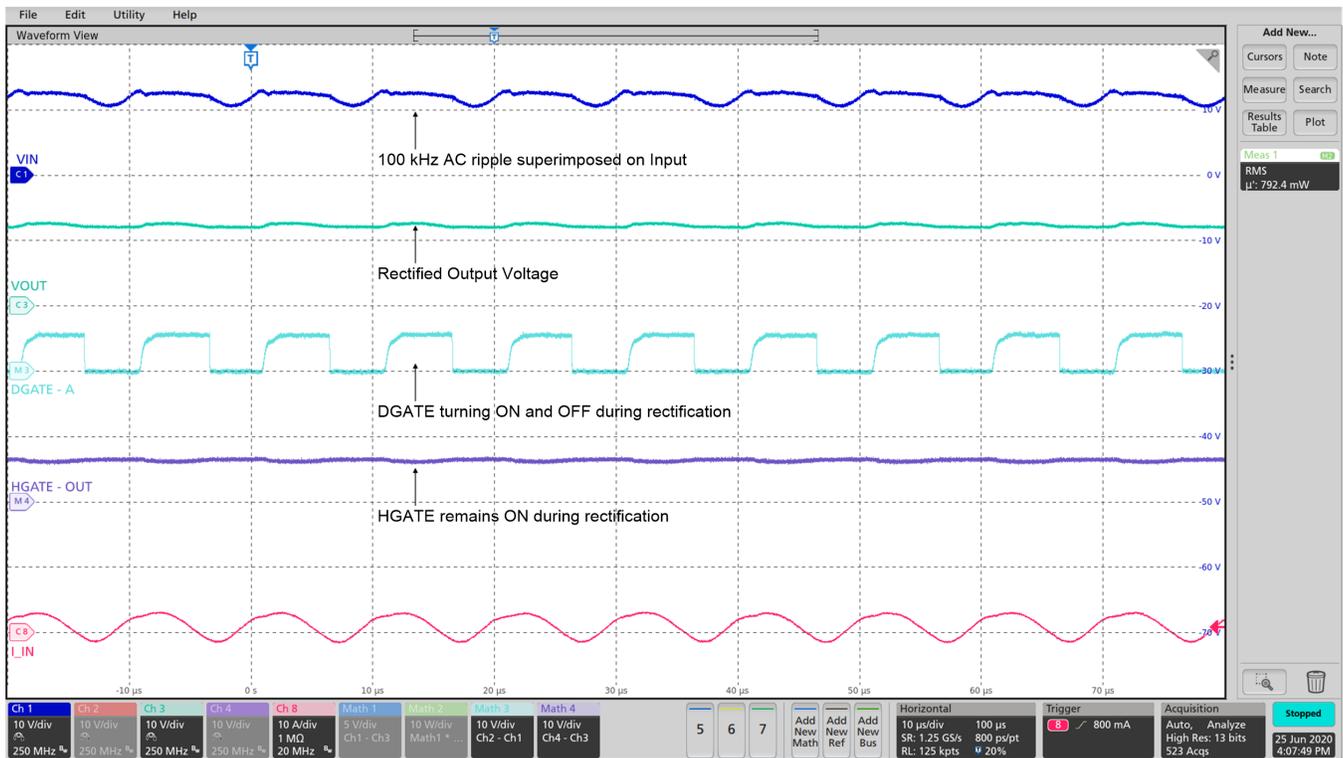


Figure 8. LM7481-Q1 Active Rectification at 100 kHz – BUK9J2R8-40H

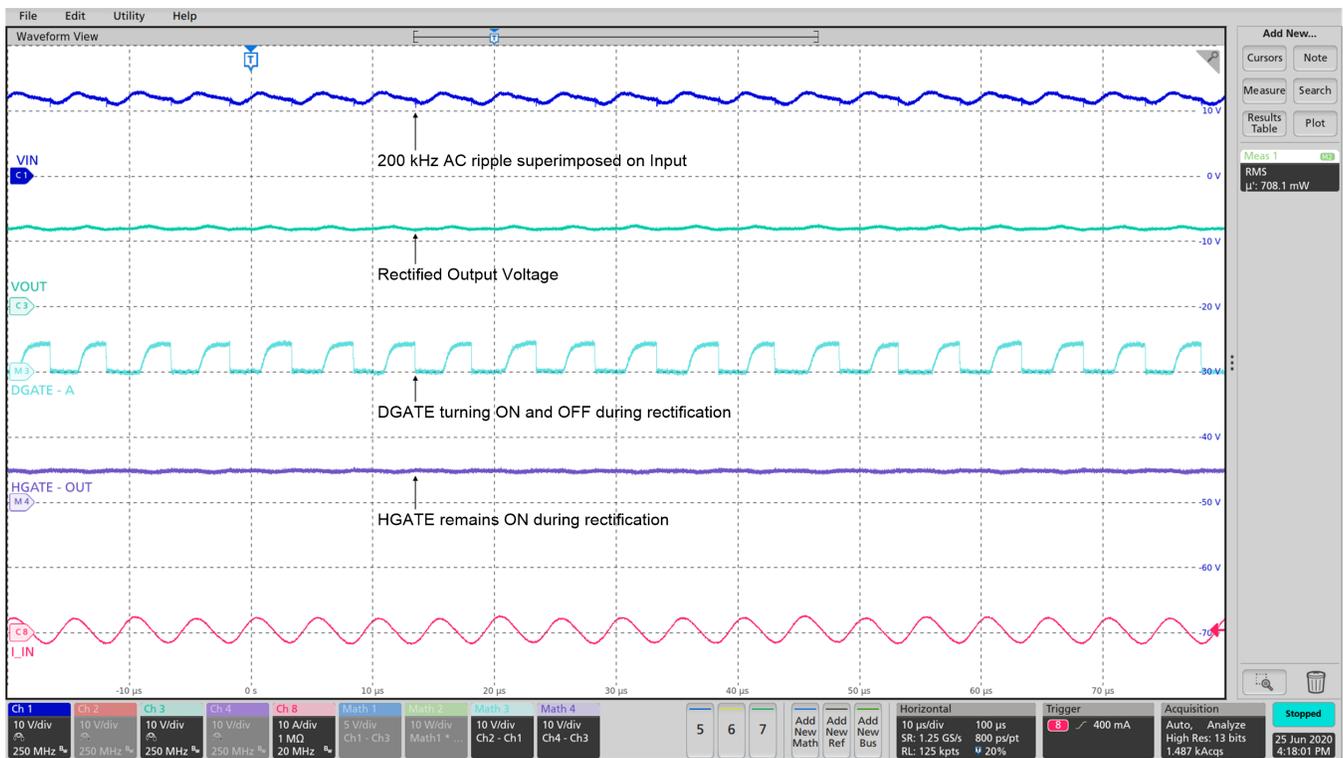


Figure 9. LM7481-Q1 Active Rectification at 200 kHz – BUK7Y3R5-40H

6 Summary

Rectification of the AC ripple by reverse battery protection circuit with Schottky Diode involves power dissipation due to high forward voltage drop along with the AC ripple current. Reverse battery protection solution using P-Channel MOSFETs lack reverse current blocking and does not rectify the AC ripple leading to increased power dissipation in MOSFET and electrolytic capacitors.

Key performance features such as very low forward voltage drop, fast gate drive, fast reverse recovery response and higher charge pump enables LM748x-Q1 family of ideal diode controllers to achieve active rectification of AC voltage ripple. Efficient active rectification results in low forward voltage drop and reduced RMS ripple current leading to lower power dissipation in MOSFET and output capacitors.

7 References

- Texas Instruments, [LM7480x-Q1 Ideal Diode Controller with Load Dump Protection Data Sheet](#)
- Texas Instruments, [LM74810-Q1 Ideal Diode Controller with Active Rectification and Load Dump Protection Data Sheet](#)
- Texas Instruments, [LM74700-Q1 Low \$I_o\$ Reverse Battery Protection Ideal Diode Controller Data Sheet](#)
- Texas Instruments, [Basics of Ideal Diodes Application Report](#)

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated