Wednesday May 22

Session 1 Starts: 10:00 CEST | 1 AM PDT | 4 AM EDT

Session 2 Starts: 17:00 CEST | 8 AM PDT | 11 AM EDT

Driving Efficiency: Ideal Diode Controllers in Automotive Systems

5/22/2024

Ralf Ohmberger, Staff Applications Engineer, MPS

All attendees are muted. Live QA available via chat.

Agenda

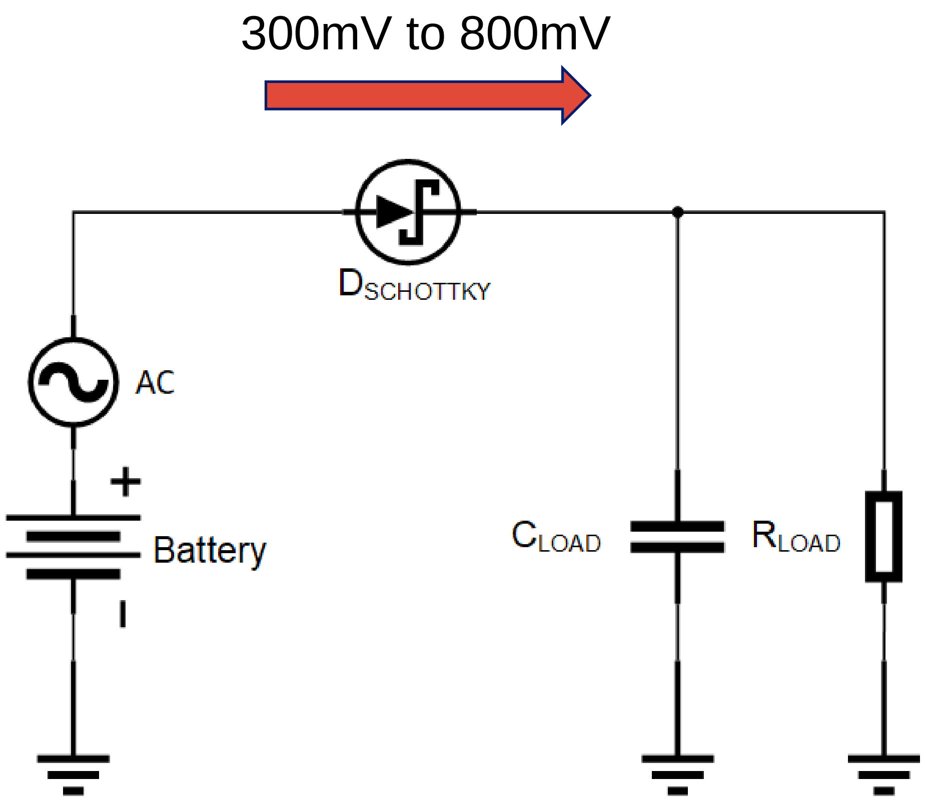
Introduction

This introductory webinar will help today’s hardware engineers understand the functionality of ideal diode controllers — including how to choose their external parts and how to apply them to a design in a practical manner.

This webinar will also compare applications using ideal diode controllers, Schottky diode rectifiers, and P-channel MOSFET rectifiers.

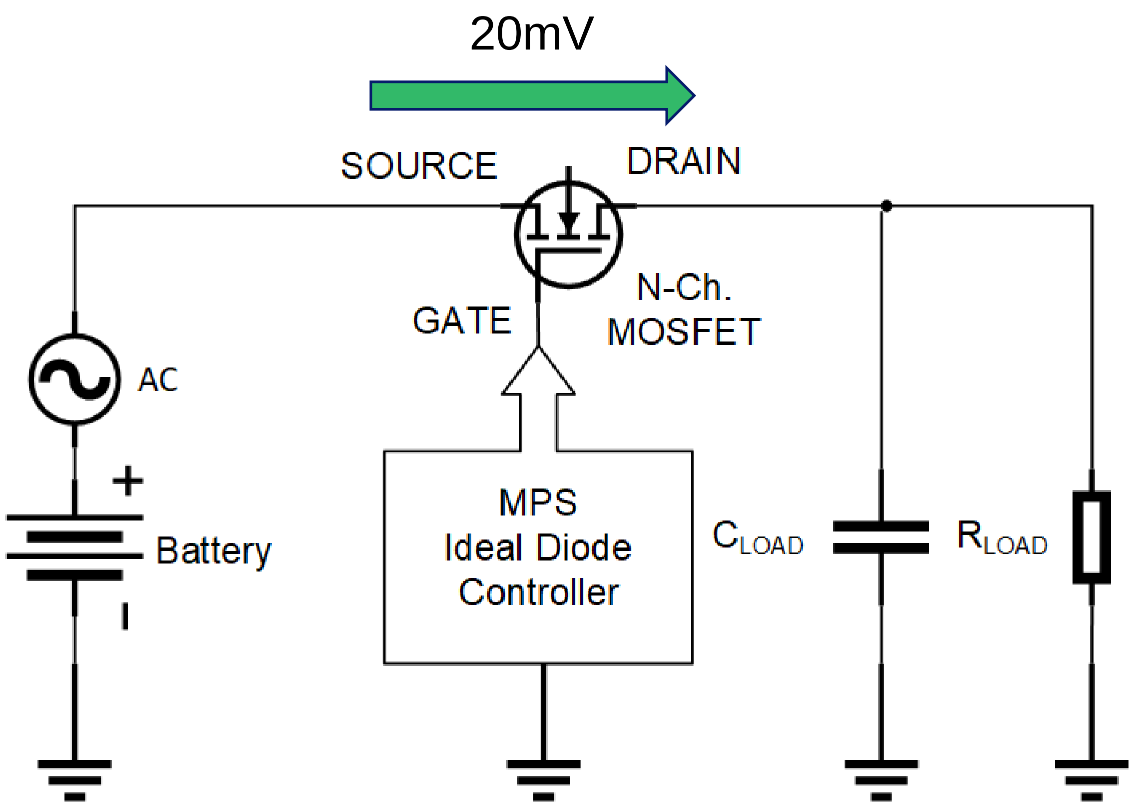
Lastly, it will discuss how to use an ideal diode controller to achieve a cool-running, cost-optimized solution, as well as how to make accurate measurements.

What is an Ideal Diode Controller?



Passive Schottky Diode

Past

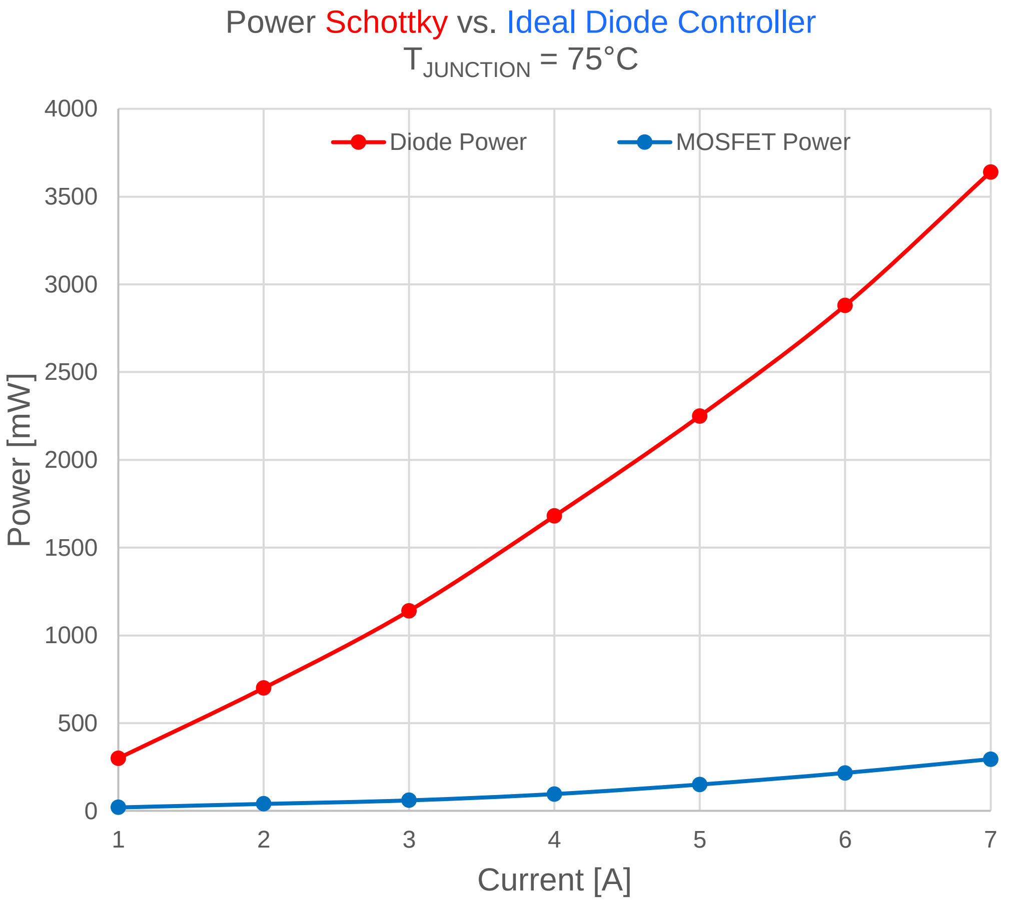


Ideal Diode Controller

Today

An ideal diode regulator uses an N-channel MOSFET with a controlled 20mV voltage drop.

Power of Ideal Diode Controller vs. Schottky Diode



The N-channel MOSFET can easily transfer its heat to a PCB, which is impossible with a 5A Schottky diode.

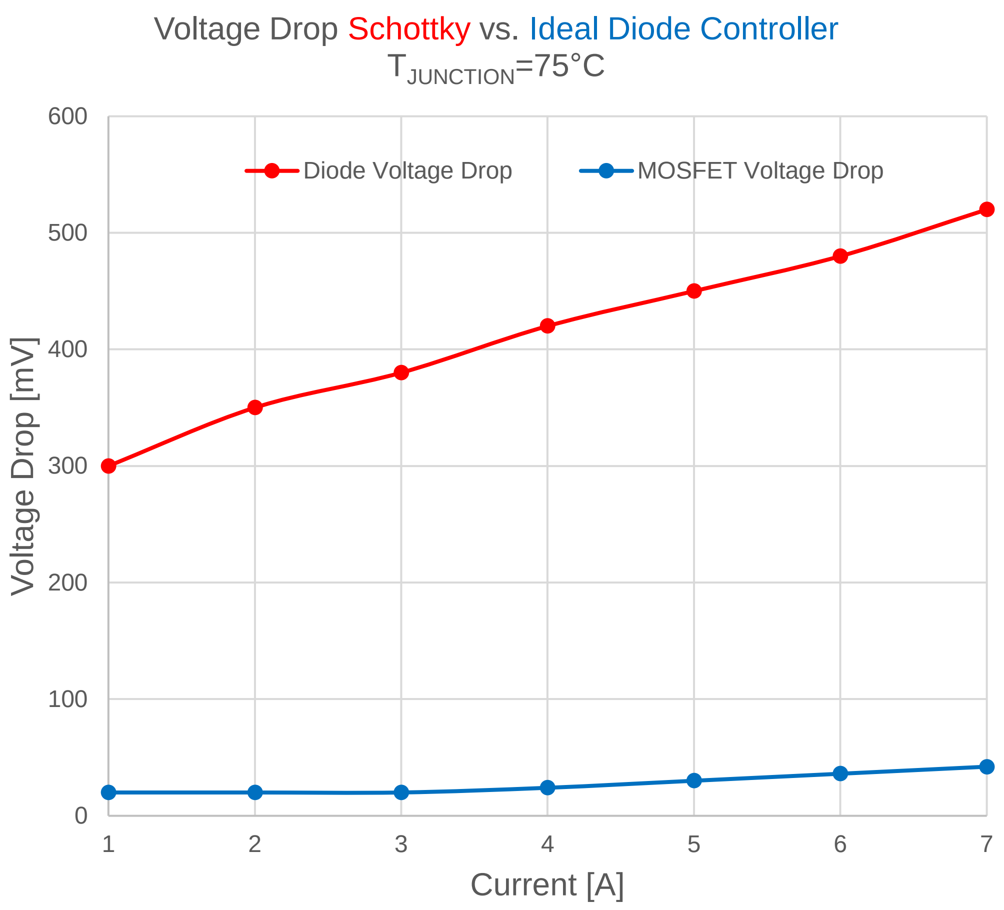
MPQ5850-AEC1 and MPQ5852-AEC1

- With External N-Channel MOSFET
- MOSFET: $R_{DS(ON)}$ = 6mΩ, $I_{DRAIN\ MAX}$ = 80A, BV_{DSS} = 60V
- MOSFET Package: 3.3mmx3.3mm
- MOSFET Package Max: 2.2W on 1in², 2oz copper FR4

Passive Schottky Diode

- Schottky Diode: $I_{FORWARD}$ = 5A, $I_{FORWARD\ PEAK}$ = 100A, $V_{REVERSE}$ = 60V
- Schottky Diode Package: 4.7mmx2.5mm
- Schottky Diode Package Max: 1.5W, 4A at T_J = 150°C

Voltage Drop of Ideal Diode Controller vs. Schottky Diode



The Schottky diode has a higher voltage drop.

MPQ5850-AEC1 and MPQ5852-AEC1

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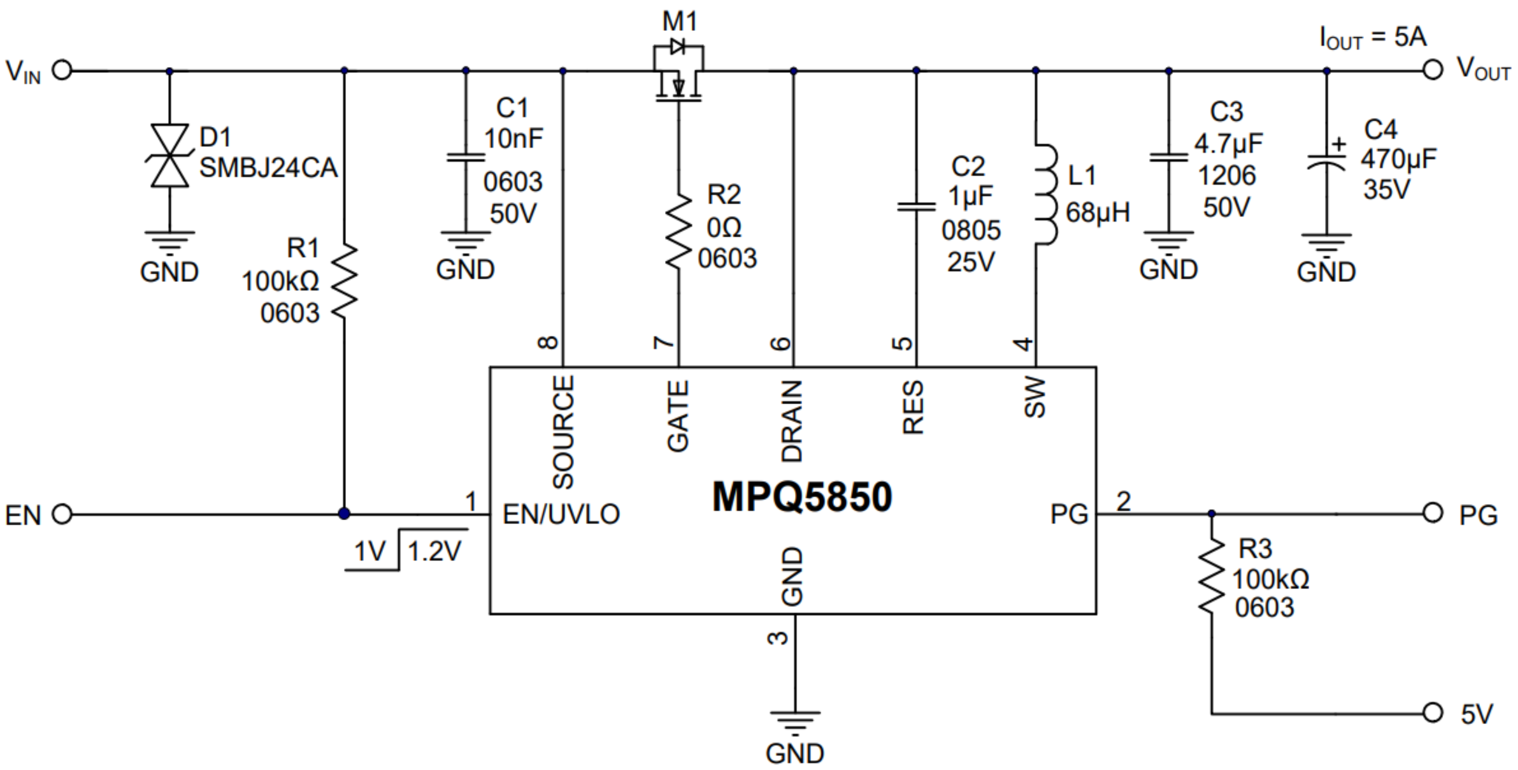
The Schottky diode voltage drop follows the U vs. I curve characteristic.

MPQ5850-AEC1 – Diode Controller with External MOSFET

ACTIVE

Rectifies up to 100kHz



Typical Application Circuit: 12V Automotive Battery, I_{OUT} = 5A.

Features	Applications
-36V to +42V	Automotive System Prot.
Low Dropout: 20mV	Automotive ADAS
Gate Boost Converter	Automotive Infotainment
Gate Drive: 430mA	Digital Head Units
Gate Sink: 170mA	Battery-Powered Systems
Standby: 4µA	O-Ring Hot-Swapping
Steady State: 30µA	
Power Good	
TSOT-23-8 (2mmx3mm)	
AEC-Q100	

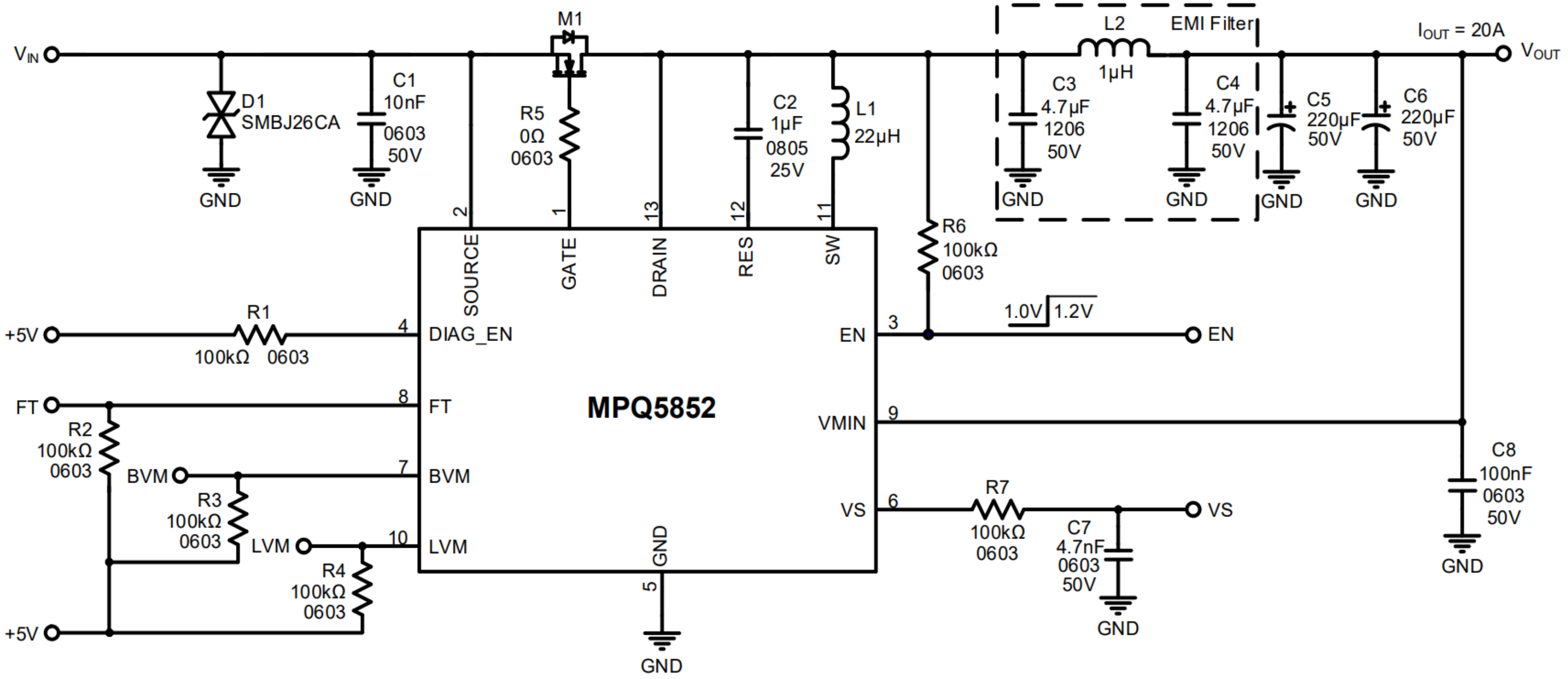
VW80000 LV124
AC-Superimposed
Load Dump Up to 42V
Cold Crank Down to 0V
Reverse Polarity
Transient ISO-Pulses

MPQ5852-AEC1 – Diode Controller, External MOSFET, Monitor

PRE-RELEASE

Rectifies up to 100kHz

EMI filter decreases MOSFET and peak currents in C5, C6.



Typical Application Circuit: $V_{IN} = V_{OUT} = 5V$ to 36V, $I_{OUT} = 20A$.

Features	Applications
-40V to +42V	Automotive System Prot.
Low Dropout: 20mV	Automotive ADAS
Gate Boost Converter	Automotive Infotainment
Strong Gate Drive	Digital Head Units
Standby: 4µA	Battery-Powered Systems
Steady State: 30µA	O-Ring Hot-Swapping
Monitor Battery UV/OV	
Monitor Load UV/OV	
Battery Voltage Sensing	**VW80000 LV124**
Over-Temp Warning	AC-Superimposed
Fault Indication	Load Dump Up to 42V
Functional Safety	Cold Crank Down to 0V
QFN-13 (3mmx3mm)	Reverse Polarity
AEC-Q100	Transient ISO-Pulses

MPS

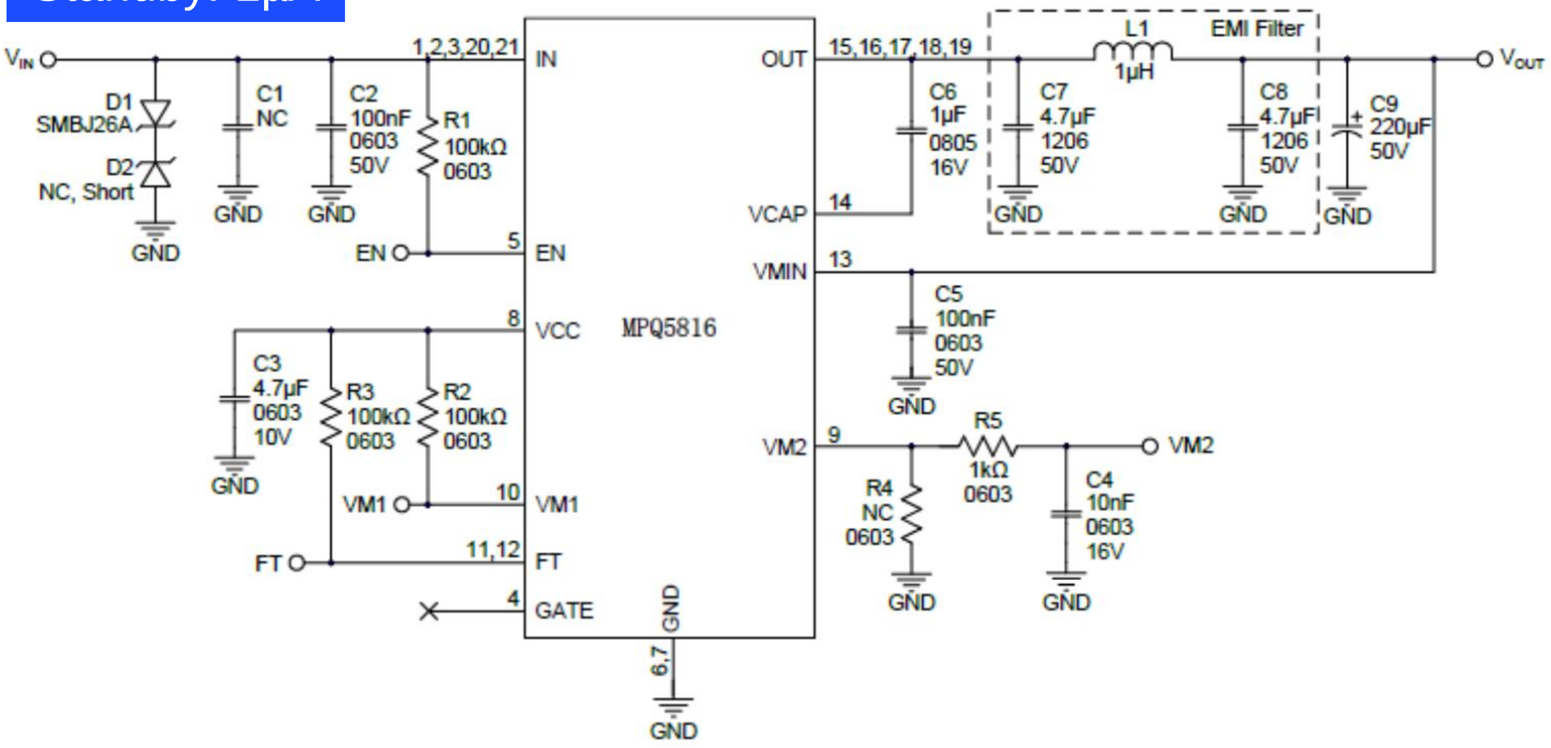
MPQ5816-AEC1 – Diode Controller, Internal MOSFET, Charge Pump

PRE-RELEASE

Gate Charge Pump

Internal 10mΩ MOSFET rectifies up to 100kHz

Standby: 1µA



Typical Application Circuit: $V_{IN} = V_{OUT}$ = 5V to 42V, I_{OUT} = 9A.

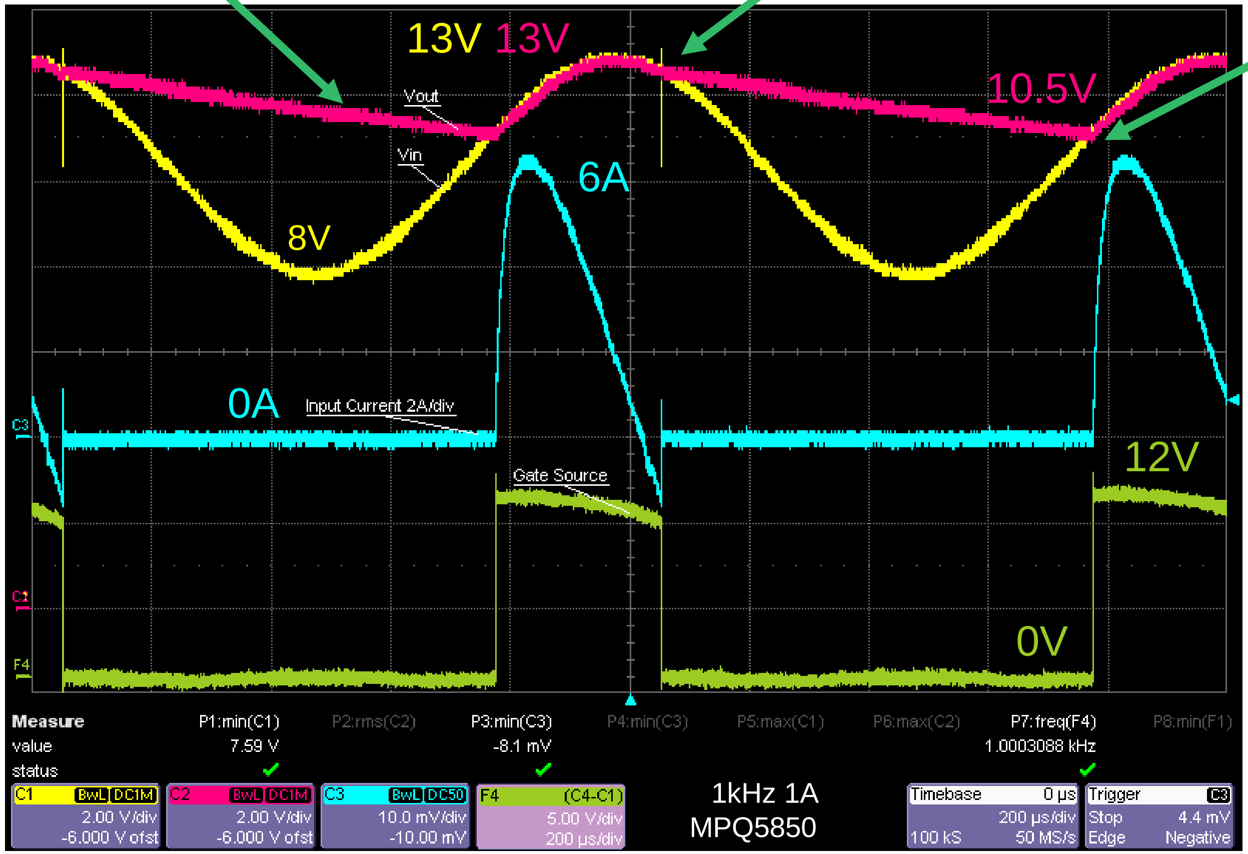
Features	Applications
-40V to +42V	Automotive System Prot.
3V to 42V Start-Up	Automotive ADAS
Gate On, 2A; Off, 0.11A	Automotive Infotainment
Steady State: 75µA	Digital Head Units
Monitor Load UV/OV	Battery-Powered Systems
Monitor Battery UV/OV	O-Ring Hot-Swapping
Battery Voltage Sensing	
Independent Voltage Monitor and UV Indicator	
Selectable OV/UV Thresholds	
Over-Current Warning	**VW80000 LV124**
Over-Temp Warning	AC-Superimposed
Fault Indication	Load Dump Up to 42V
Functional Safety	Cold Crank Down to 0V
QFN-21 (3mmx4mm)	Reverse Polarity
AEC-Q100	Transient ISO-Pulses

Rectifier – AC-Superimposed

V_{OUT} 470µF Capacitor Supplies 1A Load

$V_{IN} < V_{OUT}$
Gate Off

$V_{IN} > V_{OUT}$
Gate On



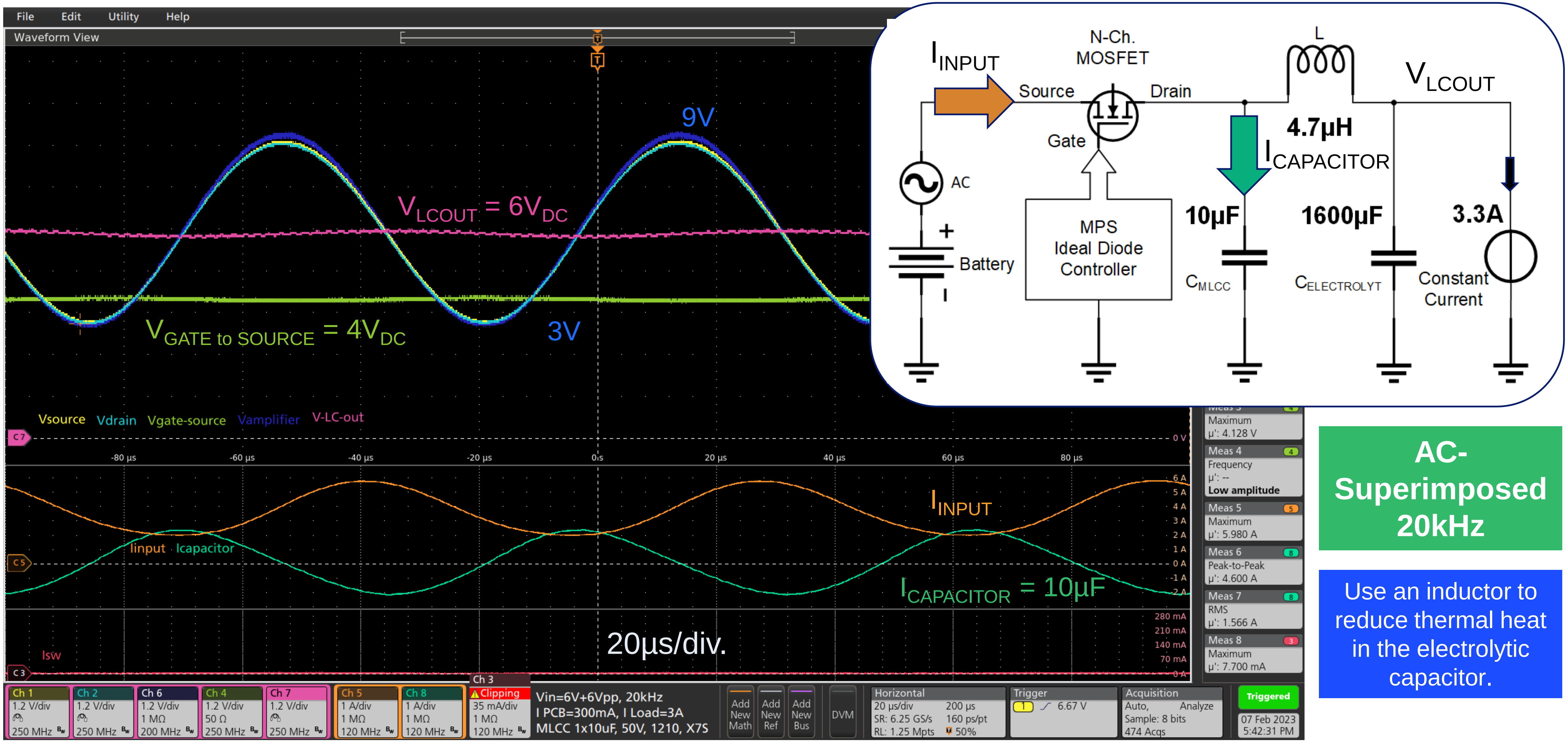
Clear Rectifier Waveforms

Channels

- C1: V_{IN} (2V/div.)
- C2: V_{OUT} (2V/div.)
- C3: Input Current (2A/div.)
- F4: $V_{GATE\ to\ SOURCE}$ (5V/div.)

V_{IN} = 10.5V_{DC} + 5$V_{PEAKPEAK}$, 1kHz, I_{OUT} = 1A electronic constant load

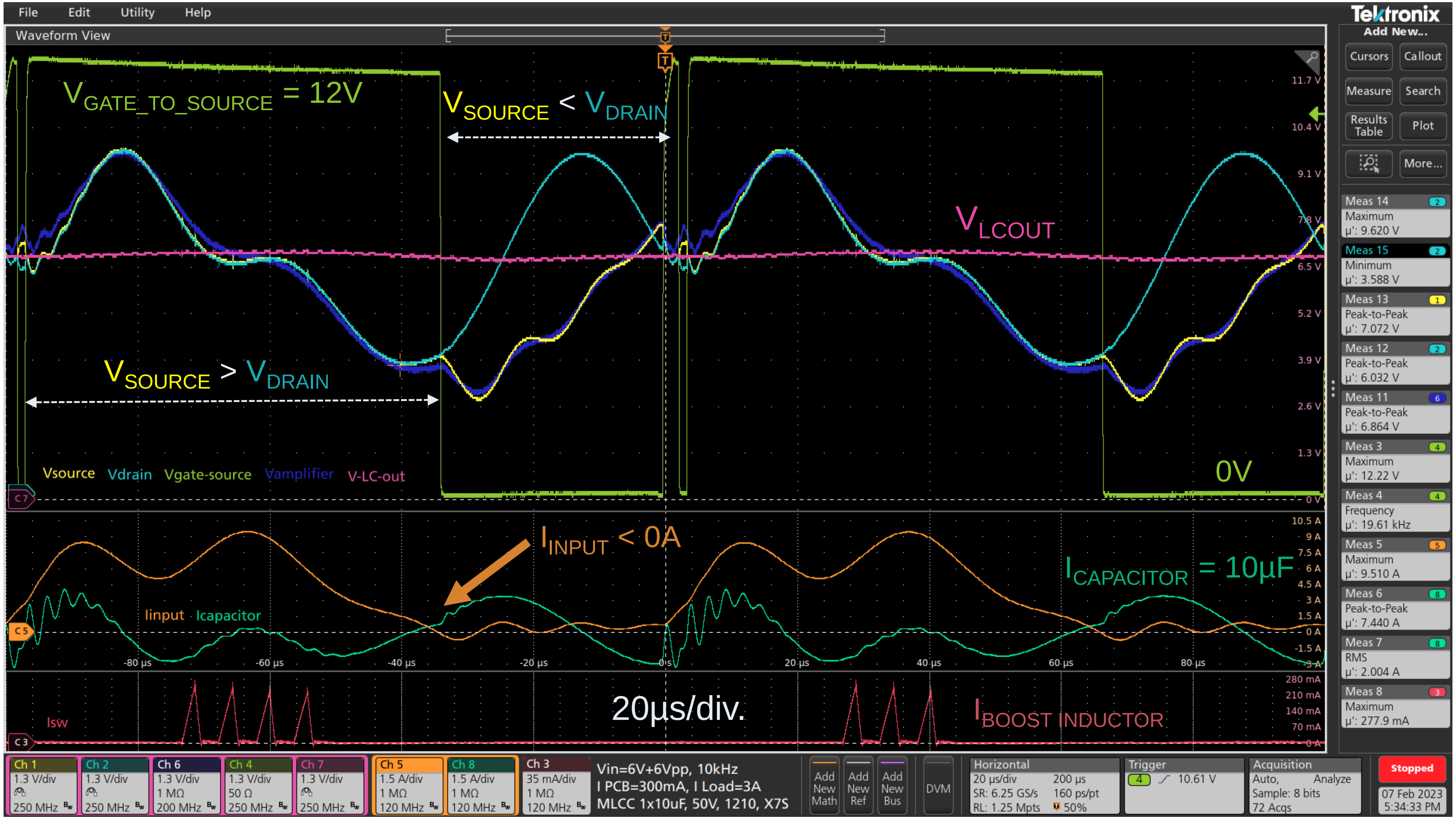
Rectifier – AC Superimposed – with LC_{OUT} Filter



AC-Superimposed 20kHz

Use an inductor to reduce thermal heat in the electrolytic capacitor.

Rectifier – AC Superimposed – with LC_{OUT} Filter



AC-Superimposed 10kHz

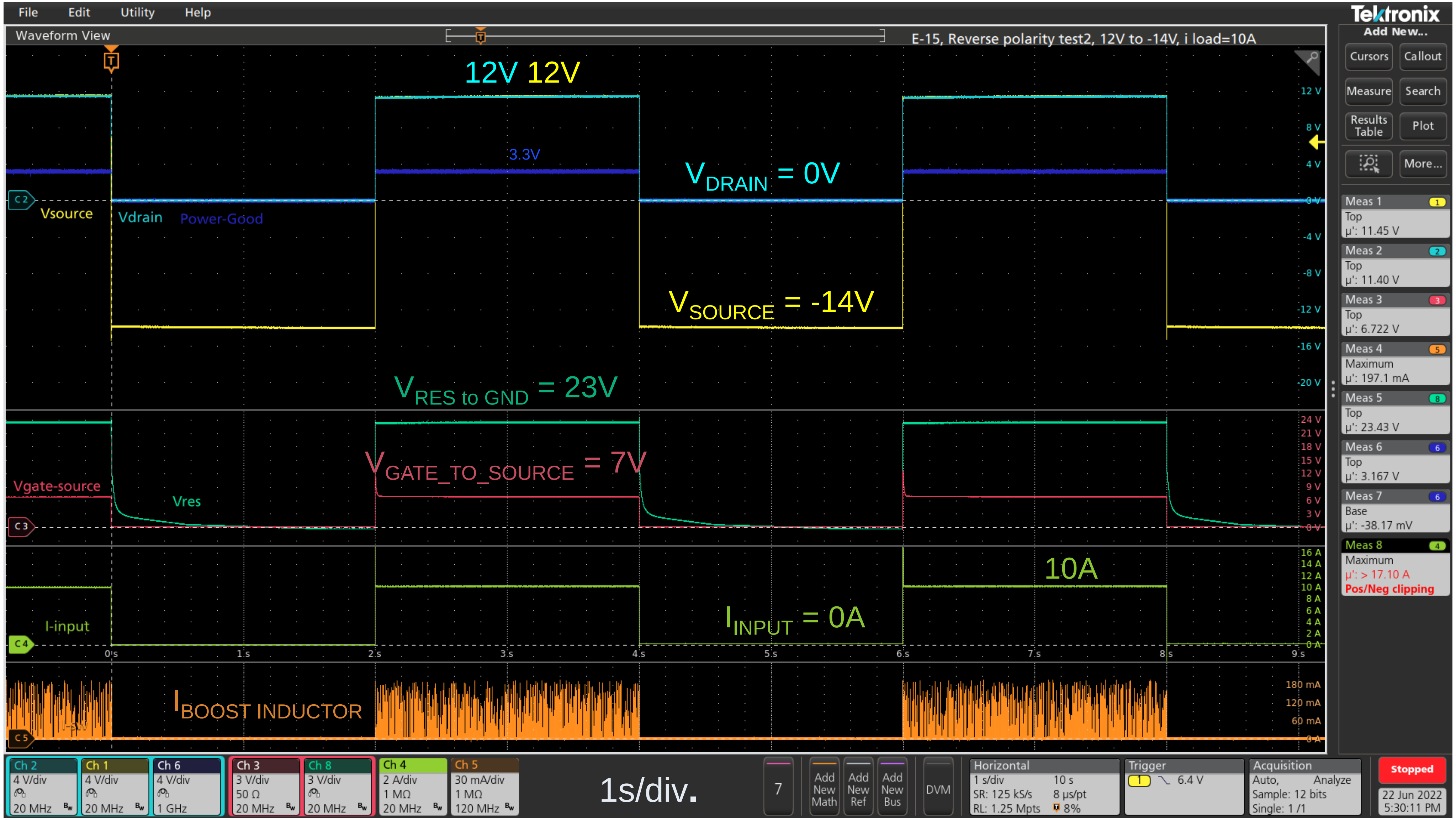
Clear V_{LCOUT}

C-L-C
Output Filter

10µF
4.7µH
1600µF

No current back into battery

Reverse Polarity, LV124, E-15, +12V to -14V



Reverse polarity alternating +12V to -14V

Reverse polarity blocked

Test time 8s

I_{LOAD} = 10A

No current back into battery

MPS

Automotive Test – VW80000 LV124

MPS Ideal Diode Controller

Designed to Pass Automotive LV124

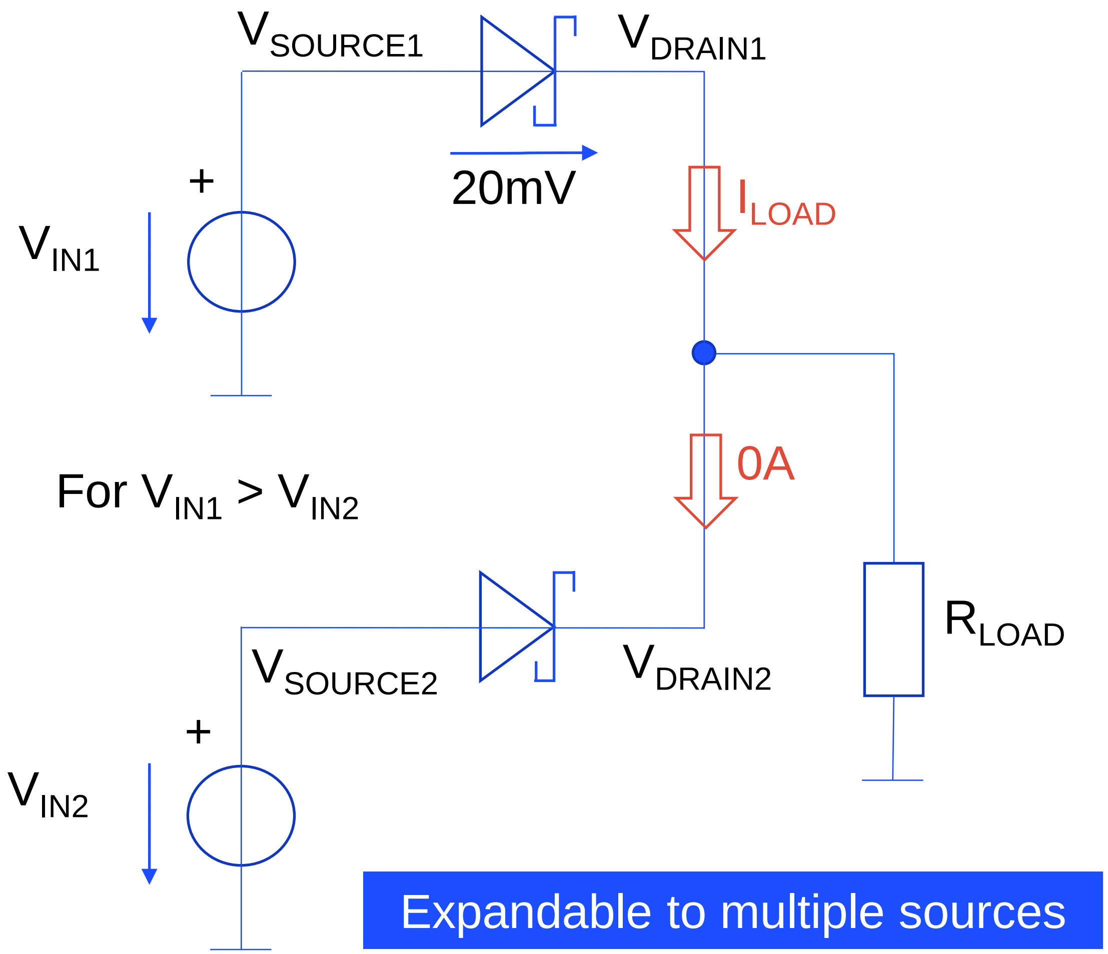
- E-01: Long-term over-voltage
- E-02: Transient over-voltage
- E-03: Transient under-voltage
- E-04: Jump start
- E-05: Load dump
- E-06: Superimposed alternating voltage
- E-07: Slow decrease and increase of the supply voltage
- E-08: Slow decrease, quick increase of the supply voltage
- E-09: Reset behavior
- E-11: Start pulses
- E-15: Reverse polarity
- TL81000, ISO7637-2 and ISO16750-2:Transient, positive and negative pulses

Ideal Diode Controller – O-Ring

O-Ring

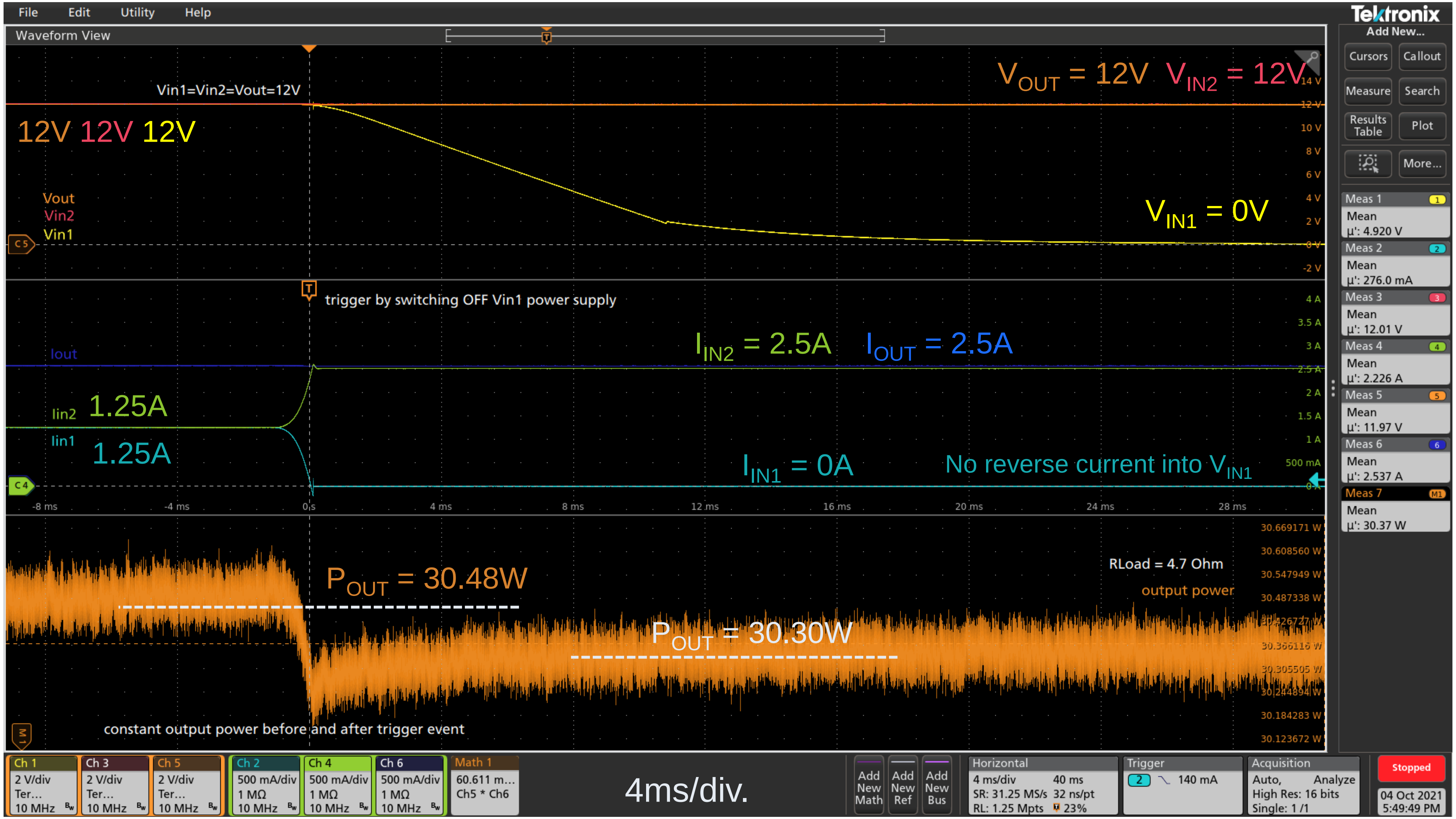
- Parallel batteries or power supplies
- Protect power supplies from reverse currents
- Hot-swapping
- The highest voltage supplies the load
- Equal voltages sharing the load current

O-Ring Block Diagram



Expandable to multiple sources

O-Ring – Removing V_{IN1}

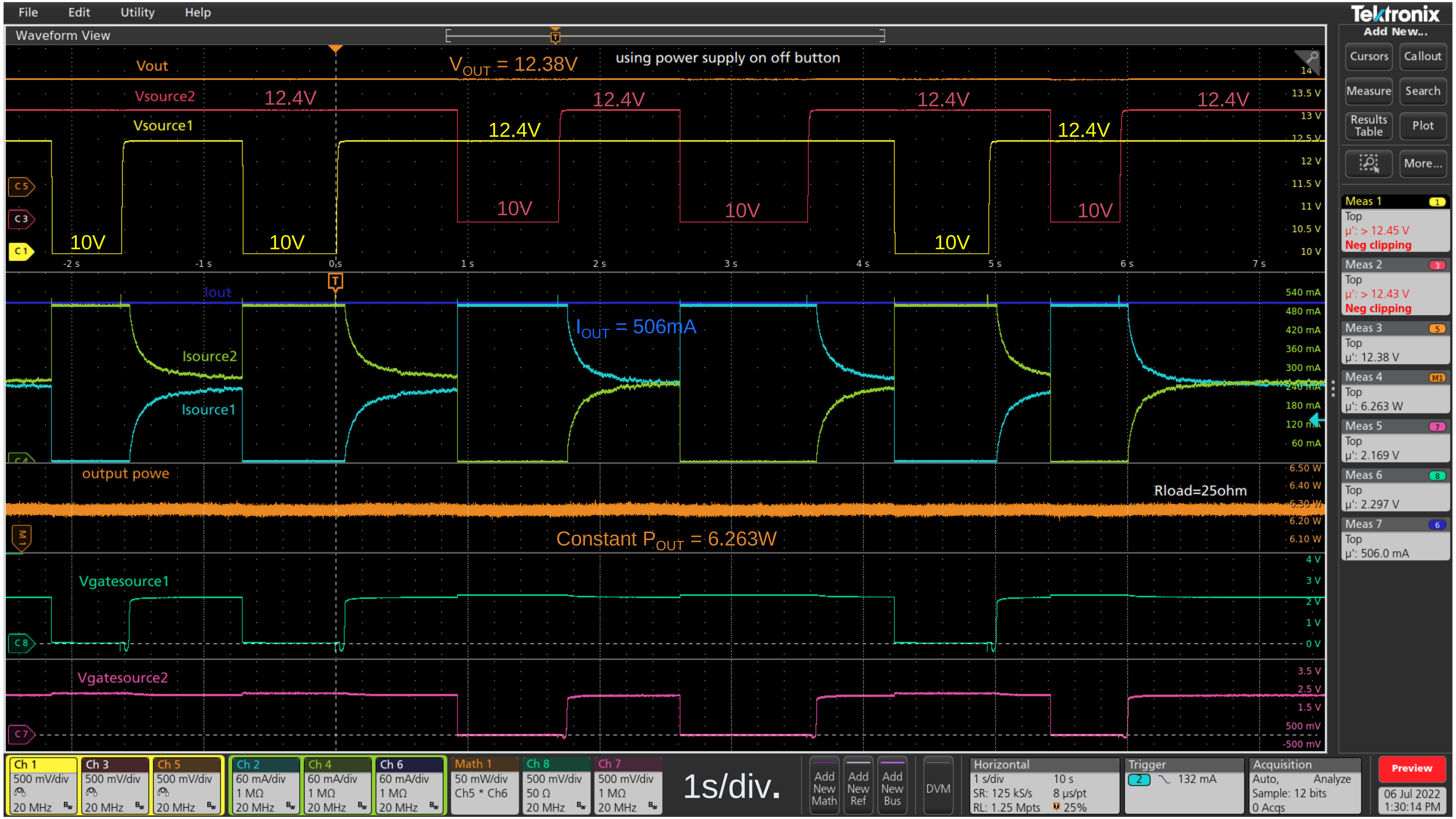


Power Off V_{IN1}

O-ring after removing power supply (V_{IN1}).

Output power constant

O-Ring – On/Off Offset on $V_{SOURCE1}$ and $V_{SOURCE2}$

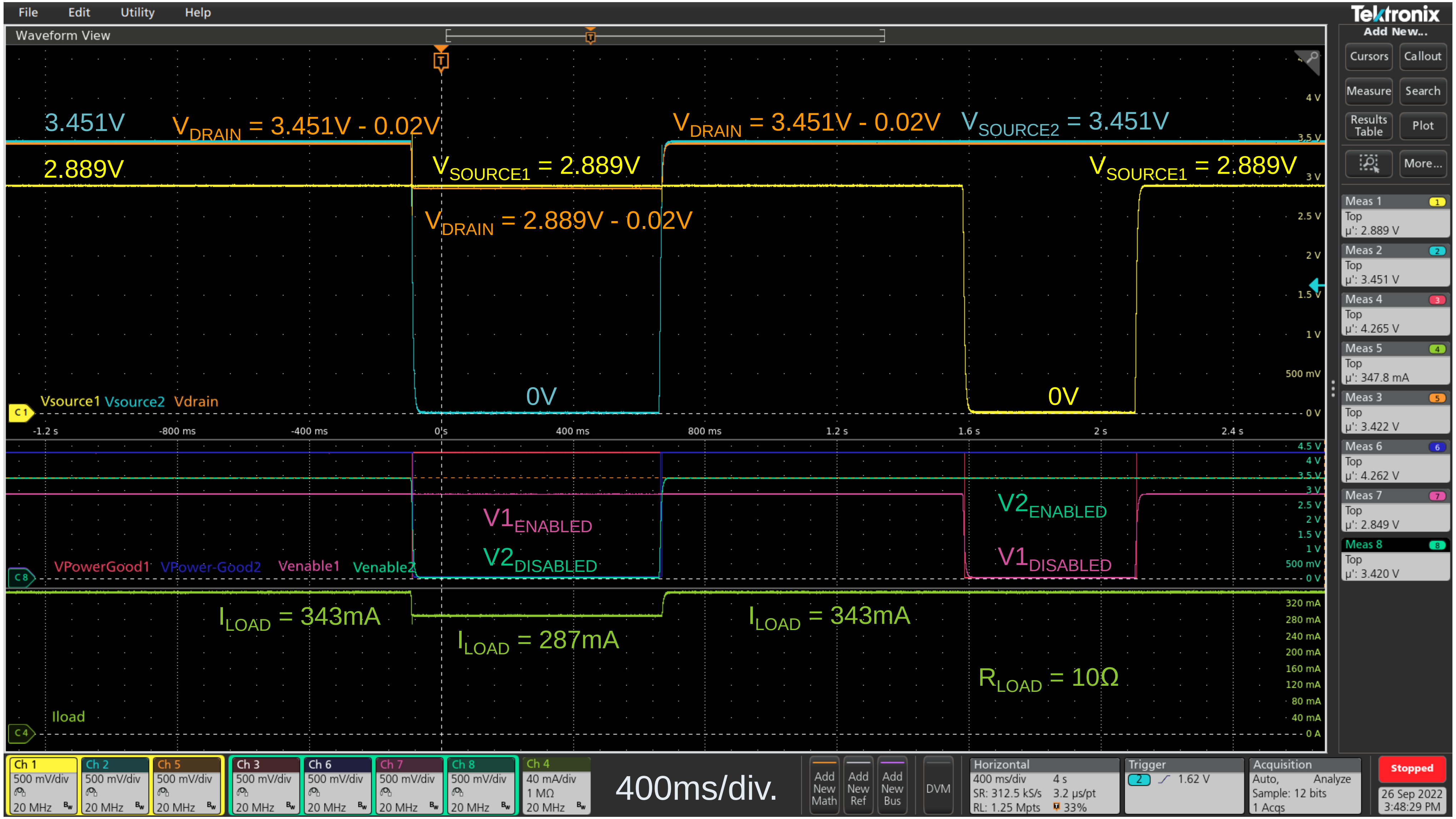


Switching On-Off-On

O-Ring power supplies with $10V_{DC}$ offset voltage

Output power constant

O-Ring – for Low-Voltage Sources

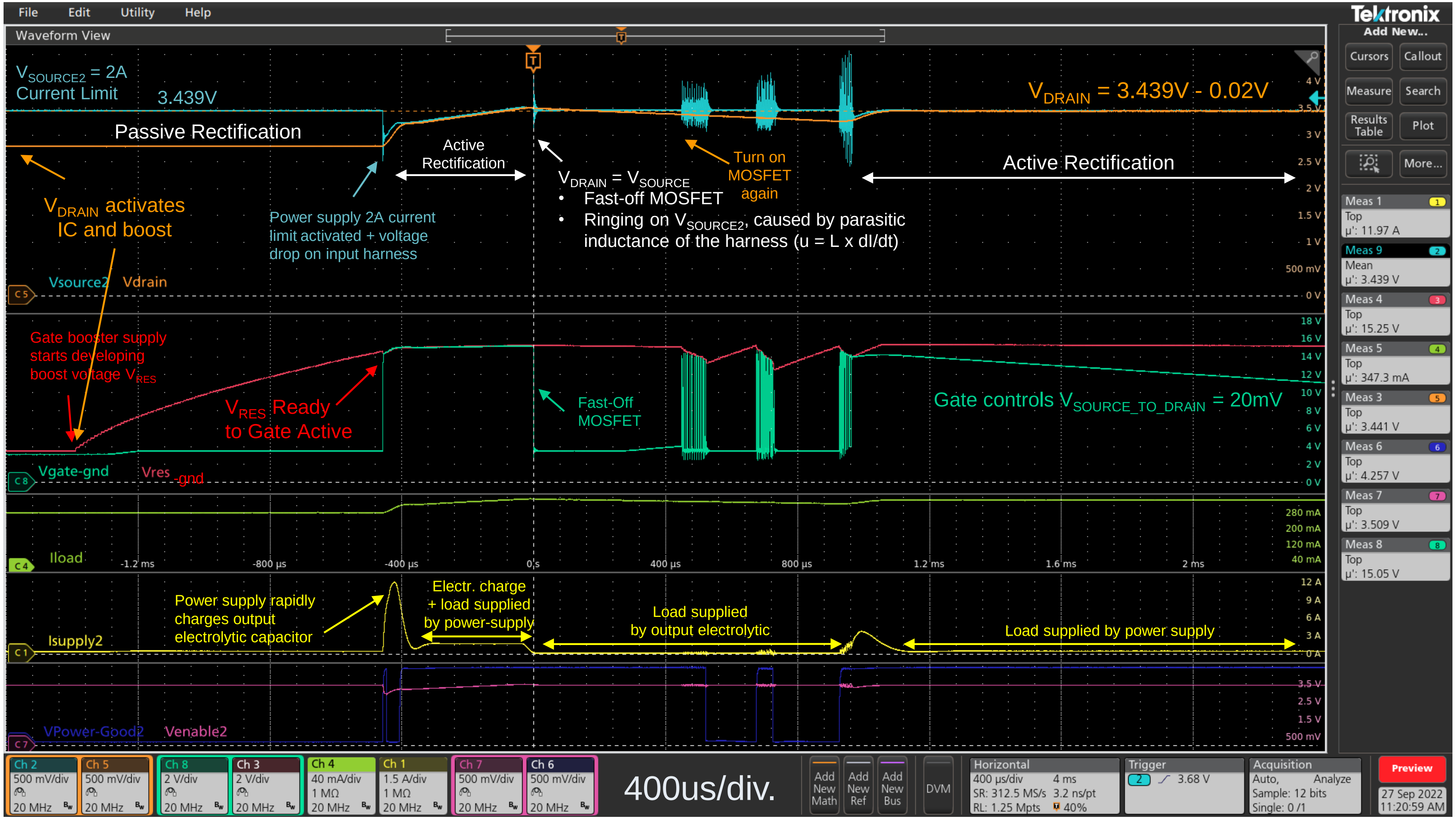


Low Voltage Operation

$V_{SOURCE1}$: 2.889V
$V_{SOURCE2}$: 3.451V

Operates down to V_{DRAIN} (typ. 2.6V)

IC Starts after V_{DRAIN} < UVLO



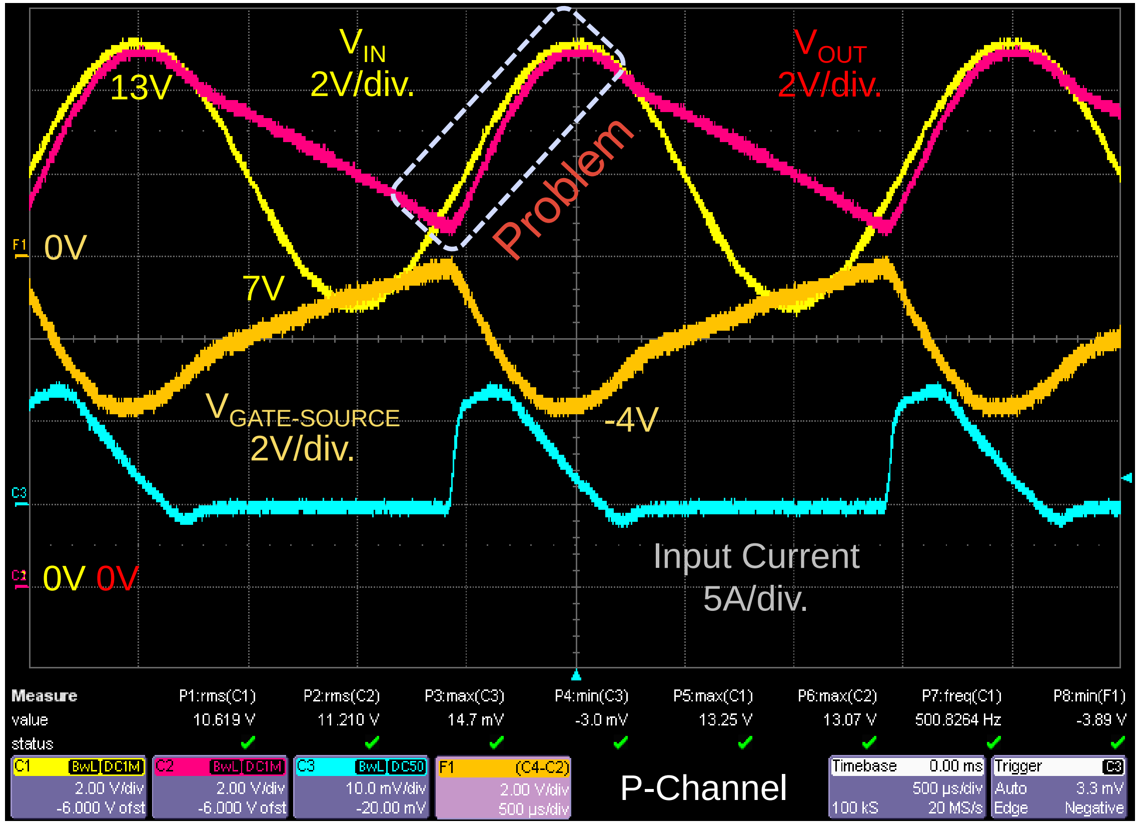
IC starts after V_{DRAIN} < V_{UVLO}

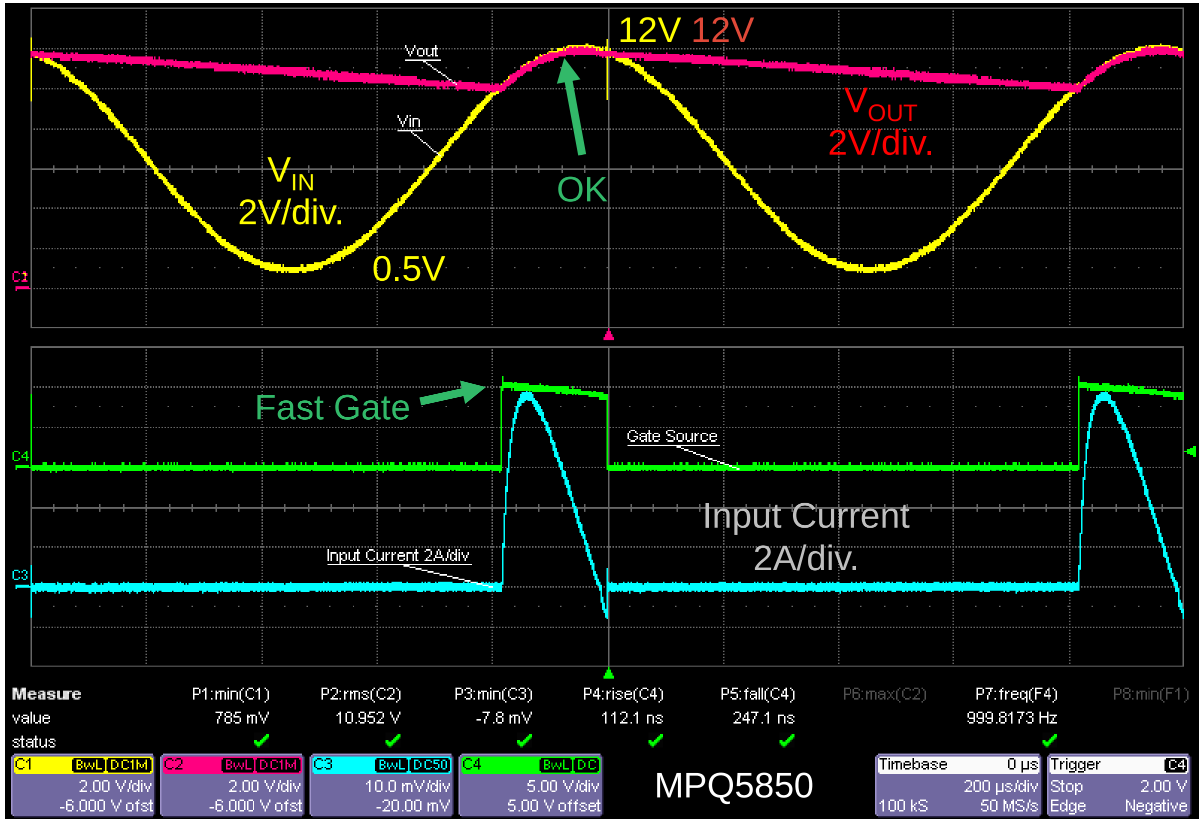
Ideal diode controller reset after under-voltage lockout (UVLO)

Start time only typ. 1ms

MPS

Passive P-Channel MOSFET Rectifier vs. Ideal Diode Controller





Past | **P-Channel MOSFET Rectifier**

- Problematic under AC waveforms
- Small useable V_{IN} range
- Higher MOSFET temperature
- Higher costs (P-channel MOSFET)

Today | **MPQ5850-AEC1**

- Clean AC waveforms
- Wide V_{IN} range
- Lower MOSFET temperature
- Lower cost

Why Gate Booster and why Gate Charge Pump?

MPQ5850-AEC1 and MPQ5852-AEC1 with Gate Booster

- The gate booster can drive a wide range of external N-channel MOSFETs of different sizes.
- The gate booster can easily output lower and higher gate voltages.
- The gate booster enables large gate currents, as well as fast rising and falling times for the external MOSFET.

MPQ5816-AEC1 with Gate Charge Pump

- The design of the gate charge pump can be specifically optimized for the internal N-channel MOSFET's gate capacitances and curve characteristics.

Does an Ideal Diode Controller Create EMC Problems?

No – Negligible

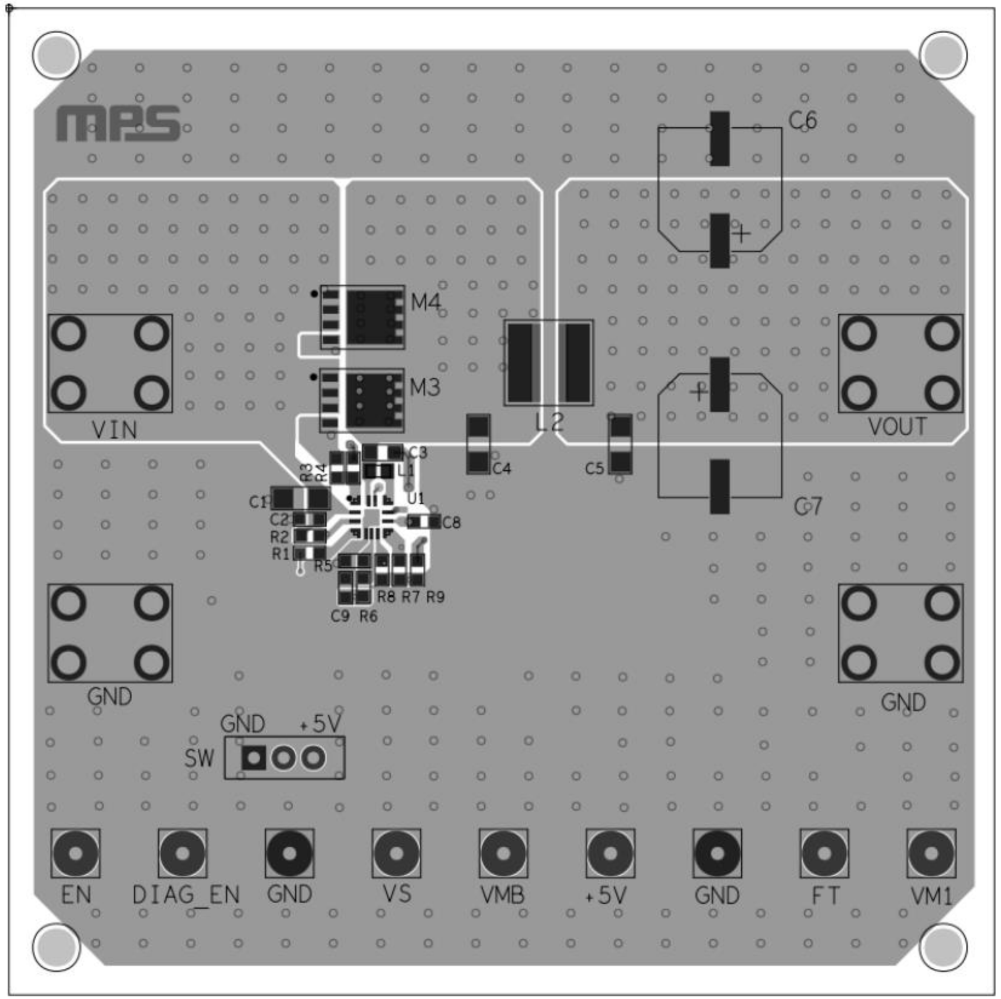
- The gate booster and the charge pump have their highest activity at the transient gate load. This is the case with a power supply that is superimposed with AC. EMC tests are defined and measured under normal operating conditions.
- The peak currents of the gate booster and the charge pump are low — around 200mA$_{PEAK}$ for the gate booster at a frequency in the lower kHz range. The gate booster inductor has a small physical size and therefore a low radiated emission.
- The radiated magnetic and electric fields from the gate booster and charge pump are low and cannot be compared to the higher fields from a typical buck converter.
- Check the diode controller datasheets for EMC measurements. All measurements are close to the noise level of the EMC receiver and are therefore unproblematic.

Does a Diode Controller Require a Special PCB Layout?

No – Consider a Few Points

- Place the V_{RES} MLCC for the gate booster (MPQ5850-AEC1, MPQ5852-AEC1) or the V_{CAP} MLCC for the charge pump (MPQ5816-AEC1) as close as possible to the package.
- Place the switching inductor of the gate booster as close as possible to the package.
- Route the trace of the gate short such that it is encapsulated with GND.
- Place the bypass MLCCs close to the VDRAIN and VSOURCE pins.
- Place copper polygons near the external and internal N-channel MOSFET. The PCB copper polygons are the heatsink for the components.

Does a Diode Controller Require a Special PCB Layout?



Top Layer

MPQ5852-AEC1 on a 4-Layer PCB

- The board is designed for an I_{OUT} = 20A.
- The polygons help to cool down the MOSFETs, EMC filter inductance, and the electrolytic capacitor.
- The polygon size and number of vias must be selected according to the expected I_{OUT}, temperature conditions, and transient V_{IN} specifications.
- The tiny components around the MPQ5852-AEC1 are easy to place.
- Place the TVS diode for the VIN filter on the bottom side. It can also be placed on the top side.

An ideal diode controller layout is easy to create.

How to Select the N-Channel MOSFET?

MOSFET Selection

- Use the smallest N-channel MOSFETs suitable for I_{DRAIN}.
- BV_{DSS} = 40V to 60V for 12V automotive applications; other BV_{DSS} values can be selected for industrial, computer, or battery management systems.
- MPS's ideal diode controllers are designed for standard logic level MOSFETs with a $V_{GATE\text{-}SOURCE\_MAX}$ >14V.
- Do not to use logic level MOSFETs with their lower $V_{GATE\text{-}SOURCE\_MAX}$.
- All MOSFET sizes are possible. A 10nF gate capacitance is possible, which corresponds to a higher-power MOSFET (typically 1mΩ, 400A).
- MOSFETs (of the same type) can be connected in parallel. Increasing $R_{DS(ON)}$ and T_J produces feedback on the gate, which can help balance current sharing. If possible, use a single MOSFET.

Design Tips

Circuit Details

- The wire harness helps attenuate transient V_{IN} waveforms. The parasitic inductance of the harness length, together with the 10nF V_{IN} MLCC, creates a second order low pass that attenuates HF.
- When selecting the gate booster inductor, follow the recommendations in the datasheets. Consider the temperature and the applied V_{IN_MAX}. Measure the inductor’s current waveforms (I_{PEAK} and I_{RMS}) at high gate activity, and with a frequently changing V_{IN} or I_{LOAD}. A shielded inductor is not required to pass CISPR25 Class 5.
- Focus on a stable V_{DRAIN} and use sufficient capacity on the load. A V_{DRAIN} < UVLO (about 2.6V) forces the controller to reset. Under reset conditions, the gate is inactive for about 1ms. When the gate is inactive, the MOSFET’s parasitic body diode conducts. The diode then carries I_{LOAD}, resulting in a higher T_J. The controller’s internal VCC is powered from V_{DRAIN}, so keep the VDRAIN pin stable and attenuate RF interference with a bypass MLCC.
- V_{SOURCE} is designed for rapidly changing waveforms and can withstand reverse polarity.
- The negative TVS diode on V_{IN} is required to prevent negative voltage spikes on V_{SOURCE}. They are generated when the MOSFET quickly turns off I_{LOAD}. The rapid change in current creates a negative voltage across the parasitic inductance of the circuit board and wire harness.

Measurement Tips

Test Equipment Details

- A multi-channel oscilloscope is recommended for measurements on diode controllers; a 100MHz bandwidth is sufficient.
- When measuring V_{SOURCE} with an oscilloscope, always measure directly at the IN or SOURCE pins, as fast transient signals will cause a voltage drop on the board and wire harness. Remember that you are interested in the waveform of the pins, not anywhere on the copper. Refer to a ground near the IC's GND pin.
- Testing transient V_{IN} waveforms requires power amplifiers with a fast slew rate that are stable and can drive MLCCs.
- Focus on V_{DRAIN} and V_{SOURCE} with the oscilloscope.
- Use a differential probe or the MATH function to measure $V_{GATE\text{-}SOURCE}$, V_{RES} or V_{CAP} .
- I_{SOURCE} is an important waveform. Try measuring it directly at the MOSFET's SOURCE pin. Note that the current probe in the wiring harness contains the AC portion of the 10nF V_{IN} MLCC.
- Measure transient $V_{BATTERY}$ waveforms with a differential probe, especially when using a long wire harness.

Conclusion

- The MPQ5850-AEC1 from MPS is a solution for any N-channel MOSFET size.
- The MPQ5852-AEC1 has rectifier functionality similar to the MPQ5850-AEC1 with two additional voltage monitors, fault indication, and functional safety.
- The MPQ5816-AEC1 shows a solution with internal N-Channel MOSFET, two voltage monitors, fault reporting and functional safety.

The devices cover a wide range of applications from automotive, industry, computer, and battery management systems.

The MPQ5850-AEC1 and MPQ5852-AEC1 enable a wide current range with the choice of an external N-channel MOSFET.

The MPQ5816-AEC1 is an outstanding product with an internal 9A N-channel MOSFET. It is designed for minimal board space, reduced bill of materials, and simplified purchasing.

Let us know your questions

Q&A

Articles and Videos on Our Website:

monolithicpower.com

Technical Information about MPS Ideal Diode Controllers

Thank You – Q&A

For more information, contact:
automotive@monolithicpower.com

Check out our AEC-Q100 Power Management Solutions at **MonolithicPower.com**