Technical Conference Oct 2011

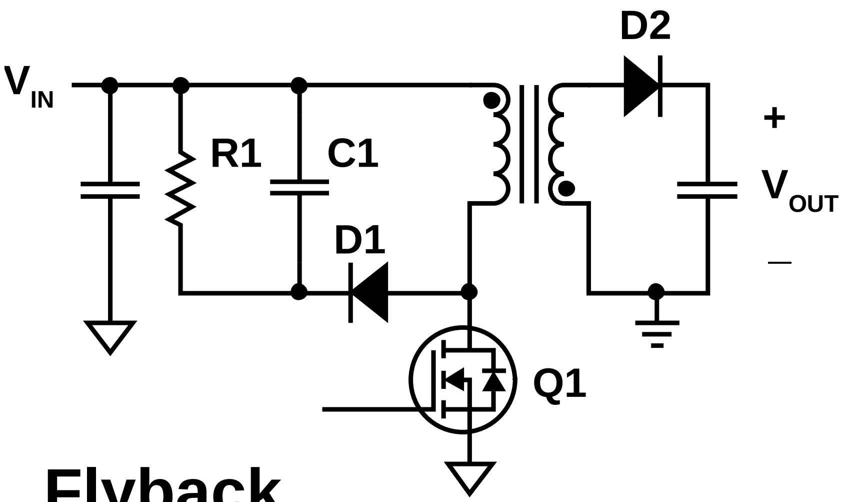
# Using Active Clamp Technology to Maximize Efficiency in a Telecom Bus Converter

**Bernd Geck**

# Agenda

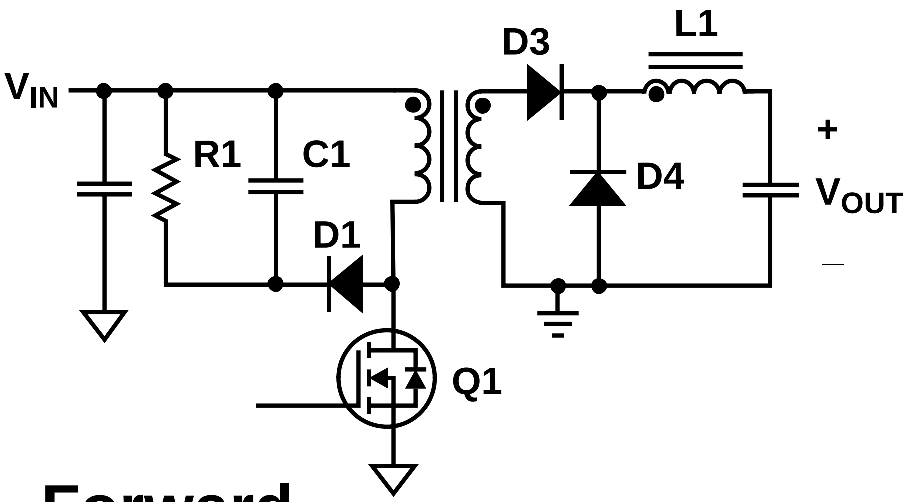
1. **Basic Operation of Flyback and Forward Converters**
2. Active Clamp Operation and Benefits
3. Active Clamp Forward Design
4. Design Review PMP5711

# Basic Power Stages



### Flyback

- Transformer stores energy
- R1 dissipates leakage and some magnetizing energy
  - Typically 2 to 5% of output power

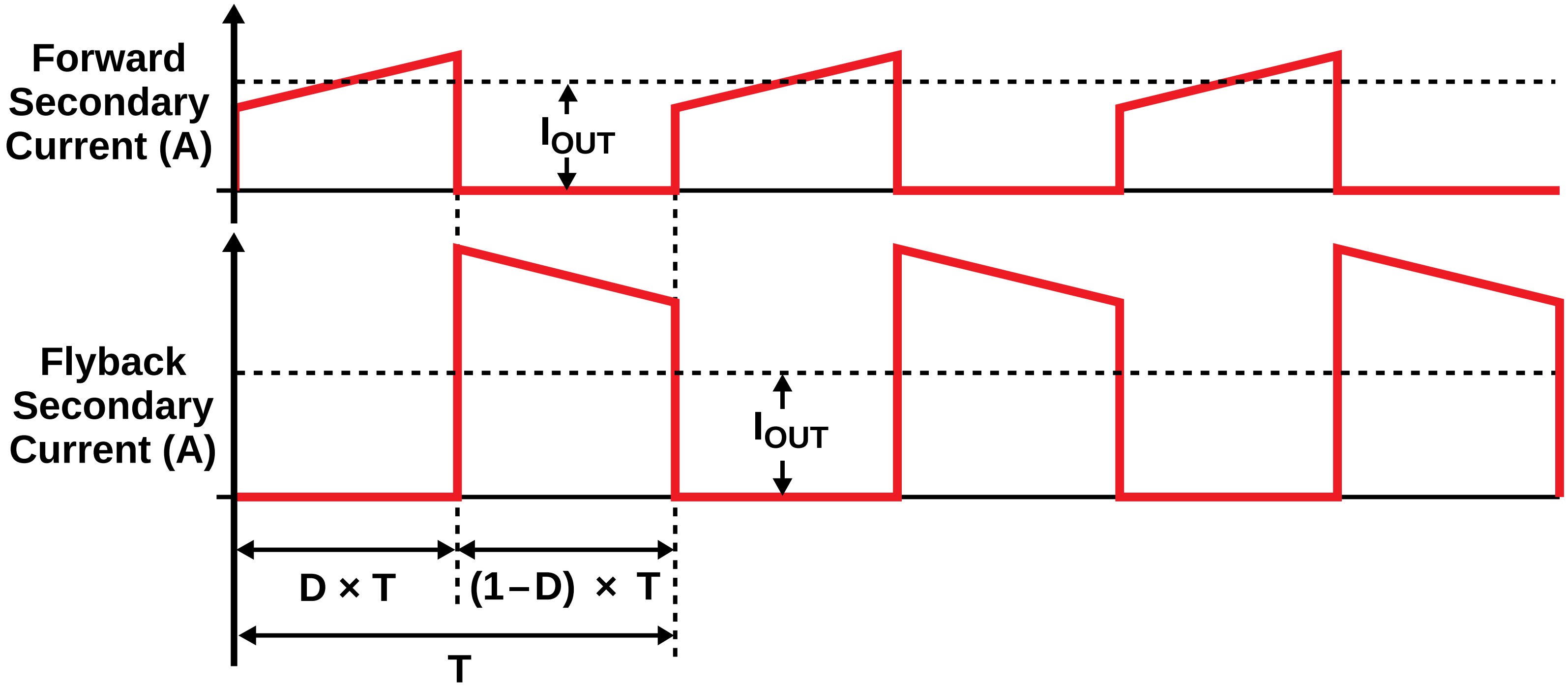


### Forward

- Transformer transfers energy
  - Storage is in L1
- R1 dissipates magnetizing plus leakage energy
  - Typically 3 to10% of output power

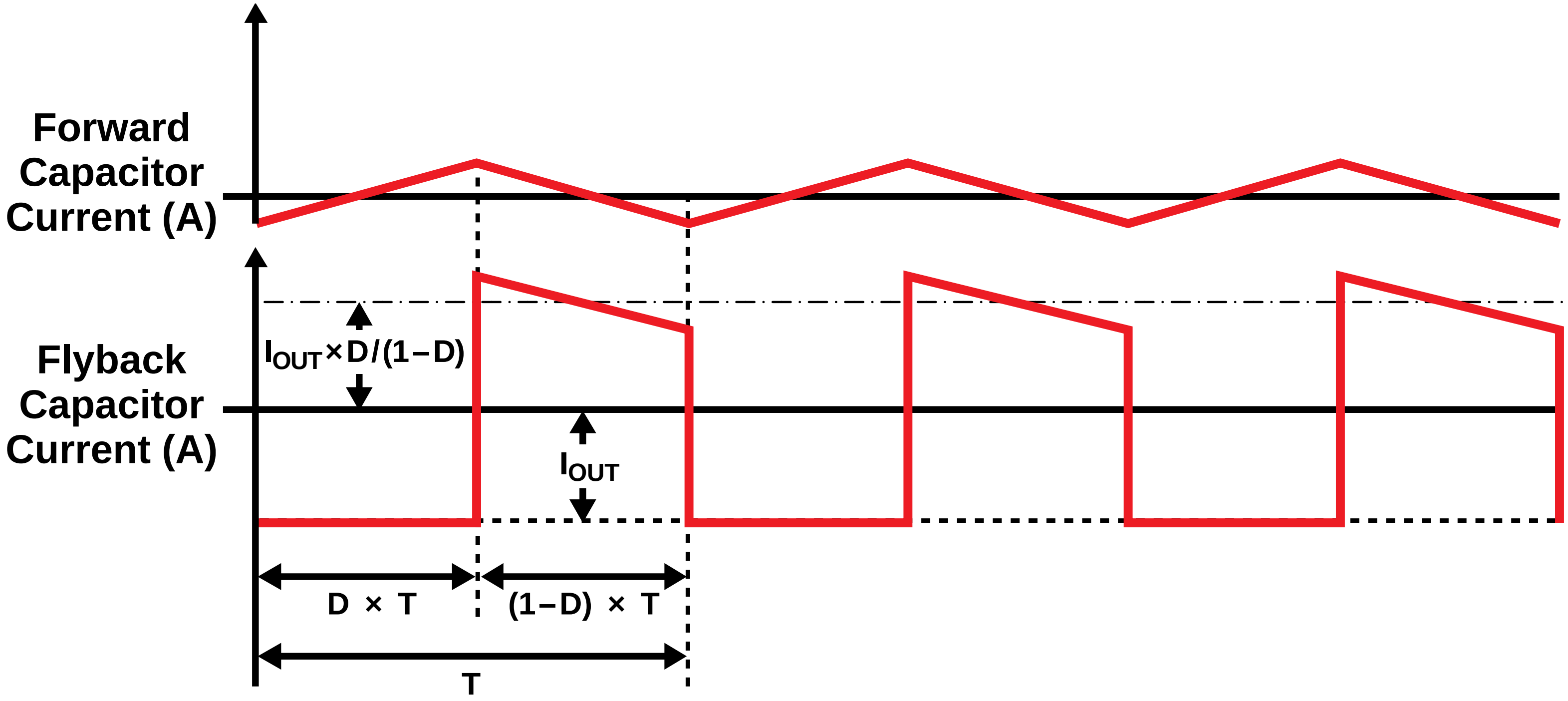
How can we avoid loss in R1?

# Secondary Winding Currents



- Assuming 50% duty cycle and CCM
  - Synchronous rectifiers force CCM
- RMS flyback current = 2 X RMS forward current
- For low voltage/high current output, forward is best choice

# Output Capacitor Currents

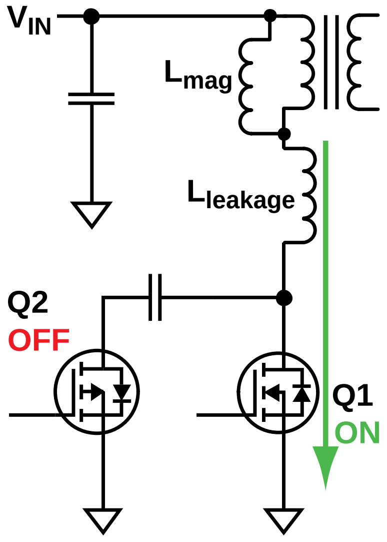


- Flyback output capacitors see much higher current
  - – Higher RMS current increases heating
  - – Higher peak current requires much lower ESR
- Result is more, higher quality capacitors in flyback

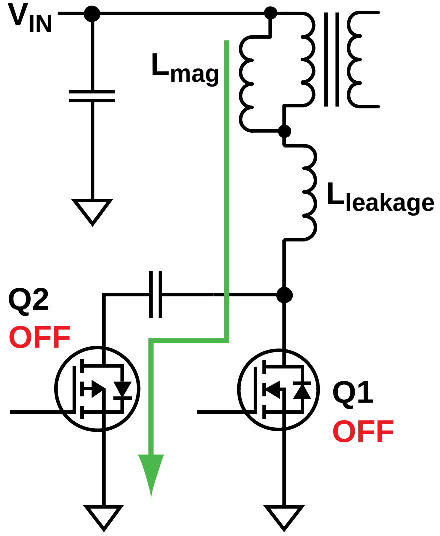
# Agenda

1. Basic Operation of Flyback and Forward Converters
2. **Active Clamp Operation and Benefits**
3. Active Clamp Forward Design
4. Design Review PMP5711

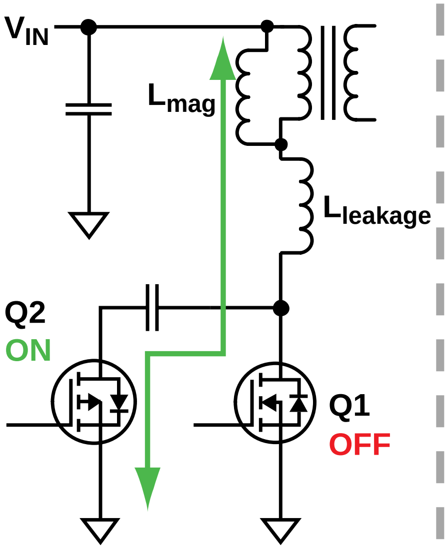
# Active Clamp Operation



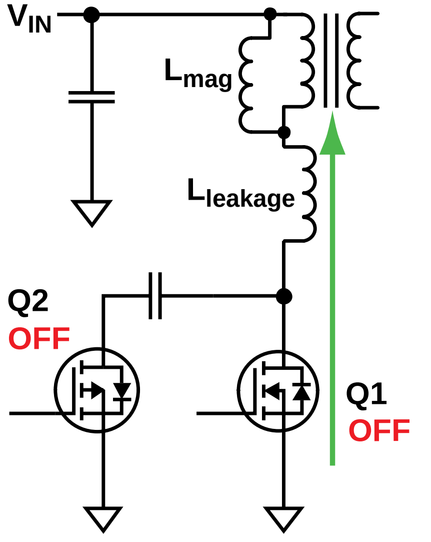
$L_{mag}$ and $L_{leakage}$ are energized



Current commutes to Q2 body diode



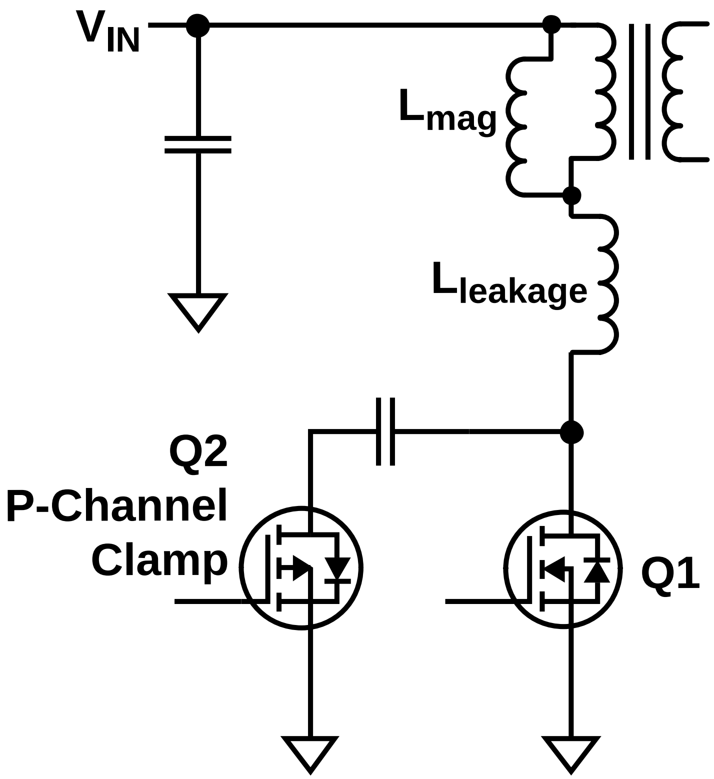
Current resonates, changes direction



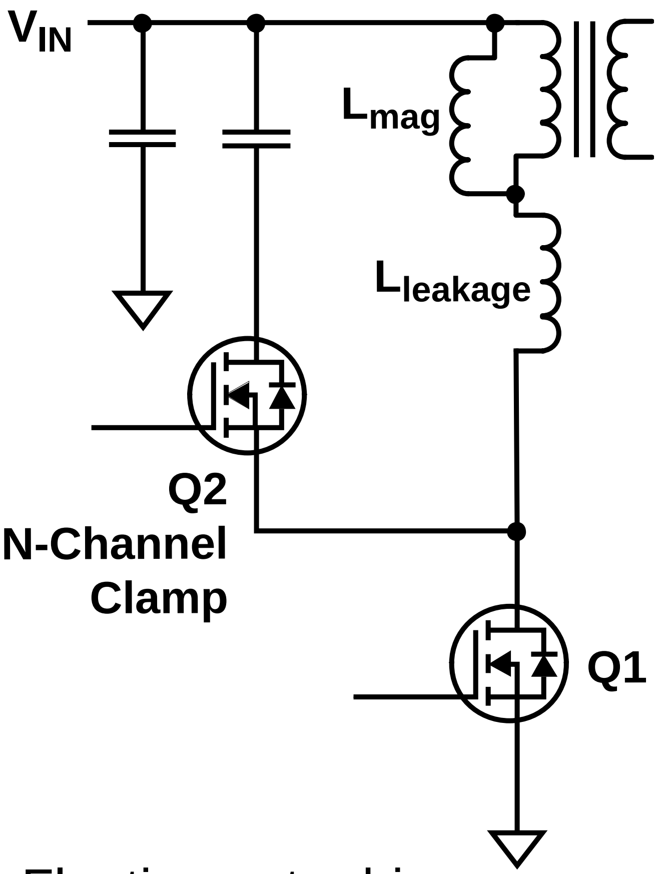
Current commutes to Q1 body diode or $C_{oss}$

$D \times T_{sw}$ → $t_{delay}$ → $(1\text{-}D) \times T_{sw}$ → $t_{delay}$

# Active Clamp Configurations



+ Easy to drive clamp FET
- Higher capacitor voltage
- P-channel FET



- Floating gate drive

+ Lower capacitor voltage
+ N-channel FET

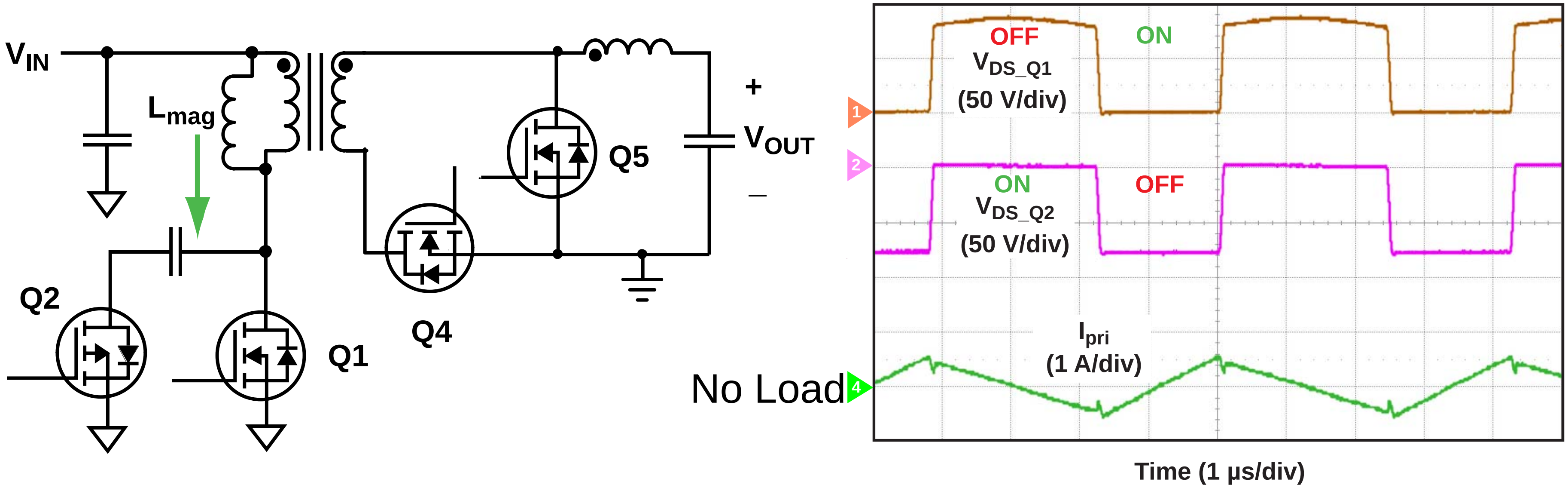
# Active Clamp Benefits

| RCD Clamp | Active Clamp |
|---|---|
| • Most of leakage energy is dissipated as heat | • Most of leakage energy is reclaimed |
| • “Hard” switching results in power losses | • Zero voltage switching reduces losses |
| • More difficult implementation of self-driven synchronous rectifiers with Forward | • Simple Implementation of self-driven synchronous rectifiers with forward |
| • Voltage spike on Q1 drain at turn off can be EMI issue | • No voltage spike on Q1 drain at turn off |
|  | • Nearly lossless recovery of magnetizing energy in forward |

# Agenda

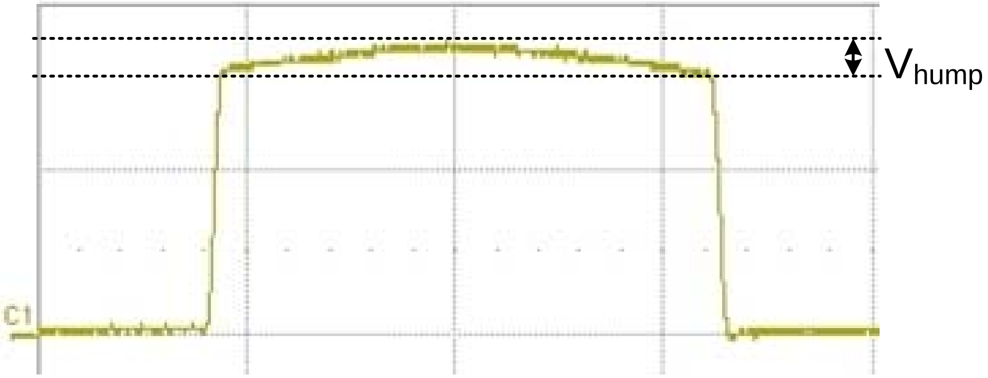
1. Basic Operation of Flyback and Forward Converters
2. Active Clamp Operation and Benefits
3. **Active Clamp Forward Design**
4. Design Review PMP5711

# Active Clamp Forward Design



- Reflected primary voltage during reset time allows self driven sync rectifiers
- No leakage spike at Q1 turn off
- Primary current resets to third quadrant resulting in better core utilization
- Unlike flyback, clamp resonant frequency is determined by magnetizing inductance and $C_{clamp}$

# Forward Clamp Circuit



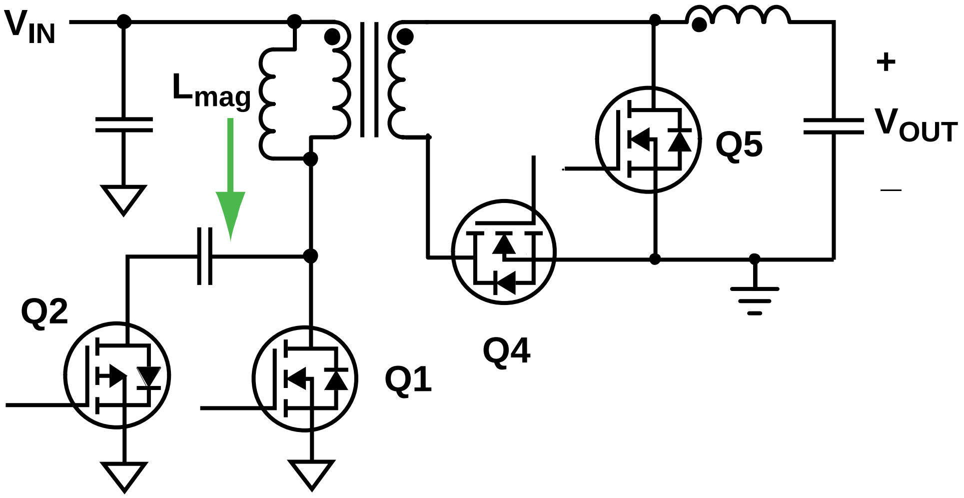
$$f_{clamp} = \frac{1}{2 \times \pi \times \sqrt{L_{magnetizing} \times C_{clamp}}}$$

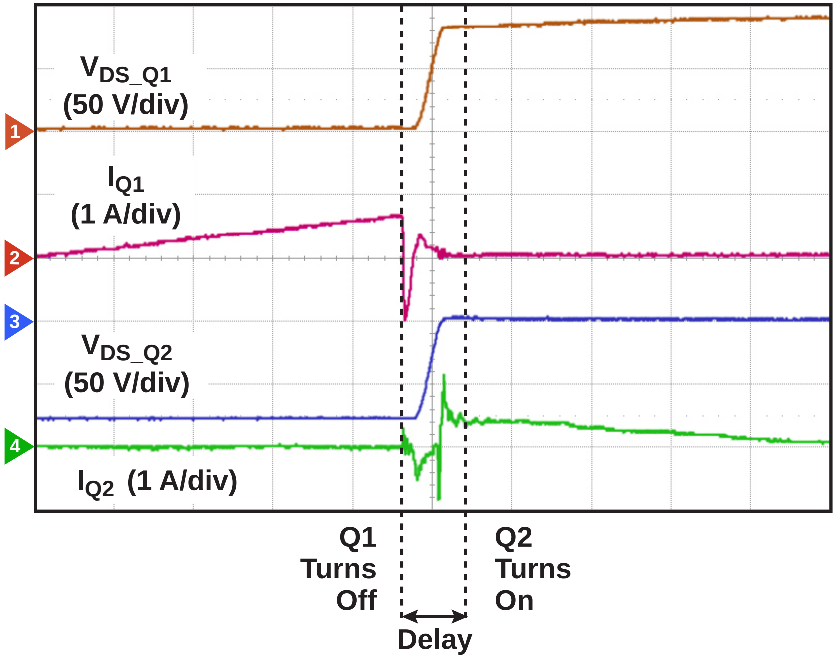
$$V_{hump} = \frac{V_{in} \times D \times (1 - D)}{8 \times L_{magnetizing} \times f_{SW}^{2} \times C_{clamp}}$$

$$I_{Q2\_RMS} = \frac{V_{in} \times D \times \sqrt{1 - D}}{2 \times \sqrt{3} \times L_{magnetizing} \times f_{sw}}$$

(Peak current is $I_{mag}$; RMS clamp current is much less than flyback)

# Forward Soft Switching – Q1 Turn-Off

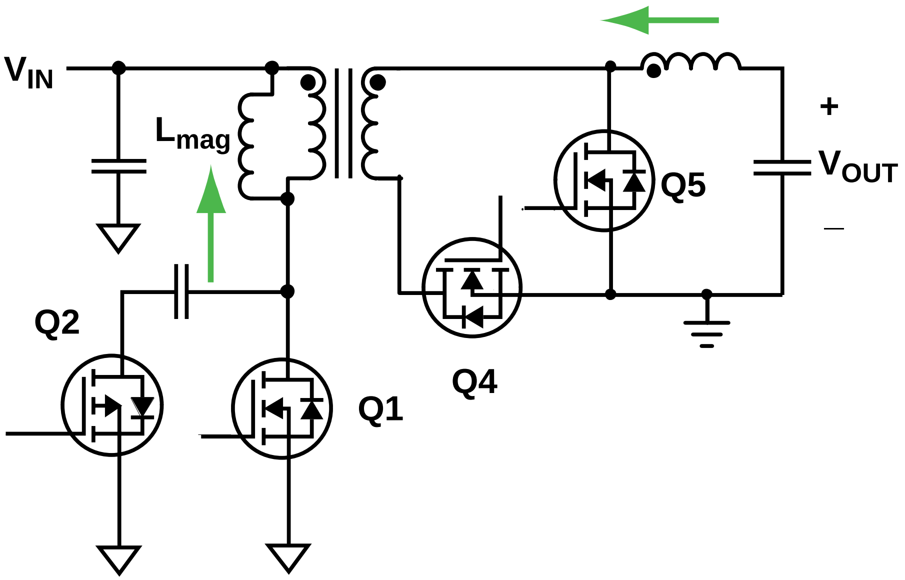


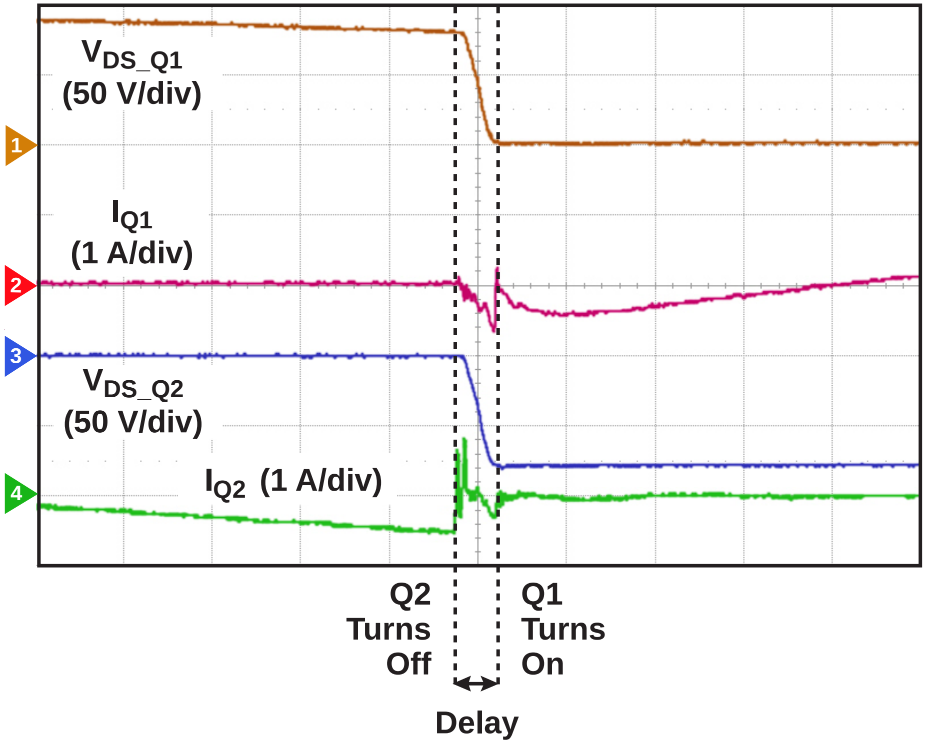


- Magnetizing and reflected load current flowing in Q1
- Transfers to Q2 body diode
  - Delay from Q1 turn-off to Q2 turn-on
- Zero voltage switching of Q2
- Not load or line dependent

# Forward Soft Switching – Q1 Turn-On

## Light Loads

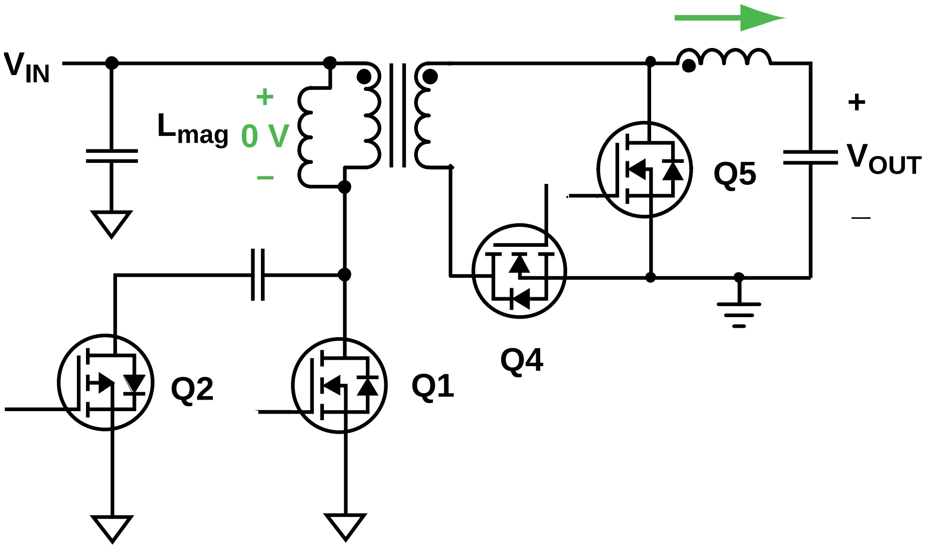


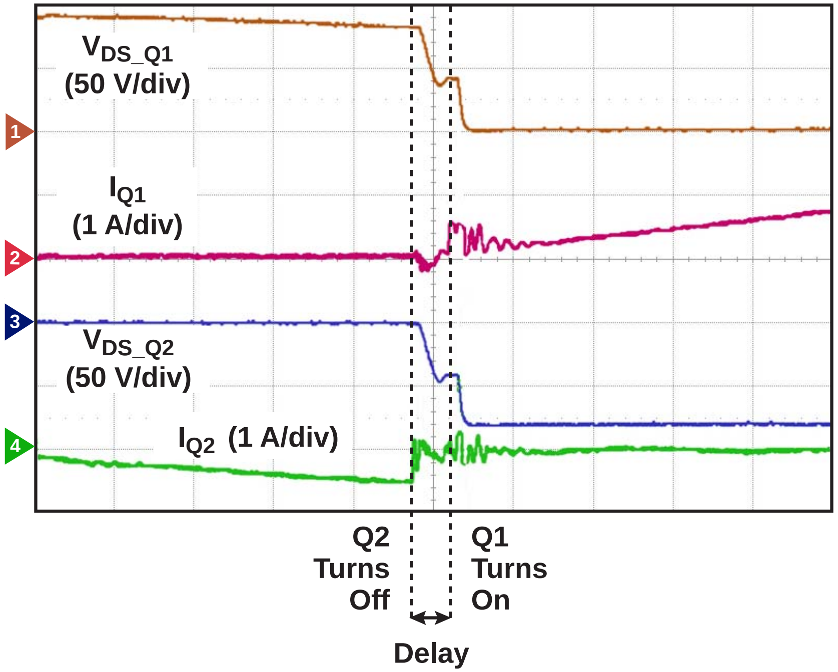


- No current in Q4 or Q5 during delay time
- Allows Q1 to achieve ZVS

# Forward Soft Switching – Q1 Turn-On

## Heavy Loads



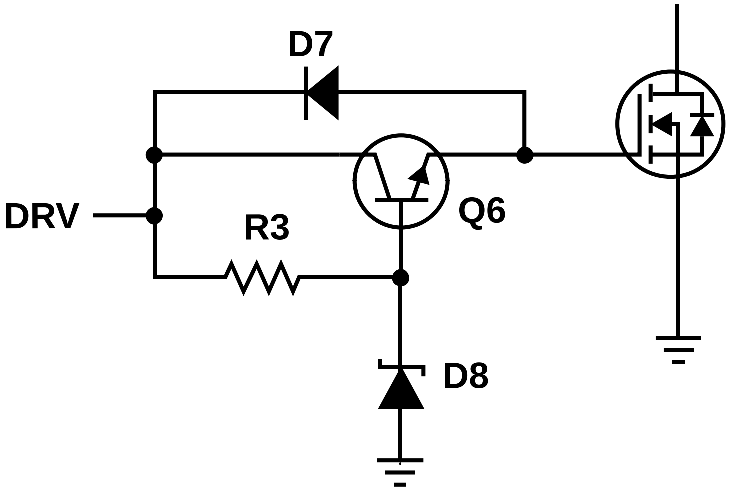


- Current flows in body diodes of Q4 and Q5 during delay time
- Q1 drain voltage = $V_{IN}$ when Q1 turns On
- <u>Partial</u> zero voltage switching

# Forward Synchronous Rectifiers

| Output Voltage | PRI:SEC Turn Ratio | MAX Sync FET $V_{DS}$ Stress | Sync FET $V_{DS}$ Rating |
|---|---|---|---|
| 3.3 V | 6:1 | 12.5 V | 20 V |
| 5 V | 4.5:1 | 17 V | 30 V |
| 12 V | 1.88:1 | 40 V | 60 V |

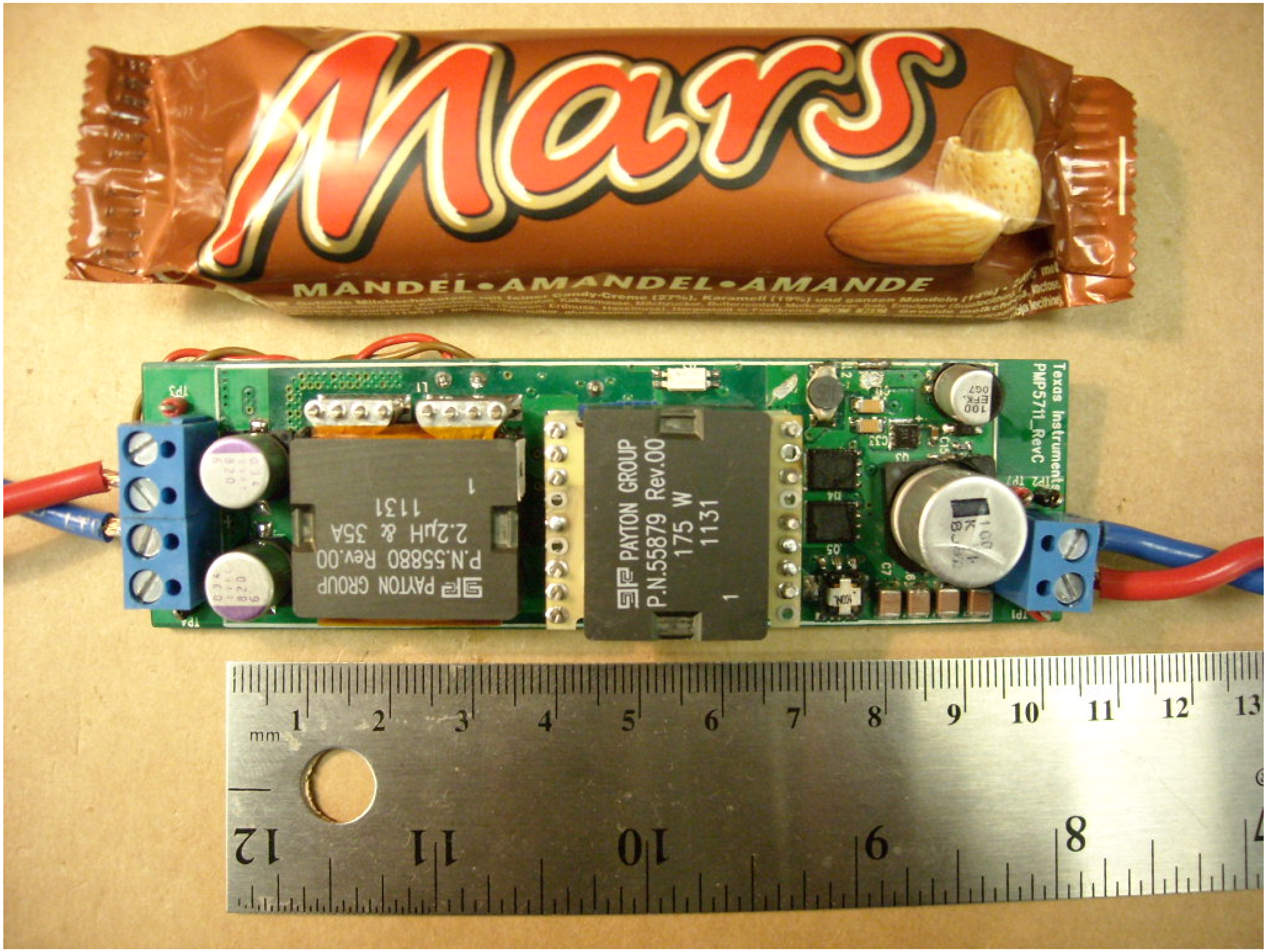
- Turn ratios and voltages for telecom 35- to 75-VDC input
- FET gate rating of 20 V or less
- 3.3-V output can be driven directly from transformer winding
- Outputs >3.3 V require gate protection



# Agenda

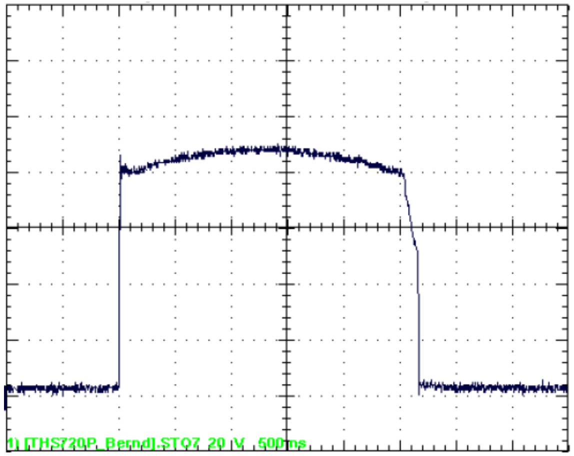
1. Basic Operation of Flyback and Forward Converters
2. Active Clamp Operation and Benefits
3. Active Clamp Forward Design
4. **Design Review PMP5711**

# Physical Size – 5.0V/35A Forward Converter

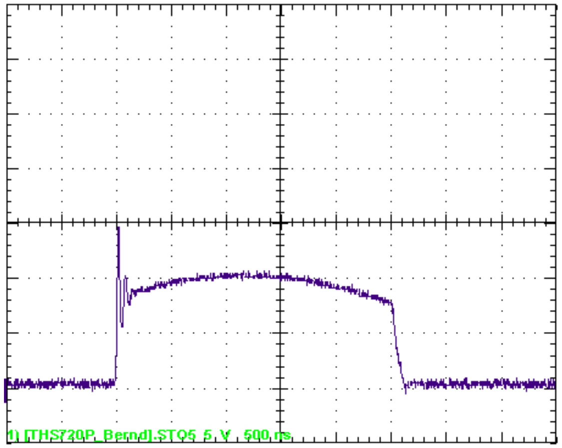


*L x W x H = 93mm x 31mm x 19mm*

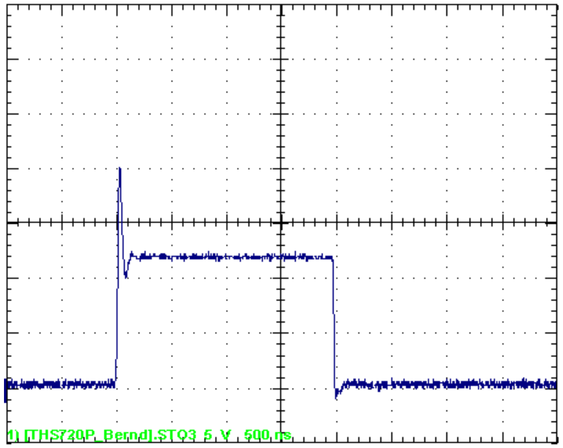
# Waveforms – 5.0V/35A Forward Converter



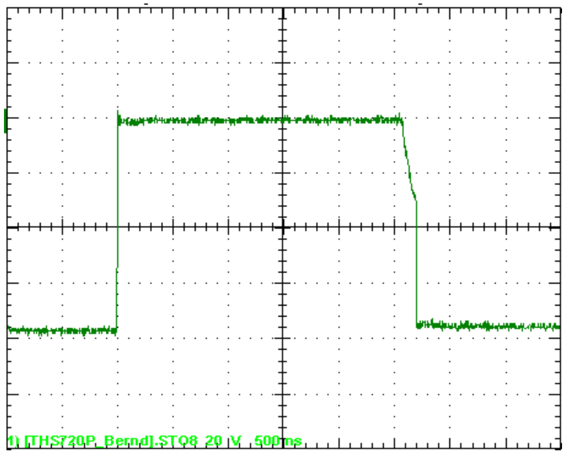
Vds primary NFETs



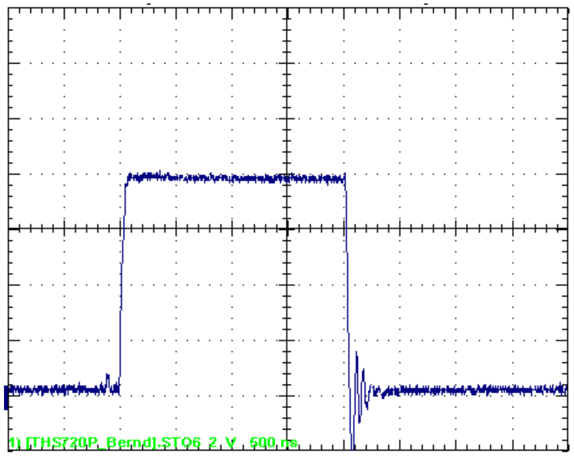
Vds sync. rectifiers



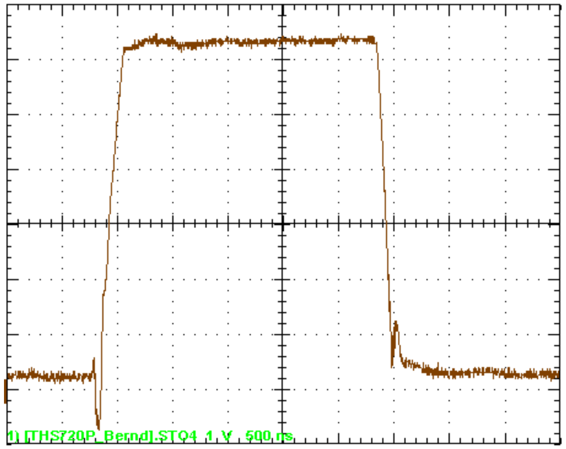
Vds freewheeling FET



Vds clamping PFET

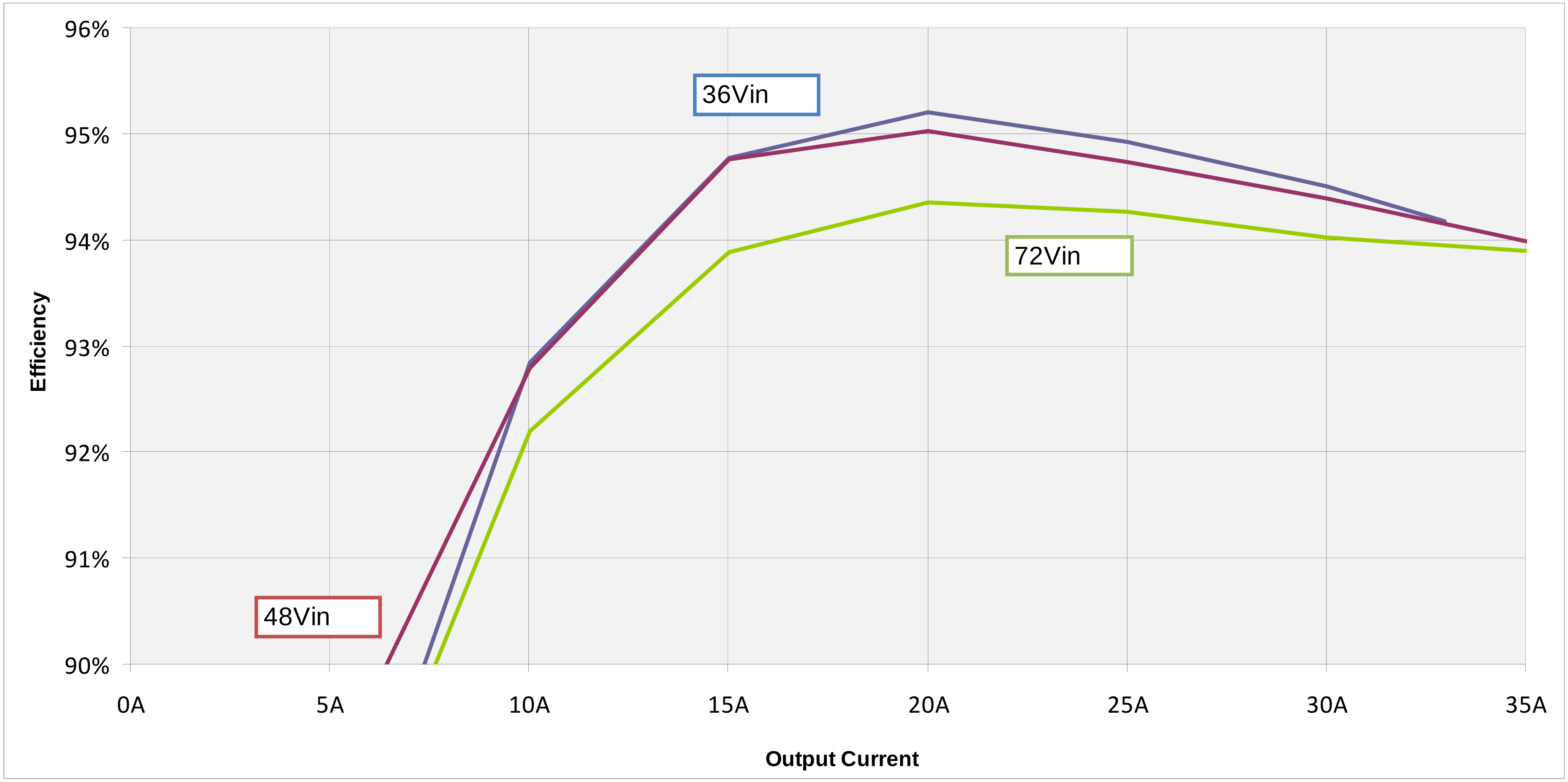


Vgs sync. rectifiers



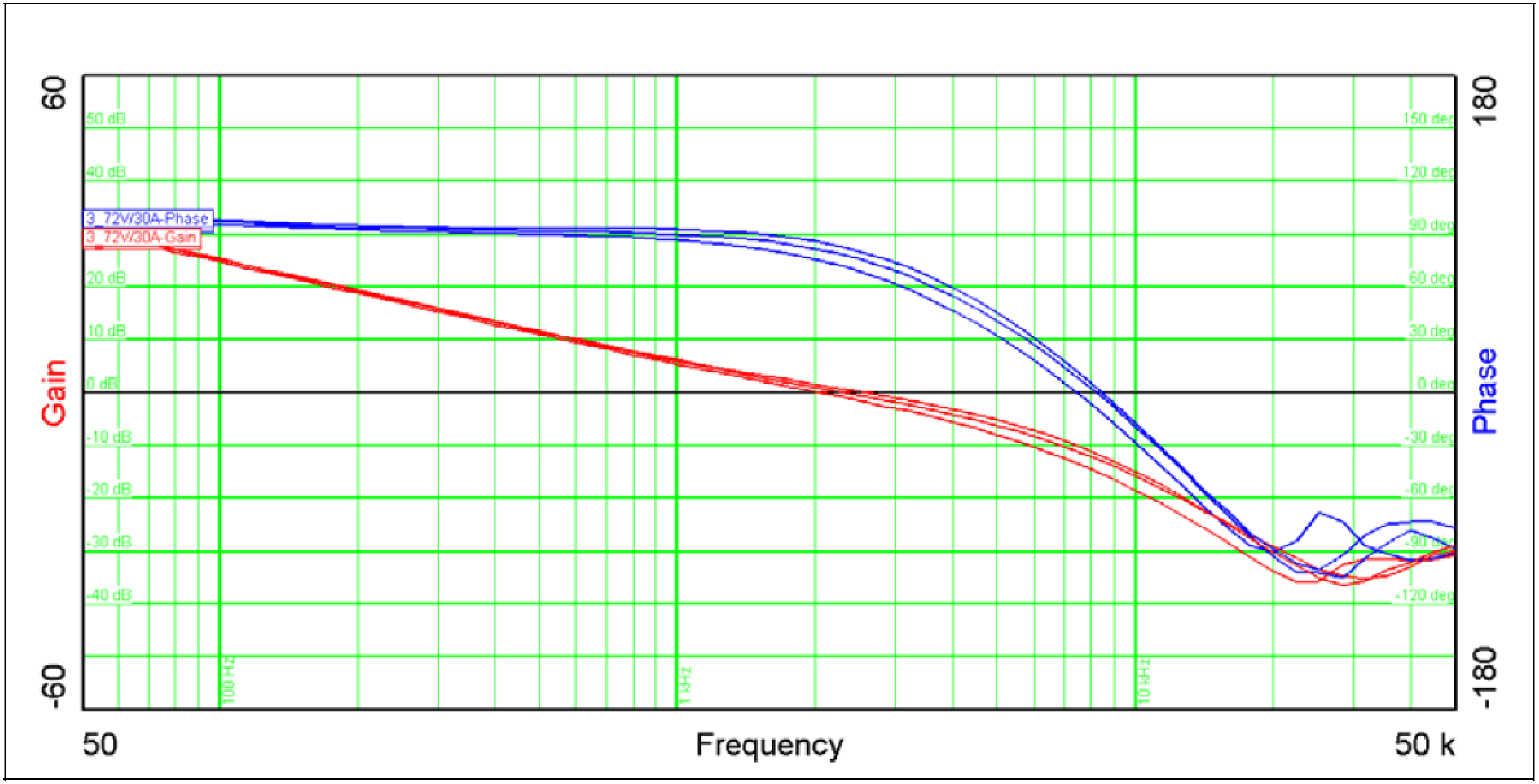
Vgs freewheeling FET

# Efficiency – 5.0V/35A Forward Converter



effcy > 94% in a range of 13A to 35A, 95% around 20A

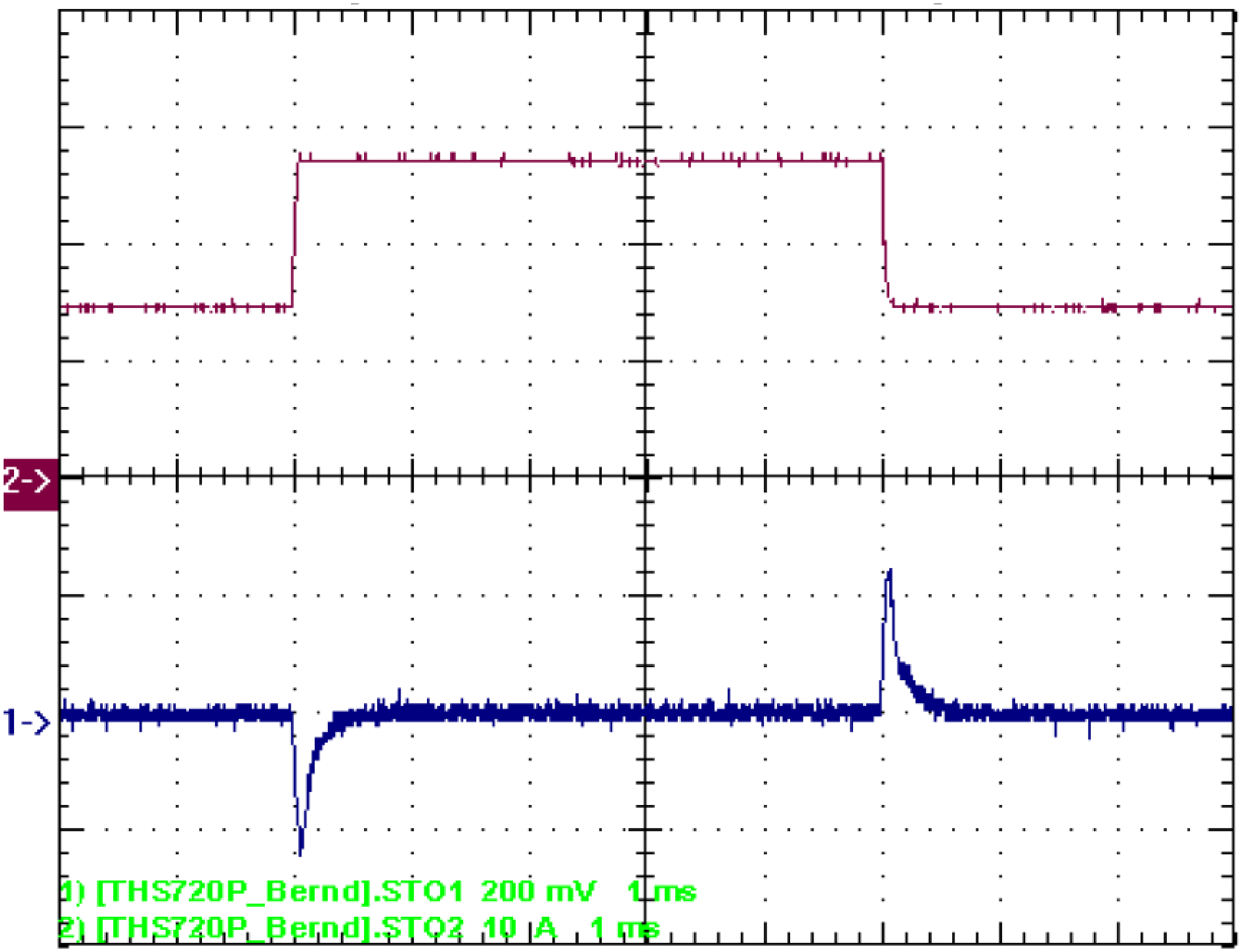
# Dynamic Behavior – 5.0V/35A Forward Conv.



small signal analysis of outer loop w/ network analyzer at 30Amps load, results in:

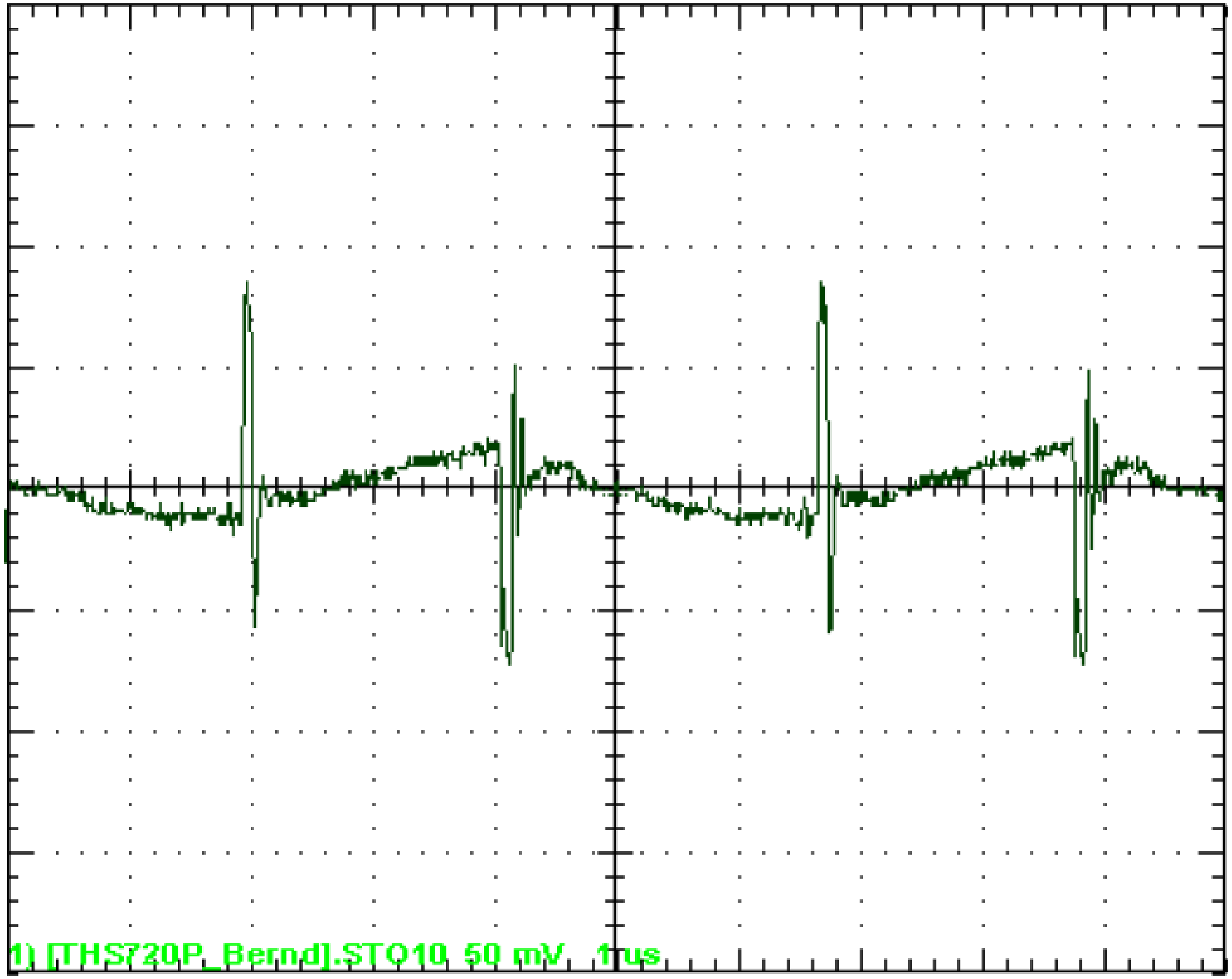
bandwidth > 2kHz, phasemargin >70degs, gain margin <-12dB

# Dynamic Behavior – 5.0V/35A Forward Conv.



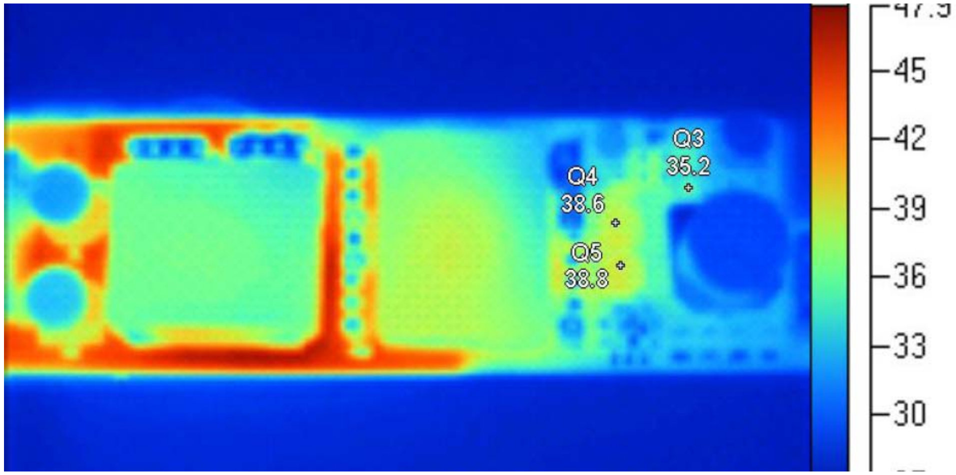
large signal analysis with load step 50%, 15Amps / 30Amps

# Ripple & Noise – 5.0V/35A Forward Conv.



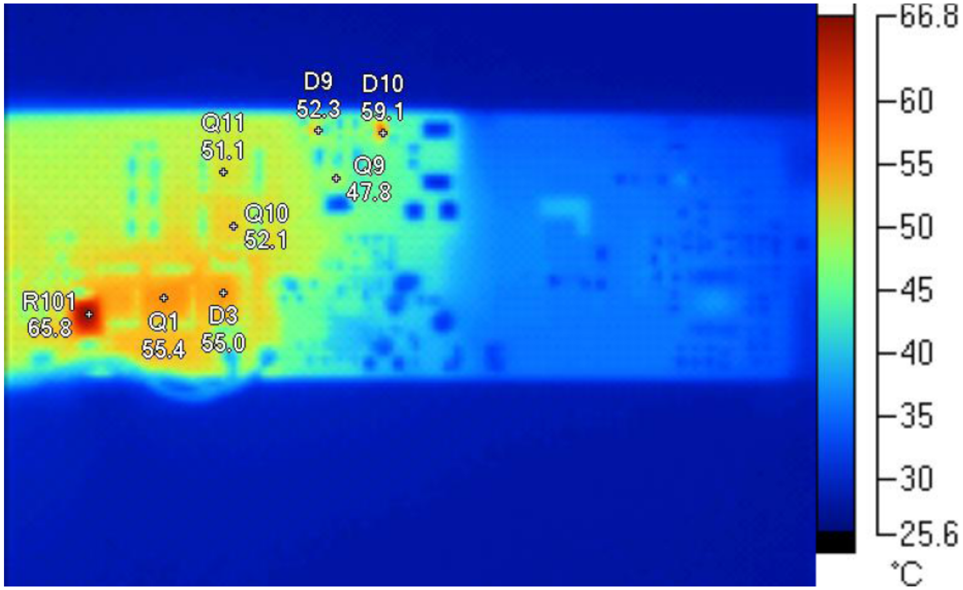
ripple 40mVpp, noise 110mVp at max. load 35Amps

# Thermal Behavior – 5.0V/35A Forward Conv.



| Name | Temperature |
|---|---|
| Q5 | 38.8°C |
| Q4 | 38.6°C |
| Q3 | 35.2°C |

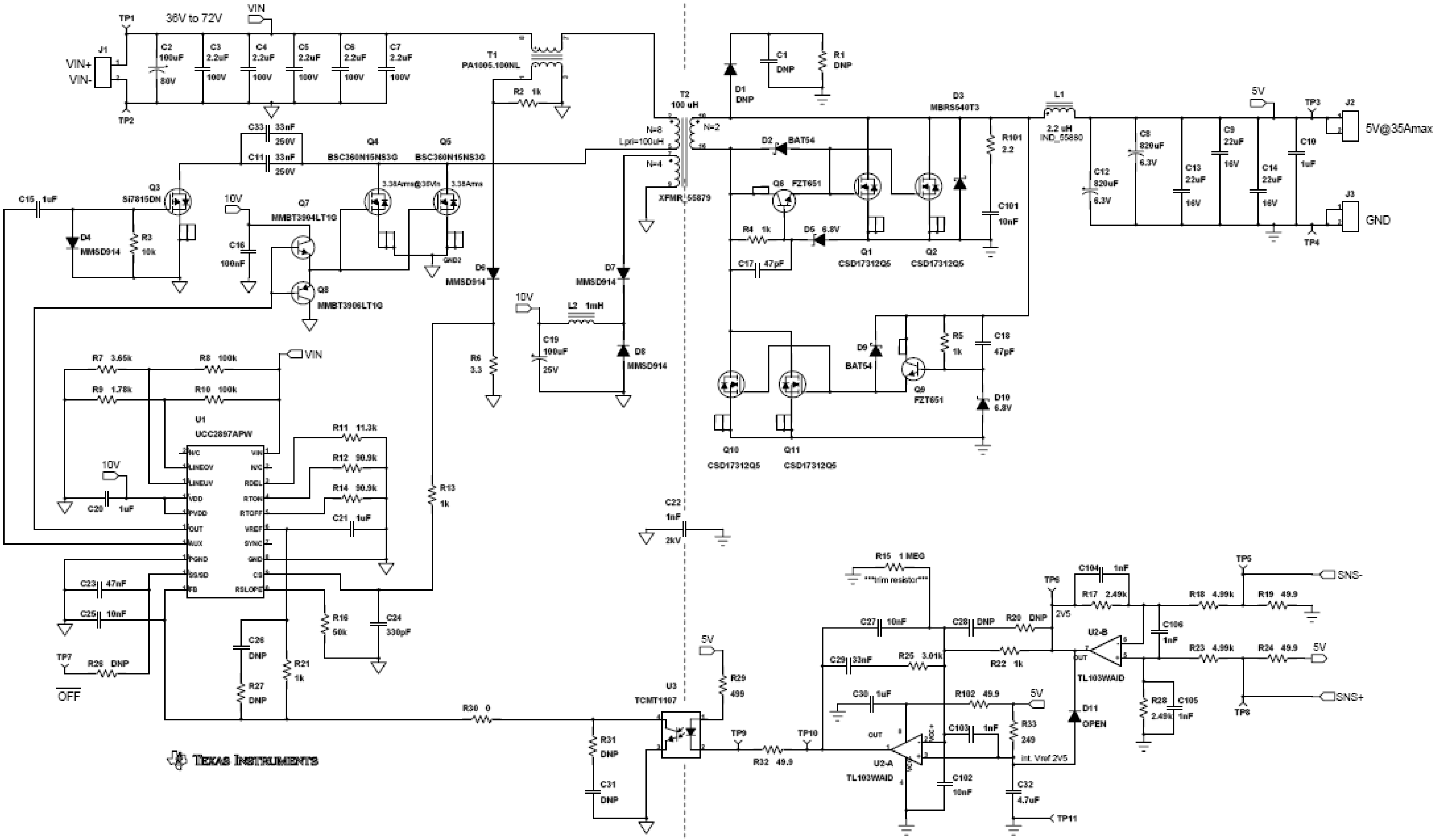
top side at max. load 35A
at forced cooling 400lfm



| Name | Temperature |
|---|---|
| R101 | 65.8°C |
| D10 | 59.1°C |
| D9 | 52.3°C |
| Q1 | 55.4°C |
| D3 | 55.0°C |
| Q9 | 47.8°C |
| Q10 | 52.1°C |
| Q11 | 51.1°C |

bottom side at max. load 35A
at forced cooling 400lfm

# Active Clamp Forward 5.0V/35A, 175-W Bus Converter Using UCC2897A



# Summary

- Adding active clamp and sync rectifiers improves efficiency of forward (and flyback) up to 5% (Efficiencies >90%, here up to 95%)
- Forward provides best efficiency due to lower conduction losses than flyback
- Forward can be scaled to higher output power with similar results
- Flyback for multiple outputs or when cost is most important

# IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have ***not*** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2013, Texas Instruments Incorporated