# AND9173/D

# A 3.3-V/20-A Active Clamp DC-DC Converter with NCP1565

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## APPLICATION NOTE

The NCP1565 is a new high-performance voltage or peak-current mode control integrated circuit dedicated to active-clamp forward converters. Designed in a BiCMOS process, the part can switch up to several MHz and offers everything needed to build rugged and cost-effective dc-dc converters for the telecommunication market. Available in a QFN package, the part will equally work well with a self-driven synchronous rectified output stage or with dedicated drivers such as the new NCP81178. This application note describes the part implemented in a 3.3-V/20-A quarter brick dc-dc converter implementing self-driven synchronous MOSFETs.

### General Description

The part initial power is given by a high-voltage current source delivering up to 40 mA as a guaranteed minimum current across the allowed temperature range. Once connected to the input rail, the current source charges the $V_{CC}$ capacitor and lifts its positive terminal to the controller start-up voltage, 9.5 V. At this point, the source turns off and the part begins to initialize. During this short period of time, there are no output pulses. In case $V_{CC}$ falls down to 9.4 V the current source is turned on again and maintains $V_{CC}$ between 9.5/9.4 V in a hysteretic way. This is a so-called Dynamic Self-Supply (DSS) operation.

Once all internal flags are cleared, the current source is turned off and the soft-start pin is released. When the soft-start (SS) voltage passes 1.35 V, the main drive output, OUTM, starts to pulse. Please note that OUTA was already pulled high at $V_{CC}$ equals 9.5 V to pre-charge the active clamp P-channel negative bias circuitry. Figure 1 shows a typical power-on sequence in which the UVLO filter delays the switching operations. Please note the DSS mode until the UVLO level gives the green light to pulse. The small leap on the UVLO signal illustrates the hysteresis action.

Figure 2 offers a different view of the start-up sequence and in particular, the duty ratio evolution along the soft-start rising voltage. Please note that pulses appear after the SS voltage exceeds 1.35 V.

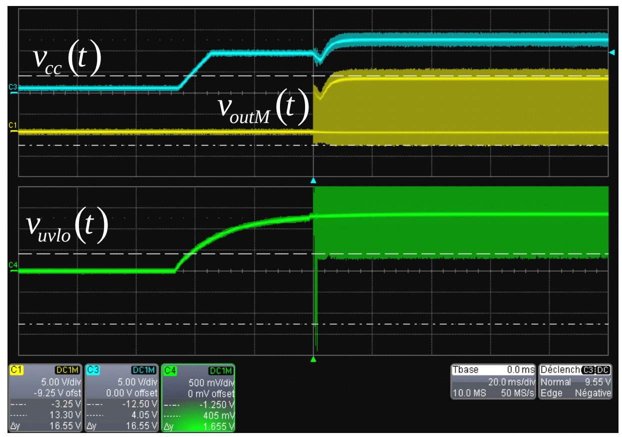



**Figure 1. A Typical Power-on Sequence where the UVLO Time Constant Dictates the Moment at which the Part Starts to Pulse**

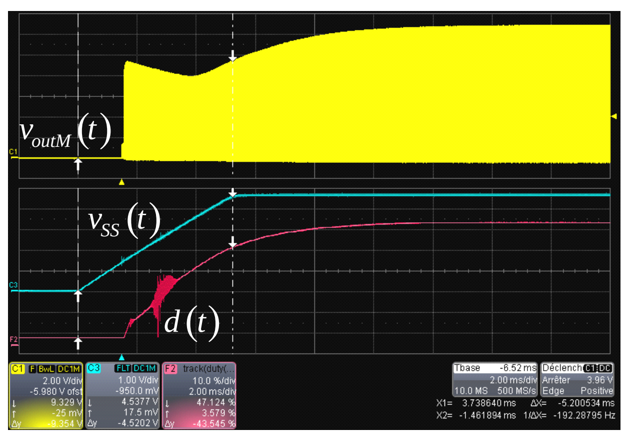



**Figure 2. It is Possible to Monitor the Duty Ratio Evolution During the Soft-start Sequence**

In this example, the auxiliary winding takes over after several switching cycles. In case it does not happen, e.g. because the primary-side rectification diode is broken, the current source will reactivate and will maintain the $V_{CC}$ voltage, self-supplying the controller until a proper auxiliary voltage takes over. It is important to insist on power dissipation in this mode as the current absorbed by the high-voltage pin (22) is roughly the average current consumed by the part. This current depends on the part internal consumption and the driver current. The part, alone, consumes around 5 mA. Assume you drive a 50-nC $Q_G$ MOSFET at a 300-kHz switching frequency. In this case, the current consumed from the driver is

$$I_{drv} = F_{SW} \cdot Q_G = 300k \cdot 50n = 15\ mA \quad \text{(eq. 1)}$$

which added to the 5-mA consumption makes 20 mA. If the part is biased from a 72-V dc source, the controller will roughly dissipate 1.5 W. Needless to say that in lack of a wide and thick dissipative copper area, the part temperature will quickly rise, potentially destroying the die as the internal shutdown cannot stop the DSS. For a QFN package mounted on a 4-layer PCB together with a 100-mm$^2$ 35-µm copper area, the junction-to-ambient thermal resistance is evaluated to 48°C/W. If we consider a maximum junction temperature of 110°C at a 70-°C ambient temperature, the part will be able to dissipate a maximum power of

$$P_{max} = \frac{T_{j,max} - T_A}{R_{\theta JA}} = \frac{100 - 70}{48} = 833\ mW \quad \text{(eq. 2)}$$

Therefore, a permanent DSS mode is only acceptable when the part enters skip cycle in a deep no-load discontinuous mode (in lack of synchronous rectification for instance) where the total consumption is reduced via hysteretic operation. The total consumption according to Eq. 2 must remain below

$$I_{DSS,max} = \frac{P_{max}}{V_{in,max}} = \frac{0.833}{72} = 11.6\ mA \quad \text{(eq. 3)}$$

In case the $V_{CC}$ capacitor is purposely selected of small value, the DSS can be solicited for a few tens of ms until the auxiliary takes over at start up. The peak power dissipated in this mode must remain within the package power dissipation capability. In this case, we need the transient thermal resistance $r(t)$ as plotted in the below chart for $T_A$ equals 25°C, a maximum junction temperature of 150°C and an input voltage of 72 V.

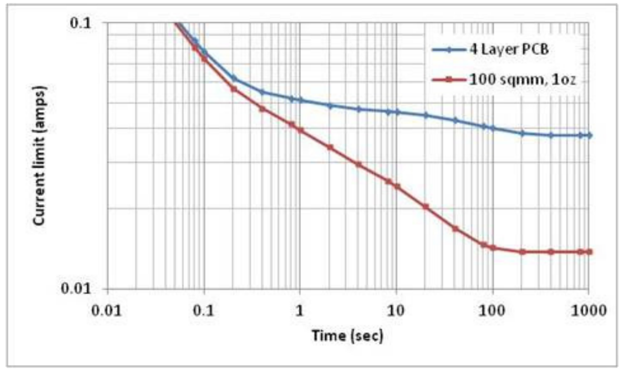



**Figure 3. This Transient Thermal Resistance can be Used to Check the Peak Power Capability of the QFN Package. $T_A$ is 25°C for this Chart**

The chart tells you that a 50-mA average current can be consumed from the 72-V input during 1 s at a 25-°C ambient temperature. From this value, we can rederive the transient thermal resistance obtained from simulation.

$$r(t) = \frac{150 - 25}{50\ m \cdot 72} = 34.7^{o}C/W \quad \text{(eq. 4)}$$

Now, at a 70-°C ambient temperature, during 1 s, the maximum power the part will safely dissipate is equal to

$$P_{max} = \frac{150 - 70}{34.7} = 2.3\ W \quad \text{(eq. 5)}$$

or a 32-mA current from the 72-V input line.

The part is able to issue a status via its dual-function dedicated pin, $\overline{\text{FLT/SDN}}$. When observed, the pin is low to signal a problem or a working sequence in progress. As an example, if the soft-start pin is shorted to ground, all pulses are immediately stopped and the fault is signaled via the assertion of the $\overline{\text{FLT/SDN}}$ pin. This is what you can see in Figure 4.

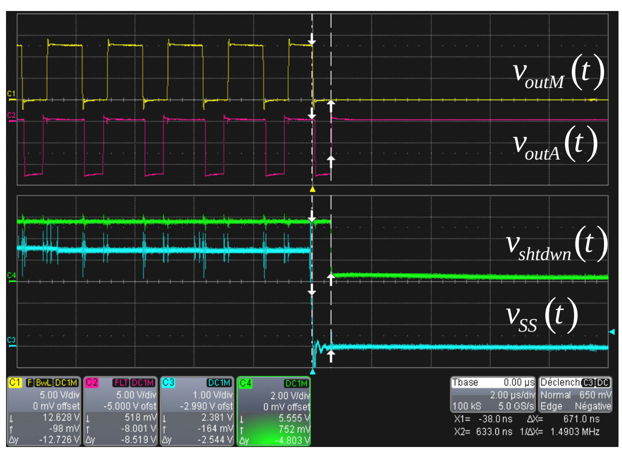



**Figure 4. If the SS Pin is Shorted to Ground, All Pulses are Stopped and the $\overline{\text{FLT/SDN}}$ is Asserted Low to Signal the Fault**

NCP1565 includes a protection against short circuit or overload that is of auto recovery nature. An internal circuitry reconstructs the dc output current by sampling and averaging the primary-side current during the on time. When this voltage image exceeds 300 mV, the capacitor connected to the RES pin (restart), begins to charge with a 20-μA current source. While charging, should the detected fault disappear, e.g. the voltage on the CS pin passes below 300 mV, the 20-μA current source stops and the capacitor is discharged via a 5-μA source to ground. When the fault comes back, charging resumes and the capacitor voltage grows. When touching the 1-V threshold, all pulses stop and the part remains silent for 32 charge/discharge cycles of the RES capacitor. This is what Figure 5 illustrates. At the end of the 32 cycles, the part attempts to re-start but if the fault it still present, hiccup continues. Should the fault disappear, the converter will resume operations.

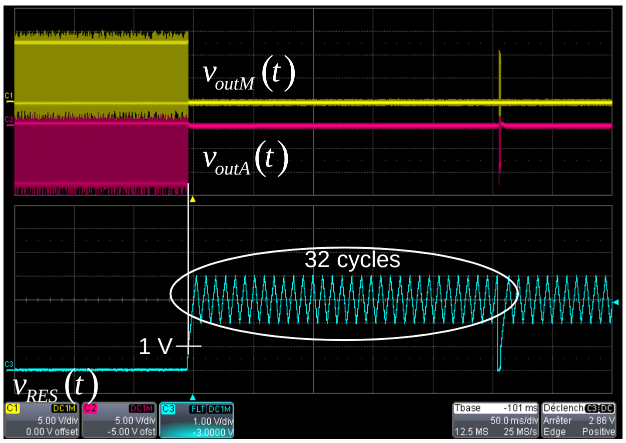



**Figure 5. The Part Enters a Safe Auto-recovery Hiccup Mode when a Fault is Detected**

The controller also hosts a pulse-by-pulse current limit set to 450 mV which terminates a pulse in progress in case this limit is exceeded. Finally, in case an overcurrent is sensed for two consecutive clock cycles, e.g. because the secondary-side winding is accidentally shorted, the part immediately stops and enters the auto-restart mode.

An important feature of NCP1565 lies in its capability to adjust the dead time in relationship to the load and the input voltage. As the load is getting lighter, the dead time will expand to help reach quasi ZVS at turn on. At full load, it is difficult to switch on again at a drain voltage below $V_{in}$. This is because the magnetizing current conflicts with the reflected output current $N.i_L(t)$ that appears in the primary side as soon as the drain drops below $V_{in}$. In light load, however, as $I_{out}$ has decreased, it is possible to force the drain fall well below $V_{in}$. The adaptive dead time helps reaching this goal, significantly improving the situation in moderate to light load conditions.

Loop control requires current injection in the feedback pin. Injecting current reduces the duty ratio. When this current exceeds 850 μA, the duty ratio hits 0% and the controller skips cycles. With a synchronous rectifier, this situation never happens since the output inductor current remains continuous, even in a no-load situation. The duty ratio will remain almost constant across the load range at a given input voltage. On the opposite, with a classical set of diodes in the secondary side, Discontinuous Conduction Mode (DCM) will happen in light or no-load operation. This situation will naturally induce skip cycle operation in the primary side.

In presence of narrow pulses randomly distributed, typical of skip operation, it is very likely that the auxiliary $V_{CC}$ collapses. In this case, the internal DSS will take over and maintain the controller dc supply around 7.5 V. As this operation can last a certain time, it is the designer duty to make sure that the average power dissipation in worst case (high input voltage, highest MOSFET $Q_G$), keeps the controller die temperature below a safe limit. Figure 6 displays a typical operation when skip cycle is entered in no-load ($V_{in}$ = 36 V, $I_{out}$ = 0 A)

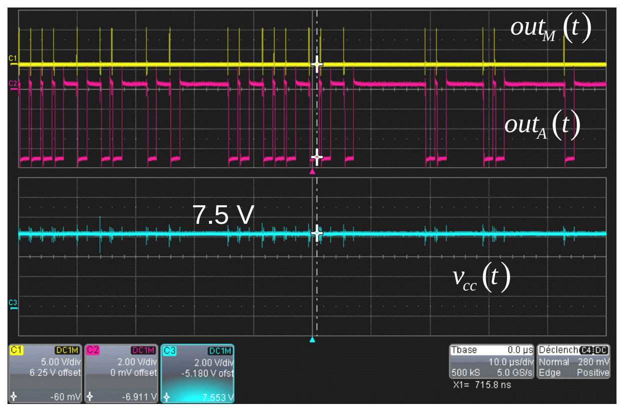



**Figure 6. In Skip Mode, the DSS Takes Over the $V_{CC}$ Rail which Collapses Given Narrow Drive Pulses**

### The Application Circuit

We have designed a 500-kHz 36-72-V dc-dc converter delivering 3.3 V with a nominal output current of 20 A. Over current cutoff happens at $I_{out}$ is 25 A in our prototype. The board is laid out to a quarter brick dimensions and its electric plugs are compatible with off-the-shelf modules.

The primary side section appears in Figure 7 while the secondary side is drawn in Figure 8.

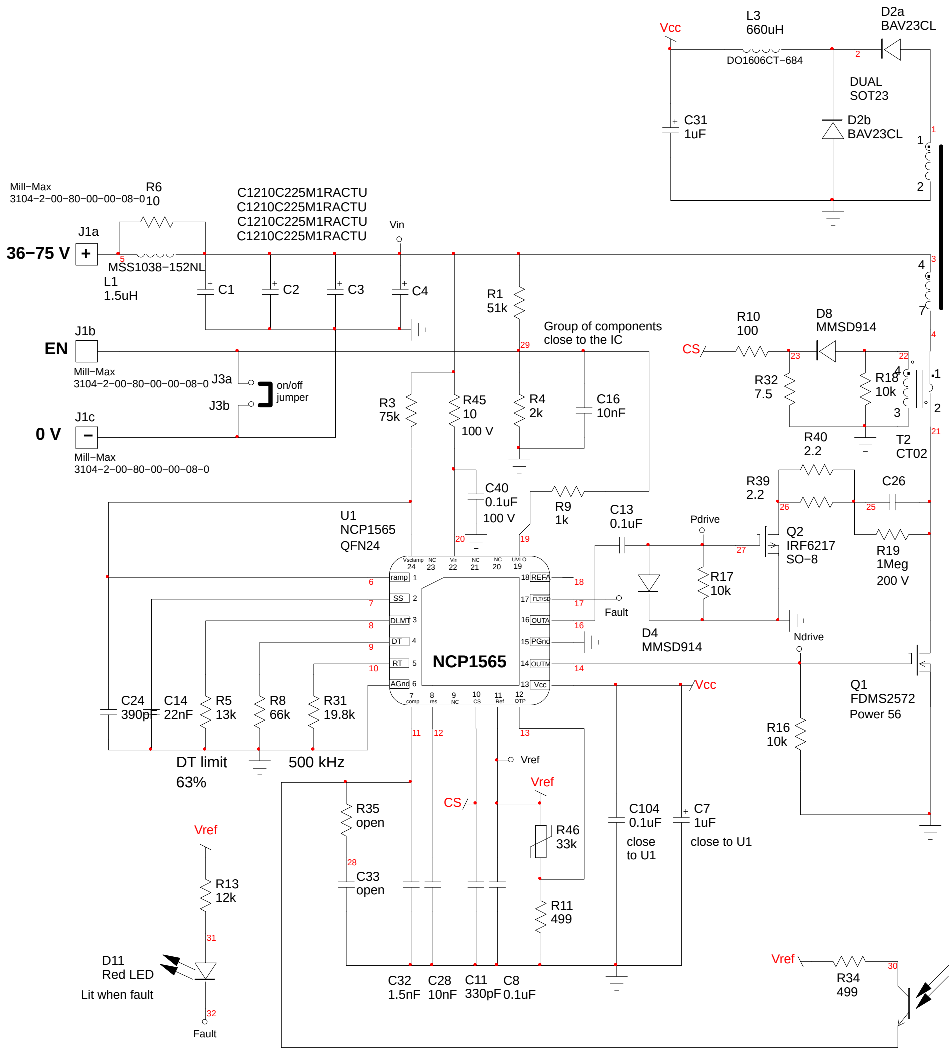



**Figure 7. The Primary Side of the Active-clamp Forward Uses a P-channel Transistor**

The input line first goes through an EMI filter made of a simple damped $LC$ filter. Some resonance can occur at high frequency and potentially affect the transfer function in a wide-bandwidth design. Damping is possible via the addition of a large electrolytic capacitor connected across $C_{1,2,3,4}$. As its ESR is naturally larger than that of the Multi-Layer Capacitors (MLC), it will provide an efficient natural ac damping. Check that its ESR changes at high temperature are still compatible with the required damping. Damping can also be provided by the parallel resistor $R_6$. The input voltage splits in several paths then:

- One goes to the controller VIN pin. It biases the DSS circuitry and provides energy to the chip a) at start up b) when the auxiliary winding disappears in deep DCM. Please note the insertion of a small $RC$ network made of $R_{45}C_{40}$ that provides additional filtering in case of surge events.
- The second undergoes a division by $R_1/R_4$ to feed the controller undervoltage lockout pin. You will adjust this level to define the input voltage at which the converter starts to pulse and the level at which it stops. The formulas are as follows:

$$R_{upper} = \frac{V_{on} - V_{off}}{I_{hyst}} \qquad \text{(eq. 6)}$$

$$R_{lower} = \frac{R_{upper} \cdot V_{enable}}{V_{enable} - V_{off}} \qquad \text{(eq. 7)}$$

For a 34-V turn-on voltage and a turn off at 33 V, the upper and lower resistances ($R_1$ and $R_4$) must respectively be 50 kΩ and 1.9 kΩ.

- Another path is the PWM sawtooth generation. The connection of resistance $R_3$ to the input rail provides natural feedforward operation by modifying $C_{24}$ charging current on the fly as the input voltage varies. This alters the PWM block small-signal gain and helps getting rid of $V_{in}$ in the final transfer function dc gain expression.

To the controller left, you find all the timing components such as switching frequency and dead time settings. Board layout around these elements is critical and their grounds must return to the controller analog GND via the shortest path.

NCP1565 directly drives one low-$r_{DS(on)}$ MOSFETs $Q_1$. The clamp section is built around a P-channel MOSFET $Q_2$ that is referenced to ground. You could also use an N-channel type and hook it to the upper rail but a more complex driving circuitry would be necessary. The primary-side current sense signal is delivered by transformer $T_2$, further demagnetized by $D_8$ and $R_{18}$. The auxiliary voltage is provided by a buck converter supplied by the auxiliary winding. Different structures for this auxiliary section can be envisaged without problem.

Synchronous rectification is accomplished by paralleling MOSFETs. Active Clamp Forward (ACF) represents the perfect structure for self-driven rectifiers. By forcing the magnetizing current circulation along the entire switching period, the drive voltage is always present in the secondary side. 2.2-Ω resistances are inserted in series with the gate signal and damp parasitic elements present in the driving path.

The secondary side implements a type 3 compensator, directly driving the optocoupler LED whose anode goes to a stable voltage. The auxiliary $V_{CC}$ is provided by a simple bipolar ballast whose role is to provide a regulated rail but also a $V_{out}$ ac-decoupled feedback bias for the optocoupler LED. Failure to perfectly ac-isolate this point from $V_{out}$ creates an unwanted fast lane which hampers the phase boost brought by the type 3 arrangement. The bipolar stage brings a first rejection barrier while the added TL431 in active Zener configuration brings rejection further down: the LED ac current must be solely be imposed by the op amp and not by $V_{out}$. To extend the crossover frequency, we have purposely compensated the optocoupler pole via $R_{28}$ and $C_{103}$.

The auxiliary $V_{CC}$ is obtained by a direct rectification of forward and flyback voltages. It is important that this auxiliary supply comes up quickly at power on so that the secondary stage takes the lead immediately and imposes a soft voltage output rise through a soft-start on the op amp reference pin.

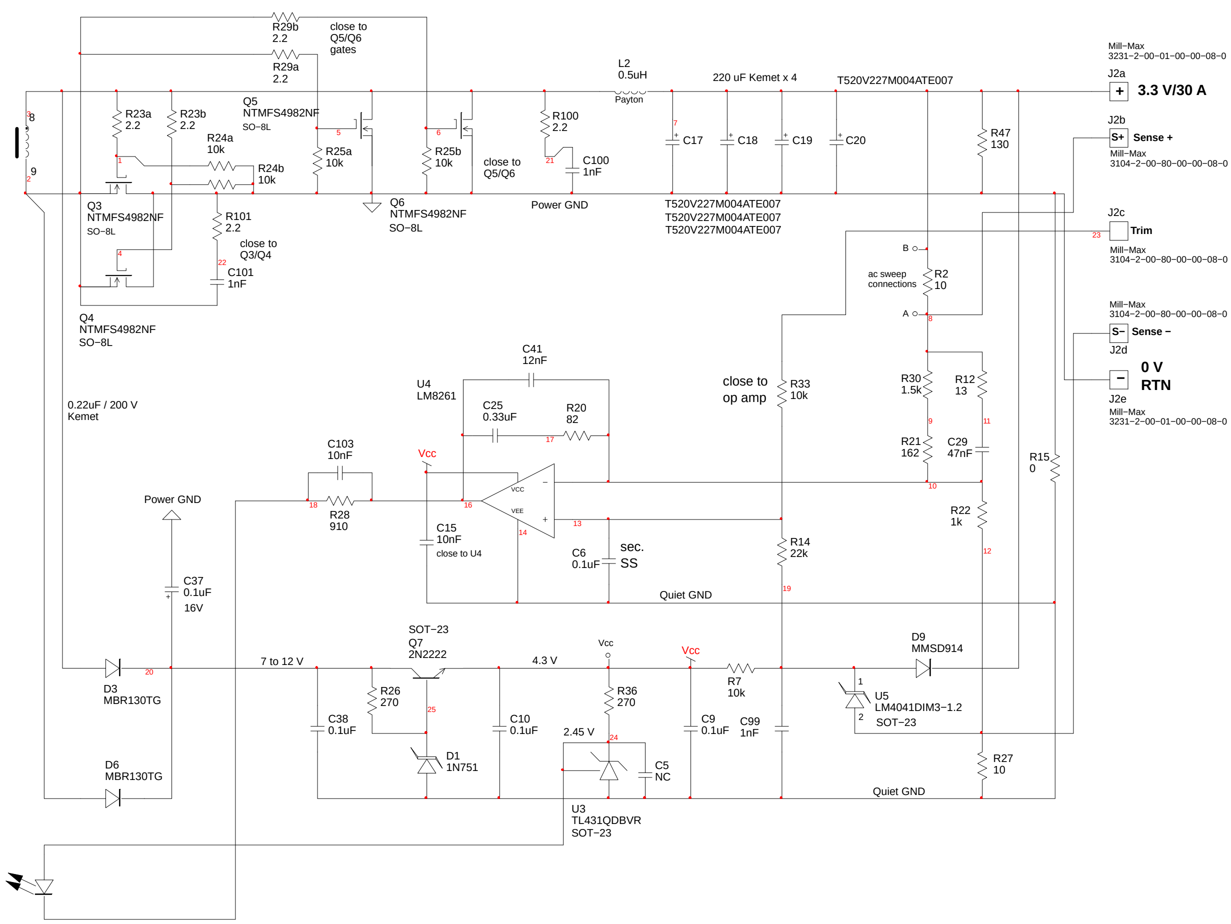



Figure 8. The Secondary Side Implements a Dual Op Amp with a Separate Reference Voltage

For a monotonic output voltage rise, capacitor $C_6$ and resistance $R_{14}$ soft-start the reference voltage at pin (+) of $U_4$. This forces the secondary side to take over control during the start-up sequence and impose the output voltage shape via this network. This is the reason why the auxiliary $V_{CC}$ must come up quickly, hence a rather low value for $C_{37}$. PCB routing distinguishes two grounds, noisy and quiet ones, via the 0-Ω series resistor $R_{15}$. Reference 1 gives details on how to compensate the op amp for a particular crossover frequency selection.

### Operational Results

These components have been assembled on a quarter brick 6-layer PCB whose pictures appears in Figure 9.

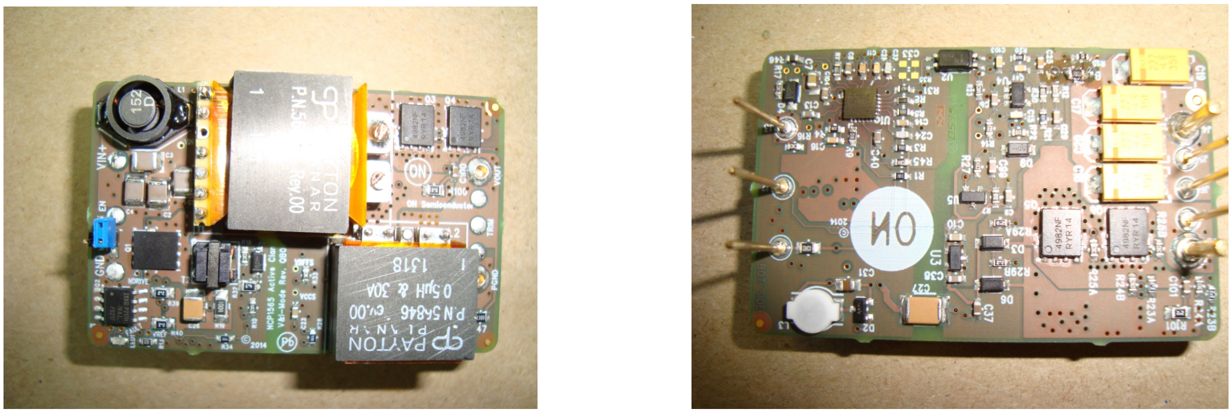


**Figure 9. The 100-W Converter Fits in a Compact 6-layer Quarter Brick PCB Size**

Below are some operational oscilloscope shots captured at different bias points:

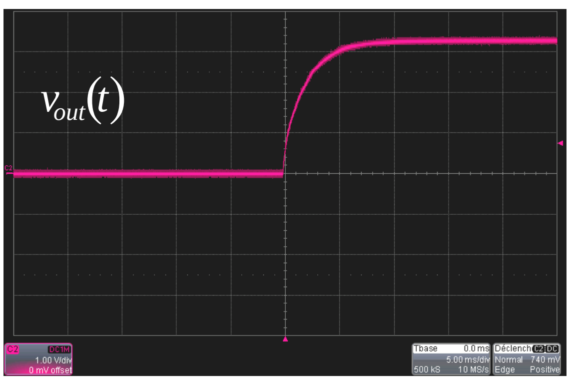



**Figure 10. Start-up Sequence at a 20-A Output Current, $V_{in}$ is 48 V**

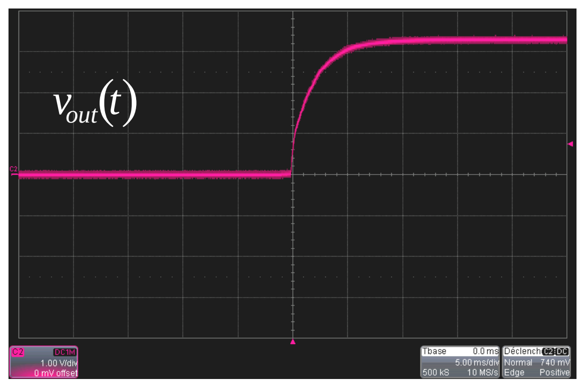
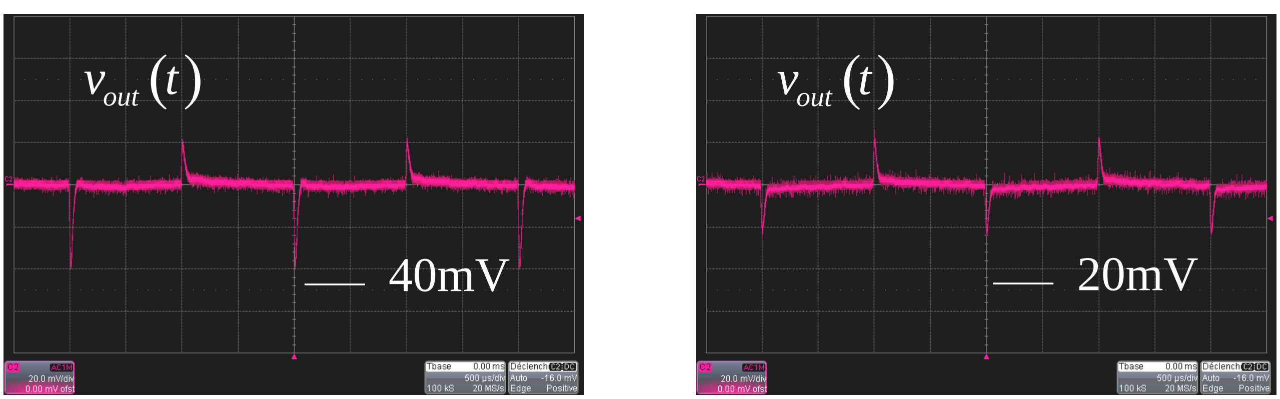



**Figure 11. Start-up Sequence at a 0-A Output Current, $V_{in}$ is 48 V**




$V_{in}$ = 36 V, $I_{out}$ = 15 to 20 A, 1 A/μs

$V_{in}$ = 48 V, $I_{out}$ = 15 to 20 A, 1 A/μs

**Figure 12. Transient Response for Two Different Configurations, Low and Nominal Line**

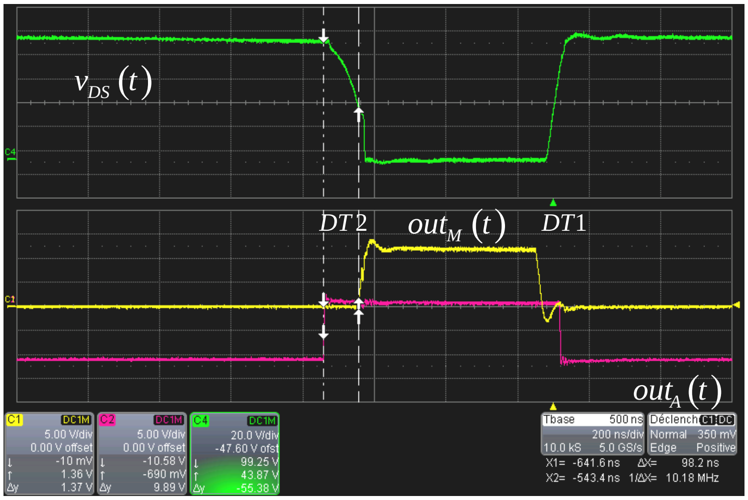



**Figure 13. The Adaptive Dead Time Helps Obtain Quasi-ZVS at a Low Operating Current. $V_{in}$ = 72 V, $I_{out}$ = 3 A**

Efficiency results appear below for a constant output current of 20 A:

$V_{in}$ = 36 V  $\eta$ = 90.88%
$V_{in}$ = 48 V  $\eta$ = 90.65%
$V_{in}$ = 72 V  $\eta$ = 88.65%

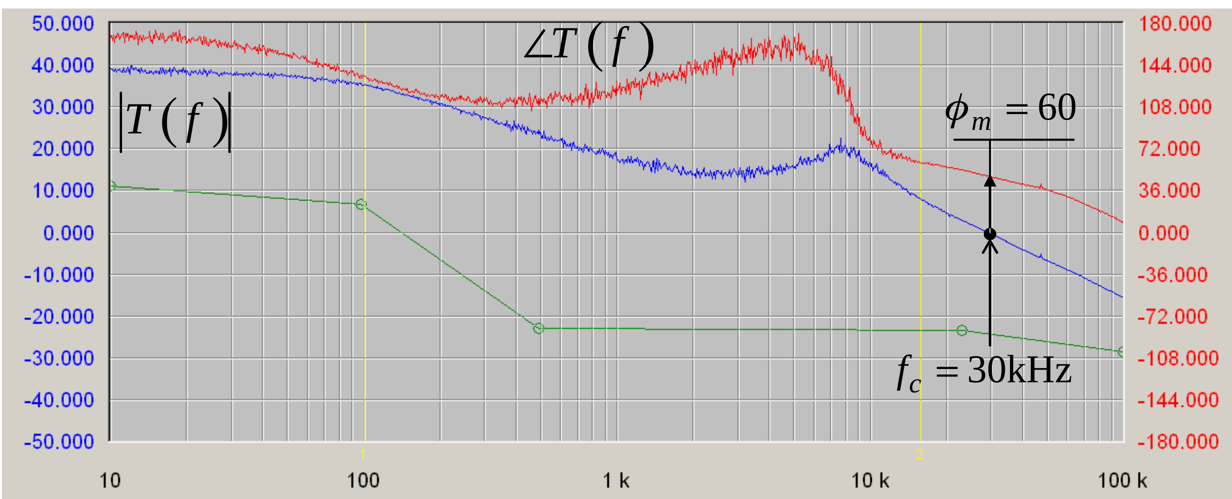



**Figure 14. Open-loop AC Sweep at a 36-V Input Voltage. A 30-kHz Crossover Frequency is Measured Together with a 60° Phase Margin**

Several open-loop measurements have been performed on this board using the series resistance $R_2$ across which an ac signal is injected. One typical result at a 36-V input voltage is given in Figure 14 where a comfortable crossover frequency of 30 kHz is observed. The phase margin is also good with 60° with the absence of conditional stability zones.

The author wishes to thank Payton and ICE Components for kindly providing samples for power magnetics and the current sense transformer.

**Reference**

[1] Christophe Basso, “Designing Control Loops for Linear and Switching Power Supplies: A Tutorial Guide”, Artech House, Boston 2012, ISBN-13: 978-1-60807-557-7
[2] http://www.paytongroup.com/
[3] http://www.icecomponents.com/

## PCB ASSEMBLY

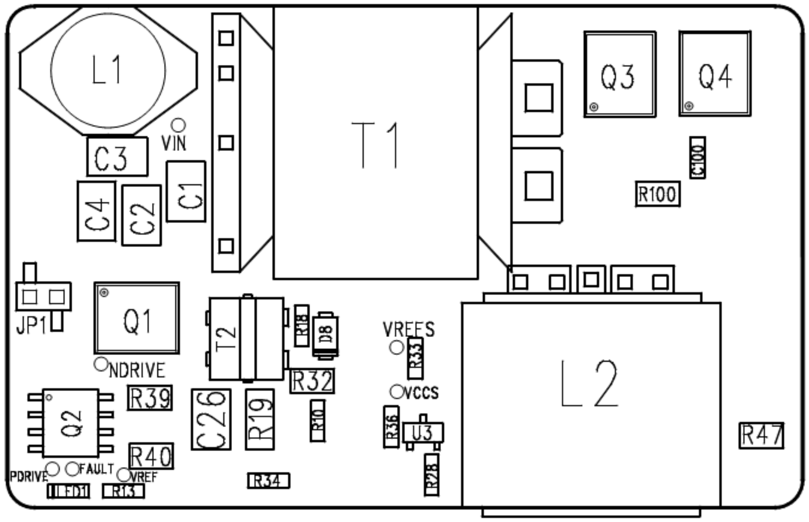



Figure 15. Primary-side Components Assembly

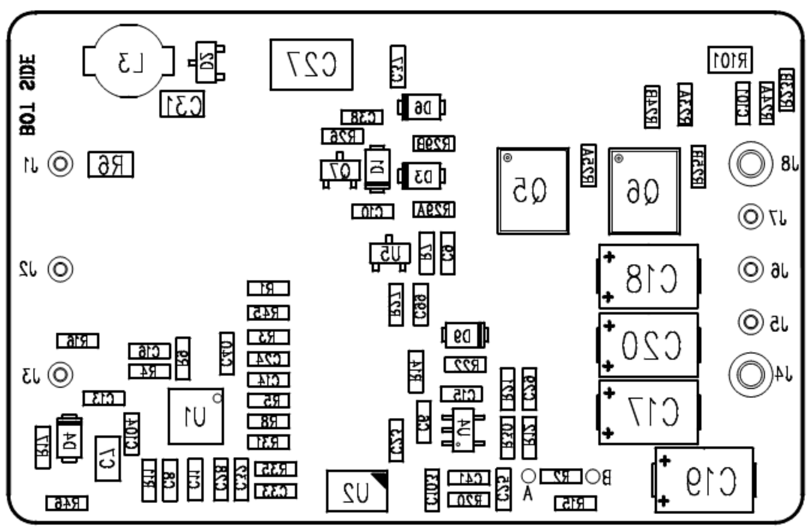


Figure 16. Secondary-side Components Assembly

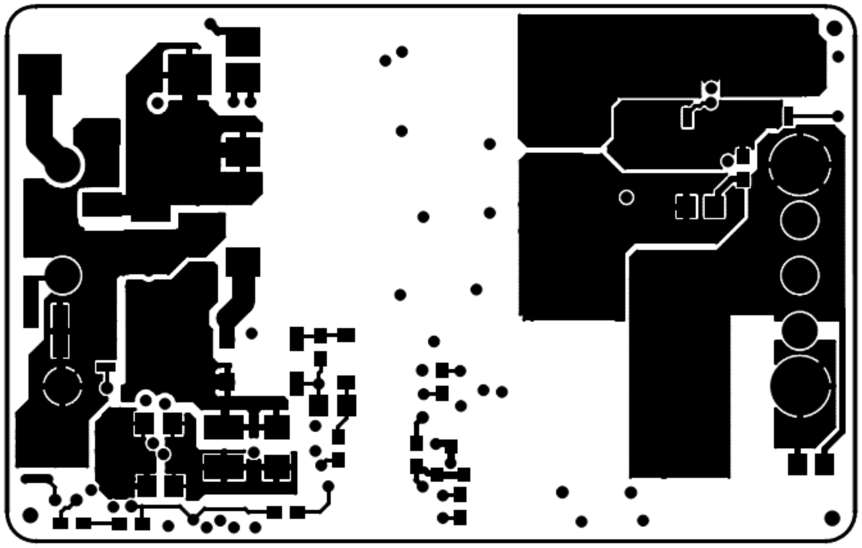


Figure 17. Primary-side Layer 1

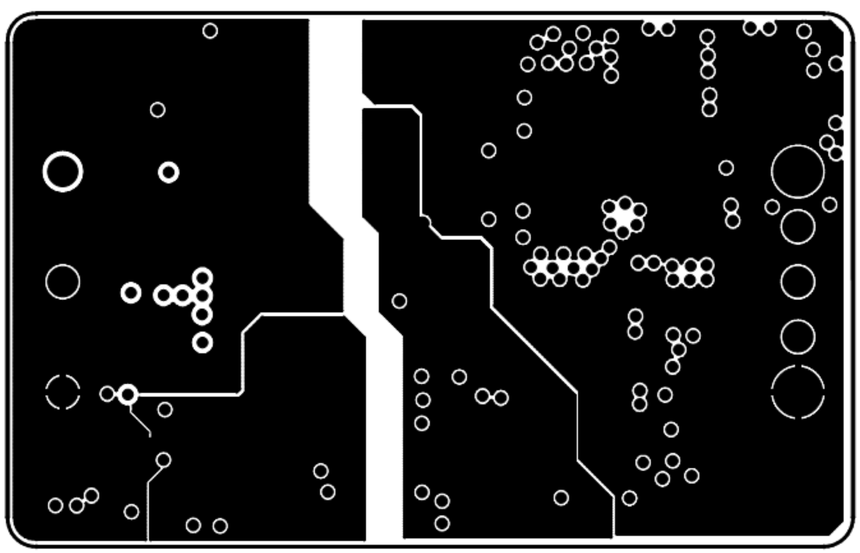


Figure 18. Layer 2, Ground Plane

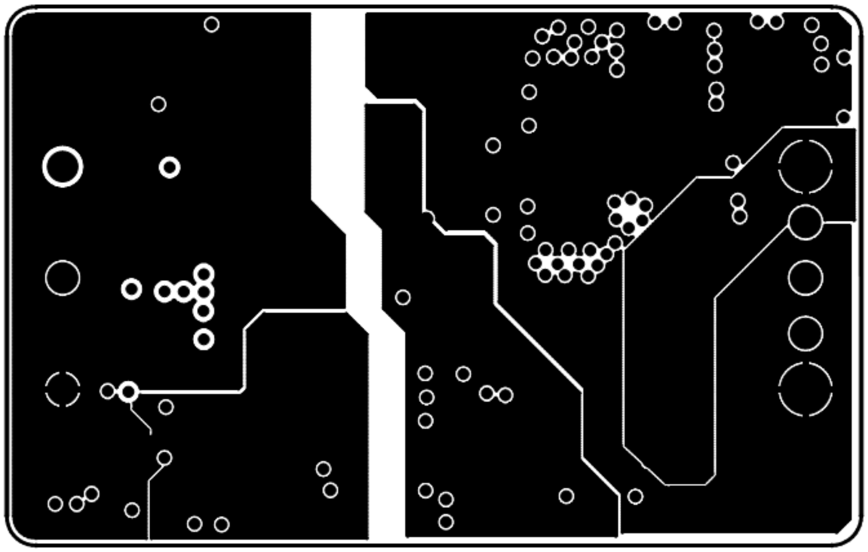


Figure 19. Layer 3, Ground Plane

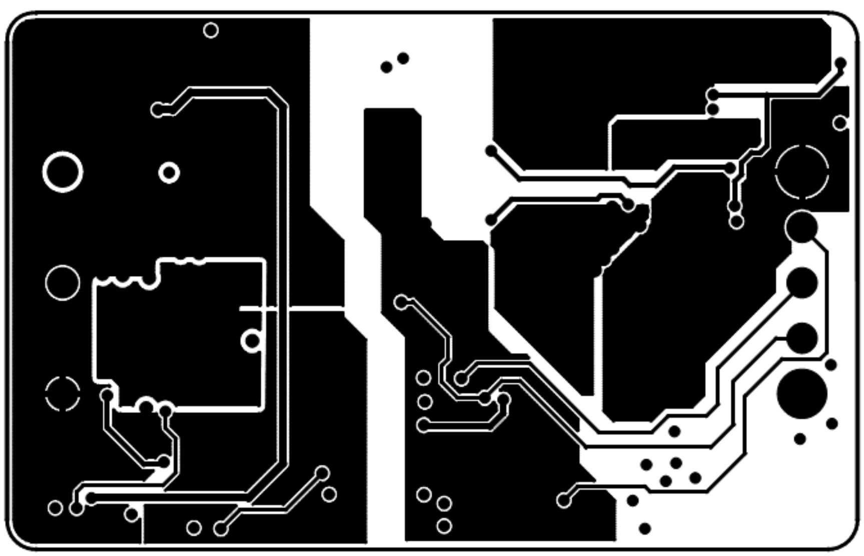


Figure 20. Layer 4, Signal Plane

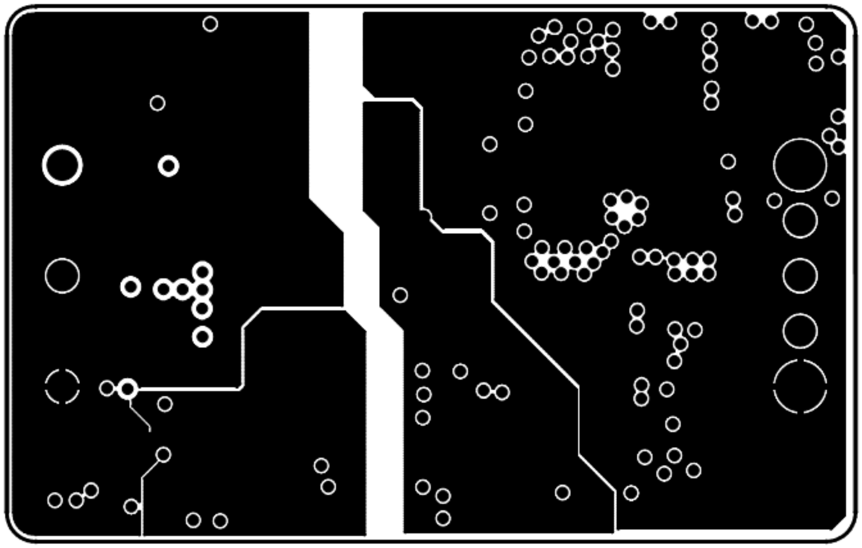


Figure 21. Layer 5, Signal Plane

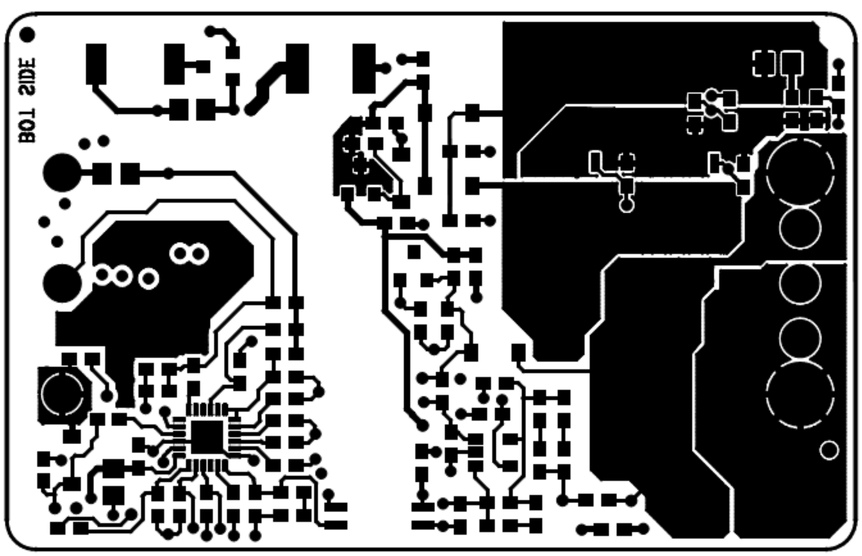


Figure 22. Layer 6, Secondary Side

## BILL OF MATERIALS

### Table 1. BILL OF MATERIALS

| Designator | Qty. | Description | Value | Tolerance | Rating | Footprint | Manufacturer | Part Number | Substi-tution Allowed | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| C7, C31 | 2 | Capacitor | 1 μF | | 20 V | 805 | Yageo | CC0805KKX5R8BB105 | Yes | |
| C26 | 1 | Capacitor | 0.22 μF | | 200 V | 1210 | TDK | CGA6M3X7R2E224K200AA | No | |
| C27 | 1 | Capacitor | 2200 pF | | 2 kV | 1812 | TDK | C4532X7R3D222K | No | |
| C1, C2, C3, C4 | 4 | Capacitor | 2.2 μF | | 100 V | 1210 | Kemet | C1210C225M1RACTU | No | |
| C17, C18, C19, C20 | 4 | Capacitor | 220 μF | | 6.3 V | − | Kemet | T520V227M004ATE007 | No | |
| C6, C8, C9, C13, C37, C38, C40, C104, C10 | 9 | Capacitor | 0.1 μF | | 50 V | 0603 | Yageo | CC0603MRX7R9BB104 | Yes | |
| C32 | 1 | Capacitor | 1.5 nF | | 16 V | 0603 | Yageo | CC0201KRX7R7BB152 | Yes | |
| C15, C16, C28, C103 | 4 | Capacitor | 10 nF | | 16 V | 0603 | Yageo | CC0201KRX7R7BB103 | Yes | |
| C25 | 1 | Capacitor | 330 nF | 5% | 16 V | 0603 | Yageo | CC0603KRX7R7BB334 | Yes | |
| C99, C100, C101 | 3 | Capacitor | 1 nF | | 16 V | 0603 | Yageo | CC0603KRX7R7BB102 | Yes | |
| C14 | 1 | Capacitor | 22 nF | 5% | 16 V | 0603 | Yageo | CC0603KRX7R7BB223 | Yes | |
| C11 | 1 | Capacitor | 330 pF | | 16 V | 0603 | Yageo | CC0201KRX7R7BB331 | Yes | |
| C24 | 1 | Capacitor | 390 pF | 5% | 50 V | 0603 | Yageo | CC0603GRNPO9BN391 | Yes | 2% |
| C41 | 1 | Capacitor | 12 nF | 5% | 25 V | 0603 | Yageo | CC0603KRX7R8BB123 | Yes | |
| C29 | 1 | Capacitor | 47 nF | | 16 V | 0603 | Yageo | CC0603KPX7R7BB473 | Yes | |
| C23, C33 | 2 | Capacitor | Open | − | − | − | − | − | Yes | |
| L1 | 1 | Inductor | 1.5 μF | | − | − | Coilcraft | DS3316P-152MLB | No | |
| L3 | 1 | Inductor | 680 μF | | − | − | Coilcraft | DO1606CT-684 | No | |
| L2 | 1 | Inductor | 0.5 μF | | 30 A | − | Payton | 56846 | No | Planar |
| R19 | 1 | Resistor | 1 MΩ | 5% | 200 V | 1206 | Yageo | RV1206FR-071ML | Yes | |
| R6 | 1 | Resistor | 10 Ω | 5% | 150 V | 805 | Yageo | RC0805FR-7W10RL | Yes | |
| R47 | 1 | Resistor | 130 Ω | 5% | 150 V | 805 | Yageo | RC0805FR-7W130RL | Yes | |
| R39, R40, RR100, R101 | 4 | Resistor | 2.2 Ω | 5% | 150 V | 805 | Yageo | RC0805FR-072R2L | Yes | |
| R32 | 1 | Resistor | 7.5 Ω | 1% | 150 V | 805 | Yageo | RC0805FR-077R5L | Yes | |
| R15 | 1 | Resistor | 0 Ω | 5% | 50 V | 603 | Yageo | AC0603JR-070RL | Yes | 0-Ω res. |
| R23A, R23B, R29A, R29B | 4 | Resistor | 2.2 Ω | 5% | 50 V | 603 | Yageo | RC0603FR-072R2L | Yes | |
| R2, R27, R45 | 3 | Resistor | 10 Ω | 5% | 50 V | 603 | Yageo | RC0603FR-0710RL | Yes | |
| R12 | 1 | Resistor | 12 Ω | 1% | 50 V | 603 | Yageo | RC0603FR-0712RL | Yes | |
| R20 | 1 | Resistor | 82 Ω | 1% | 50 V | 603 | Yageo | RC0603FR-0782RL | Yes | |
| R10 | 1 | Resistor | 100 Ω | 5% | 50 V | 603 | Yageo | RC0603FR-07100RL | Yes | |
| R21 | 1 | Resistor | 162 Ω | 1% | 50 V | 603 | Yageo | RC0603FR-07162RL | Yes | |
| R26, R36 | 2 | Resistor | 270 Ω | 5% | 50 V | 603 | Yageo | RC0603FR-07270RL | Yes | |
| R11, R34 | 2 | Resistor | 499 Ω | 1% | 50 V | 603 | Yageo | RC0603FR-07499RL | Yes | |
| R28 | 1 | Resistor | 910 Ω | 1% | 50 V | 603 | Yageo | RC0603FR-13910RL | Yes | |
| R9, R22 | 2 | Resistor | 1 kΩ | 5% | 50 V | 603 | Yageo | RC0603FR-071KL | Yes | |
| R30 | 1 | Resistor | 1.5 kΩ | 1% | 50 V | 603 | Yageo | RC0603FR-071K5L | Yes | |
| R4 | 1 | Resistor | 2 kΩ | 1% | 50 V | 603 | Yageo | RC0603FR-072KL | Yes | |

**Table 1. BILL OF MATERIALS** (continued)

| Designator | Qty. | Description | Value | Tolerance | Rating | Footprint | Manufacturer | Part Number | Substi-tution Allowed | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| R7, R16-18, R33, R24A, R24B, R25A, R25B | 9 | Resistor | 10 kΩ | 5% | 50 V | 603 | Yageo | RC0603FR-0710KL | Yes | |
| R13 | 1 | Resistor | 12 kΩ | 5% | 50 V | 603 | Yageo | RC0603FR-0712KL | Yes | |
| R5 | 1 | Resistor | 13 kΩ | 1% | 50 V | 603 | Yageo | RC0603FR-0713KL | Yes | |
| R31 | 1 | Resistor | 19.6 kΩ | 1% | 50 V | 603 | Yageo | RC0603FR-0719K6L | Yes | |
| R14 | 1 | Resistor | 22 kΩ | 5% | 50 V | 603 | Yageo | RC0603FR-0722KL | Yes | |
| R1 | 1 | Resistor | 51 kΩ | 1% | 100 V | 603 | Yageo | RV0603FR-0751KL | Yes | |
| R8 | 1 | Resistor | 66.5 kΩ | 1% | 50 V | 603 | Yageo | RC0603FR-0766K5L | Yes | |
| R3 | 1 | Resistor | 75 kΩ | 1% | 100 V | 603 | Yageo | RV0603FR-0775KL | Yes | |
| R35 | 1 | Resistor | Open | – | – | – | – | – | Yes | |
| R46 | 1 | Resistor | 33 kΩ NTC | | – | 603 | AVX | NB 21 M 0 0333 | 33 k @25°C | Thermistor |
| LED1 | 1 | LED | Red LED | | – | LED0805 | ROHM | TLMS1000GS08 | No | SMD Type |
| Q1 | 1 | MOSFET | FDMS2572 | | 150 V | CASE488AA | Fairchild | FDMS2572 | No | Flat Lead |
| Q3-Q6 | 1 | MOSFET | NTMFS4982 | | 30 V | CASE488AA | ON Semiconductor | NTMFS4982NFT1G | No | Flat Lead |
| Q2 | 1 | MOSFET | IRF6217 | | 150 V | SO8 | International Rectifier | IRF6217TRPBF | No | P-channel |
| Q7 | 1 | Bipolar | MMBT2222 | | | SOT23 | ON Semiconductor | MMBT2222ALT1 | No | NPN |
| D1 | 1 | Zener Diode | MMSZ4689 | | | SOD-123 | ON Semiconductor | MMSZ4689T1G | No | |
| D2 | 1 | Diode | BAV23CL | | | SOD-123 | ON Semiconductor | BAV23CLT1G | No | |
| D4, D8, D9 | 3 | Diode | MMSD914 | | | SOD-123 | ON Semiconductor | MMSD914 | No | |
| D3, D6 | 2 | Diode | MBR130T1G | | | SOD-123 | ON Semiconductor | MBR130T1G | No | |
| J1, J2, J3, J5, J6, J7 | 6 | Pin | PLOT 1 mm | | | 3104_ LOPOWER | MILL-MAX | 3104-1-00-80-00-00-08-0 | No | |
| J4, J8 | 2 | Pin (Power) | PLOT 2 mm | | 15 A | 3231_ POWER | MILL-MAX | 3231-2-00-01-00-00-08-0 | No | |
| JP1 | 1 | Jumper | TMM102-0X-X-S-SM | | | JUMP TMM-SM | Samtec | TMM102-01-L-S-SM | No | |
| JP1 | 1 | Jumper | | | | | Harwin | M22-1920005 | No | |
| T1 | 1 | Transformer | 500 μH | | 30 A | – | Payton | 56847 | No | |
| T2 | 1 | Current Sense | CT02-100 | | | – | ICE | CT02 | | |
| U1 | 1 | Controller | NCP1565 | | | QFN24 | ON Semiconductor | NCP1565 | | |
| U2 | 1 | Optocoupler | PS2801 | | | SMD | NEC | PS2801 | | |
| U3 | 1 | IC | TL431 | | | SOT23 | TI | TL431ACDBZT | | |
| U4 | 1 | Op Amp | LM8261M5 | | | TSOP-5 | TI | LM8261M5 | | |
| U5 | 1 | Reference | LM4041-1.2 | | | SOT23 | TI | LM4041DIM3-1.2 | | |

NOTE: All devices are Pb-Free

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