

## **AN-2043 LM5035C Evaluation Board**

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### **1 Introduction**

The LM5035C evaluation board is designed to provide the design engineer with a fully functional power converter based on the half bridge topology to evaluate the LM5035C controller. The LM5035C is a functional variant of the LM5035B half-bridge PWM controller. The amplitude of the SR control signals are 5V instead of the  $V_{CC}$  level. The evaluation board is provided in an industry standard quarter-brick footprint.

The performance of the evaluation board is as follows:

- Input operating range: 36V to 75V
- Output voltage: 3.3V
- Output current: 0 to 30A
- Measured efficiency: 89% at 30A, 92% at 15A
- Frequency of operation: 400kHz
- Board size: 2.28 x 1.45 x 0.5 inches
- Load Regulation: 0.2%
- Line Regulation: 0.1%
- Line under-voltage lock-out (UVLO) (33.9V/31.9V on/off)
- Line over-voltage protection (OVP) (79.4V/78.3V off/on)
- Hiccup current limit

The printed circuit board consists of 6 layers; 2 ounce copper outer layers and 3 ounce copper inner layers on FR4 material with a total thickness of 0.062 inches. The unit is designed for continuous operation at rated load at  $<40^{\circ}\text{C}$  and a minimum airflow of 200 CFM.

### **2 Theory of Operation**

Power converters based on the half bridge topology offer high efficiency and good power handling capability in applications up to 500 Watts. The operation of the transformer causes the flux to swing in both directions, thereby better utilizing the magnetic core.

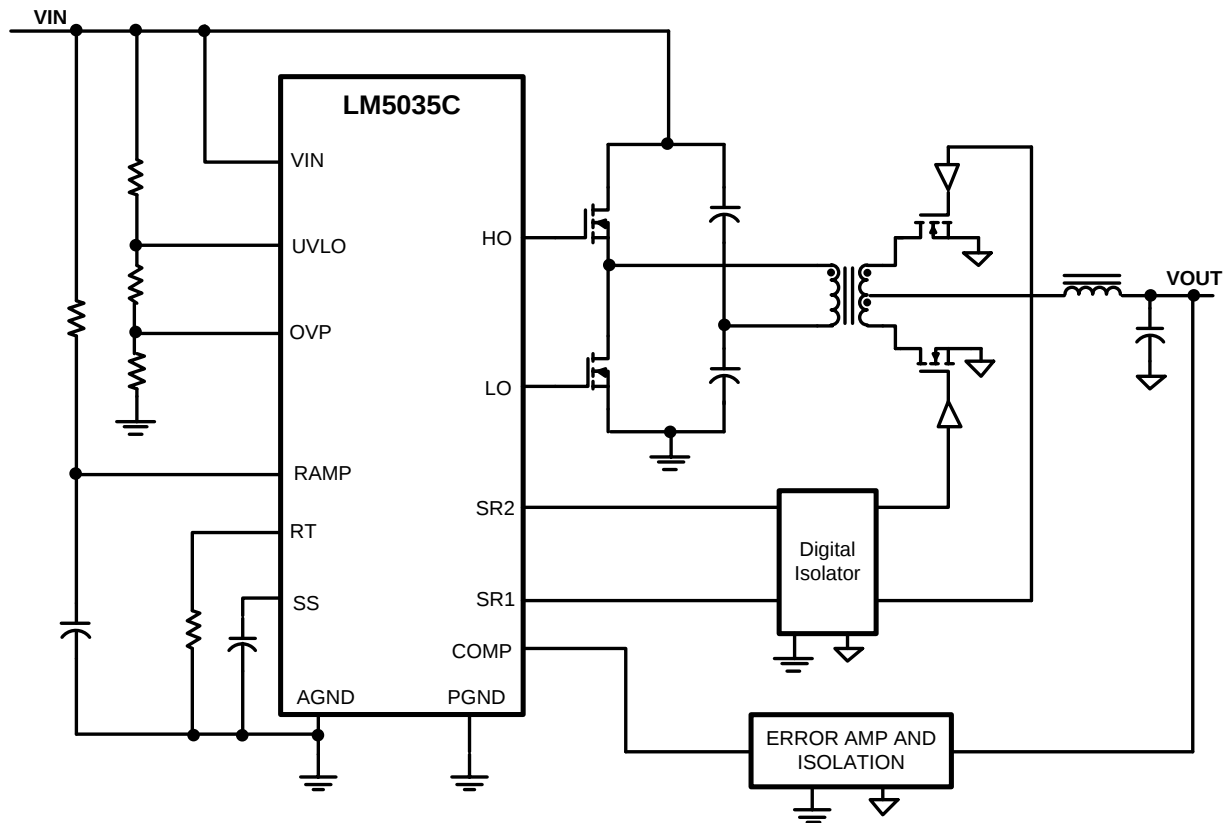
The half bridge converter is derived from the Buck topology family, employing separate high voltage (HO) and low voltage (LO) modulating power switches with independent pulse width timing. The main difference between the topologies are, the Half Bridge topology employs a transformer to provide input/output ground isolation and a step down or step up function.

Each cycle, the main primary switch turns on and applies one-half the input voltage across the primary winding, which has 8 turns. The transformer secondary has 2 turns, leading to a 4:1 step-down of the input voltage. For an output voltage of 3.3V, the composite duty cycle (D) of the primary switches varies from approximately 75% (low line) to 35% (high line).

The secondary employs synchronous rectification controlled by the LM5035C. During soft-start, the sync FET body diodes act as the secondary rectifiers until the main transformer energizes the gate drivers. The DLY resistor programs the non-overlap timing for the sync FETs to maximize efficiency while eliminating shoot through current. The Sync FET control signals are sent across the isolation boundary using a digital isolator.

Feedback from the output is processed by an amplifier and reference, generating an error voltage, which is coupled back to the primary side control through an optocoupler. The COMP input to the LM5035C greatly increases the achievable loop bandwidth. The capacitance effect (and associated pole) of the optocoupler is reduced by holding the voltage across the optocoupler constant. The LM5035C voltage mode controller pulse width modulates the error signal with a ramp signal derived from the line voltage (feedforwarding) to reduce the response time to input voltage changes. A standard "type III" network is used for the compensator.

The evaluation board can be synchronized to an external clock with a recommended frequency range of 420KHz to 500KHz.



**Figure 1. Simplified Half Bridge Converter**

### 3 Powering and Loading Considerations

When applying power to the LM5035C evaluation board, certain precautions need to be followed. A misconnection can damage the assembly.

### 4 Proper Connections

When operated at low input voltages, the evaluation board can draw up to 3.5A of current at full load. The maximum rated output current is 30A. Be sure to choose the correct connector and wire size when attaching the source supply and the load. Monitor the current into and out of the evaluation board. Monitor the voltage directly at the output terminals of the evaluation board. The voltage drop across the load connecting wires will cause inaccurate measurements. This is especially true for accurate efficiency measurements.

## 5 Source Power

The evaluation board can be viewed as a constant power load. At low input line voltage (36V) the input current can reach 3.5A, while at high input line voltage (75V) the input current will be approximately 1.5A. Therefore, to fully test the LM5035C evaluation board a DC power supply capable of at least 85V and 5A is required.

The power supply must have adjustments for both voltage and current. The power supply and cabling must present low impedance to the evaluation board. Insufficient cabling or a high impedance power supply will cause voltage droop during turn-on due to the evaluation board inrush current. If large enough, this droop will cause a chattering condition upon power up. This chattering condition is an interaction with the evaluation board undervoltage lockout, the cabling impedance and the inrush current.

## 6 Loading

An appropriate electronic load, with specified operation down to 1.0V minimum, is desirable. The resistance of a maximum load is 0.11Ω. The high output current requires thick cables! If resistor banks are used there are certain precautions to be taken. The wattage and current ratings must be adequate for a 30A, 100W supply. Monitor both current and voltage at all times. Ensure there is sufficient cooling provided for the load.

## 7 Air Flow

Full power loading should never be attempted without providing the specified 200 CFM of air flow over the evaluation board. A stand-alone fan should be provided.

## 8 Powering Up

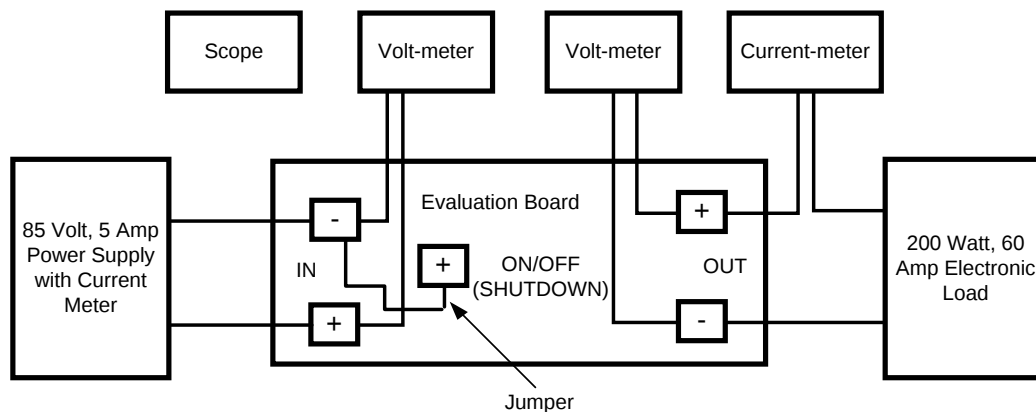
Using the ON/OFF pin (J2) provided will allow powering up the source supply with the current level set low. It is suggested that the load be kept low during the first power up. Set the current limit of the source supply to provide about 1.5 times the wattage of the load. As you remove the connection from the ON/OFF pin to ground (J1), immediately check for 3.3 volts at the output.

A most common occurrence, that will prove unnerving, is when the current limit set on the source supply is insufficient for the load. The result is similar to having the high source impedance referred to earlier. The interaction of the source supply folding back and the evaluation board going into undervoltage shutdown will start an oscillation, or chatter, that may have undesirable consequences.

A quick efficiency check is the best way to confirm that everything is operating properly. If something is amiss you can be reasonably sure that it will affect the efficiency adversely. Few parameters can be incorrect in a switching power supply without creating losses and potentially damaging heat.

## 9 Over Current Protection

The evaluation board is configured with hiccup over-current protection. In the event of an output overload (approximately 35A) the unit will discharge the softstart capacitor, which disables the power stage. After a delay the softstart is released. The shutdown, delay and slow recharge time of the softstart capacitor protects the unit, especially during short circuit event where the stress is highest.



**Figure 2. Typical Evaluation Setup**

## 10 Digital Isolator

There is a total of four crossing of the isolation boundary; the power transformer, the feedback and control of the two synchronous MOSFETs. Usually an opto-coupler is used for isolation of the feedback signal since this is a relatively slow analog signal. Most opto-couplers are too slow to use for the synchronous MOSFET gate drive. There are fast opto-couplers available but there is a big cost premium. Historically, the most common approach has been to use gate drive transformers to provide isolation for the synchronous gate drive signals. The transformers can be used to directly drive the MOSFET gates or the transformers can be used to just isolate the control signal which is then applied to a gate driver IC on the secondary side. Gate drive transformers have their challenges and limitations. Transformers cannot pass DC. A given size transformer can only pass a finite voltage and time product across the isolation boundary. After each on-time, the transformer needs to be reset, which imposes duty cycle limitations. Further, during a sudden switch-off of the power converter, the DC restorer capacitor on the secondary of the gate drive transformer does not have a quick discharge path. This will keep SR FET's turned on, resulting in a non-monotonic decay of the output voltage.

These limitations can be addressed using a digital isolator. The digital isolators are CMOS devices that use an RF coupler to transmit digital information across the isolation barrier. The isolation capability is up to 2500 VRMS. In simple words, the digital isolators are similar to an opto-coupler. While, the opto-couplers modulate light to transmit electrical signals, the digital isolators modulate an RF signal across a semiconductor barrier. Furthermore, the digital isolators have lower propagation delay than the gate drive transformers and do not suffer volt-second limitations.

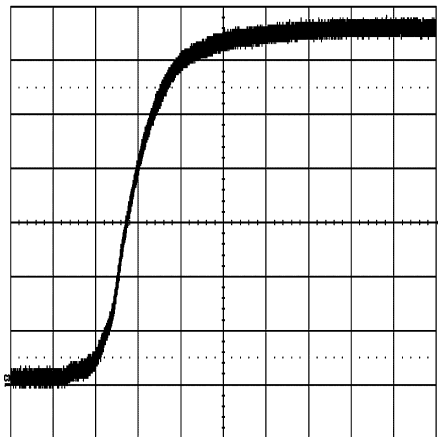
## 11 Performance Characteristics

### 11.1 Turn-On Waveforms

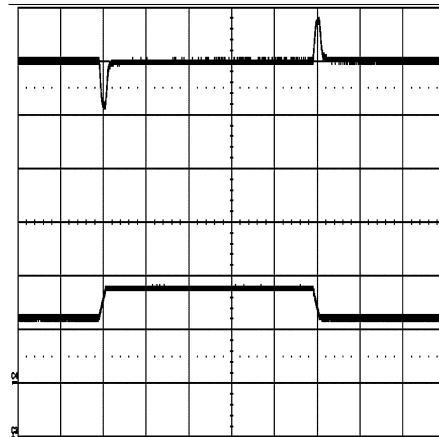
A certain sequence of events occurs when applying power to the LM5035C evaluation board. The soft-start capacitor values and other components allow for a minimal output voltage for a short time until the feedback loop can stabilize without overshoot. [Figure 1](#) shows the output voltage during a typical start-up with a 48V input and a load of 5A. There is no overshoot during startup.

## 11.2 Output Ripple Waveforms

Figure 3 shows the transient response for a load change from 15A to 22.5A. The upper trace shows minimal output voltage droop and overshoot during the sudden change in output current shown by the lower trace.



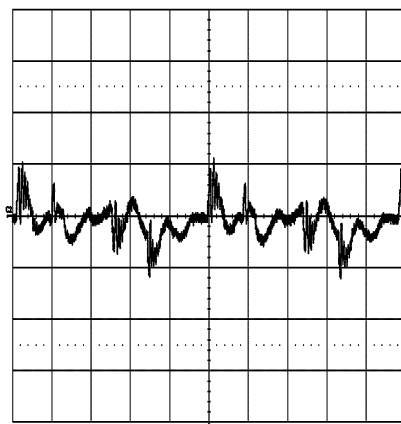
Conditions: Input Voltage = 48VDC Output Current = 5A  
Trace 1: Output Voltage Volts/div = 500mV Horizontal  
Resolution = 0.5ms/div



Conditions: Input Voltage = 48VDC Output Current = 15A to  
22.5A Upper Trace: Output Voltage Volts/div = 50mV Lower  
Trace: Output Current = 15A to 22.5A to 15A Horizontal  
Resolution = 0.5ms/div

**Figure 3. Output Voltage During a Typical Start-Up**

**Figure 4. Transient Response for a Load Change From  
15A to 22.5A**



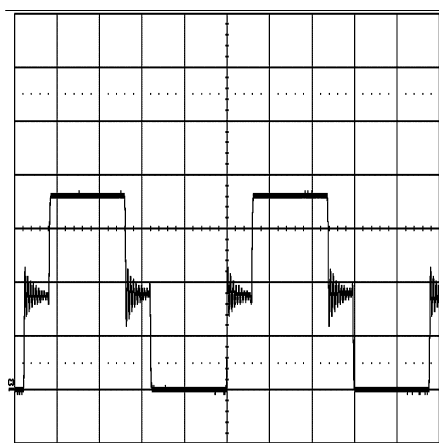
Conditions: Input Voltage = 48VDC Output Current = 30A Bandwidth Limit = 20MHz Trace 1: Output Ripple Voltage  
Volts/div = 20mV Horizontal Resolution = 1μs/div

**Figure 5. Typical Output Ripple Seen Across the Output Terminals**

Figure 5 shows typical output ripple seen across the output terminals (with standard 10 $\mu$ F and 1 $\mu$ F ceramic capacitors) for an input voltage of 48V and a load of 30A. This waveform is typical of most loads and input voltages.

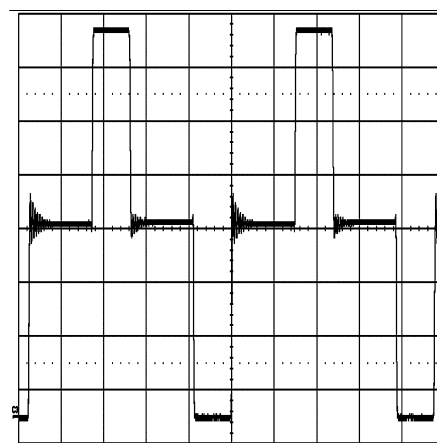
Figure 6 and Figure 7 show the drain voltage of Q1 with a 5A load. Figure 6 represents an input voltage of 36V and Figure 7 represents an input voltage of 72V.

Figure 8 shows the gate voltages of the synchronous rectifiers. The deadtime provided by the 20k $\Omega$  DLY resistor is difficult to see at this timescale.



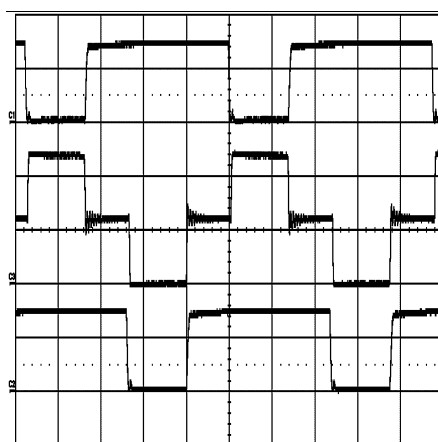
Conditions: Input Voltage = 36VDC Output Current = 5A  
Trace 1: Q1 drain voltage Volts/div = 10V Horizontal  
Resolution = 1 $\mu$ s/div

**Figure 6. Drain Voltage of Q1 With a 5A Load (input voltage of 36V)**



Conditions: Input Voltage = 72VDC Output Current = 5A  
Trace 1: Q2 drain voltage Volts/div = 10V Horizontal  
Resolution = 1 $\mu$ s/div

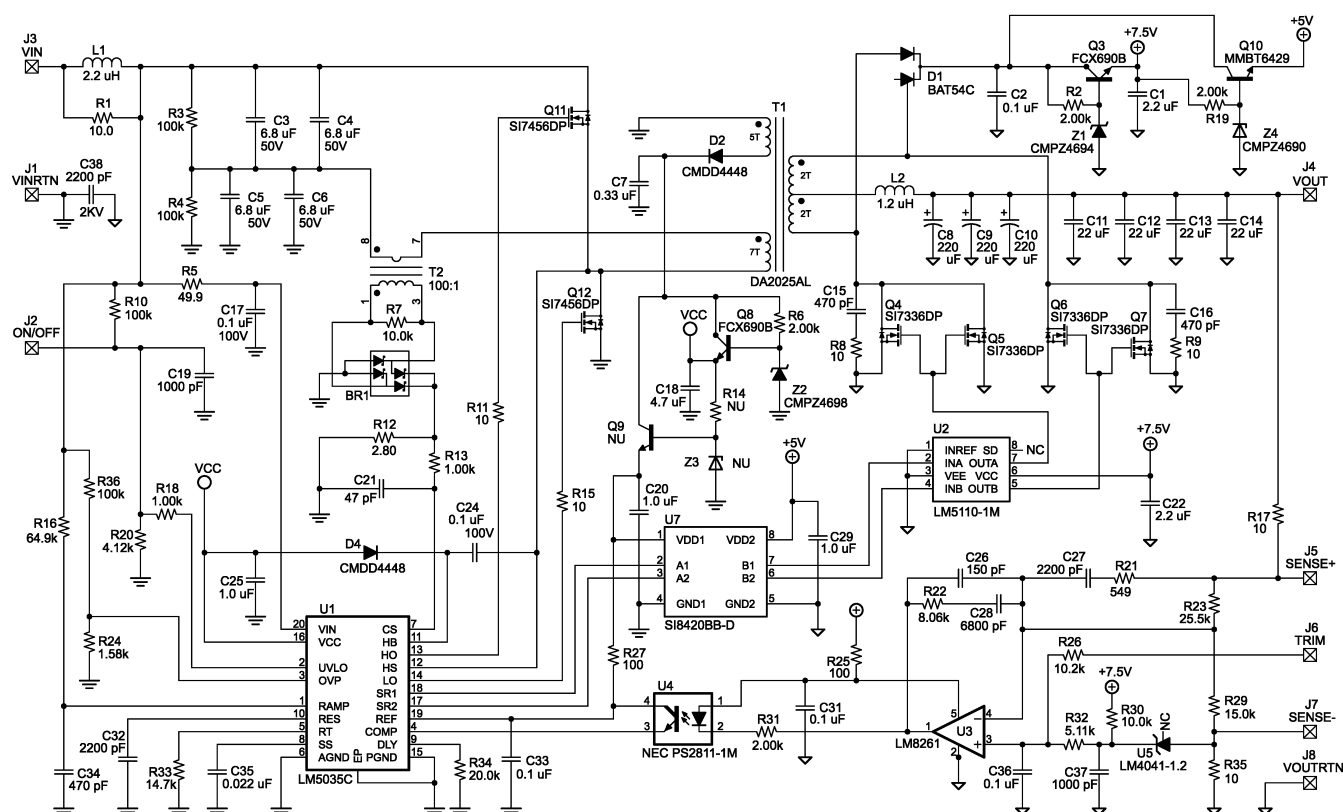
**Figure 7. Drain Voltage of Q1 With a 5A Load (input voltage of 72V)**



Conditions: Input Voltage = 48VDC Output Current = 5A Upper Trace: SR1, Q4 gate Volts/div = 5V Middle Trace: HS, Q2 drain Volts/div = 20V Lower Trace: SR2, Q6 gate Volts/div = 5V Horizontal Resolution = 1 $\mu$ s/div

**Figure 8. Gate Voltages of the Synchronous Rectifiers**

## 12 Application Circuit



**Figure 9. Application Circuit: Input 36 to 75V, Output 3.3V, 30A**

**Table 1. Bill of Materials (BOM)**

| Item | Part Description             | Qty | Ref Designator     | Remark                  |
|------|------------------------------|-----|--------------------|-------------------------|
| 1    | LM5035 Controller MH20       | 1   | U1                 | TI LM5035               |
| 2    | LM5110 Dual Driver           | 1   | U2                 | TI LM5110               |
| 3    | LM8261 Op Amp SOT23-5        | 1   | U3                 | TI LM8261               |
| 4    | LM4041 Ref Amp SOT23         | 1   | U5                 | TI LM4041               |
| 5    | Opto-Coupler PS2811-1M       | 1   | U4                 | NEC PS2811-1M           |
| 6    | Digital Isolator IC SOIC-8   | 1   | U6                 | Silicon Labs SI8420BB-D |
| 7    | Cer Cap 47pF 50V COG 0603    | 1   | C21                | TDK C1608COG1H470J      |
| 8    | Cer Cap 150pF 50V COG 0603   | 1   | C26                | TDK C1608COG1H151J      |
| 9    | Cer Cap 470pF 50V COG 0603   | 1   | C34                | TDK C1608COG1H471J      |
| 10   | Cer Cap 1000pF 50V X7R 0603  | 2   | C19, C37           | TDK C1608X7R1H102K      |
| 11   | Cer Cap 2000pF 50V COG 0603  | 2   | C27, C32           | TDK C1608COG1H222J      |
| 12   | Cer Cap 6800pF 50V COG 0603  | 1   | C28                | TDK C1608COG1H682J      |
| 13   | Cer Cap 0.022uF 25V COG 0603 | 1   | C35                | TDK C1608COG1E223J      |
| 14   | Cer Cap 0.1uF 50V X7R 0603   | 3   | C2, C33, C36       | TDK C1608X7R1H104K      |
| 15   | Cer Cap 1.0uF 16V X7R 0603   | 2   | C25, C31, C29, C20 | TDK C1608X7R1C105K      |
| 16   | Cer Cap 470pF 50V COG 0805   | 2   | C15, C16           | KEMT C0805C471M5RAC     |
| 17   | Cer Cap 0.1uF 100V X7R 0805  | 2   | C17, C24           | TDK C2012X7R2A104K      |
| 18   | Cer Cap 0.33uF 50V X7R 0805  | 1   | C7                 | TDK C2012X7R1H334K      |
| 19   | Cer Cap 2.2uF 16V X7R 0805   | 2   | C1, C22            | TDK C2012X7R1C225K      |

**Table 1. Bill of Materials (BOM) (continued)**

| Item | Part Description                 | Qty | Ref Designator | Remark                  |
|------|----------------------------------|-----|----------------|-------------------------|
| 20   | Cer Cap 4.7uF 16V X7R 1206       | 1   | C18            | TDK C3216X7R1C475K      |
| 21   | Cer Cap 22uF 6.3V X5R 1206       | 4   | C11–C14        | TDK C3216X5R0J226M      |
| 22   | Cer Cap 2200pF 2000V X7R 1812    | 1   | C38            | TDK C4532X7R3D222K      |
| 23   | Cer Cap 6.8uF 50V X7R 1812       | 4   | C3–C6          | TDK C4532X7R1H685M      |
| 24   | POSCAP 220uF 6.3V                | 3   | C8–C10         | Sanyo 6TPE220MI         |
| 25   | Res 2.8 $\Omega$ 0.1W 1% 0603    | 1   | R12            | Vishay CRCW06032R80F    |
| 26   | Res 10 $\Omega$ 0.1W 1% 0603     | 2   | R17, R35       | Vishay CRCW060310R0F    |
| 27   | Res 100 $\Omega$ 0.1W 1% 0603    | 3   | R25, R27       | Vishay CRCW06031000F    |
| 28   | Res 549 $\Omega$ 0.1W 1% 0603    | 1   | R21            | Vishay CRCW06035490F    |
| 29   | Res 1K $\Omega$ 0.1W 1% 0603     | 4   | R13, R18       | Vishay CRCW06031001F    |
| 30   | Res 1.58K $\Omega$ 0.1W 1% 0603  | 1   | R24            | Vishay CRCW06031581F    |
| 31   | Res 2.0K $\Omega$ 0.1W 1% 0603   | 1   | R31            | Vishay CRCW06032001F    |
| 32   | Res 4.12K $\Omega$ 0.1W 1% 0603  | 1   | R20            | Vishay CRCW06034121F    |
| 33   | Res 5.11K $\Omega$ 0.1W 1% 0603  | 1   | R32            | Vishay CRCW06035111F    |
| 34   | Res 8.06K $\Omega$ 0.1W 1% 0603  | 1   | R22            | Vishay CRCW06038061F    |
| 35   | Res 10K $\Omega$ 0.1W 1% 0603    | 2   | R7, R30        | Vishay CRCW06031002F    |
| 36   | Res 10.2K $\Omega$ 0.1W 1% 0603  | 1   | R26            | Vishay CRCW06031022F    |
| 37   | Res 14.7K $\Omega$ 0.1W 1% 0603  | 1   | R33, R46       | Vishay CRCW06031472F    |
| 38   | Res 15K $\Omega$ 0.1W 1% 0603    | 1   | R29, R41       | Vishay CRCW06031502F    |
| 39   | Res 20K $\Omega$ 0.1W 1% 0603    | 1   | R34            | Vishay CRCW06032002F    |
| 40   | Res 25.5K $\Omega$ 0.1W 1% 0603  | 1   | R23            | Vishay CRCW06032552F    |
| 41   | Res 100K $\Omega$ 0.1W 1% 0603   | 2   | R3, R4         | Vishay CRCW06031003F    |
| 42   | NU 0805                          | 1   | R14            | NU                      |
| 43   | Res 10 $\Omega$ 1/10W 1% 0805    | 3   | R1, R11, R15   | Vishay CRCW080510R0F    |
| 44   | Res 49.9 $\Omega$ 1/10W 1% 0805  | 1   | R5             | Vishay CRCW080549R9F    |
| 45   | Res 2K $\Omega$ 1/10W 1% 0805    | 1   | R2, R19        | Vishay CRCW08052001F    |
| 46   | Res 10K $\Omega$ 1/10W 1% 0805   | 1   | R6             | Vishay CRCW08051002F    |
| 47   | Res 64.9K $\Omega$ 1/10W 1% 0805 | 1   | R16            | Vishay CRCW08056492F    |
| 48   | Res 100K $\Omega$ 1/10W 1% 0805  | 2   | R10, R36       | Vishay CRCW08051003F    |
| 49   | Res 10 $\Omega$ 1% 2010          | 2   | R8, R9         | Vishay CRCW201010R0F    |
| 50   | Schottky, Diode, 75V 150mA SOT23 | 1   | D1             | BAV70-TP                |
| 51   | Diode, 75V 250mA SOD-323         | 2   | D2, D4         | Central CMD4448         |
| 52   | Diodes, Rectifier, Bridge, 30V   | 1   | BR1            | BAT54BRW                |
| 53   | Zener 8.2V 5% SOT23              | 1   | Z1             | Central CMPZ4694        |
| 54   | Zener 11V 5% SOT23               | 1   | Z2             | Central CMPZ4698        |
| 55   | Zener 5.6V, 5% SOT23             | 1   | Z4             | Central CMPZ4690        |
|      | NU SOT23                         | 1   | Z3             | NU                      |
| 56   | N-FET 100V 25m $\Omega$          | 2   | Q1, Q2         | Vishay Si7456DP         |
| 57   | N-FET 30V 3m $\Omega$            | 4   | Q4–7           | Vishay Si7336ADP        |
| 58   | NPN, ZETEX 45V 2A                | 2   | Q3, Q8         | ZETEX FCX690B           |
| 59   | NPN, ON SEMI 45V, 225mW          | 1   | Q10            | MMBT6429LT1G            |
| 60   | NU                               | 1   | Q9             | NU                      |
| 61   | Inductor 2.2uH 5.4A              | 1   | L1             | TDK RLF7030T-2R2M5R4    |
| 62   | Inductor 1.2uH 37A               | 1   | L2             | Coilcraft SER2010-122MX |
| 63   | Transformer 8:5:2:2              | 1   | T1             | Coilcraft DA2025-AL     |
| 64   | Current XFR 100:1, 10A           | 1   | T2             | Pulse Engr P8208        |

**Table 1. Bill of Materials (BOM) (continued)**

| <b>Item</b> | <b>Part Description</b>     | <b>Qty</b> | <b>Ref Designator</b> | <b>Remark</b>                    |
|-------------|-----------------------------|------------|-----------------------|----------------------------------|
| 65          | Test Pin, Brick 0.040X0.5   | 6          | J1–3, J5–7            | Mill-Max 3104-2-00-80-00-00-08-0 |
| 66          | Test Pin, Brick 0.080X0.375 | 2          | J4, J8                | Mill-Max 3231-2-00-01-00-00-08-0 |

## 13 PCB Layouts

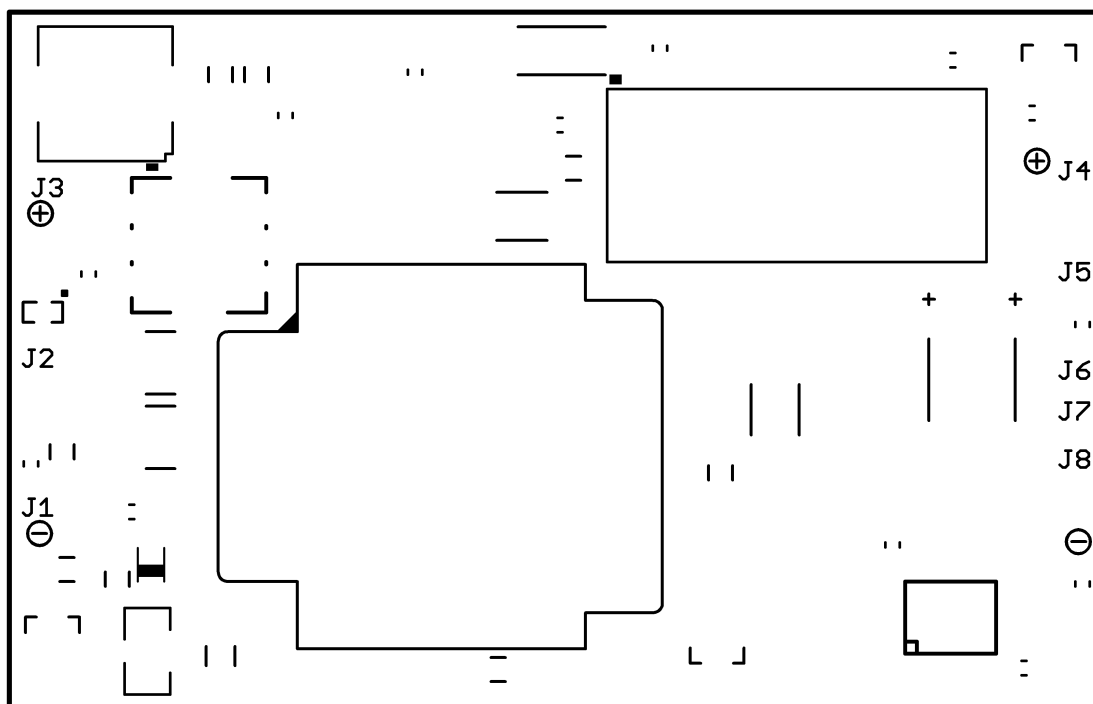


Figure 10. Top Side

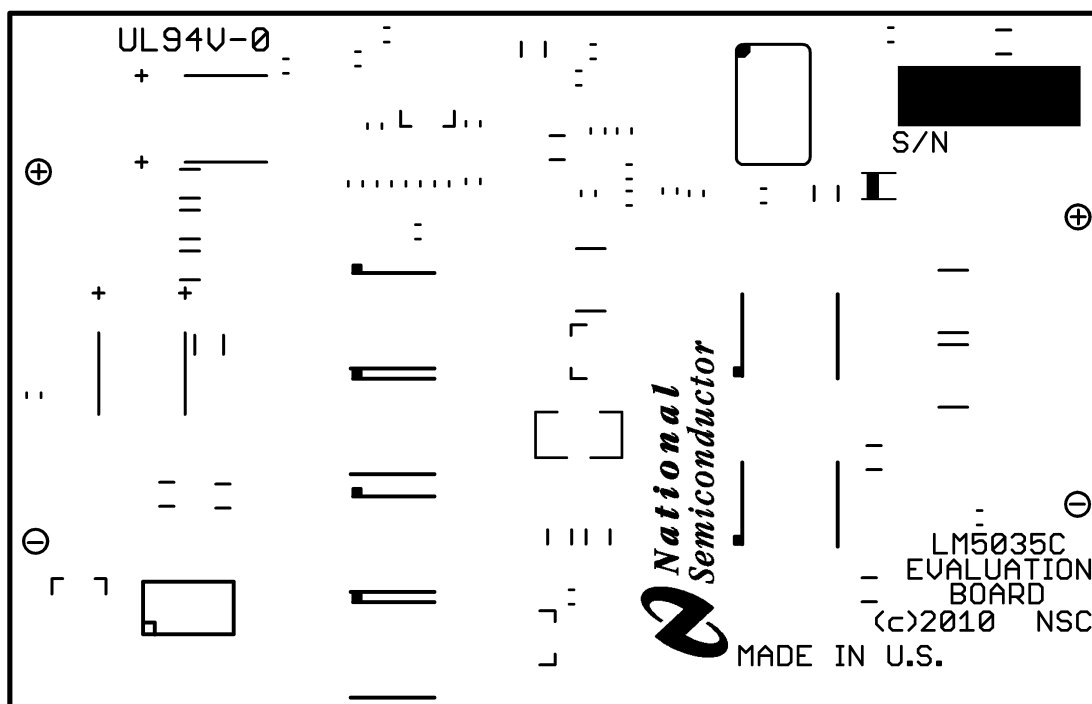


Figure 11. Bottom Side

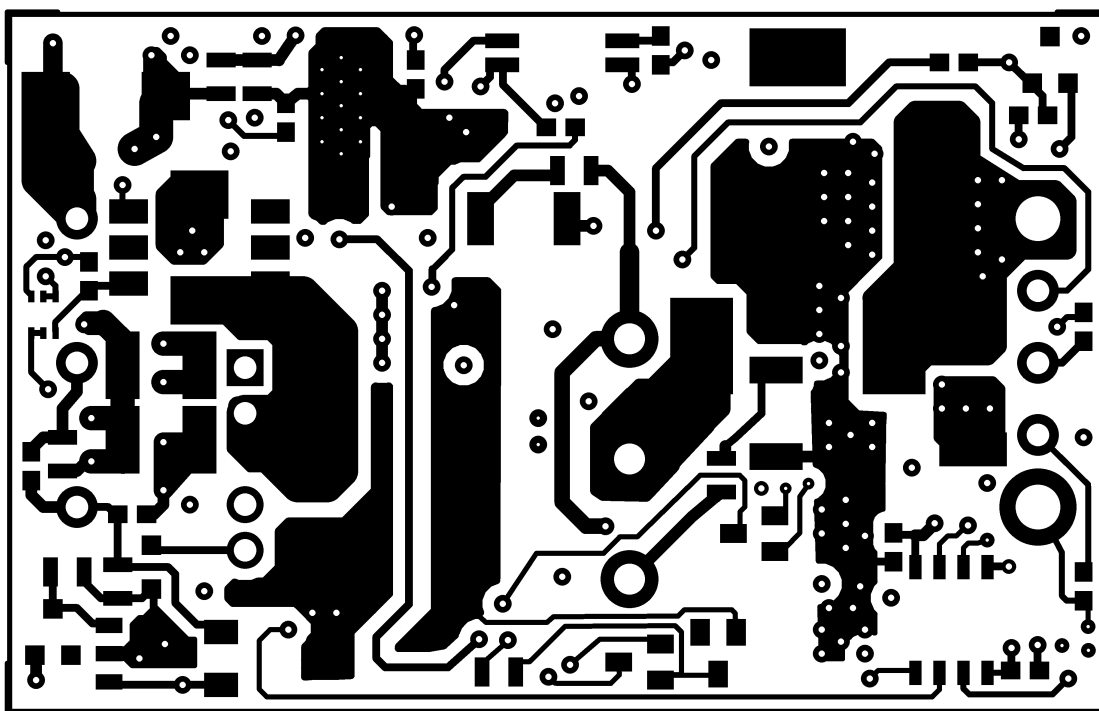


Figure 12. Layer 1

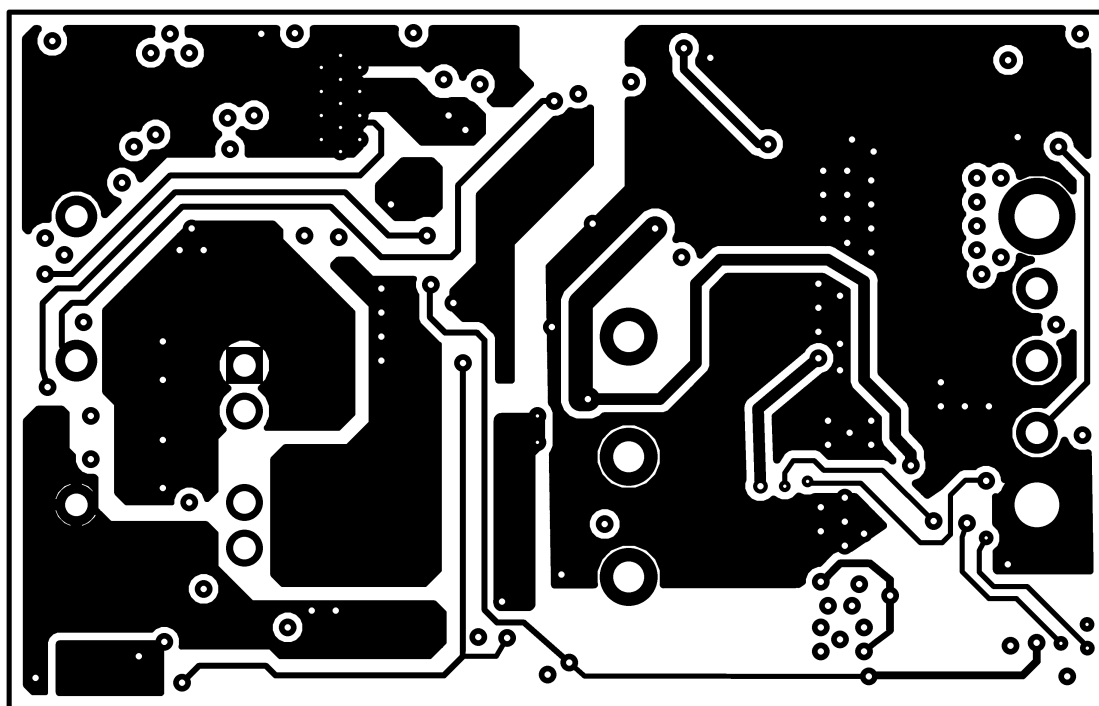


Figure 13. Layer 2

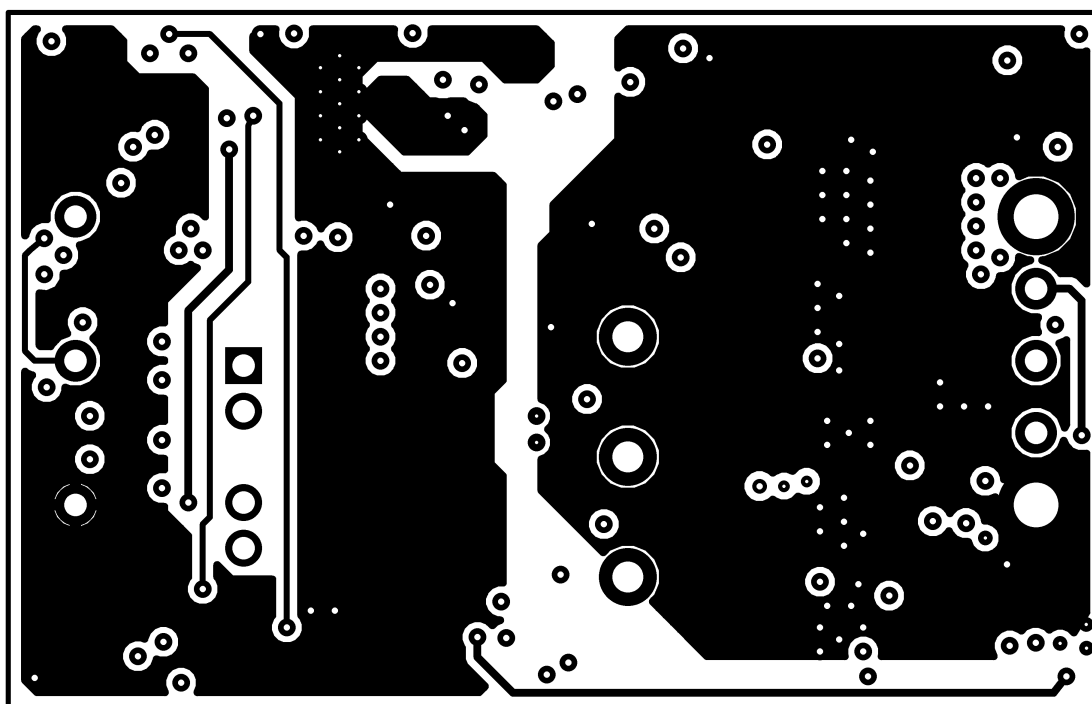


Figure 14. Layer 3

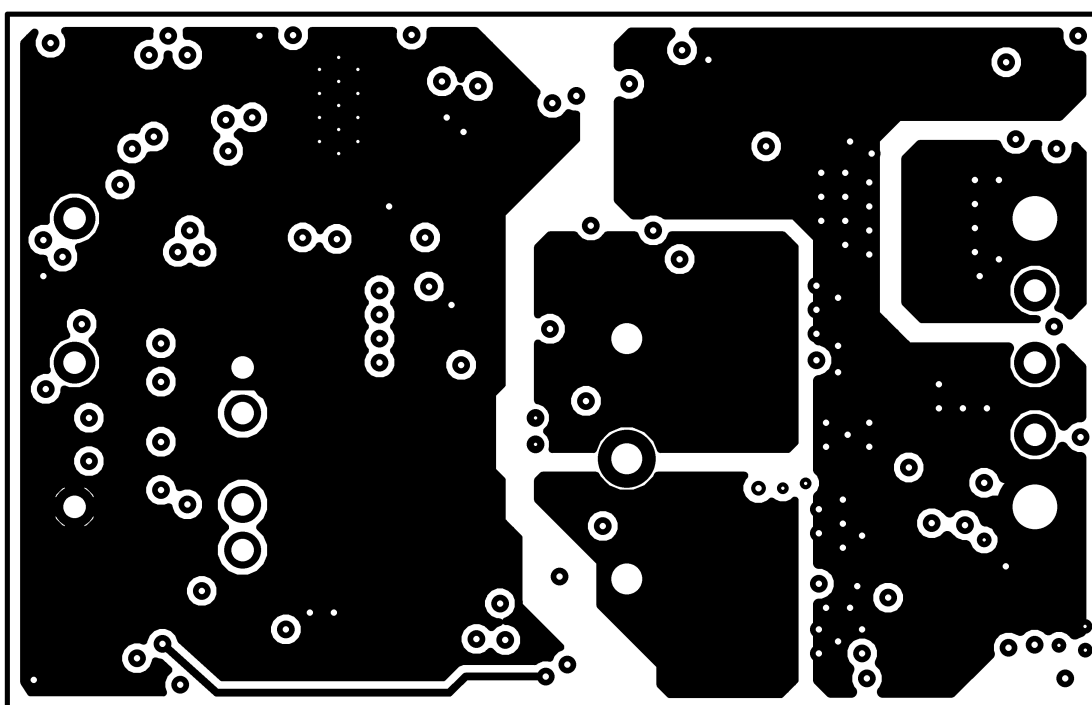


Figure 15. Layer 4

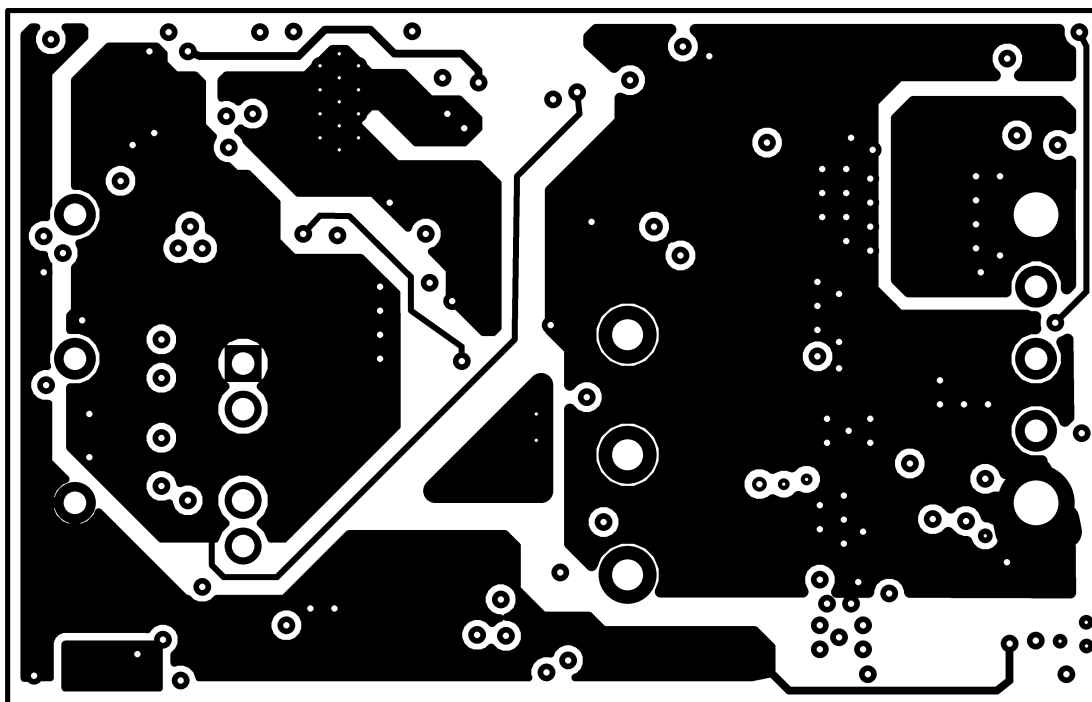


Figure 16. Layer 5

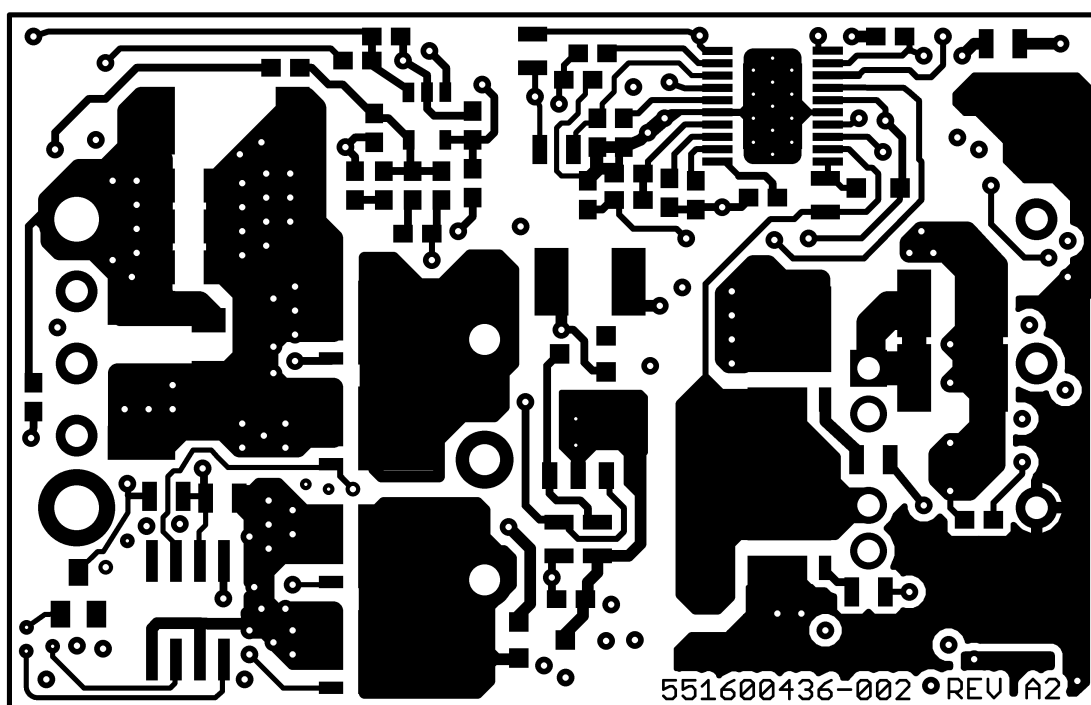


Figure 17. Layer 6

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### Products

|                              |                                                                                      |
|------------------------------|--------------------------------------------------------------------------------------|
| Audio                        | <a href="http://www.ti.com/audio">www.ti.com/audio</a>                               |
| Amplifiers                   | <a href="http://amplifier.ti.com">amplifier.ti.com</a>                               |
| Data Converters              | <a href="http://dataconverter.ti.com">dataconverter.ti.com</a>                       |
| DLP® Products                | <a href="http://www.dlp.com">www.dlp.com</a>                                         |
| DSP                          | <a href="http://dsp.ti.com">dsp.ti.com</a>                                           |
| Clocks and Timers            | <a href="http://www.ti.com/clocks">www.ti.com/clocks</a>                             |
| Interface                    | <a href="http://interface.ti.com">interface.ti.com</a>                               |
| Logic                        | <a href="http://logic.ti.com">logic.ti.com</a>                                       |
| Power Mgmt                   | <a href="http://power.ti.com">power.ti.com</a>                                       |
| Microcontrollers             | <a href="http://microcontroller.ti.com">microcontroller.ti.com</a>                   |
| RFID                         | <a href="http://www.ti-rfid.com">www.ti-rfid.com</a>                                 |
| OMAP Applications Processors | <a href="http://www.ti.com/omap">www.ti.com/omap</a>                                 |
| Wireless Connectivity        | <a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a> |

### Applications

|                               |                                                                                          |
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