

HIP6006/7EVAL1

DC-DC Converters for Microprocessors with Fixed Core Voltage Requirements

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**Introduction**

Today's high-performance microprocessors present many challenges to their power source. High power consumption, low bus voltages, and fast load changes are the principal characteristics which have led to the need for a switch-mode DC-DC converter local to the microprocessor.

Intel has specified Voltage Regulator Modules (VRMs) for the Pentium Pro and Pentium II microprocessors [1]. These specifications detail the requirements imposed upon the input power source(s) by the Pentium Pro and Pentium II and provide the computer industry with standard DC-DC converter solutions. A common requirement of these and similar processors are decreasing supply voltages as the processor clock frequency increases.

The Intersil HIP6002-5 pulse-width modulator (PWM) controllers are targeted specifically for DC-DC converters powering the Pentium Pro, Pentium II, and other high-performance microprocessors with varying core voltage requirements. The HIP6002 and HIP6003 have a 4-bit digital to analog converter (DAC) and the HIP6004-5 have a 5-bit DAC to address the 'moving target' processor core voltage.

The HIP6006 and HIP6007 use the same basic architecture of the HIP6002-5, but have a reduced feature set. One feature removed is the DAC, which allows the HIP6006 and HIP6007 to be packaged in a smaller 14 lead SOIC. These chips provide cost-effective solutions for point-of-use switch-mode DC-DC converters for many applications. This application note details the HIP6006 and HIP6007 in DC-DC converters for high-performance microprocessors with a fixed core voltage.

**Intersil HIP6006 and HIP6007**

The Intersil HIP6006 and HIP6007 are voltage-mode controllers with many functions needed for high-performance processors. Figure 1 shows a simple block diagram of the HIP6006 and HIP6007. Each contains a high-performance error amplifier, a high-accuracy reference, a programmable free-running oscillator, and overcurrent protection circuitry. The HIP6006 has two MOSFET drivers for use in synchronous-rectified Buck converters. The HIP6007 omits the lower MOSFET driver for standard Buck configurations. A more complete description of the parts can be found in their data sheets [2, 3].

**HIP6006/7 Reference Designs**

The HIP6006/7EVAL1 is an evaluation board which highlights the operation of the HIP6006 or the HIP6007 in an embedded motherboard application. The evaluation board can be configured as either a synchronous Buck (HIP6006EVAL1) or standard Buck (HIP6007EVAL1) converter.

**HIP6006EVAL1**

The HIP6006EVAL1 is a synchronous Buck converter capable of providing up to 9A of current at a fixed 2.5V output voltages. Simple resistor value changes allow for outputs as low as 1.3V. The schematic and bill-of-materials for this design can be found in the appendix.

**Efficiency**

Figure 2 displays the HIP6006EVAL1 efficiency versus load current for both 5V and 12V inputs with 100 linear feet per minute (LFM) of airflow. For a given output voltage and load, the efficiency is lower at higher input voltages. This is due primarily to higher MOSFET switching losses and is displayed in Figure 2.

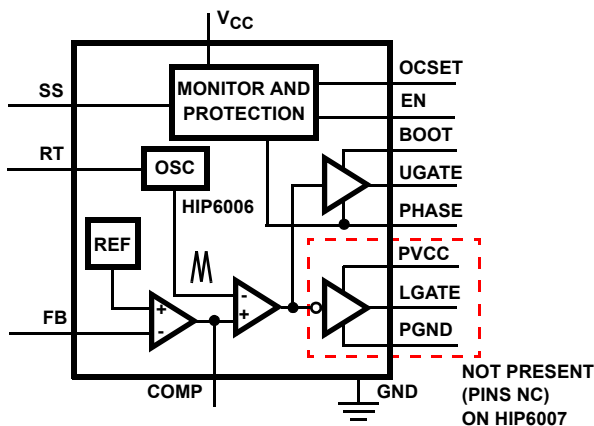


FIGURE 1. BLOCK DIAGRAM OF HIP6006 AND HIP6007

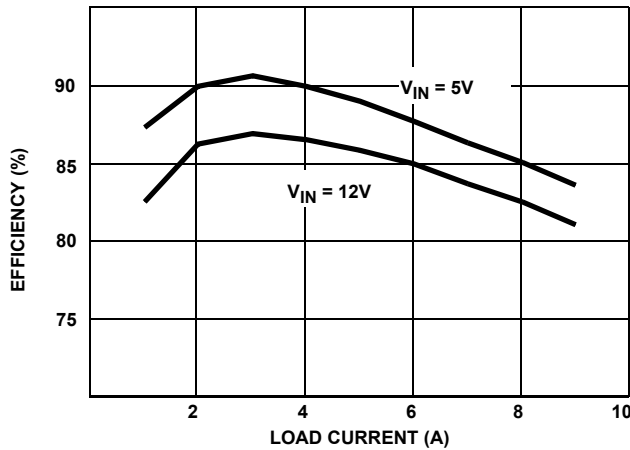


FIGURE 2. HIP6006EVAL1 EFFICIENCY vs LOAD

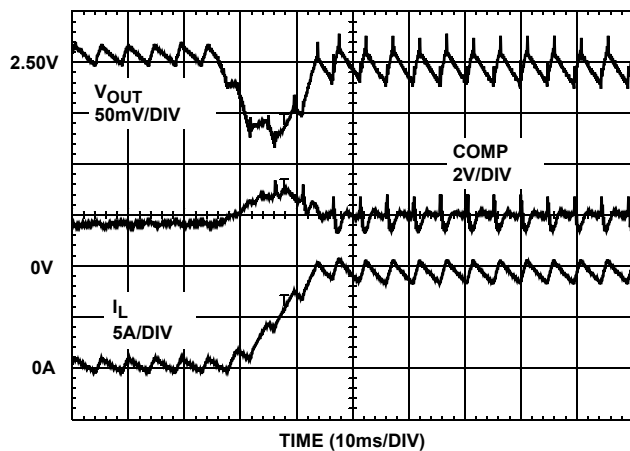


FIGURE 3. HIP6006EVAL1 TRANSIENT RESPONSE WITH  $V_{IN} = 12V$

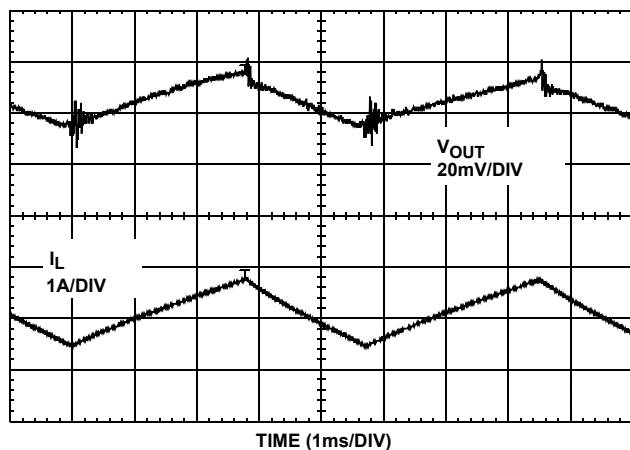


FIGURE 4. HIP6006EVAL1 OUTPUT VOLTAGE RIPPLE

**Transient Response**

Figure 3 shows a laboratory oscilloscope of the HIP6006EVAL1 in response to a 0-9A load transient application. The output voltage responds rapidly and is within 1% of its nominal value in less than 15 $\mu$ s.

**Output Voltage Ripple**

The output voltage ripple and inductor current of the HIP6006EVAL1 is shown in Figure 4. The input voltage is 5V and the load current is 9A for this oscilloscope. Peak-to-peak voltage ripple is about 20mV under these conditions.

**HIP6007EVAL1**

The HIP6007EVAL1 is a standard Buck converter capable of providing up to 9A of current. The schematic and bill-of-materials for this design can be found in the appendix. The HIP6007EVAL1 differs from the HIP6006EVAL1 in four ways:

1. U1 is a HIP6007
2. CR3 replaces Q2 and CR2
3. Jumper JP1 is added
4. L1 is a larger inductor

JP1 is needed because CR3 is a dual, common-cathode device and it is replacing a MOSFET. JP1 connects one device's anode (the MOSFET gate in the HIP6006EVAL1) to ground. The other anode and the common cathode replace the MOSFET source and drain respectively.

**Efficiency**

Figure 5 shows the efficiency data for the HIP6007EVAL1 under identical conditions as Figure 2 for the HIP6006EVAL1. Comparing the two graphs reveals that the Synchronous-Buck design is a little more efficient than the Standard-Buck design over most of the load range.

**Transient Response**

Figure 6 shows a laboratory oscilloscope of the HIP6007EVAL1 in response to a 0-9A load transient application. The output voltage responds a little slower than the HIP6006EVAL1, but still is within 1% of its nominal value in less than 25ms. Since the HIP6007EVAL1 uses a larger output inductor and identical control loop compensation (R3, R5, C14, and C15), the closed-loop gain crossover frequency is lower than for the HIP6006EVAL1. Check the Feedback Compensation section of either data sheet for details on loop compensation design. Table 1 details simulated closed-loop bandwidth and phase margin for both reference boards at both +5V and +12V input sources.

TABLE 1. CONTROL LOOP CHARACTERISTICS

|               | HIP6006EVAL1  |                | HIP6007EVAL1  |                |
|---------------|---------------|----------------|---------------|----------------|
|               | $V_{IN} = 5V$ | $V_{IN} = 12V$ | $V_{IN} = 5V$ | $V_{IN} = 12V$ |
| $f_{0dB}$     | 27KHz         | 61KHz          | 12KHz         | 28KHz          |
| $\phi$ MARGIN | 72°           | 62°            | 68°           | 71°            |

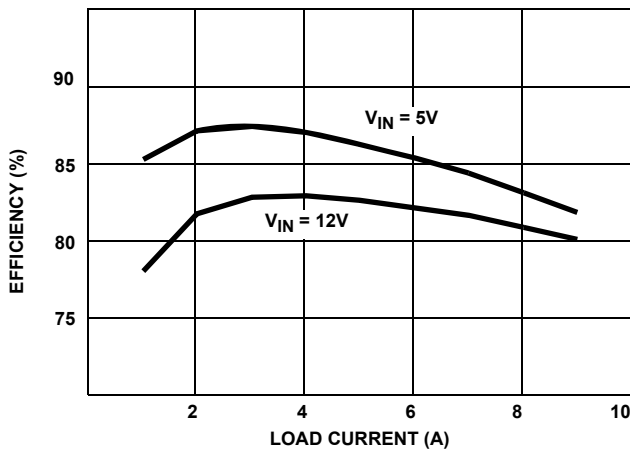


FIGURE 5. HIP6007EVAL1 EFFICIENCY vs LOAD

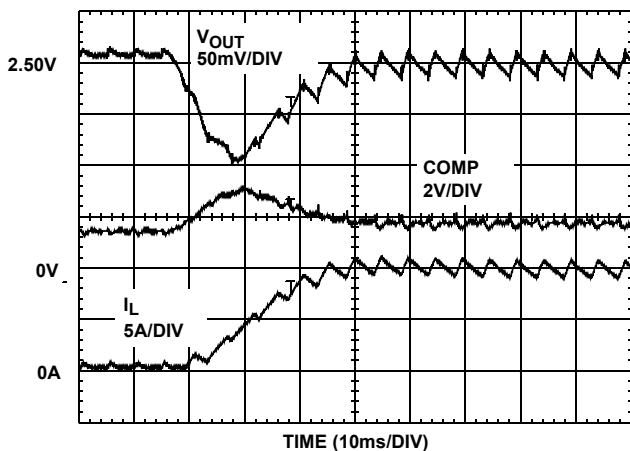
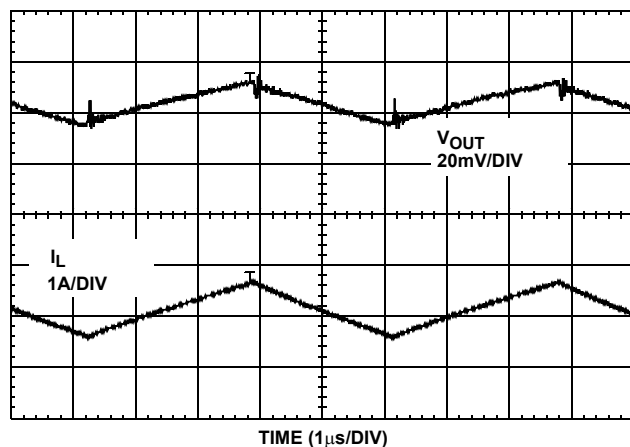
FIGURE 6. HIP6007EVAL1 TRANSIENT RESPONSE  
WITH  $V_{IN} = 12V$ 

FIGURE 7. HIP6007EVAL1 OUTPUT VOLTAGE RIPPLE

### Output Voltage Ripple

The output voltage ripple and inductor current of the HIP6007EVAL1 is shown in Figure 7. The input voltage is 5V and the load current is 9A for this oscillogram. Peak-to-peak voltage ripple is less than that for the HIP6006EVAL1 (about 15mV), since the output inductor is larger.

### OC Protection

Both the HIP6006EVAL1 and HIP6007EVAL1 have lossless overcurrent (OC) protection. This is accomplished via the current-sense function of the HIP600x family. The HIP6006 and HIP6007 sense converter load current by monitoring the drop across the upper MOSFET (Q1 in the schematics). By selecting the appropriate value of the OCSET resistor (R6), an overcurrent protection scheme is employed without the cost and power loss associated with an external current-sense resistor. See the *Over-Current Protection* section of either the HIP6006 and HIP6007 data sheet for details on the design procedure for the OCSET resistor.

### Customization of Reference Designs

The HIP6006EVAL1 and HIP6007EVAL1 reference designs are solutions for Pentium-class microprocessors with current demands of up to 9A. The two designs share much common circuitry and the same printed circuit board. Other than the four items listed under the *HIP6007EVAL1* section, one basic design is employed to meet many different applications. The evaluation boards can be powered from +5V or +12V and a standard Buck or a synchronous Buck topology may be employed. Employing one basic design for numerous applications involves some trade-offs. These trade-offs are discussed below to help the user optimize for a given application.

### Control Loop Bandwidth/Transient Response

Table 1 shows how the control loop characteristics vary with line voltage and topology. The line voltage determines the amount of DC gain, which directly affects the modulator (control-to-output) transfer function. The topology (standard buck or synchronous buck) is important because we have chosen to use a larger output inductor for the standard buck (HIP6005) design. This lowers the boundary of continuous conduction mode (ccm) and discontinuous conduction mode (dcm) operation. Staying in ccm at light loads can have an adverse affect on transient response of the converter. The HIP6006EVAL1 design will not go into dcm operation because the lower MOSFET conducts current even at light or zero load conditions.

From Table 1, we see that the highest control loop bandwidth is the HIP6006EVAL1 with  $V_{IN} = 12V$ . The transient response of the converter for this case is shown in Figure 3. The other three cases have slower responding loops and can be improved with value changes in the compensation components. Table 2 details suggested changes and the improved control loop characteristics for the three applications with slower control loops.

TABLE 2. MODIFICATIONS TO CONTROL LOOP

|                     | HIP6006EVAL1         |                       | HIP6007EVAL1         |                       |
|---------------------|----------------------|-----------------------|----------------------|-----------------------|
|                     | V <sub>IN</sub> = 5V | V <sub>IN</sub> = 12V | V <sub>IN</sub> = 5V | V <sub>IN</sub> = 12V |
| R5                  | 30.1K                | no change             | 80.6K                | 30.1K                 |
| C14                 | no change            | no change             | 10p                  | no change             |
| f <sub>0dB</sub>    | 47kHz                | 61kHz                 | 44kHz                | 48kHz                 |
| Φ <sub>MARGIN</sub> | 53°                  | 62°                   | 40°                  | 52°                   |

### Ripple Voltage

The amount of ripple voltage on the output of the DC-DC converter varies with input voltage, switching frequency, output inductor, and output capacitors. For a fixed switching frequency and output filter, the voltage ripple increases with higher input voltage. The ripple content of the output voltage can be estimated with the following simple equation:

$$\Delta V_{OUT} = \Delta I_L \cdot ESR$$

where

$$\Delta I_L = \frac{(V_{IN} - V_{OUT}) \cdot \frac{V_{OUT}}{V_{IN}} \cdot T_s}{L_{OUT}}$$

ESR = equivalent series resistance of output capacitors

T<sub>s</sub> = switching period (1/F<sub>s</sub>)

L<sub>OUT</sub> = output inductance

Therefore, for equivalent output ripple performance at V<sub>IN</sub> = 12V as at 5V, the output filter or switching frequency must change. Assuming 200KHz operation is desired, either the output inductor value should increase or the number of parallel output capacitors should increase (to decrease the effective ESR).

### Increased Output Power Capability

The HIP6006/7EVAL1 printed circuit board is laid out with flexibility to increase the power level of the DC-DC converter beyond 9A. Locations for additional input capacitors and output capacitors are provided. In conjunction with higher current MOSFETs, Schottky rectifiers, and inductors, the evaluation board can be tailored for applications requiring upwards of 15A. The HIP6006 and HIP6007 data sheets' Component Selection Guidelines sections help the user with the design issues for these applications. Of course, the HIP6006/7EVAL1 can be modified for more cost-effective solutions at lower currents as well.

### MOSFET Selection

As a supplement to the data sheets' application information on MOSFET Selection Considerations, this section shows graphically that a larger, lower r<sub>DS(ON)</sub> MOSFET does not always improve converter efficiency. Figure 8 shows that smaller RFP25N05 MOSFETs are more efficient over most of the line and load range than larger RFP45N06 MOSFETs. The

RFP25N05 (used on the HIP6006/7EVAL1) has a r<sub>DS(ON)</sub> equal to 47mΩ (maximum at 25°C) versus 28mΩ for the RFP45N06. In comparison to the RFP25N05, the RFP45N06 MOSFETs increased switching losses are greater than its decreased conduction losses at load currents up to about 7A with a 5V input and about 9A with a 12V input.

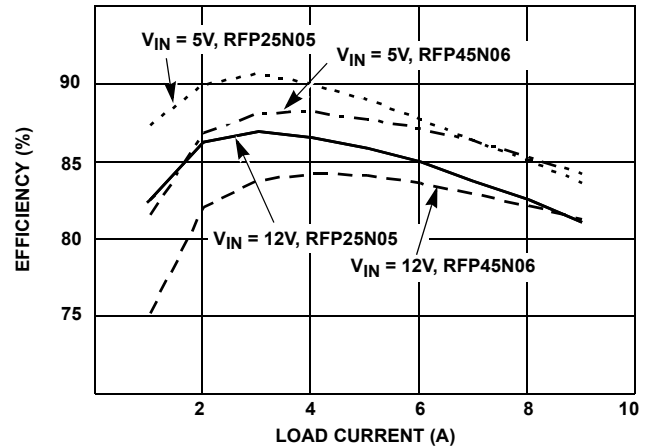


FIGURE 8. HIP6006EVAL1 EFFICIENCY WITH EITHER RFP25N05 MOSFETs OR RFP45N06 MOSFETs

### Conclusion

The HIP6006EVAL1 and HIP6007EVAL1 are DC-DC converters reference designs for microprocessors with fixed core voltages and current requirements of up to 9A. In addition, the designs can be modified for applications with different requirements. The printed circuit board is laid out to accommodate the necessary components for operation at currents up to 15A.

### References

For Intersil documents available on the web, see <http://www.intersil.com/>

- [1] *Pentium-Pro Processor Power Distribution Guidelines*, Intel Application Note AP-523, November, 1995.
- [2] *HIP6006 Data Sheet*, Intersil Corporation, Doc. No. 4306.
- [3] *HIP6007 Data Sheet*, Intersil Corporation, Doc. No. 4307.

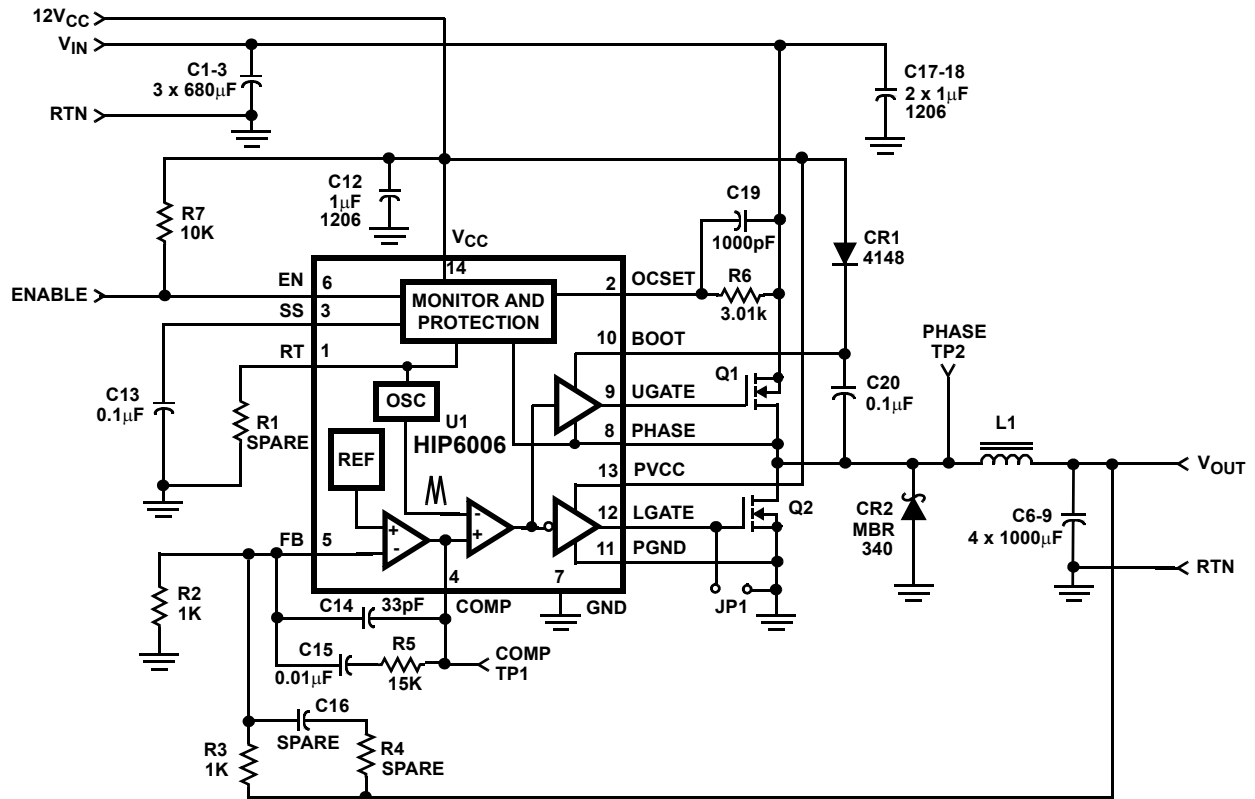


FIGURE 9. HIP6006EVAL1 SCHEMATIC

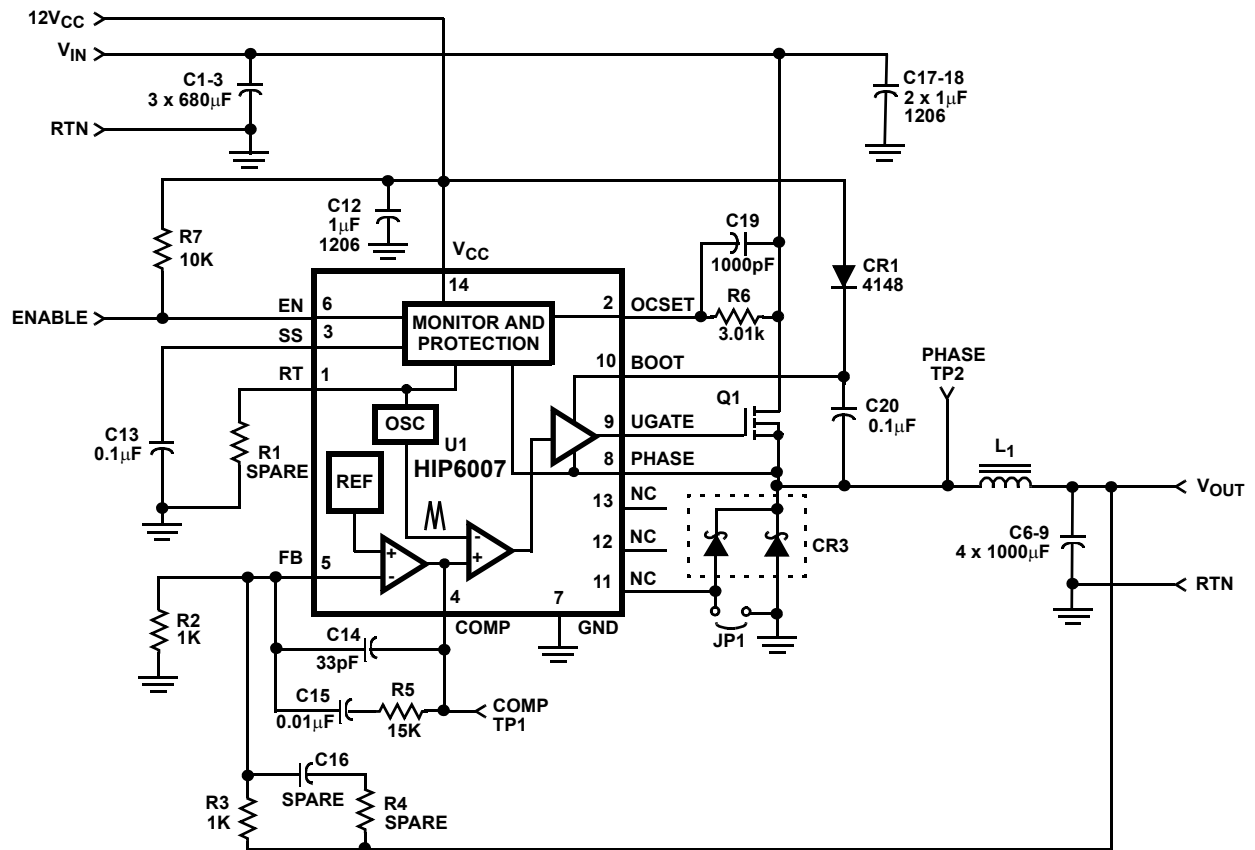


FIGURE 10. HIP6007EVAL1 SCHEMATIC

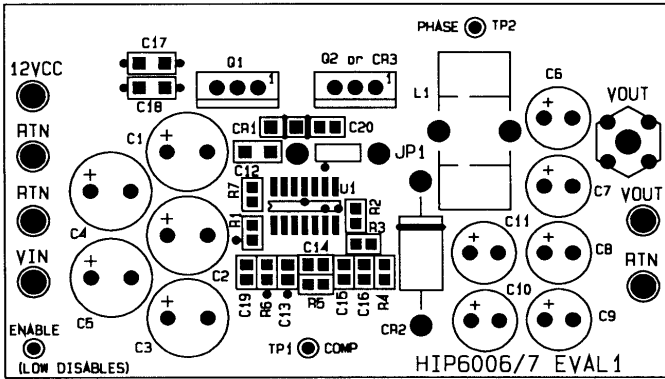
**Bill of Materials for HIP6006EVAL1**

| PART NUMBER             | DESCRIPTION  | PACKAGE        | QTY | REF   | VENDOR               |
|-------------------------|--|----------------|-----|---|----------------------|
| 25MV680GX               | 680 $\mu$ F, 25V Aluminum Capacitor                                | Radial 10 x 22 | 3   | C1 - C3   | Sanyo                |
| 6MV1000GX               | 1000 $\mu$ F, 6.3V Aluminum Capacitor                              | Radial 8 x 20  | 4   | C6 - C9   | Sanyo                |
| 1206YZ105MAT1A          | 1.0 $\mu$ F, 16V, X7S Ceramic Capacitor                            | 1206           | 3   | C12, C17-C18  | AVX                  |
| 1000pF Ceramic          | 1nF, X7R Ceramic Capacitor   | 0805           | 1   | C19   | Various              |
| 0.1uF Ceramic           | 0.1 $\mu$ F, 25V X7R Ceramic Capacitor                             | 0805           | 2   | C13, C20  | AVX/Panasonic        |
| 0.01uF Ceramic          | 0.01 $\mu$ F, X7R Ceramic Capacitor                                | 0805           | 1   | C15   | Various              |
| 33pF Ceramic            | 33pF, X7R Ceramic Capacitor  | 0805           | 1   | C14   | Various              |
| Spare                   | Spare Ceramic Capacitor  | 0805           |     | C16   |                      |
| 1N4148                  | Rectifier 75V  | DO35           | 1   | CR1   | Various              |
| MBR340                  | 3A, 40V, Schottky  | Axial          | 1   | CR2   | Motorola             |
| CTX09-13313-X1<br>PO343 | 5.3 $\mu$ H, 12A Inductor<br>T50-52B Core, 10 Turns of 16 AWG Wire | Wound Toroid   | 1   | L1  | Coiltronics<br>Pulse |
| RFP25N05                | 47m $\Omega$ , 50V MOSFET  | TO220          | 2   | Q1, Q2  | Intersil             |
| HIP6006                 | Synchronous Rectified Buck Controller                              | SOIC-14        | 1   | U1  | Intersil             |
| 10k $\Omega$            | 10k $\Omega$ , 5% 0.1W, Resistor                                   | 0805           | 1   | R7  | Various              |
| Spare                   | Spare 0.1W, Resistor   | 0805           |     | R1,R4   |                      |
| 15k $\Omega$            | 15k $\Omega$ , 5%, 0.1W, Resistor                                  | 0805           | 1   | R5  | Various              |
| 1k $\Omega$             | 1k $\Omega$ , 5%, 0.1W, Resistor                                   | 0805           | 2   | R2-R3   | Various              |
| 3.01k $\Omega$          | 3.01k $\Omega$ , 1%, 0.1W, Resistor                                | 0805           | 1   | R6  | Various              |
| 576802B00000            | TO-220 Clip-on Heatsink  |                | 2   |   | AAVID                |
| 1514-2                  | Terminal Post  |                | 6   | V <sub>IN</sub> , 12V <sub>CC</sub> ,<br>V <sub>OUT</sub> , RTN | Keystone             |
| 1314353-00              | Scope Probe Test Point   |                | 1   | V <sub>OUT</sub>  | Tektronics           |
| SPCJ-123-01             | Test Point   |                | 3   | ENABLE, TP1,<br>TP2   | Jolo                 |

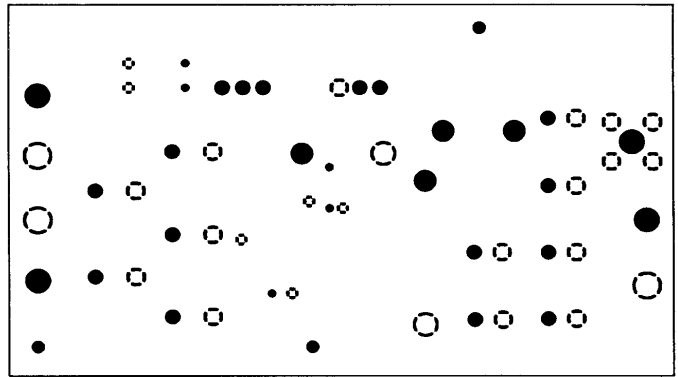
**Bill of Materials for HIP6007EVAL1**

| PART NUMBER             | DESCRIPTION   | PACKAGE        | QTY | REF   | VENDOR               |
|-------------------------|---|----------------|-----|---|----------------------|
| 25MV680GX               | 680 $\mu$ F, 25V Aluminum Capacitor                             | Radial 10 x 22 | 3   | C1 - C3   | Sanyo                |
| 6MV1000GX               | 1000 $\mu$ F, 6.3V Aluminum Capacitor                           | Radial 8 x 20  | 4   | C6 - C9   | Sanyo                |
| 1206YZ105MAT1A          | 1.0 $\mu$ F, 16V, X7S Ceramic Capacitor                         | 1206           | 3   | C12, C17-C18  | AVX                  |
| 1000pF Ceramic          | 1nF, X7R Ceramic Capacitor                                      | 0805           | 1   | C19   | Various              |
| 0.1 $\mu$ F Ceramic     | 0.1 $\mu$ F, 25 V X7R Ceramic Capacitor                         | 0805           | 2   | C13, C20  | AVX/Panasonic        |
| 0.01 $\mu$ F Ceramic    | 0.01 $\mu$ F, X7R Ceramic Capacitor                             | 0805           | 1   | C15   | Various              |
| 33pF Ceramic            | 33pF, X7R Ceramic Capacitor                                     | 0805           | 1   | C14   | Various              |
| Spare                   | Spare Ceramic Capacitor   | 0805           |     | C16   |                      |
| 1N4148                  | Rectifier 75V   | DO35           | 1   | CR1   | Various              |
| MBR1535CT               | 15A, 35V, Schottky  | TO220          | 1   | CR3   | Motorola             |
| CTX09-13337-X1<br>PO345 | 7 $\mu$ H, 12A Inductor<br>T60-52 Core, 14 turns of 17 AWG wire | Wound Toroid   | 1   | L1  | Coiltronics<br>Pulse |
| RFP25N05                | 47m $\Omega$ , 50V MOSFET                                       | TO220          | 1   | Q1  | Intersil             |
| HIP6007                 | Synchronous Rectified Buck Controller                           | SOIC-14        | 1   | U1  | Intersil             |
| 10k $\Omega$            | 10k $\Omega$ , 5%, 0.1W, Resistor                               | 0805           | 1   | R7  | Various              |
| Spare                   | Spare 0.1W, Resistor  | 0805           |     | R1, R4  |                      |
| 15k $\Omega$            | 15k $\Omega$ , 5%, 0.1W, Resistor                               | 0805           | 1   | R5  | Various              |
| 1k $\Omega$             | 1k $\Omega$ , 5%, 0.1W, Resistor                                | 0805           | 2   | R2-R3   | Various              |
| 3.01k $\Omega$          | 3.01k $\Omega$ , 1%, 0.1W, Resistor                             | 0805           | 1   | R6  | Various              |
| 576802B00000            | TO-220 Clip-on Heatsink   |                | 2   |   | AAVID                |
| 1514-2                  | Terminal Post   |                | 6   | V <sub>IN</sub> , 12V <sub>CC</sub> ,<br>V <sub>OUT</sub> , RTN | Keystone             |
| 1314353-00              | Scope Probe Test Point  |                | 1   | V <sub>OUT</sub>  | Tektronics           |
| SPCJ-123-01             | Test Point  |                | 3   | ENABLE, TP1,<br>TP2   | Jolo                 |

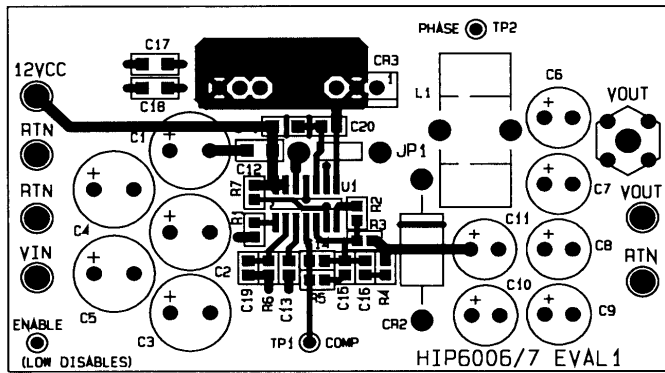
TOP  
SILK SCREEN



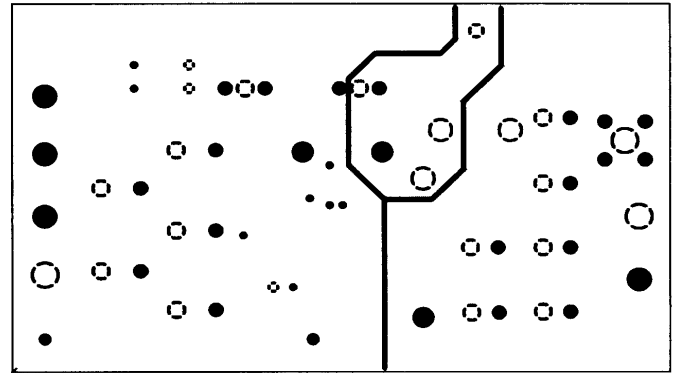
INT. GND. PLANE



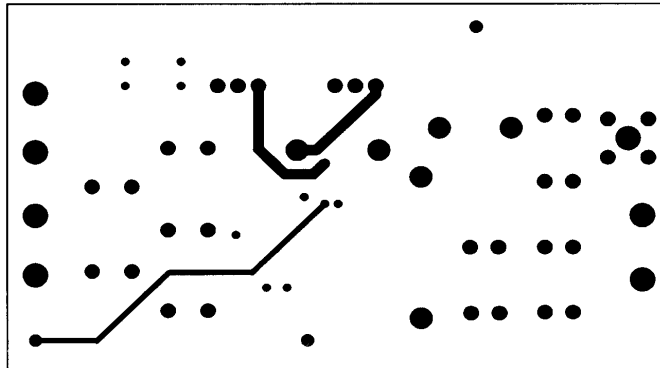
COMPONENT SIDE



INTERNAL ONE



SOLDER SIDE





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