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ISL6559EVAL1: Voltage Regulator Module Solution for AMD Hammer Family Processors

Application Note

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AN1132

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Introduction

The AMD Hammer family microprocessors feature higher clock speeds and greater device density than previous product families. The power management solution for this next generation family of microprocessors must contend with lower core voltages, tighter transient specifications, and higher peak current demands. Responding to the changing power management needs of its customers, Intersil introduces the ISL6559 controller to power the AMD Hammer family microprocessors.

Intersil ISL6559 and ISL6605

The ISL6559EVAL1 is a versatile voltage regulator-module (VRM) design. The evaluation board comes configured for 4-phase multi-phase buck operation, designed to meet AMD Hammer Family Desktop Processor specifications. The board can easily be modified to support evaluation at lower current specifications. The ISL6559 controller functions are specifically designed to compliment and support the Hammer Family feature set with ISL6605 drivers. The chipset forms a highly integrated solution for AMD Hammer processor applications.

The ISL6559 regulates output voltage and balances load currents for two to four synchronous buck converter channels. The controller features a 5-bit DAC, which provides a digital interface for accurate voltage programming over the entire Hammer Family range of 0.800V to 1.550V. New multi-phase family features include differential remote output voltage sensing, to improve regulation tolerance; pin-adjustable reference offset, for ease of implementation; VID-on-the-Fly, to respond to DAC changes during operation; and optional load line regulation. For a more detailed description of the ISL6559 functionality, refer to the data sheet [1].

The ISL6605 driver is chosen to drive two N-Channel power MOSFETs in a synchronous-rectified buck converter channel. Each channel has a single logic input that controls the upper and lower MOSFETs. Dead time is optimized on both switching edges to provide shoot-thru protection. Internal bootstrap circuitry only requires an external capacitor and provides better enhancement of the upper MOSFET. For a more detailed description of the ISL6605, refer to the data sheet [2].

The Intersil multi-phase family controller and driver portfolio continues to expand with new selections to better fit our customer's needs. Refer to our website for updated information, www.intersil.com.

ISL6559 VRM Reference Design

The evaluation kit consists of the ISL6559EVAL1 board, associated data sheets on the ISL6559 controller and ISL6605 driver, as well as this application note. The evaluation kit also includes the Elcon VRM test board which has an edged connector for the VRM to plug into. The evaluation kit provides convenient test points, a banana jack for power supply connectors, and an on-board transient load generator to facilitate the evaluation process. The ISL6559EVAL1 board and test board is configured to run off of a single 12V supply.

TABLE 1. 4-PHASE VRM DESIGN PARAMETERS

| PARAMETER | MIN | MAX |
|-------------------------|--------|----------------|
| Static Regulation | 1.109V | 1.250V |
| Transient Regulation | 1.109V | 1.250V |
| Continuous Load Current | 3A | 100A |
| Load Current Step | | 100A |
| Load Current Transient | | ~560A/ μ s |

The evaluation board meets the output voltage and current specifications, shown in Table 1, with the VID DIP switch (set to 01100 (1.250V)). The 1U VRM board is fabricated using 6 layers with 3oz copper on outer and 4oz copper on inner layers. The test board is implemented in 4-layer, 2oz copper. Layout plots and part lists are provided at the end of the application note for this design.

Quick Start Evaluation

Circuit Setup

The ISL6559EVAL1 board will arrive with the VID DIP switch (U2) set to 01100 (1.250V). If another output voltage level is desired, refer to the ISL6559 data sheet for the complete DAC table and change the VID switches accordingly. Note that changing the U2 VID states will change the dynamics of the load generator.

Input Power Connections

A single power supply connection is provided on the VRM test board. Insure connection is secure.

Two female banana jacks are provided for connection of the bench top power supply. Connect the +12V terminal to J5, and the common ground to terminal J6.

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Power Output Connections

The ISL6559EVAL1 output can be exercised using either resistive or electronic loads. Copper alloy terminal lugs provide connection points for loading. Tie the positive load connection to V_{CORE}, terminal J2 or J3, and the negative to ground, terminal J4 and J10. A shielded scope probe test point, J8, allows for inspection of the output voltage, V_{CORE}.

Enabling the Controller

The state of V_{CC}, EN, and FS/DIS dictate the beginning of a soft-start interval. The FS/DIS pin is used to set the per phase switching frequency on the evaluation board. Once the input and output terminal connections are made, remove the shunt across the jumper (J11) pins 3, 4 labeled OUT_EN if installed. The EN signal is released to rise above the ENABLE threshold of 1.23V nominal. Once the ENABLE threshold is exceeded, a soft-start interval is initiated. The output voltage will ramp in a controlled manner.

A resistor divider from the +12V input is connected to EN on the controller and the drivers to insure that the drivers and controller come up at the same time.

On-Board Load Transient Generator

Most bench-top electronic loads are not capable of producing the current slew rates required to emulate modern microprocessors. For this reason, a discrete transient load generator is provided on the VRM test board for evaluation.

The VRM test board is designed to work in conjunction with the ISL6559 eval board. The VRM test board schematic is located in later pages of this application note. In addition to the transient load generator, the board consists of a card edge connector (J1), pull up resistors for the VID pins, and scope probes as well as turrets for monitoring the input and output voltage. This board comes configured with an all ceramic output filter, but you have the option to add Oscon or larger ceramic capacitors.

The on board transient circuit can be modified to operate at different frequencies or have different load steps. As received the on-board transient is designed to operate at 33Hz. The current step is dependent on the di/dt of the transient load which is dependent on the output voltage and the number of switches being used as seen in Figure 1.

Where: (EQ. 1)

- $di/dt = V_{out} \times N / (t_{rise} \times R_{EQ})$
- di/dt is the transient slew rate
- N is the number of switches
- t_{rise} is the rise time
- R_{EQ} is the equivalent resistance
- V_{OUT} is the output voltage

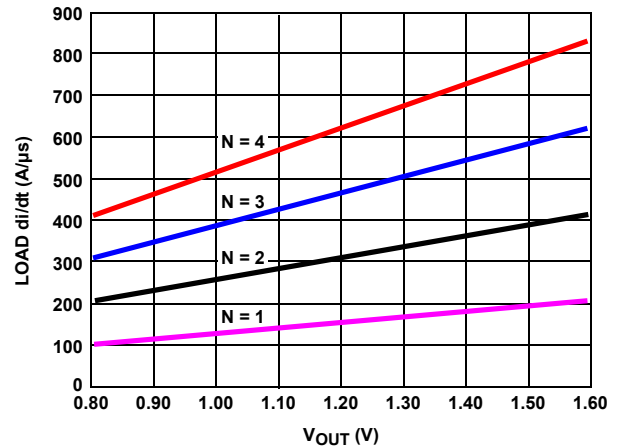


FIGURE 1. PLOT OF TRANSIENT LOAD CIRCUIT

The load step can be verified by measuring the voltage at J7 of the test board. Once you have that value you can calculate your current step. The di/dt can be verified by measuring the rise time of the load step. Rise time is measured from 10% and 90% of the transient voltage. Plug that value into equation 1 to calculate the di/dt. The rise time can be improved by switching to thin film resistors from the wire wound resistors.

The low frequency transient is running at 33Hz but can be modified to run faster by simply adjusting the values of R₆, R₇ and C₈₀. Frequency can be increased by decreasing the value of C₈₀ (currently 10μF). If you want to change the duty cycle, ON time is proportional to R₇ (402Ω) and the OFF time is proportional to R₆ (46.7kΩ). It may be necessary to decrease the ON time at high frequency. If the duty cycle is too high, the switching transistor and sense resistors will overheat. Do not use less than 10Ω for R₇ or the max pulsed current in Q1 will exceed its rating.

The load resistor values are 120mΩ stacked 3 high that gives effectively 40mΩ, the $r_{DS(ON)}$ of the FETs is 16mΩ. Thus, the equivalent resistance for each switch is 56mΩ.

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ISL6559 VRM Performance

Soft-Start Interval

The typical start-up waveforms for the ISL6559EVAL1 are shown in Figure 2. The DAC is set to 01100 (1.250V) and the converter is started into a 100A load. The OUT_EN jumper is removed and the voltage on EN quickly rises above the ISL6559 enable threshold, triggering a soft-start interval. The switching frequency of the converter is 600kHz, therefore the soft-start interval (SS Interval) is approximately 3.4ms per the datasheet. On this evaluation board the 5V linear supply that is used to power up the controller is disabled when the enable pin is tied low. This causes the PGOOD pin to float high until VCC rises above the POR threshold of the controller and pulls the PGOOD pin low.

The output undervoltage threshold is defined as the DAC setting minus 350mV. Once this threshold is surpassed, the internal pull down on the PGOOD pin is released.

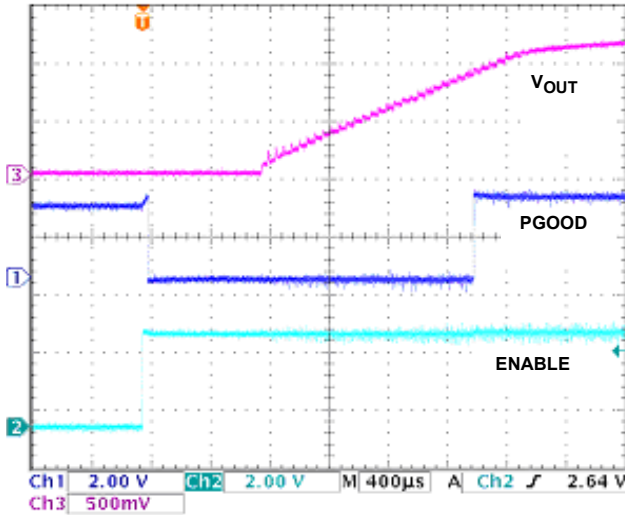


FIGURE 2. SOFT-START INTERVAL WAVEFORMS

Transient Response

The transient slew rate is designed for a nominal 560A/µs, but can be adjusted as described previously. During a transient, the core voltage is required to remain within the static window of ±50mV around the DAC setting. The on-board load generator and a bench-top electronic load simulate these conditions.

The OFS pin allows the user to positively offset the DAC reference voltage by placing a correctly sized resistor from this pin to ground, R14. For this design, the resistor value is 0Ω, which equates to no offset at no-load. Load-line regulation is supported by the ISL6559. The average current of the four active channels flows out I_{OUT}. When this pin is connected to FB, this average current creates a voltage drop across R9. This voltage drop is proportional to the output

current of the converter and effectively creates an output voltage droop; the output impedance is 0.91mΩ.

The rising edge transient response of the ISL6559EVAL1 to the aforementioned maximum load conditions is shown in Figure 3. A bench-top electronic load draws 0A continuously from the converter, while the on-board load generator provides a ~100A load step. This design incorporates an all ceramic output filter which reduces the effective ESR/ESL resulting in an excellent transient response with a measured bandwidth of 140kHz.

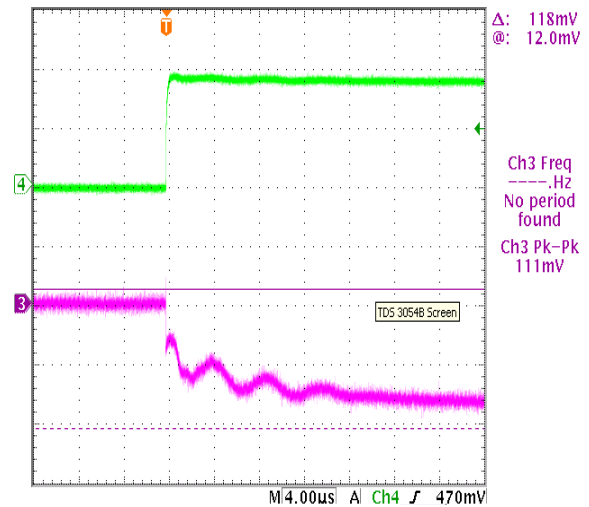


FIGURE 3. RISING EDGE TRANSIENT RESPONSE

Figure 4 shows the load release response of the converter. There is no overshoot due to the low ESR and ESL of the all ceramic output capacitor bank and small output inductors (100nH) employed in this design.

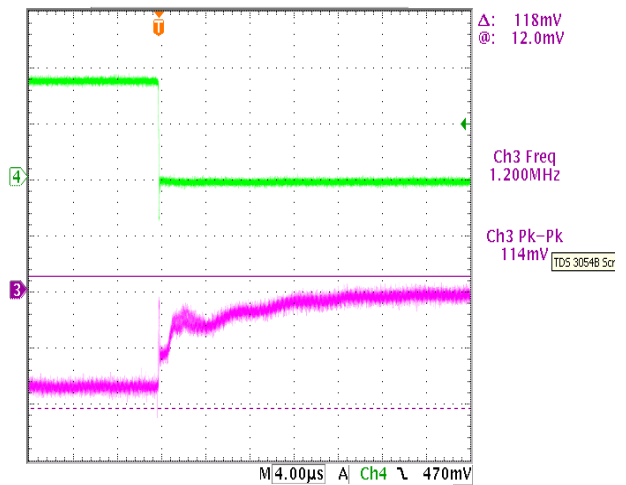


FIGURE 4. FALLING EDGE TRANSIENT RESPONSE

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Overcurrent Protection

The ISL6559 monitors the output current level by averaging the sampled current from each ISEN pin. The R_{ISEN} resistors (R1, R2, R3, R4) are selected such that the current sourced by the ISEN pins is 50µA at maximum load current. The average of the sampled currents is compared with an overcurrent trip level of 90µA. Once the average current meets or exceeds the OC reference current, the controller immediately places all PWM signals in a high-impedance state, quickly removing gate drive to the ISL6605 drivers. This forces the core voltage to decay as the output capacitors discharge. The PGOOD signal transitions low when the core voltage drops below the UV threshold.

After the overcurrent event is detected, the controller waits a short delay time before initiating a soft-start interval to allow the disturbance to clear. The delay time is equivalent to the soft-start interval and for this design is 3.4ms. If during the soft-start interval another overcurrent trip is detected, the PWM signals are again placed in a high impedance state and PGOOD remains low. The controller waits another 3.4ms before another soft-start interval is attempted. This hiccup mode of operation repeats up to six times, with a seventh successive event causing the converter to latch off.

Figure 5 shows the hiccup mode operation of the converter when a hard short is applied across the output terminals of the evaluation board. The converter quickly places the PWM signals in a high-impedance state and the core voltage decays quickly. The short is not removed, resulting in the controller latching off after the seventh attempt. The hiccup mode is explained more thoroughly in the datasheet.

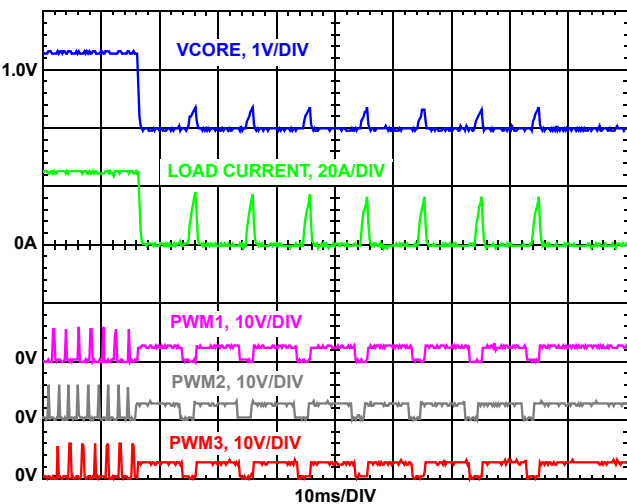


FIGURE 5. OVERCURRENT PROTECTION

VID on the Fly

The AMD Hammer Family microprocessors can change VID inputs at any time while the regulator is in operation. The power management solution is required to monitor the DAC inputs and respond to VID voltage transitions in a controlled manner, supervising the safe output voltage transition within the DAC range of the processor without discontinuity or disruption. The ISL6559 checks the five VID inputs at the beginning of each switching cycle. If the VID code has changed, the controller waits one complete switching cycle to validate the new code. If the new code is stable during this one cycle delay, then the controller begins incrementing the reference voltage toward the new DAC code in 25mV steps, every two switching-cycles, until the new DAC code is reached.

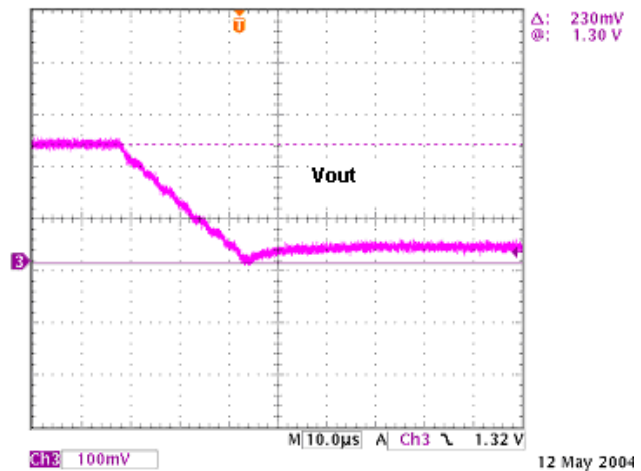


FIGURE 6. VID-ON-THE-FLY TRANSITION FROM 1.55V TO 1.30V

Figure 6 shows a 250mV DAC change prompted by changing VID3 and VID1 simultaneously. Originally at 1.550V (00000), the core voltage ramps to the new DAC setting of 1.300V (01010). The VID-on-the-Fly transition is completed in 30µs, well within the 100µs maximum window allowed. The converter is supporting a 26A load during the transition. The cursors on the scope shot reflect only a 230mV transition because the transition happened very fast and the final voltage was not captured.

Figure 7 shows the converter returning to a DAC level of 1.550V after the VID3 and VID1 states are returned to ground. Again, the converter is loaded at 26A during the DAC change.

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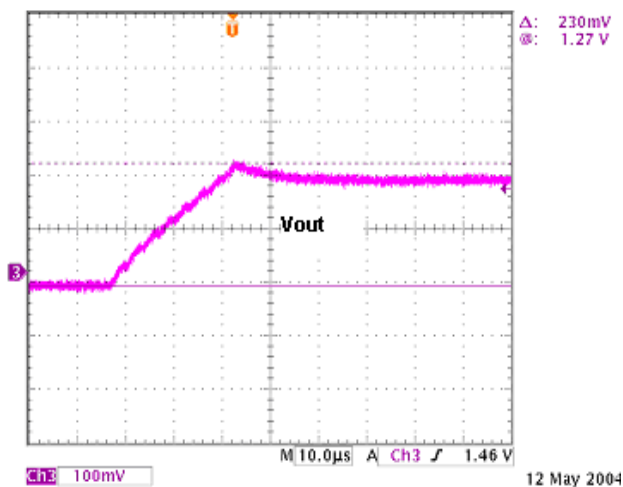


FIGURE 7. VID-ON-THE-FLY TRANSITION FROM 1.30V TO 1.55V

Efficiency

The efficiency of the ISL6559EVAL1 board, loaded up to 100A is plotted in Figure 8. Measurements were performed at room temperature and taken at thermal equilibrium with 400 LFM of air and heatsink. The design exceeds the AMD Hammer Desktop minimum requirements of 50% efficiency under minimum loading and 80% efficiency at maximum loading.

Additional testing was performed in a wind tunnel where we were able to achieve a 120A constant load at 45°C ambient and 300LFM of airflow. The board temperature was monitored and stabilized at around 100°C.

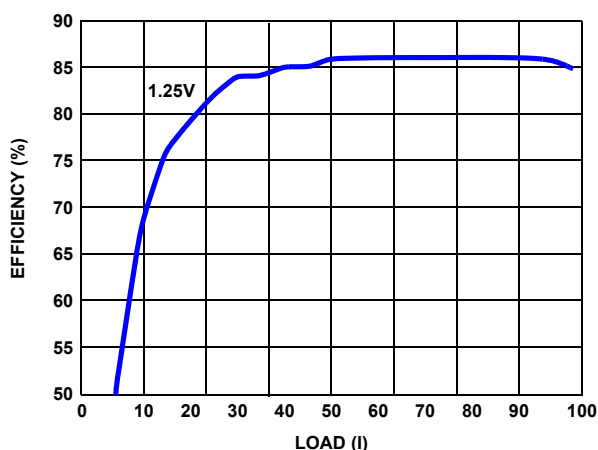


FIGURE 8. VRM EFFICIENCY vs LOAD CURRENT

Adapting Circuit Performance

Higher $r_{DS(ON)}$ MOSFETs can be employed in the design, if the cost curve must be tilted lower. The tradeoff for lowering

cost is reduced thermal and efficiency performance of the solution. Select an upper MOSFET with an $r_{DS(ON)}$ no larger than 12mΩ and keep the total gate charge below 15nC. This combined with a lower MOSFET of no more than 7mΩ with a total gate charge of 50nC to 70nC can provide a cost effective and thermally acceptable solution.

Summary

The ISL6559EVAL1 is an adaptable evaluation tool which showcases the performance of the ISL6559 and ISL6605 chip set. Designed to meet the performance requirements of AMD's Hammer Family Desktop microprocessors, the board allows the user the flexibility to configure the board for current as well as future microprocessor offerings. The following pages provide a schematic of the board, bill of materials and layout drawings to support implementation of this solution.

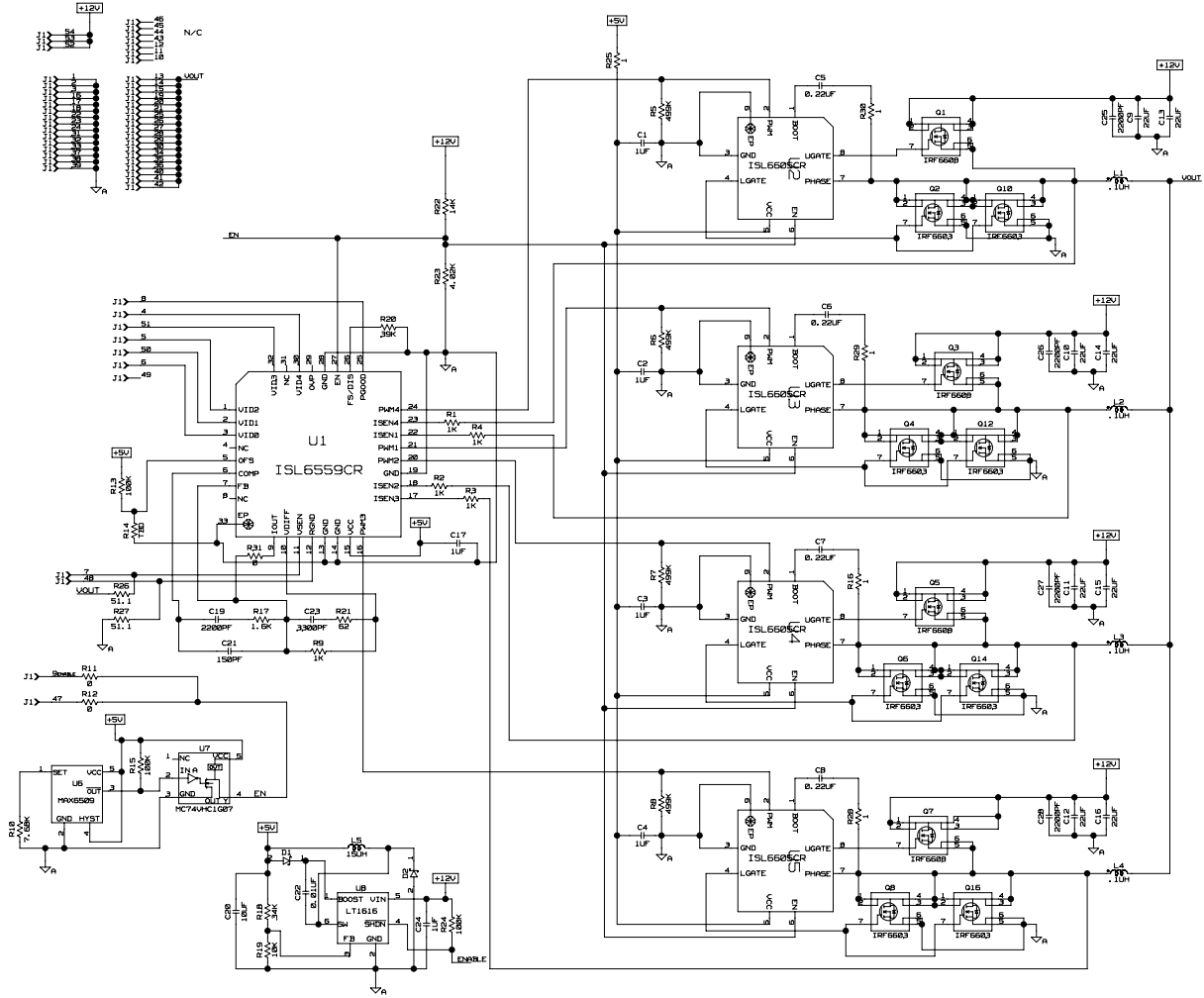
References

Intersil documents are available on the web at <http://www.intersil.com/>.

[1] ISL6559 Data Sheet, Intersil Corporation, File No. FN9084.

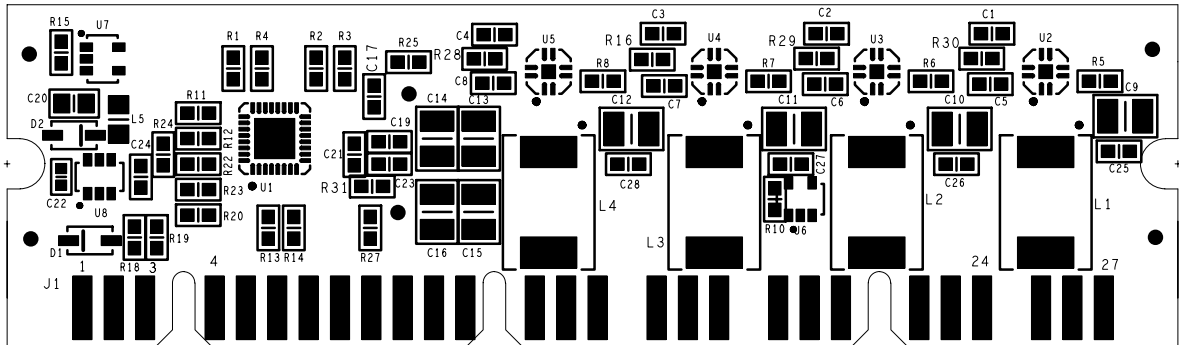
[2] ISL6605 Data Sheet, Intersil Corporation, File No. FN9091.

Schematic



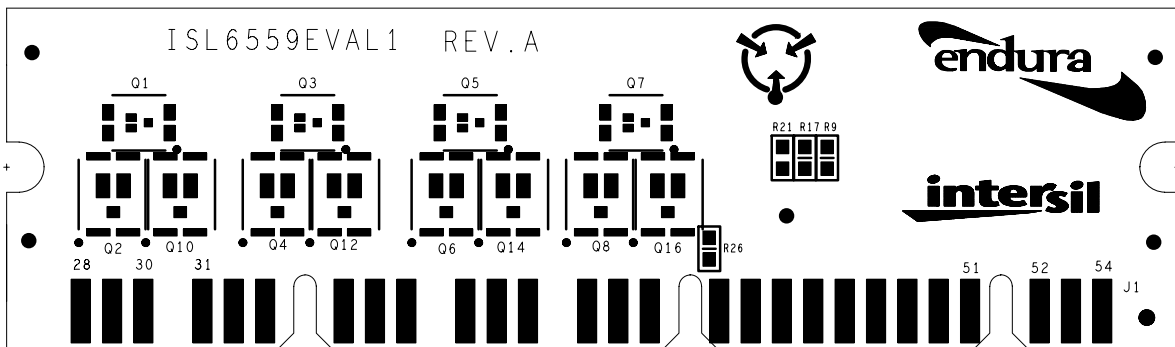
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ISL6559EVAL1 Layout



INTERSIL CORPORATION
 PART # ISL6559EVAL1 REVA
 DATE 02/20/2004

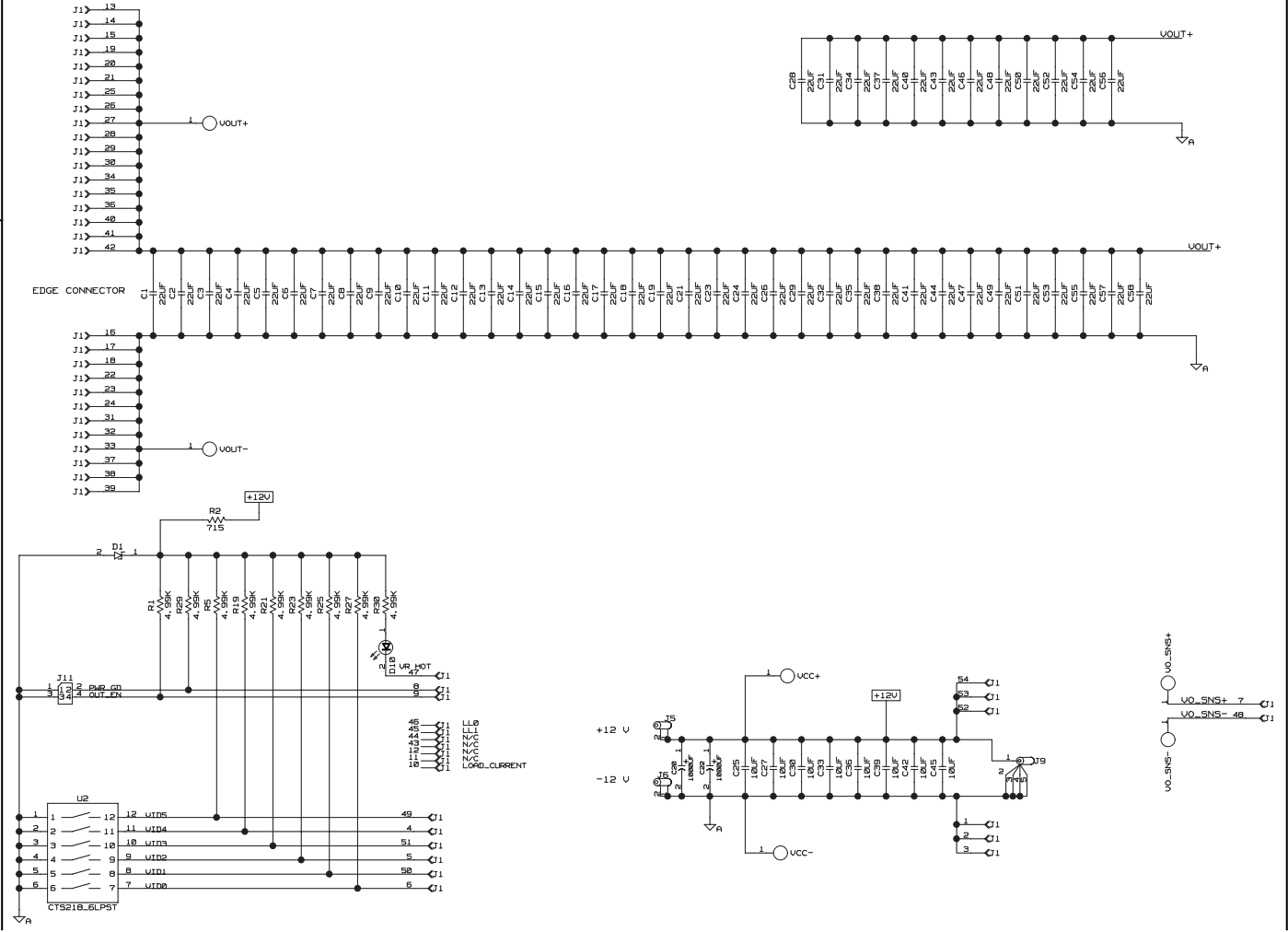
FIGURE 9. TOP



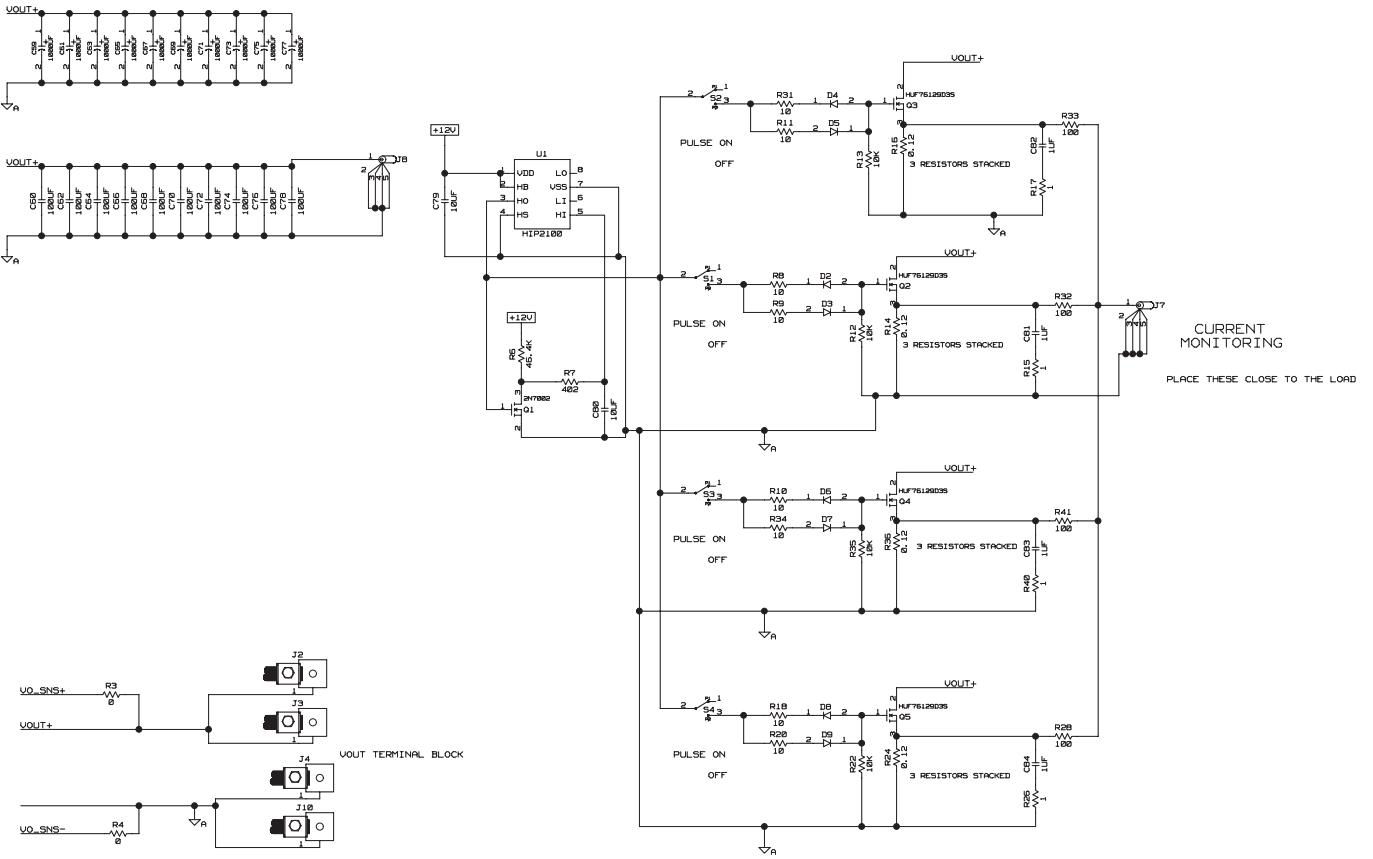
INTERSIL CORPORATION
 PART # ISL6559EVAL1 REVA
 DATE 02/20/2004

FIGURE 10. BOTTOM

VRM Test Board Schematic



VRM Test Board Schematic



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Bill of Materials

| QTY | REFERENCE | COMPONENT | DESCRIPTION/COMMENT | MFG NAME | MFG NUMBER |
|-----|------------------------------------|-----------------------|---|-------------------------|---------------------|
| 1 | C22 | H1044-00103-25V8020-T | Capacitor, SMD, 0402, 0.01 μ F, 25V, +80-20%, Y5V | Panasonic | ECJ-0EF1E103Z |
| | | | | Venkel | C0402Y5V250-103ZNE |
| 6 | C1-C4, C17, C24 | H1045-00105-16V20-T | Capacitor, SMD, 0603, 1 μ F, 16V, 20%, Y5V | Murata | GRM188R61C105KA12D |
| | | | | Venkel | C0603Y5V160-105MNE |
| 1 | C21 | H1045-00151-50V5-T | Capacitor, SMD, 0603, 150pF, 50V, 5%, NPO | Panasonic | ECJ-1VC1H151J |
| | | | | Venkel | C0603C0G500-151JNE |
| 5 | C19, C25-C28 | H1045-00222-50V10-T | Capacitor, SMD, 0603, 2200pF, 50V, 10%, X7R | Panasonic | ECJ-1VB1H222K |
| | | | | Samsung | CL10B222KBNC |
| | | | | TDK | C1608X7R1H222K |
| | | | | Venkel | C0603X7R500-222KNE |
| 4 | C5-C8 | H1045-00224-10V10-T | Capacitor, SMD, 0603, 0.22 μ F, 10V, 10%, X7R | AVX | 0603YC224KAT2A |
| | | | | TDK | C1608X7R1C224K |
| | | | | Venkel | C0603X7R100-224KNE |
| 1 | C23 | H1045-00332-50V10-T | Capacitor, SMD, 0603, 3300pF, 50V, 10%, X7R | BC Components | 0603B332K500BT |
| | | | | Venkel | C0603X7R500-332KNE |
| 1 | C20 | H1046-00106-6R3V10-T | Capacitor, SMD, 0805, 10 μ F, 6.3V, 10%, X5R | Venkel | C0805X5R6R3-106KNE |
| 8 | C9-C16 | H1082-00226-16V20-T | Capacitor, SMD, 1210, 22 μ F, 16V, 20%, X5R | AVX | 1210YD226MAT2A |
| | | | | Murata | GRM32ER61C226ME20L |
| | | | | Taiyo Yuden | EMK325BJ226MM (X7R) |
| | | | | TDK | C3225X5R1C226M |
| | | | | Venkel | C1210X5R160-226MNE |
| 4 | L1-L4 | FP4-100 | Coil-Pwr Inductor, SMD, 10X6.8mm, 0.1 μ H, 64A | Cooper Bussmann | FP4-100 |
| | | | | Cooper Electronic Tech. | FP4-100 |
| | | | | BI Technologies | HM00-03852 |
| 1 | L5 | PM1210-150J | Coil-Inductor, SMD, 1210, 15 μ H, 10% @ 2.52MHz | J.W. Miller | PM1210-150J |
| 2 | D1, D2 | MBR0540T1-T | Diode-Rectifier, TH, TO220, 2PIN, 45V, 7.5A | Motorola | MBR0540T1-T |
| 1 | U1 | ISL6559CR | IC-2-4 Phase Buck Controller, 32P, MLFP, 5X5 | Intersil | ISL6559CR |
| 4 | U2-U5 | ISL6605CR | IC-P6 HV Synch Buck MOSFET, 8P, QFN, 3X3 | Intersil | ISL6605CR |
| 1 | U8 | LT1616ES6 | IC-Switching Regulator, 6P, SOT23, 0.6A, 1.4 | Linear Technology | LT1616ES6 |
| 1 | U6 | MAX6509HAUK-T | IC-Temp.Switch, 5P, SOT23, 2.7-5.5V | Maxim | MAX6509HAUK |
| 1 | U7 | MC74VHC1G07DT | IC-Non-Inverting Buffer, 5P, SOT23-5 | On Semiconductor | MC74VHC1G07DT |
| 8 | Q2, Q4, Q6, Q8, Q10, Q12, Q14, Q16 | IRF6607 | Transis-PwrMOS, N-Channel, SMD, 2P, S0-8, 30V | International Rectifier | IRF6607 |
| | | | | International Rectifier | IRF6603 |
| | | | | International Rectifier | IRF6618 |

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Bill of Materials (Continued)

| QTY | REFERENCE | COMPONENT | DESCRIPTION/COMMENT | MFG NAME | MFG NUMBER |
|-----|-------------------|----------------------|--|-------------------------|-------------------|
| 4 | Q1, Q3, Q5, Q7 | IRF6608 | Transist-MOS, N-Channel, SMD, DIRECTFET, 30V | International Rectifier | IRF6608 |
| 5 | R16, R25, R28-R30 | H2511-00010-1/16W5-T | Resistor, SMD, 0603, 1Ω, 1/16W, 5%, TF | Venkel | CR0603-16W-1R0JT |
| 1 | R21 | H2511-00620-1/10W5-T | Resistor, SMD, 0603, 62Ω, 1/10W, 5%, TF | Panasonic | ERJ-3GEYJ620V |
| | | | | Venkel | CR0603-16W-620JT |
| 3 | R11, R12, R31 | H2511-00R00-1/16W-T | Resistor, SMD, 0603, 0Ω, 1/16W, 5%, TF | Panasonic | ERJ-3GEY0R00V |
| | | | | Venkel | CR0603-16W-000T |
| 5 | R1-R4, R9 | H2511-01001-1/16W1-T | Resistor, SMD, 0603, 1K, 1/16W, 1%, TF | Panasonic | ERJ-3EKF1001 |
| | | | | Samsung | RC1608F1001CS |
| | | | | Venkel | CR0603-16W-1001FT |
| 1 | R19 | H2511-01002-1/16W1-T | Resistor, SMD, 0603, 10K, 1/16W, 1%, TF | Cal-chip | RM06F1002CT |
| | | | | Panasonic | ERJ-3EKF1002V |
| | | | | Venkel | CR0603-16W-1002FT |
| 2 | R15, R24 | H2511-01003-1/16W1-T | Resistor, SMD, 0603, 100K, 1/16W, 1%, TF | Panasonic | ERJ-3EKF1003 |
| | | | | Venkel | CR0603-16W-1003FT |
| 1 | R13 | H2511-01003-1/16W5-T | Resistor, SMD, 0603, 100K, 1/16W, 5%, TF | Dale | CRCW0603-104JRT1 |
| 1 | R22 | H2511-01402-1/16W1-T | Resistor, SMD, 0603, 14K, 1/16W, 1%, TF | NIC Comp Corp. | NRC06F1402TR |
| | | | | Panasonic | ERJ-3EKF1402V |
| 1 | R17 | H2511-01601-1/16W5-T | Resistor, SMD, 0603, 1.6K, 1/16W, 5%, TF | Panasonic | ERJ-3GEYJ162V |
| | | | | Venkel | CR0603-16W-1601JT |
| 1 | R18 | H2511-03402-1/16W1-T | Resistor, SMD, 0603, 34K, 1/16W, 1%, TF | Panasonic | ERJ-3EKF3402V |
| | | | | Venkel | CR0603-16W-3402FT |
| | | | | Yageo | 9C06031A3402FKHFT |
| 1 | R20 | H2511-03902-1/10W5-T | Resistor, SMD, 0603, 39K, 1/10W, 5%, TF | Panasonic | ERJ-3GEYJ393V |
| | | | | Venkel | CR0603-16W-393JT |
| 1 | R23 | H2511-04021-1/16W1-T | Resistor, SMD, 0603, 4.02kΩ, 1/16W, 1%, TF | Panasonic | ERJ-3EKF4021V |
| | | | | Venkel | CR0603-16W-4021FT |
| 4 | R5-R8 | H2511-04993-1/16W1-T | Resistor, SMD, 0603, 499K, 1/16W, 1%, TF | Panasonic | ERJ-3EKF4993V |
| | | | | Venkel | CR0603-16W-4993FT |
| 2 | R26, R27 | H2511-051R1-1/16W1-T | Resistor, SMD, 0603, 51.1Ω, 1/16W, 1%, TF | Panasonic | ERJ-3EKF51R1V |
| | | | | Venkel | CR0603-16W-51R1FT |
| | | | | Vishay | CRCW060351R1F100 |
| 1 | R10 | H2511-07681-1/16W1-T | Resistor, SMD, 0603, 7.68K, 1/16W, 1%, TF | Panasonic | ERJ-3EKF7681V |
| | | | | Venkel | CR0603-16W-7681FT |
| | | | | Yageo | 9C06031A7681FKHFT |
| 1 | Heatsink | | | Wakefield | |

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