

ISL6327EVAL5

Voltage Regulator Coupled Inductor Solution using the ISL6327 and ISL6609

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Introduction

Today's microprocessors are continuing towards higher power consumption and functionality. Vcore regulators have the burden of increasing load demands coupled with tighter voltage regulation requirements. Power designers are challenged with the design of high performance regulators that can meet tight load regulation windows with increasing maximum load and transient requirements and falling output voltages. Add to that the push for higher efficiency solutions and decreasing PCB real estate; meeting today's microprocessor power requirements is no simple task.

Intersil ISL6327 With Coupled Inductors

To help meet these design challenges Intersil offers a complete reference design and evaluation package that takes advantage of the features of the ISL6327 controller and an output filter topology using coupled inductors and fewer output capacitors.

The ISL6327 controls a microprocessor core voltage, balances channel currents, and provides protective features for up to 6 synchronous buck channels in parallel. The controller uses a 8-bit DAC giving the user a digital interface to select the output voltage, which is precisely regulated to $\pm 0.5\%$ accuracy using differential remote voltage sensing. The DAC can be set up to read VR10 or VR11 VID codes. Other features of the controller include overcurrent, overvoltage, and undervoltage protection, internal over temperature protection, programmable output voltage offset, dynamic VID circuitry, and an IOUT pin that provides a voltage proportional to the load current.

To meet the extremely fast load transients of microprocessors the ISL6327 utilizes Intersil's proprietary Active Pulse Positioning (APA™) and Adaptive Phase Alignment (APA™) modulation scheme and continuous current sensing to achieve extremely fast load transient response with fewer output capacitors.

'Coupled' with the fast control scheme a new approach to the output filter can be implement using coupled inductors. Coupling of two phases on one core allows the use of a small output inductance for fast transient response without taking the hit in efficiency due to higher individual phase peak-to-peak current for an equivalent standard inductance.

The ISL6327 and ISL6609 datasheets along with the latest documentation can be found on our website:

www.intersil.com.

ISL6327EVAL5 VRD Reference Design

The evaluation kit consists of the ISL6327EVAL5 evaluation board, the ISL6327 datasheet, and this application note. The evaluation board is designed to meet the output voltage and current specifications shown in Table 1, with the VID DIP switches, SW2, set to 00101010 (1.35V).

TABLE 1. ISL6327EVAL5 DESIGN PARAMETERS

| PARAMETER | MAX | TYPICAL | MIN |
|--------------------------|----------|---------|-------|
| No Load VCORE Regulation | 1.35V | 1.33V | 1.31V |
| VCORE Tolerance | +20mV | | -20mV |
| Load Line Slope | | 1.25mΩ | |
| Continuous Load Current | 130A | | |
| Load Current Step | 100A | | |
| Load Current Transient | 1200A/μs | | |

The board is configured for down conversion from 12V to the DAC setting. The evaluation board provides many test points, two types of power supply connectors, an on-board LGA775/771 socket for transient response evaluation and terminal connectors for DC load testing. An on-board LED is present to indicate the status of the PGOOD signal.

The printed circuit board is implemented in 6-layer, 1-ounce copper. The layout and stackup are designed to emulate a real world CPU/VCORE implementation. The board schematic and BOM is provided at the end of the application note.

Quick Start Evaluation

The ISL6327EVAL5 is designed for quick start-up and evaluation. All that is required is a single ATX power supply. To begin evaluating the ISL6327EVAL5 follow the steps below.

1. Before doing anything to the evaluation board, make sure the "Enable" switch (EN1) is in the OFF position.
2. Using an ATX power supply, connect the 24-pin main power supply header to the "5V Power" connector (5V_PWR1) on the board. Next connect the 4-pin 12V header to the "12V Power" connector (12V_PWR1) on the board.
3. Set the "Static VID" DIP switch (SW2) to 00101010 (VID7:0 as printed on the silkscreen). Set SW1 to 0001.
4. Move the "Enable" switch (S1) to the ON position to begin regulation.

After step 4, the ISL6327EVAL5 should be regulating the output voltage. The test points "TPVCORE1" and "TPGND1" can be used to monitor the output voltage initially to verify regulation.

ISL6327EVAL5 Board Features

Input Power Connections

The ISL6327EVAL5 includes two different methods for powering up the board. The first method allows for the use of an ATX power supply. The 24-pin header, 5V_PWR1, allows for the connection of the main ATX power connector, while the 4-pin header, 12V_PWR1, connects the 12V AUX power. It is very important that both connections are secure and the EN1 switch is in the OFF position before switching on the ATX supply.

The second method of powering the ISL6327EVAL5 board is with bench power supplies. Four female banana jacks are provided for connecting bench-top supplies. A +5V, 1A and +12V, 20A supply will be needed for full evaluation. Connect the +5V terminal to the 5V1 jack and the +5V GND terminal to 5V_GND1. Connect the +12V terminal to 12V1 and the +12V GND terminal to 12V_GND1. Voltage sequencing is not required when powering the evaluation board.

Once power is applied to the board, the PGOOD LED indicator will illuminate red. With EN1 in the OFF position, the ENABLE input of the ISL6327 is held low and the start-up sequence is inhibited.

Output DC Power Connections

The ISL6327EVAL5 output can be exercised using a DC electronic load through the output terminal lugs labeled VCORE1 and GND1. Tie the positive load connection to VCORE1 and the negative load connection to GND1. A shielded scope probe test point, TP1, allows for inspection of the output voltage, VCORE. This probe is connected to VSENSE through 0 Ω resistors on the back of the PCB labeled VTT_R1 and VTT_R2.

LGA775/771 VTT Evaluation

To fully exercise the regulation of the ISL6327EVAL5 a LGA775/771 VTT is needed. A LGA775/771 VTT socket is populated on the PCB. To ensure the ISL6327 regulates to the die sense location on the VTT, 0 Ω resistors are populated on the back side of the PCB labeled R40 and R42. These must be populated for correct voltage measurements when using the VTT.

After inserting the interposer and VTT in the LGA775/771 socket a differential voltage probe should be connected to the VCC-REG-N/VSS-REG-N connector for voltage monitoring and the AMP and GND connector for load measurements.

For accurate measurements with the differential probes you must make sure that the ground terminal of your oscilloscope is connected to the ground plane of the ISL6327EVAL5. An easy way to do this is use a wire to connect the GND terminal of the scope to one of the GND test points on the ISL6327EVAL5 (TP10 for example).

The VTT must also be powered with +5V and +12V at the 4-pin power input connector. Refer to your VTT users guide and software for details on exact test setup and software use.

VID Setting

The VID input on the ISL6327EVAL5 can be set by using the on board SW2 DIP switch. The switches are labeled VID7 to VID0. Or the VID can be controlled through the VTT software. To select which method controls the VID pins of the ISL6327 the jumpers J_VID7 to J_VID0 need to be placed accordingly.

For VTT control of the VID, place the jumper hats on pins 1 and 2 of the 3-pin connector for J_VID7 - J_VID0. The 4th switch on SW1 should also be switched to VTT (labeled on the PCB silk-screen).

To allow the DIP switches to control the VID move switch 4 of SW1 DIP switch to DEMO and move the jumper hats to pins 2 and 3 of J_VID7 to JVID_0.

The VID DIP switches should be preset to 00101010 (1.35V with 20mV offset). If another output voltage level is desired, refer to the ISL6327 datasheet for the complete DAC table and change the VID switches accordingly.

Both VR10 and VR11 VID codes can be used with the ISL6327EVAL5. To use VR11 move switch 1 of SW1 DIP switch towards VR11. To use VR10 move switch 1 of SW1 towards VR10.

Enabling the Controller

In order to enable the controller, the board must be powered and a VID code must be set. If these steps have been properly followed, the regulator is enabled by toggling the "ENABLE" switch (EN1) to the ON position. When EN1 is switched, the voltage on the EN pin of the ISL6327 will rise above the ENLL threshold and the controller will begin the soft start sequence. The output voltage ramps up to the programmed VID setting, at which time the PGOOD indicator will switch from red to green.

Signal Test Points

There are many test points available on the ISL6327EVAL5 for monitoring of key signals. Monitoring test points include, VR_HOT and VR_RDY for monitoring the temperature FAULT outputs, OFS, IOUT, DAC, REF, COMP, EN, and DAC for monitoring control waveforms. There are also test points for monitoring VIN (VIN1 and VIN2) and VOUT (TPVCORE1 and TPGND1).

Component Selection With Coupled Inductors

There are many parameters of the operation of the ISL6327 that can be modified and tested using the ISL6327EVAL5 evaluation board. Many control signals can also be monitored through on-board test points. For detailed theory of operation and component selection guidelines for the ISL6327 please refer to the ISL6327 datasheet available on the web at www.intersil.com.

Key parameters that will be selected differently or otherwise impacted in the case where coupled inductors are used in the output filter are feedback compensation, DCR sense time constant, current sense resistor, droop control, and overcurrent set point. How to select these components will be covered in this section.

PWM Modulation Scheme and Continuous Current Sense

The ISL6327 adopts Intersil's proprietary Active Pulse Positioning (APP) modulation scheme to improve transient performance. APP control is a unique dual-edge PWM modulation scheme with both PWM leading and trailing edges being independently moved to provide the best response to transient loads. The PWM frequency, however, is constant and set by the external resistor between the FS pin and GND.

To further improve the transient response, the ISL6327 also implements Intersil's proprietary Adaptive Phase Alignment (APA) technique. APA, with sufficiently large load step currents, can turn on all phases simultaneously.

With both APP and APA control, ISL6327 can achieve excellent transient performance and reduce the demand on the output capacitors.

Under steady state conditions the operation of the ISL6327 PWM modulator appears to be that of a conventional trailing edge modulator. Conventional analysis and design methods can therefore be used for steady state and small signal operation.

The ISL6327 senses current continuously (no sample-and-hold) on each channel for fast response to changes in inductor current.

Continuous current sensing, APA and APP allow for very high bandwidth response to a load transient events.

Coupled Inductor Details

To further take advantage of the control and sensing features of the ISL6327 the use of coupled inductors in the output filter can be implemented. Coupling 2 phases on a single inductor core allows a reduction in phase inductance for fast transient response without the hit in efficiency due to larger phase ripple currents with an equivalent standard inductor.

With a standard single winding inductor the current waveform is dependant on the voltage at the two terminals of the inductor. The peak-to-peak ripple current in a synchronous buck application is determined by Equation 1.

$$I_{PPSi} = \frac{(V_{IN} - V_{OUT}) V_{OUT}}{L f_S V_{IN}} \quad (\text{EQ. 1})$$

where V_{IN} is the input voltage, V_{OUT} is the output voltage, L is the standard inductance value, and f_S is the switching frequency.

The total output ripple current is determined by the sum of all of the phase currents and its magnitude is reduced by the interleaving of N number of phases.

$$I_{TotalPPSi} = \frac{(V_{IN} - N V_{OUT}) V_{OUT}}{L f_S V_{IN}} \quad (\text{EQ. 2})$$

For a given V_{in} , V_{out} and f_s , both the channel and total ripple current are determined by L , the standard inductance of each phase.

For the case where there are two inductors coupled on one core, each providing the inductance for one phase in a synchronous buck converter, the ripple current for a *single* phase is now dependant on the voltages across *both* inductors as well as the magnetic properties of the coupled inductor.

Consider the two phase coupled inductor drawn in Figure 1.

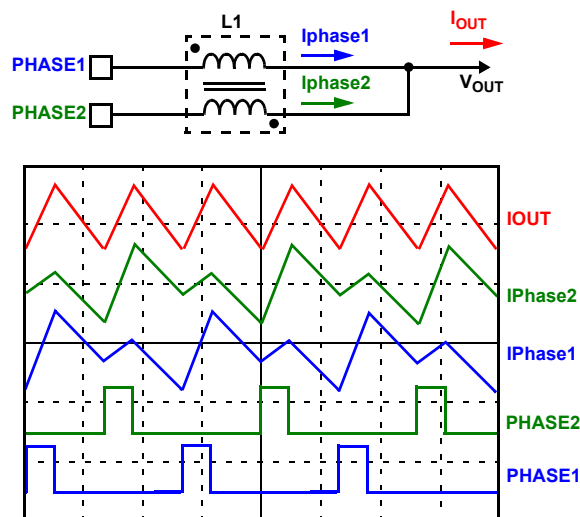


FIGURE 1. TWO PHASE COUPLED INDUCTOR RIPPLE CURRENT WAVEFORMS

Note the dot convention. If positive current flows into the dot connected to PHASE1 then current will flow out of the dot connected to PHASE2. This means when one PHASE has a positive current slew rate so will the coupled PHASE. Figure 1 shows example waveforms for a simplified 2 phase case.

The equation for peak-to-peak ripple current and total output ripple current are dependent on the magnetic properties of the coupled inductor.

The two winding coupled inductor is essentially a transformer. Like any transformer it will have a specified winding ratio, winding inductance (or self inductance, L), and mutual inductance (L_M). Parasitics will include leakage inductance (L_{LK}) and winding resistance (DCR). All these parameters must be considered in optimizing the coupled inductor performance for a given application.

An equivalent circuit for the two phase coupled inductor is shown in Figure 2. For the coupled inductor used in this reference design the windings are symmetrical and the turns ratio is 1:1.

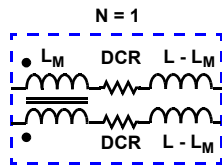


FIGURE 2. TWO PHASE COUPLED INDUCTOR

Each winding has a self inductance which is the total inductance that magnetizes the core. In an imperfect transformer some of the flux generated by the current through the winding will not couple through the core to the other winding. The mutual inductance is the portion of the winding inductance that is coupled with the other windings.

The leakage inductance is a measure of how much of the total flux does not couple to the other winding. A system of equations can be used to determine the phase peak-to-peak ripple current equation and total output peak-to-peak ripple current equation.

For the two phase coupled inductor case the phase ripple current is shown in Equation 3:

$$I_{PPCi} = \left(\frac{(V_{IN} - V_{OUT})L - L_M V_{OUT}}{(L^2 - L_M^2)(f_S)} \cdot \frac{V_{OUT}}{V_{IN}} \right) \quad (\text{EQ. 3})$$

The total ripple current will be the sum of the phase currents and can be calculated using Equation 4:

$$I_{TotalPPCi} = \frac{(V_{IN} - N V_{OUT})V_{OUT}}{(L - (n_{ci} - 1)L_M)f_S V_{IN}} \quad (\text{EQ. 4})$$

Where N is the number of phases in the multiphase converter, and n_{ci} is the number of inductors coupled on a single core, in this case $n_{ci} = 2$.

With these equations it can be determined that the output current waveform and therefore the transient response is determined by:

$$L_{Tr} = (L - (n_{ci} - 1)L_M) = L - L_M \quad (\text{EQ. 5})$$

This term is the leakage inductance, L_{LK} , of the two winding coupled inductor. The phase ripple current waveform, or steady state phase ripple current, is determined by the equivalent inductance in Equation 6:

$$L_{SS} = \frac{(V_{IN} - V_{OUT})(L^2 - L_M^2)}{(V_{IN} - V_{OUT})L - L_M V_{OUT}} \quad (\text{EQ. 6})$$

Equations 5 and 6 will be used when selecting components in a two phase coupled inductor application.

Current Sensing

ISL6327 senses phase current continuously for fast response. ISL6327 supports inductor DCR sensing, or resistive sensing techniques. For more detail on the ISL6327 theory of operation please refer to the ISL6327 datasheet.

INDUCTOR DCR SENSING

Choosing the DCR current sense circuitry is straight forward when using standard inductors but a little more complicated when using coupled inductors. Consider the inductor DCR as shown in Figure 3. The channel current I_L flowing through the inductor will also pass through the DCR. A simple R-C network across the inductor extracts the DCR voltage.

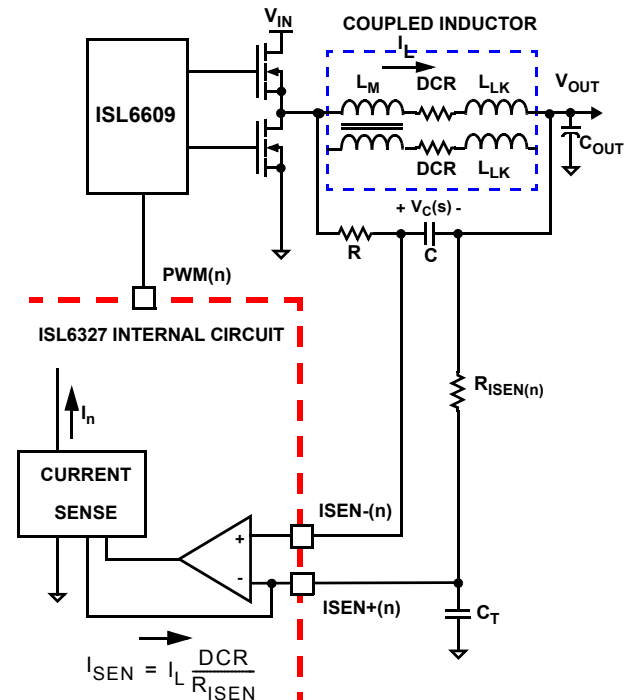


FIGURE 3. DCR CURRENT SENSING

If the R-C network components are selected such that the R-C time constant ($= R \cdot C$) matches the inductor time constant ($= L/DCR$), the voltage across the capacitor V_C is equal to the voltage drop across the DCR, i.e., proportional to the channel current.

With the internal low-offset current amplifier, the capacitor voltage V_C is replicated across the sense resistor R_{ISEN} . Therefore the current out of ISEN+ pin, I_{SEN} , is proportional to the inductor current.

Equation 7 shows that the ratio of the channel current to the sensed current I_{SEN} is driven by the value of the sense resistor and the DCR of the inductor.

$$I_{SEN} = I_L \cdot \frac{DCR}{R_{ISEN}} \quad (\text{EQ. 7})$$

But how is the RC time constant selected in the coupled inductor case? The leakage inductance of the coupled inductor should be used as the inductance in the time constant calculation. The leakage inductance for the two phase coupled inductor is $L - L_m$.

An equation for selecting the resistor of the RC time constant for a two winding coupled inductor and a given C value is shown in Equation 8. Refer the ISL6327 datasheet for additional component selection guidelines.:

$$R = \frac{L_{LK}}{DCR \cdot C} \quad (\text{EQ. 8})$$

Because of the internal filter at ISEN- pin, one capacitor C_T is needed to match the time delay between the ISEN- and ISEN+ signals. Select the proper C_T to keep the time constant of R_{ISEN} and C_T ($R_{ISEN} \times C_T$) close to 27ns.

Determining The Leakage Inductance of a Coupled Inductor

The leakage inductance of the CI must be determined to design and model with CI's, including using Equations 3-8. There are several methods for accurately determining the leakage inductance per phase of the coupled inductor; two methods are outlined here. Figure 4 depicts an equivalent magnetic circuit for the coupled inductor.

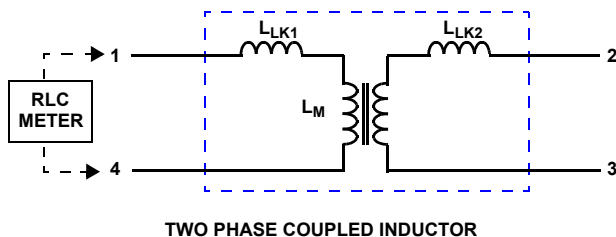


FIGURE 4. EQUIVALENT MAGNETIC CIRCUIT OF THE COUPLED INDUCTOR

A conventional method for measuring leakage inductance in a transformer is to short the secondary and measure the inductance of the primary. This is a good approximation for a

transformer since the leakage inductance is typically small compared to the self inductance. The coupled inductor in a multiphase application will have a higher percentage of leakage vs. self inductance so additional steps are needed to calculate the actual leakage inductance.

A calibrated bench RLC meter can be used for accurately measuring leakage.

Method 1

1. Leave the secondary winding, pins 2 and 3 in Figure 4, open circuit. The measured inductance from pins 1 to 4 is the primary winding inductance or self inductance. Call this L .
2. Short circuit the secondary winding, pins 2 and 3 in Figure 4. The measured inductance from pins 1 to 4 is the leakage inductance of the primary plus the reflected leakage from the secondary. Call this L_s .
3. For this application the turns ratio is 1:1.
4. The leakage can be calculated using Equation 9:

$$L_{LK} = L - \sqrt{(L^2 - (L \cdot L_s))} \quad (\text{EQ. 9})$$

5. Repeat the above steps to obtain the winding inductance and leakage of the secondary.

Method 2

1. Short pins 4 and 3. The measured inductance will be the sum of the primary and secondary leakages. In the symmetrical, 1:1 winding ratio of the multiphase buck coupled inductor this will be $2 \cdot L_{LK}$. The average leakage for each winding can be determined by dividing by 2.

IN06006 Specification Using Method 1

The coupled inductor used on the evaluation board is the IN06006. To use this inductor as an example to illustrate method 1 above refer to the IN06006 datasheet for the following steps:

1. The winding inductance listed in the IN06006 datasheet shows 315nH. So, $L = 315\text{nH}$.
2. Shorting the secondary and measuring the primary gives 150nH. $L_s = 150\text{nH}$.
3. The IN06006 winding ratio is 1:1.
4. The leakage inductance of this inductor can be calculated using Equation 9.

$$L_{LK} = 315 - \sqrt{(315^2 - (315 \cdot 150))} = 87\text{nH}$$

So, the leakage inductance for the IN06006 is 87nH. The mutual inductance can be determined by Equation 5.
 $L_m = L - L_{LK} = 228\text{nH}$.

What Inductor Parameters Do I Use?

The 87nH leakage inductance can be used in Equation 8 to calculate the required RC time constant match for DCR current sensing.

As shown in Equation 5, the leakage inductance determines the total current waveform and therefore the small signal transient response. Use L_{LK} as the phase inductance when calculating the regulator feedback compensation and small signal transient response.

For steady state phase current calculations, use Equation 4. This equation will give the peak-to-peak inductor current waveforms for input ripple calculations, MOSFET selection, and efficiency estimates.

The above analysis shows that a given transient inductance can be used while reducing the phase ripple current vs. an equivalent standard inductor.

Load-Line Regulation and Component Selection

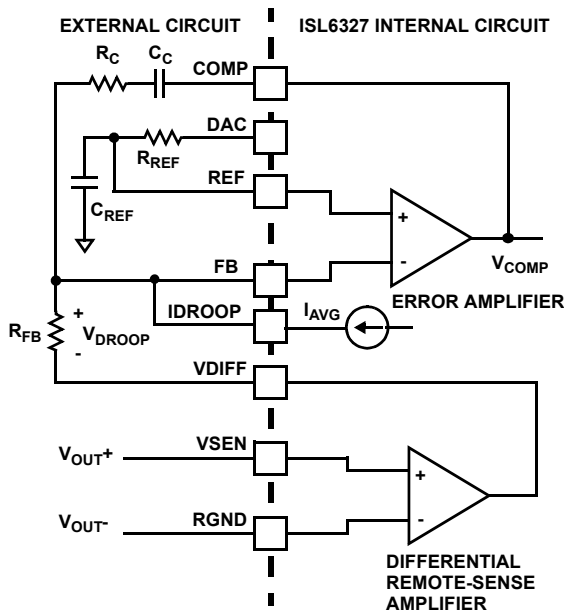


FIGURE 5. OUTPUT VOLTAGE AND LOAD-LINE REGULATION

Figure 5 shows that the average current of all active channels, I_{AVG} flows from FB through a load-line regulation resistor, R_{FB} .

$$V_{DROOP} = I_{AVG} R_{FB} \quad (\text{EQ. 10})$$

The regulated output voltage is reduced by the droop voltage V_{DROOP} . The output voltage as a function of the load current is derived by combining Equation 10 with the sensed current expression defined by the current sense method employed.

$$V_{OUT} = V_{REF} - V_{OFS} - \left(\frac{I_{OUT}}{N} \frac{R_X}{R_{ISEN}} R_{FB} \right) \quad (\text{EQ. 11})$$

Where V_{REF} is the reference voltage, V_{OFS} is the programmed offset voltage, I_{OUT} is the total output current of the converter, R_{ISEN} is the sense resistor connected to the $ISEN+$ pin, R_{FB} is the feedback resistor, N is the number of active channels, and R_X is the DCR, or sense resistor, depending on the sensing method.

Therefore, the equivalent load-line impedance (i.e., droop impedance) is:

$$R_{LL} = \frac{R_{FB}}{N} \frac{R_X}{R_{ISEN}} \quad (\text{EQ. 12})$$

Overcurrent Protection

ISL6327 has two levels of overcurrent protection. Each phase is protected from a sustained overcurrent condition by limiting its peak current, while the combined phase currents are protected on an instantaneous basis.

In instantaneous protection mode, the ISL6327 utilizes the sensed average current I_{AVG} to detect an overcurrent condition. The average current magnitude can be approximated using Equation 7, the sensed current signal for an individual phase. The average current is continuously compared with a constant 85μA. Once the average current exceeds the reference current, a comparator triggers the converter to shut-down.

For details on how the ISL6327 behaves in reaction to an overcurrent event refer to the ISL6327 datasheet.

For the individual channel overcurrent protection, the ISL6327 continuously compares the sensed current signal of each channel with the 120μA reference current. If one channel current exceeds the reference current, ISL6327 will pull PWM signal of this channel to low for the rest of the switching cycle. This PWM signal can be turned on next cycle if the sensed channel current is less than the 120μA reference current. The peak current limit of individual channel will not trigger the converter to shut-down.

The overcurrent protection level for the above two OCP modes can be adjusted by changing the value of current sensing resistors. In addition, ISL6327 can also adjust the average OCP threshold level by adjusting the value of the resistor from I_{OUT} to GND, R_{17} on the evaluation board. An overcurrent response will be initiated when the voltage on I_{OUT} reaches 2V. Use Equation 7 to approximate the average current value.

Equation 13 can be used to calculate the value of the resistor R_{IOUT} based on the desired OCP level $I_{AVG, OCP2}$.

$$R_{IOUT} = \frac{2V}{I_{AVG, OCP2}} \quad (\text{EQ. 13})$$

Which Phases Should Be Coupled?

Figure 1 has been duplicated in Figure 6 with some changes to the spacing of the PWMs modified to show the effect on the ripple current waveforms.

The bold red and blue waveforms in Figure 6 show an example of how the phase current waveforms will change if the PWM spacing is changed. Best ripple reduction performance is achieved when the two coupled phases are 180 degrees phase-shifted.

The ISL6327 in 6-phase mode fires phases sequentially, PWM1, PWM2, PWM3, PWM4, PWM5, PWM6. So, for optimal phase ripple current reduction PWM1-PWM4, PWM2-PWM5, and PWM3-PWM6 should be coupled.

For optimal layout placement two sequential PWMs should not be placed next to one another. So, from left to right on a PCB, an example placement can be PWM1, PWM4, PWM2, PWM5, PWM3, PWM6.

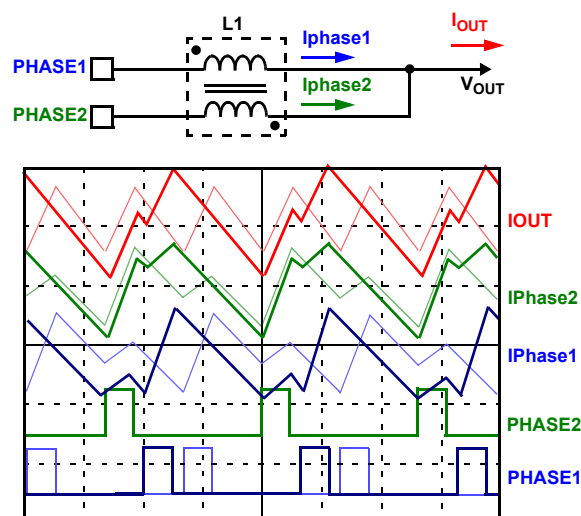


FIGURE 6. COUPLED INDUCTOR CURRENT WAVEFORMS

Modifying the Board For Other Applications

As shipped, the ISL6327EVAL5 is configured for 6 phase operation, a VR11 VID of 1.35V, and designed for operation up to 130A with a loadline of 1.25m Ω . The coupled inductors on board are IN06006.

The inductor footprints on the board are large enough to accommodate the footprints of other coupled inductors for evaluation purposes.

The following procedure can be used to modify the board for 4 phase evaluation.

Four Phase VR11 05A Configuration, $LL = 1m\Omega$

1. Change Feedback Compensation: R4 = 2.32k, R7 = 100, C6 = 390pF, C5 = 330pF, R5 = 9.09k, C7 = 33pF
2. Change the IOUT resistor to decrease the overcurrent set point: R17 = 36.5k which will give IOC = 120A
3. Change the DCR sense resistors: R22, R24, R26, R28, R30, R32 = 1.3k
4. Move jumper hats on PWM5 and PWM6 pouts: Move hats on JP_4P_SEL1 and JP_5P_SEL2 from pins 2 and 3 to short pins 1 and 2. This will disable PWM5 and PWM6
5. The 6 phase board is configured with (40) 10 μ F ceramic capacitors in the output filter. For 4 phases 05A configuration add 10 to 20 additional 10 μ F ceramic capacitors to the output filter. There are plenty of additional 1206 footprints around the socket to do this.
6. Remove unused power stage: Remove INDUCTORS L3, MOSFETS Q3L1, Q3U1, Q6L1, Q6U1, DRIVERSU4, and U7.
7. Remove R79 which is connecting PWM5 to DRIVER U6
8. Place a 0 Ω resistor on R80 to connect PWM3 to DRIVER U6.
9. On the back of the PCB remove R84 and R85. Place 0 Ω resistors on R90 and R91.
10. Follow the Quick Start Evaluation procedure on page 1 to power up the board.

ISL6327EVAL5 Six Phase Performance

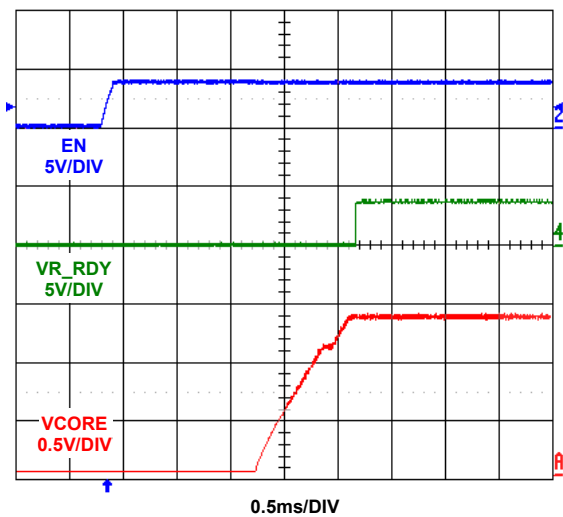


FIGURE 7. START-UP SEQUENCE

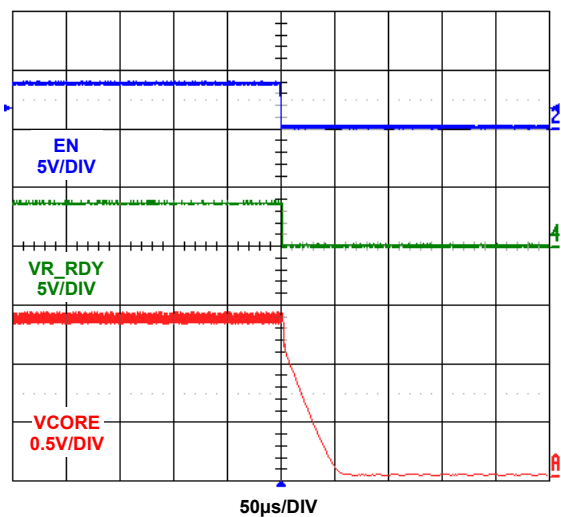


FIGURE 8. SHUT-DOWN SEQUENCE

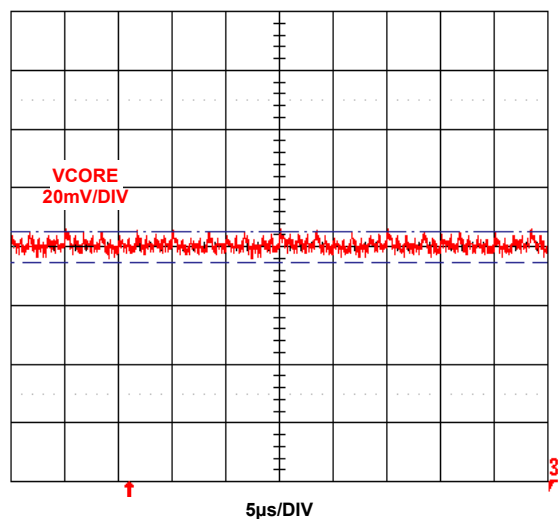


FIGURE 9. NO LOAD RIPPLE ~10mV

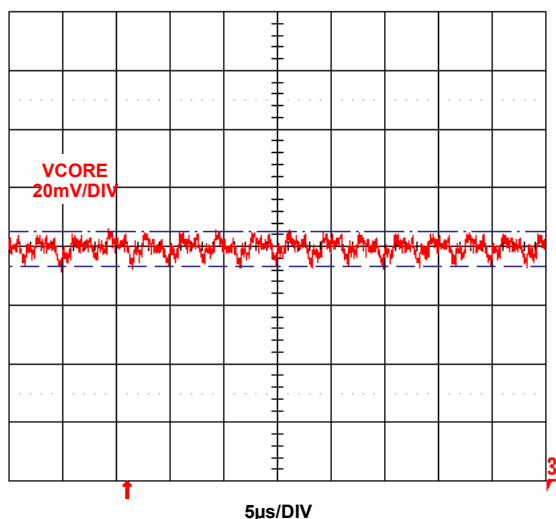


FIGURE 10. 130A RIPPLE ~12mV

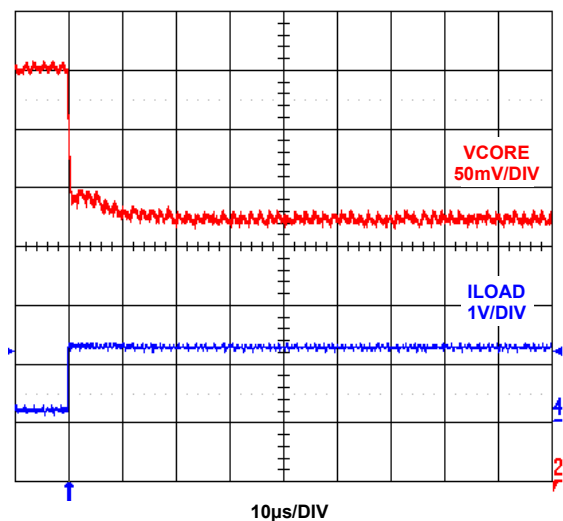


FIGURE 11. TRANSIENT RESPONSE 20A to 120A IN 1200A/μs

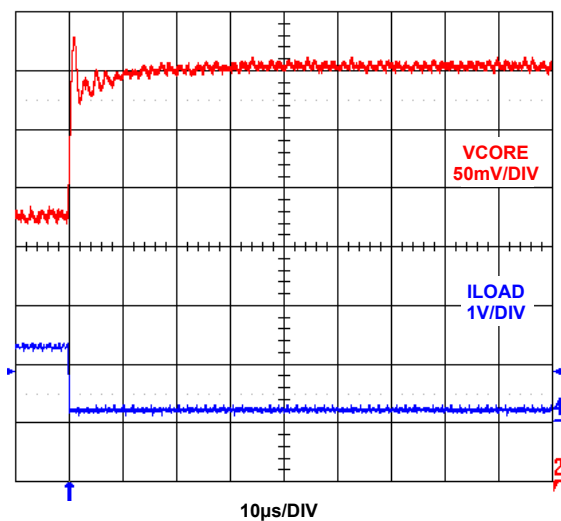


FIGURE 12. TRANSIENT RESPONSE 120A to 20A IN 1200A/μs

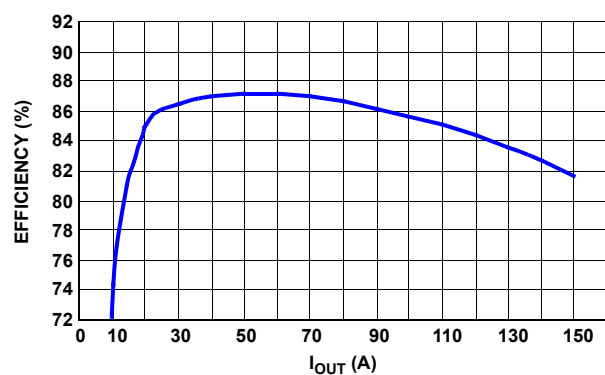
ISL6327EVAL5 Six Phase Performance (Continued)

FIGURE 13. VR EFFICIENCY $V_{IN} = 12V$, $V_{ID} = 1.35V$,
 $LL = 1.25m\Omega$, V_{OUT} MEASURED AT INDUCTOR

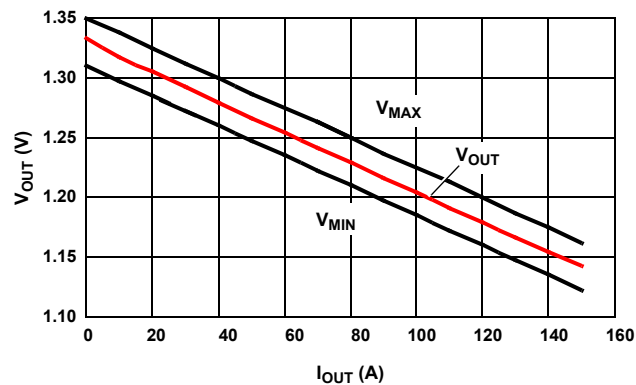


FIGURE 14. Vcore LOADLINE REGULATION FROM 0A TO 150A

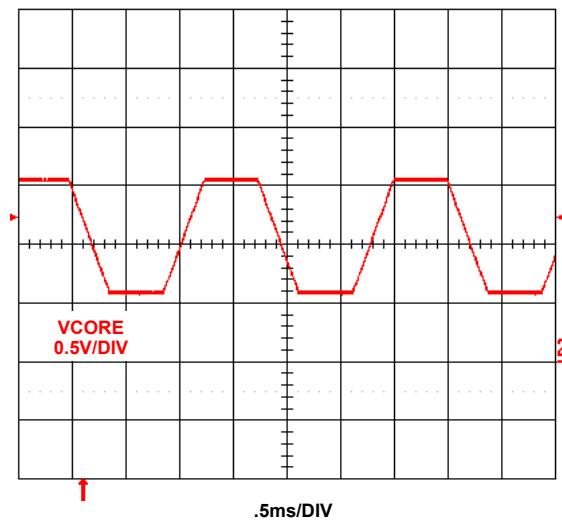


FIGURE 15. VID-ON-THE-FLY OPERATION 0.6V to 1.55V

ISL6327EVAL5 Four Phase Performance

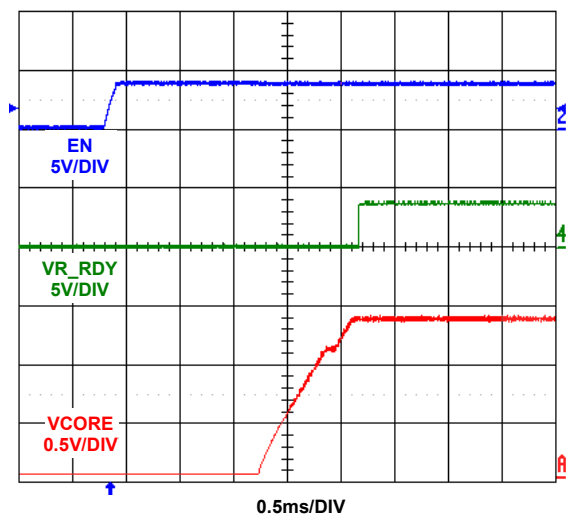


FIGURE 16. START-UP SEQUENCE

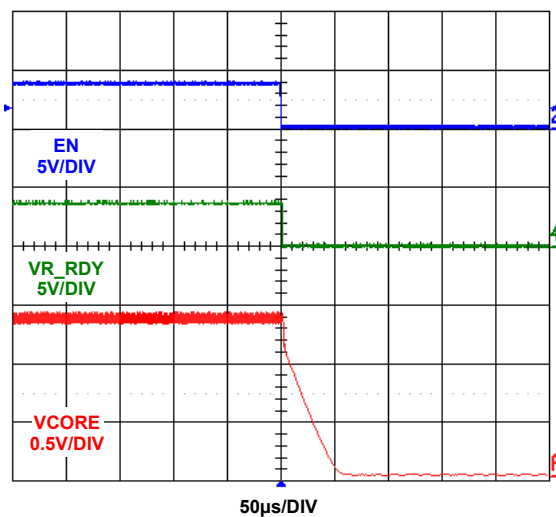


FIGURE 17. SHUT-DOWN SEQUENCE

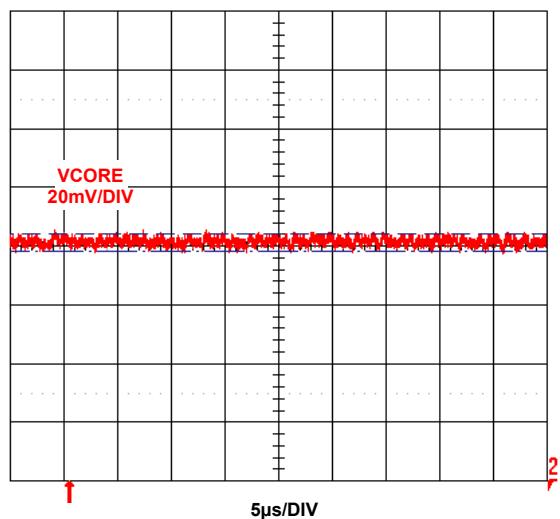


FIGURE 18. NO LOAD RIPPLE ~6mV

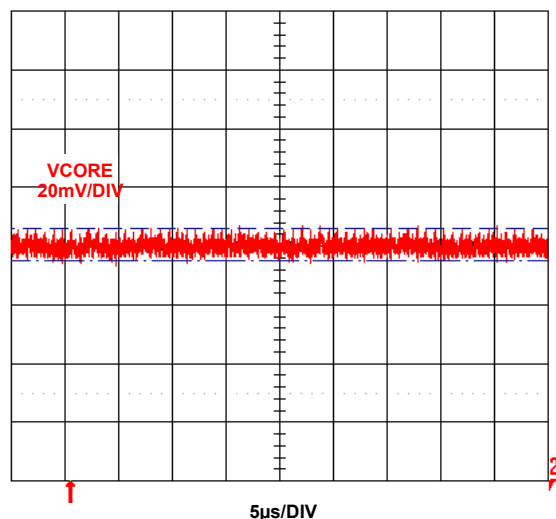


FIGURE 19. 130A RIPPLE ~11mV

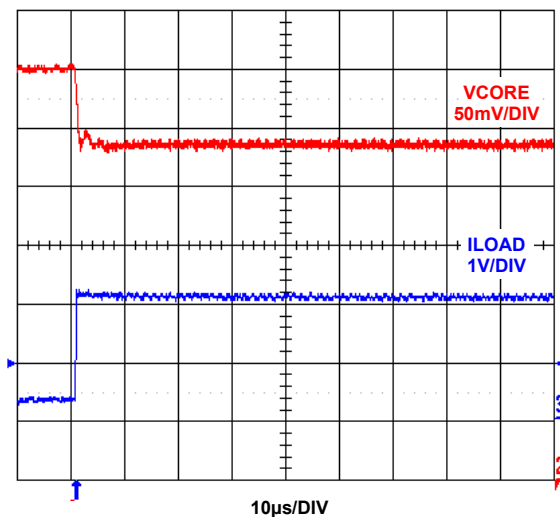


FIGURE 20. TRANSIENT RESPONSE 35A to 100A IN 50ns

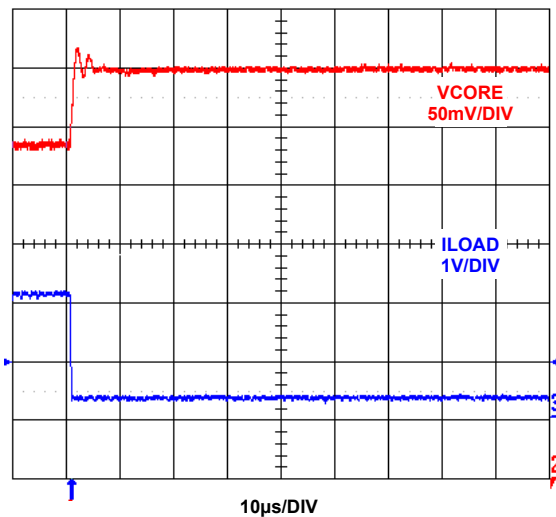


FIGURE 21. TRANSIENT RESPONSE 100A to 35A IN 50ns

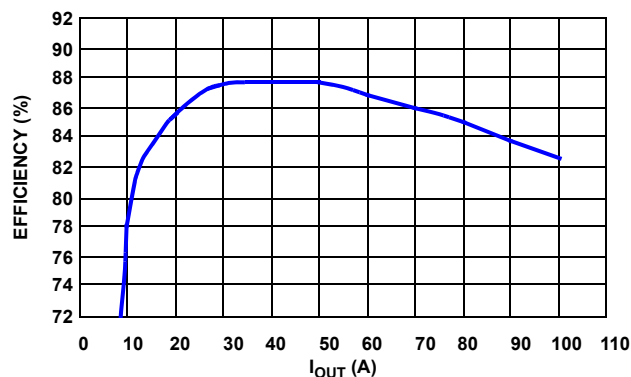
ISL6327EVAL5 Four Phase Performance (Continued)

FIGURE 22. VR EFFICIENCY $V_{IN} = 12V$, $V_{ID} = 1.4V$,
 $LL = 1.0m\Omega$, V_{OUT} MEASURED AT INDUCTOR

Summary

The ISL6327EVAL5 evaluation board provides a high performance VRD solution highlighting the ISL6327 advanced multiphase controller with the use of a coupled inductor and low capacitance output filter.

For detailed theory of operation, component selection and layout guidelines refer to the ISL6327 datasheet.

The following pages provide a board schematic and bill of materials to support implementation of this and similar solutions.

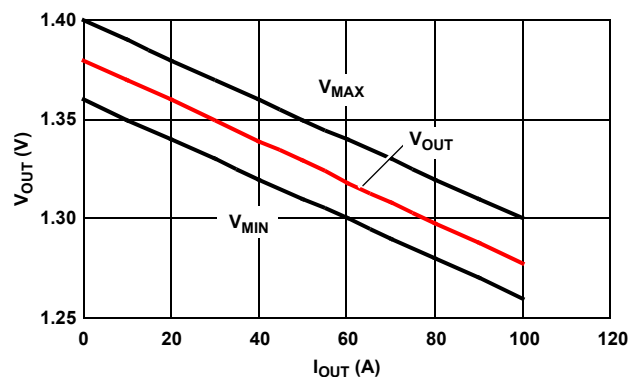


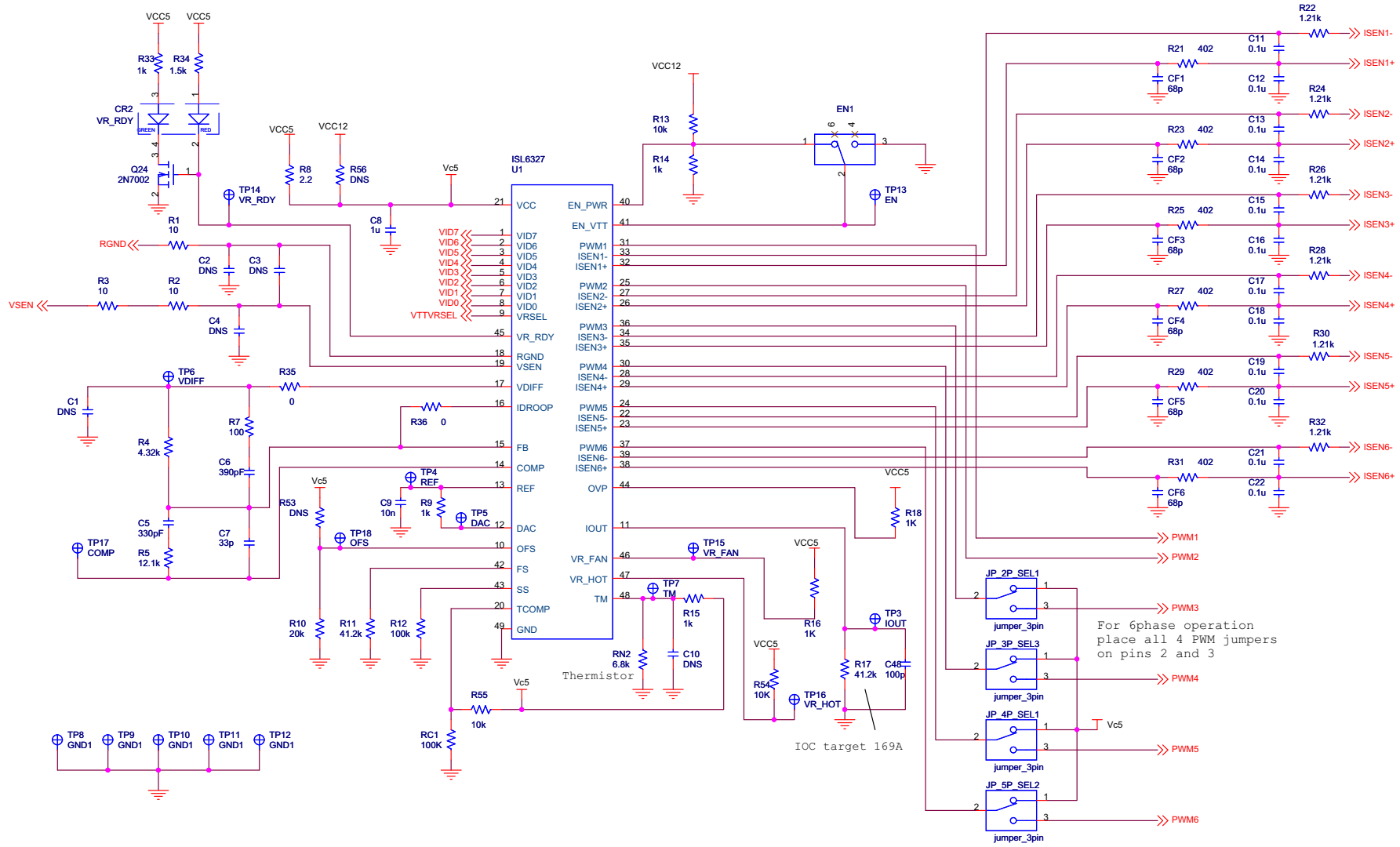
FIGURE 23. Vcore LOADLINE REGULATION FROM 0A TO 100A

References

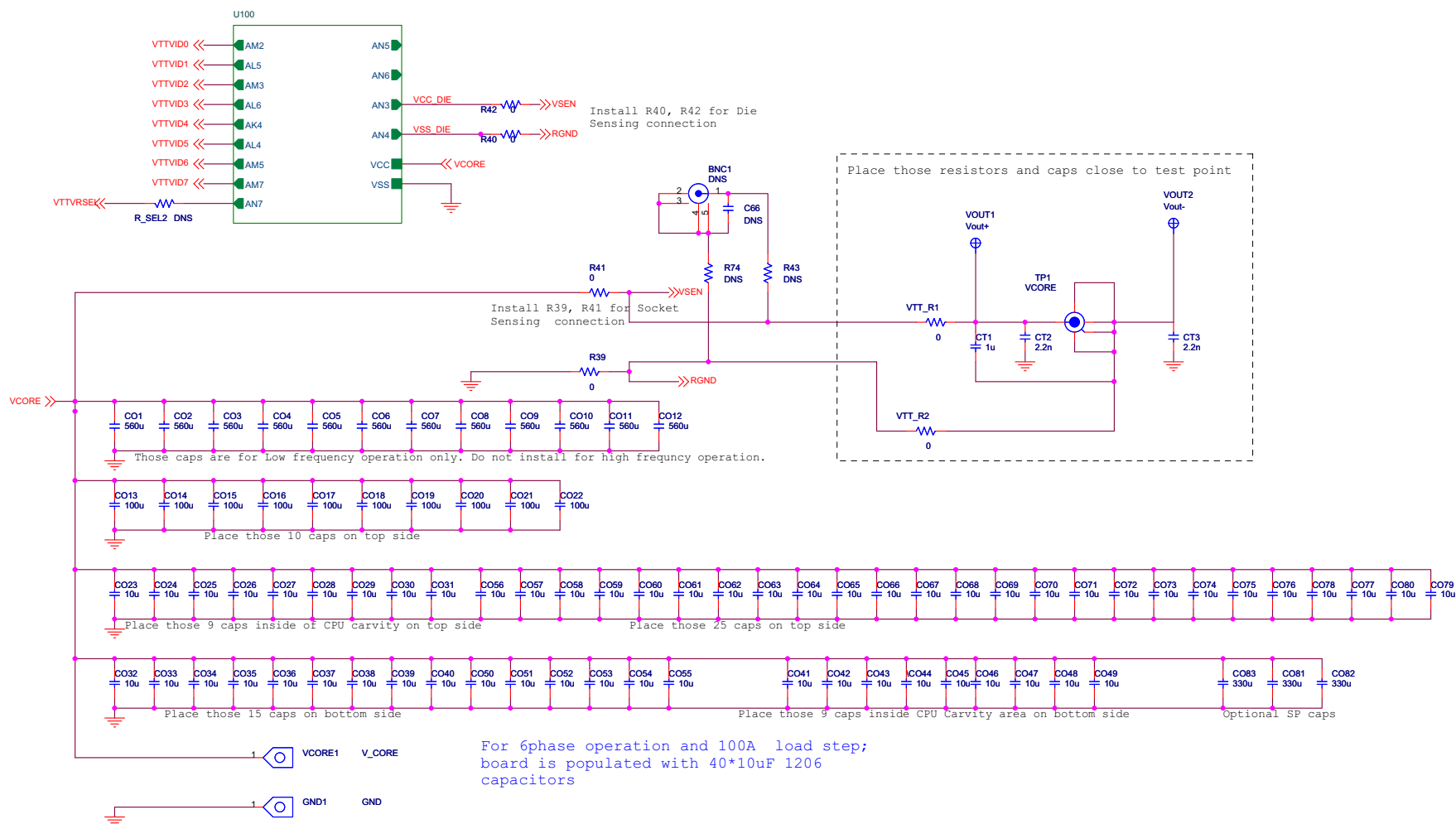
Intersil documents are available on the web at www.intersil.com.

- [1] ISL6327 Data Sheet, Intersil Corporation, File No. FN9276
- [2] ISL6609 Data Sheet, Intersil Corporation, File No. FN9221
- [3] IN06006 Coupled Inductor Datasheet ICE Components, www.icecomponents.com

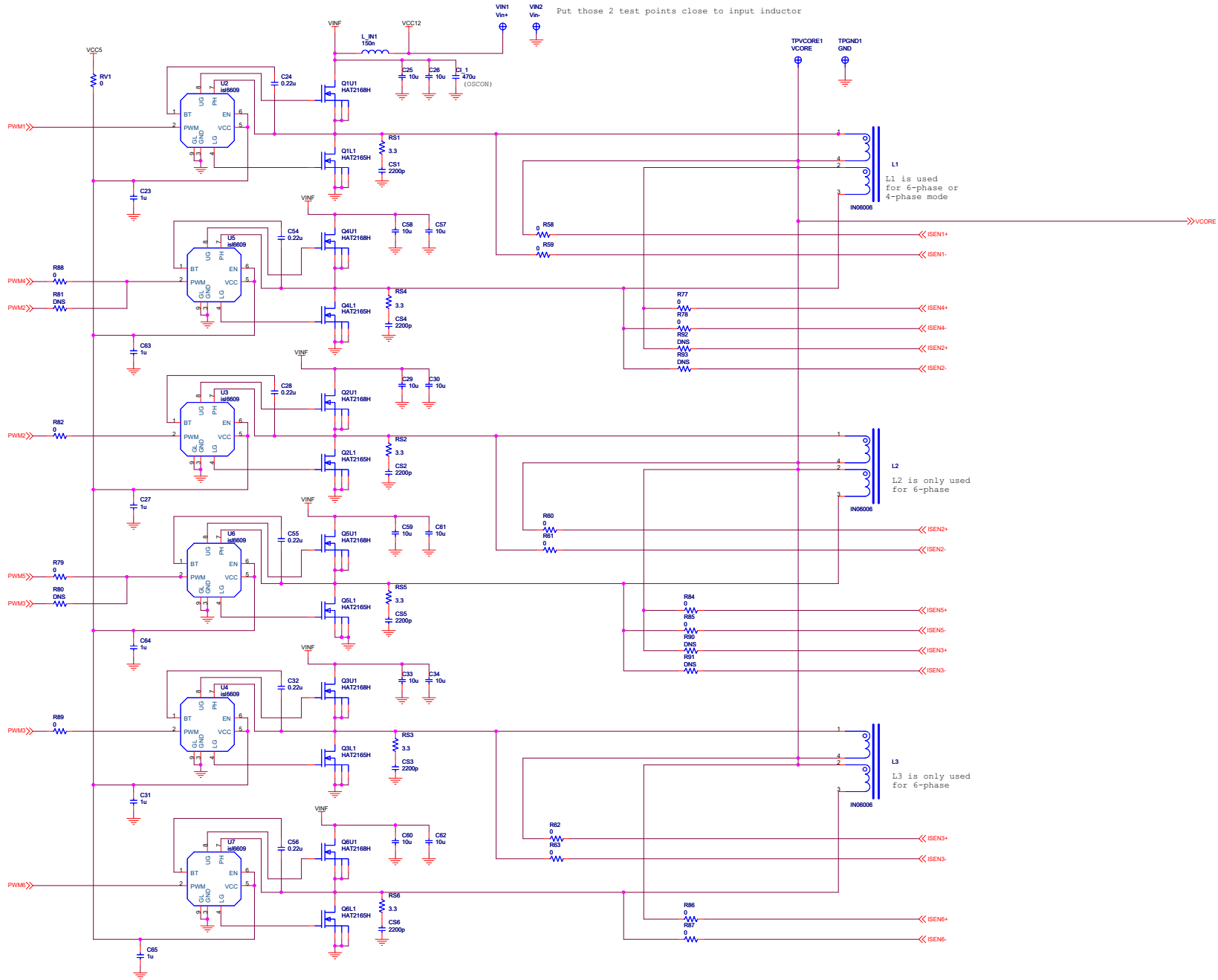
Controller Circuit



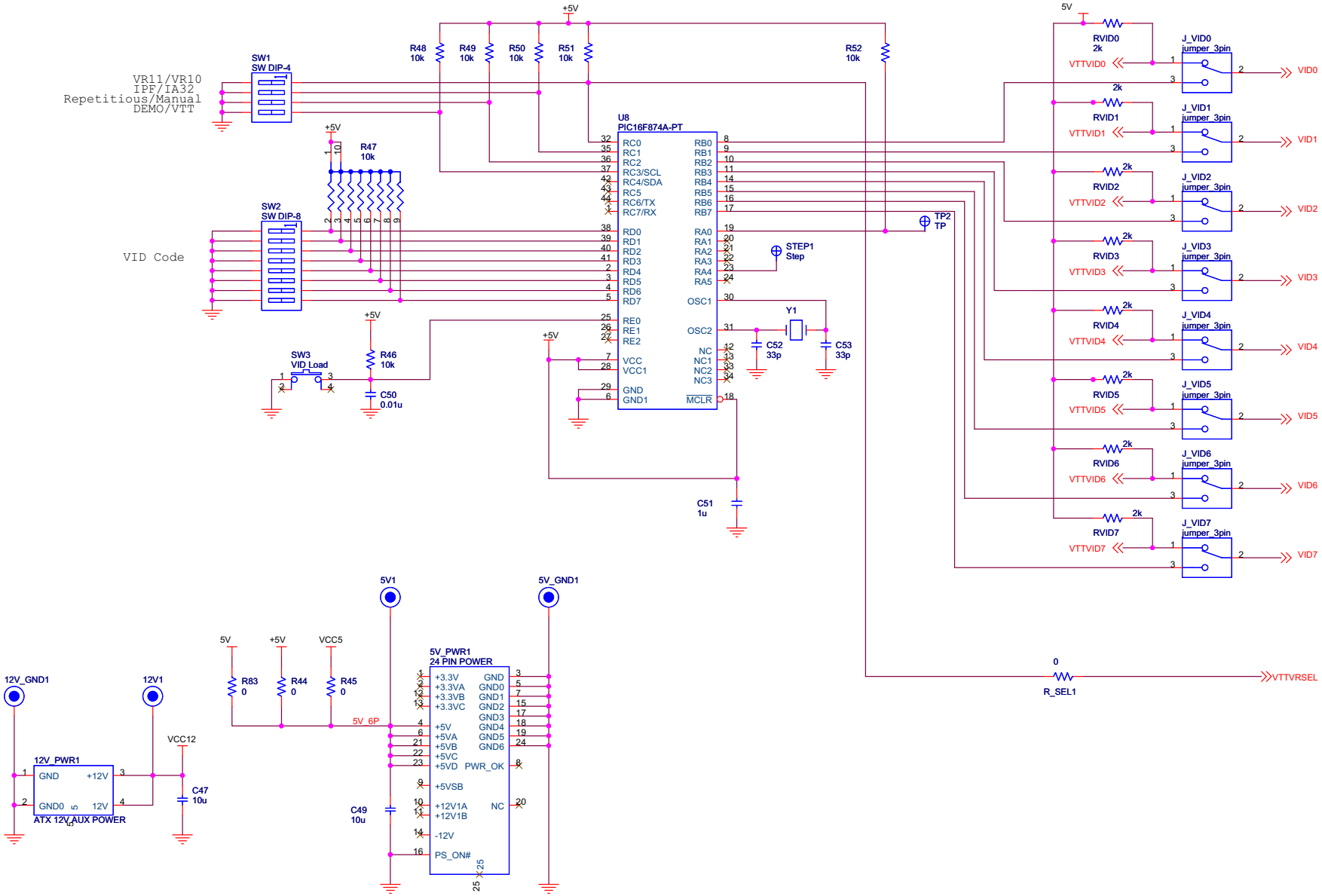
Output Capacitors and LGA775 VID Connections



Power Stage



VID Generator and Input Power Connectors



Bill of Materials

| QTY | REF DESIGNATOR | DESCRIPTION | VENDOR | VENDOR P/N | PKG |
|-----|--|--------------------------------|---------|----------------|------|
| 3 | C52, C53, C7 | 33pF, 50V COG 0603 Cap | Various | | REEL |
| 1 | C48 | 100pF, 50V COG 0603 Cap | Various | | REEL |
| 6 | CF1, CF2, CF3, CF4, CF5, CF6 | 68pF, 50V X7R 0805 Cap | Various | | REEL |
| 1 | C5 | 330pF, 50V X7R 0603 Cap | Various | | BAG |
| 1 | C6 | 390pF 50V COG 0603 Cap | Various | | BAG |
| 4 | C3, C2, CT2, CT3 | 2.2nF, 50V X7R 0603 Cap | NIC | NMC0603X7R222K | REEL |
| 2 | C9, C50 | 10nF, 50V X7R 0603 Cap | NIC | NMC0603X7R103K | REEL |
| 12 | C12, C14, C16, C18, C20, C22, C11, C13, C15, C17, C19, C21 | 0.1µF, 16V X7R 0603 Capacitor | MURATA | | BAG |
| 6 | C24, C28, C32, C54, C55, C56 | 0.22µF, 50V Y5V 0603 Cap | MURATA | GRM188F51H224Z | BAG |
| 8 | C8, C23, C27, C31, C51, C63, C64, C65 | 1µF, 16V X5R 0603 Cap | MURATA | GRM188R61C105K | BAG |
| 1 | CT1 | 1µF, 16V X7R 1206 Cap | MURATA | GRM319R71C105K | BAG |
| 1 | C49 | 10µF, 16V Y5V 0805 Cap | MURATA | GRM21BF51C106Z | BAG |
| 58 | CO23, CO24, CO25, CO26, CO27, CO28, CO29, CO30, CO31, CO32, CO33, CO34, CO35, CO36, CO37, CO38, CO39, CO40, CO41, CO42, CO43, CO44, CO45, CO46, CO47, CO48, CO49, CO50, CO51, CO52, CO53, CO54, CO55, CO56, CO57, CO58, CO59, CO60, CO61, CO62, CO63, CO64, CO65, CO66, CO67, CO68, CO69, CO70, CO71, CO72, CO73, CO74, CO75, CO76, CO77, CO78, CO79, CO80 | 10µF, 6.3V X7R 1206 Capacitor | MURATA | GRM31CR70J106M | REEL |
| 0 | | 100µF, 6.3V X5R 1210 Capacitor | MURATA | GRM31CR60J107M | REEL |
| 13 | C25, C26, C29, C30, C33, C34, C57, C58, C59, C60, C61, C62 | 10µF, 16V X5R 1206 Capacitor | MURATA | GRM31CR61C106K | BAG |
| 1 | CI_1 | 470µF, 16V Sanyo OSCON | Sanyo | 16SEPC470M | BAG |
| 29 | R39, R41, R58, R59, R60, R61, R62, R35, R36, R63, R75, R76, R79, R82, VTT_R1, VTT_R2, R_SEL1, R82, R79, R88, R89, R77, R78, R84, R85, R86, R87, R40, R42 | 0 5% Resistor; 0603 | Various | | REEL |
| 4 | R44, R45, R83, RV1 | 0 5% Resistor; 1206 | Various | | REEL |
| 1 | R8 | 2.2 5% Resistor; 1206 | Various | | REEL |
| 6 | RS1, RS2, RS3, RS4, RS5, RS6 | 3.3 Resistor, 5%, 1206 | Various | | REEL |
| 3 | R1, R2, R3 | 10 5% Resistor; 0603 | Various | | REEL |
| 6 | RF1, RF2, RF3, RF4, RF5, RF6 | 12 1% Resistor; 0603 | Various | | REEL |
| 6 | R21, R23, R25, R27, R29, R31 | 402 1% Resistor; 0603 | Various | | REEL |
| 1 | R7 | 200 1% Resistor; 0603 | Various | | REEL |
| 6 | R9, R15, R16, R18, R33, R34 | 1k 1% Resistor; 0603 | NIC | NRC06F1001TR | REEL |
| 8 | RVID0, RVID1, RVID2, RVID3, RVID4, RVID5, RVID6, RVID7 | 2k 1% Resistor; 0603 | Various | | BAG |
| 1 | R4 | 4.32k 1% Resistor; 0603 | Various | | BAG |
| 6 | R22, R24, R26, R28, R30, R32 | 1.21k 1% Resistor; 0603 | Various | | BAG |
| 10 | R13, R43, R46, R48, R49, R50, R51, R52, R54, R55 | 10k 1% Resistor; 0603 | NIC | NRC06F1002TR | REEL |
| 1 | R5 | 12.1k 1% Resistor; 0603 | NIC | NRC06F1002TR | REEL |
| 1 | R10 | 20k 1% Resistor; 0603 | NIC | NRC06F2002TR | REEL |

Bill of Materials (Continued)

| QTY | REF DESIGNATOR | DESCRIPTION | VENDOR | VENDOR P/N | PKG |
|-----|--|--|-----------|---------------------|------|
| 2 | R11, R17 | 41.2k 1% Resistor; 0603 | NIC | NRC06F1003TR | REEL |
| 2 | R12, RC1 | 100k 1% Resistor; 0603 | NIC | NRC06F1003TR | REEL |
| 1 | R47 | 10k x 8 Resistor Array | AVX | RNA4A8E103JT | REEL |
| 1 | RN2 | THERM_6.8K_0805 | Vishay | NTHS0805N02N6801 | BAG |
| 3 | L1, L2, L3 | 87nH/64A Coupled Inductor (0.55mΩ DCR) | ICE | IN-06006 | DNS |
| 1 | LIN_1 | 150nH/40A Inductor (0.48mΩ DCR) | Cooper | FP4-150 | REEL |
| 6 | Q1U1, Q2U1, Q3U1, Q4U1, Q5U1, Q6U1 | Upper MOSFETs | Hitachi | HAT2168H or RJK0305 | BAG |
| 6 | Q1L1, Q2L1, Q3L1, Q4L1, Q5L1, Q6L1 | Lower MOSFETs | Hitachi | HAT2165H or RJK0301 | BAG |
| 1 | Y1 | Crystal 16.000 MHz HC49/US | ECS | ECS-160-20-4 | BAG |
| 6 | U2, U3, U4, U5, U6, U7 | Sync Rec Buck Drvr 5V QFN | Intersil | ISL6609CR (QFN) | TUBE |
| 1 | U1 | Multiphase Buck Voltage Regulator | Intersil | ISL6327CR | BAG |
| 1 | U8 | 8-BIT Microchip Cntrl | Microchip | PIC16F874A-I/PT | BAG |
| 2 | CR1, CR2 | 4P LED 3X2.5MM SMD | Luminex | SSL-LXA3025IGC | BAG |
| 1 | Q24 | N-Ch MOSFET SOT-23 | Fairchild | 2N7002 | BAG |
| 1 | SW1 | 4 Pin DIP Switch | CTS | 219-4LPST | TUBE |
| 1 | SW2 | 8 Pin DIP Switch | CTS | 219-8LPST | TUBE |
| 1 | SW3 | Momentary Pushbutton Switch | Panasonic | EVQ-QWT03W | BAG |
| 1 | EN1 | Toggle Switch Mini SPDT SMD | ITT | GT11MSCKETR | BAG |
| 1 | 5V_PWR1 | 24 Pin ATX Connector | Molex | 39-29-9242 | BAG |
| 1 | 12V_PWR1 | 4 Pin Power Connector | Molex | 39-29-9042 | BAG |
| 17 | STEP1, VIN1, VIN2, VOUT1, VOUT2, VCORE1, TP1, TP2, TP3, TP4, TP5, TP13, TP14, TP15, TP16, TP17, TP18 | Test Points | Keystone | 5002 | BAG |
| 5 | TP8, TP9, TP10, TP11, TP12 | Test Points, Turret 0.281 Height | Keystone | 1514-2 | BAG |
| 1 | TP1 | O'scope Probe Test Point | Tektronix | K131-4244-00 | BAG |
| 12 | J_VID0, J_VID1, J_VID2, J_VID3, J_VID4, J_VID5, J_VID6, J_VID7, JP_4P_SEL1, JP_2P_SEL1, JP_3P_SEL3, JP_5P_SEL2 | 3 Pin Header | AMP/TYCO | A26512-ND | BAG |
| 2 | 5V1, 12V1 | Banana Jack | Keystone | 7006K | BAG |
| 2 | 5V_GND1, 12V_GND1 | Banana Jack | Keystone | 7007K | |
| 1 | BNC1 | BNC connector | | 31-5329-52RFX | BAG |
| 2 | VCORE1, GND1 | Terminal Lugs | Burndy | KPA8CTP | BAG |
| 5 | 5 on the back of the board | Bumpsons | | | |
| 1 | U100 | CPU socket | FOXCONN | LGA775 | TRAY |
| 47 | R53, R56, C1, C6, C7, C10, R_SEL2, CO1, CO2, CO3, CO4, CO5, CO6, CO7, CO8, CO9, CO10, CO11, CO12, CO81, CO82, CO83, R81, R80, R92, R93, R90, R91, R43, R74, C66, CS1-6, CO13, CO14, CO15, CO16, CO17, CO18, CO19, CO20, CO21, CO22 | Not Populated List | | | DNS |

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