AMD-K6®
Processor

Power Supply Design

Application Note

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Contents

List of Figures

List of Tables

Revision History

Date	Rev	Description
March 1998	E	Changed general reference voltage 2.x V to 2.2 V.
March 1998	E	Revised Example 4, "Actual 2.2 V @ 7.5A" on page 13.
March 1998	E	Revised Table 2, "Voltage Error Budget for 0.25-Micron Processors (Models 7 and 8)," on page 16.
March 1998	E	Revised Figure 8, "Bulk Decoupling versus Output Voltage Response for 2.2 V @7.5 A," on page 17.
March 1998	E	Revised Figure 17, "Linear LT1575 2.2V/2.9V/3.2V Linear Power Supply Design," on page 34.
March 1998	E	Revised Figure 18, "Linear LT1553 1.8V to 3.5V Switching Power Supply Design," on page 35.
May 1998	F	Revised to provide information for the AMD-K6®-2 processor Model 8.
May 1998	F	Removed Table 1, "AMD-K6® Processor Power Specifications". The voltage and current specifications for Models 6 and 7 are provided in the *AMD-K6® Processor Data Sheet,* order # 20695. The voltage and current specifications for Model 8 are provided in the *AMD-K6®-2 Processor Data Sheet,* order # 21850.
May 1998	F	Expanded information in "Power Supply Specification" starting on page 5.
May 1998	F	Added Example 5 "Hypothetical 2.3 V @ 15 A" on page 17 and Figure 9 on page 18.
May 1998	F	Added the following power supply solutions: "Cherry CS5166" on page 28, "Harris Semiconductor HIP6004 and HIP6005" on page 32, "Linear Technology LT1553" on page 34, "Maxim MAX1638" on page 38, "Fairchild RC5051" on page 43, "Semtech SC1182 and SC1183" on page 45, and "Unisem US3004" on page 48.
May 1998	F	Cut the following power supply solutions: Cherry CS5151/CS5156, Harris Semiconductor HIP6003, Linear Technology LT1575 and LT1430, Maxim MAX1624, Raytheon RC5036 and RC5041, Semtech SC1151, and Unisem US2075
May 1998	F	Revised description of "LINFINTY LX1664 and LX1665" on page 36.
May 1998	F	Added Table 14, "Micro Linear ML4902 Bill of Materials," on page 42.
May 1998	F	Combined and revised voltage regulator vendor information into one table. See "Voltage Regulator Vendor Information" on page 53.
Feb 1999	G	Added information about the AMD-K6-III processor Model 9.
Feb 1999	G	Added information about the 5-bit VID code on page 2.
Feb 1999	G	Added "Switching Regulator Layout" on page 10.
Feb 1999	G	Added information on determining the number of capacitors to Example 2 on page 13.
Feb 1999	G	Changed Example 5 to 2.4 V and changed Figure 9, "Bulk Decoupling versus Output Voltage Response for 2.4 V @15 A" on page 18.
Feb 1999	G	Changed the recommended utility in "Output Voltage Response Measurement Utility" on page 19.

Application Note

AMD-K6®
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Introduction

Unless otherwise noted, the information in this application note pertains to all desktop processors in the AMD-K6® family, which includes the AMD-K6 processor (Models 6, and 7), the AMD-K6-2 processor (Model 8) and the AMD-K6-III processor (Model 9). For information about mobile processor power supply considerations, see the *Mobile AMD-K6® Processor Power Supply Application Note*, order# 21677 and the *Mobile AMD-K6®-2 Processor Power Supply Application Note*, order# 22495

Processors in the AMD-K6 family are high-performance x86-compatible processors with over 8.8 million transistors. The newer generation of processors manufactured with the CS44E 0.25-micron (µm) process uses 2.2 volts (V) to power the core circuitry of the processor while the I/O portion operates at the industry-standard 3.3V. The previous 2.9V and 3.2V AMD-K6 processors were fabricated using AMD's enhanced 0.35-µm process technology. Due to the large number of transistors that can switch simultaneously, power supply designs must meet large transient power requirements.

This application note is intended to guide the board designer through the process of developing a reliable power supply that meets the low-voltage, high-current demands of the AMD-K6 processors. The goal is to design a solution that works over a wide voltage range and a 5.8 amps (A) to 14 A current range. (Previously, the suggested range was 5.8 A to 10 A. This change allows motherboard designers to prepare for the next generation of processors.) This application note also provides basic guidelines on circuit decoupling for reduction of noise generated by fast current transients.

The core voltage for the 0.25-µm process is 2.2 V/2.4V. However, AMD encourages designers to provide flexibility to support multiple voltages in their designs. This flexibility may entail a resistor-value change or changing the location of a zero-ohm resistor or a jumper. By providing flexibility in the power design, future lower voltage parts may be able to be used with little or no changes to the motherboard. As process geometries continue to shrink, the core voltages are planned to drop. An easy way to prepare for this is to use controllers that implement the 5-bit VID code. For core voltage specifications for the following AMD-K6 processors, refer to:

- Models 6 and 7 — *AMD-K6® Processor Data Sheet*, order# 20695
- Model 8 — *AMD-K6®-2 Processor Data Sheet*, order# 21850
- Model 9 — *AMD-K6®-III Processor Data Sheet*, order# 21918

This document contains the following sections:

- **Power Supply Specification on page 5**—Gives an overview of power supply design considerations. This section describes the basic elements of a power supply and the constraints of different design approaches.
- **Decoupling and Layout Recommendations on page 11**—Describes the decoupling and layout recommendations of the power supply design. Proper decoupling is required in order to deliver a reliable power source across the power planes and to reduce the noise generated from the fast current transients.
- **Power Supply Solutions on page 27**—Describes several voltage regulator circuits that are designed by voltage regulator vendors. These circuits can be used to generate the proper core and I/O voltages for the processor. Because the information provided is preliminary, AMD recommends that board designers consult with the voltage regulator vendors to obtain the most up-to-date information.

Processor Power Requirement

Voltage Planes

Two separate supply voltages are required to support the processor—V_{CC2} and V_{CC3}. V_{CC2} provides the core voltage for the processor and V_{CC3} provides the I/O voltage.

The power supply pin assignments for the 321-pin CPGA package (See Figure 1) are as follows:

V_{CC2} (Core):	A-07, A-09, A-11, A-13, A-15, A-17, B-02, E-15, G-01, J-01, L-01, N-01, Q-01, S-01, U-01, W-01, Y-01, AA-01, AC-01, AE-01, AG-01, AJ-11, AN-09, AN-11, AN-13, AN-15, AN-17, AN-19
V_{CC3} (I/O):	A-19, A-21, A-23, A-25, A-27, A-29, E-21, E-27, E-37, G-37, J-37, L-33, L-37, N-37, Q-37, S-37, T-34, U-33, U-37, W-37, Y-37, AA-37, AC-37, AE-37, AG-37, AJ-19, AJ-29, AN-21, AN-23, AN-25, AN-27, AN-29

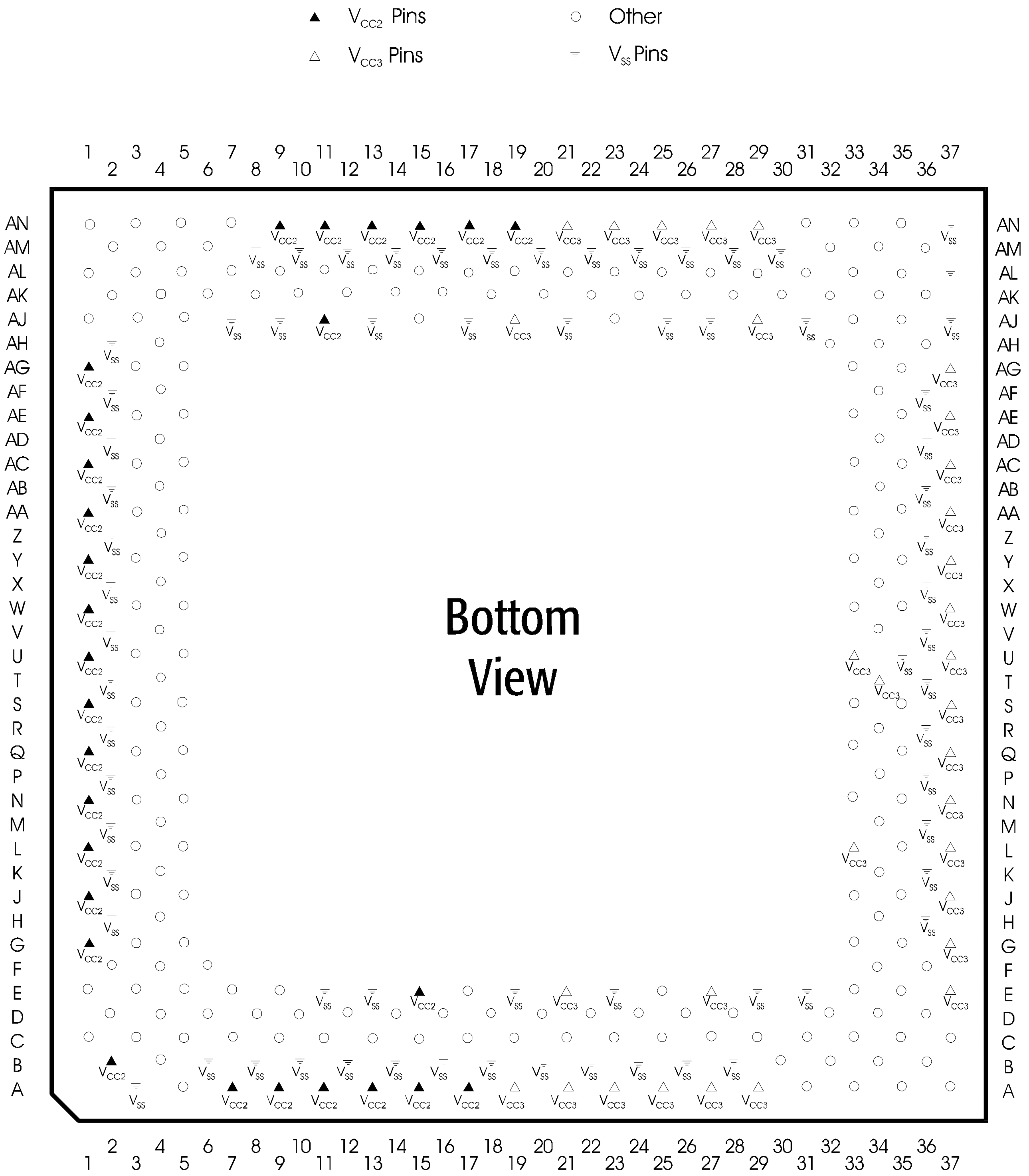


Figure 1. 321-Pin CPGA V_{CC} and Ground Pins Location

Power Supply Specification

For voltage and current specifications for the following AMD-K6 processors, refer to:

- Models 6 and 7 — *AMD-K6® Processor Data Sheet*, order# 20695
- Model 8 — *AMD-K6®-2 Processor Data Sheet*, order# 21850
- Model 9 — *AMD-K6®-III Processor Data Sheet*, order# 21918

AMD's processors have two pins that indicate the voltage requirements of the device. VCC2DET#, when asserted low, indicates that the core voltage is different than the I/O voltage. The VCC2DET# pin is available on 0.35 µm processors (Model 6) that operate at 2.9V or 3.2V. Along with VCC2DET#, the 0.25µm devices (Models 7, 8, and 9) have an additional pin—VCC2H/L#. When asserted low, VCC2H/L# indicates a 2.2V/2.4V processor core voltage. On 0.35µm devices, this pin is a No Connect.

Selecting a Power Supply Design

Most PC platforms today require DC-to-DC voltage conversion circuits to supply lower voltages to the processor core and I/O. Two types of regulators are used—linear and switching.

A linear regulator provides excellent dynamic-load response in the low-voltage, high-current environment. It also contributes to simplified design and lower cost. However, the efficiency loss and heat generated by a linear regulator should be addressed by board designs. Although most desktop system designs can tolerate the efficiency loss, care should be taken to ensure the design can handle the heat. In a high-current model, the power dissipation from the regulator can be as much as that of the processor itself. In order for the voltage regulator thermal solution to meet the case temperature requirement, the linear regulator requires a larger heatsink. As processor voltages drop and currents increase, it becomes more difficult to implement a linear solution. Linear regulator solutions are impractical for currents above 7 A.

A switching regulator meets the efficiency and size limitations of mobile board designs and is also an excellent choice for desktop designs. Switching regulators are found in most notebook computers that require both low-profile design and power dissipation reduction. Figure 2 shows linear and switching regulators. The switching regulator uses a series switch in conjunction with the output capacitor (C_O) to control the ON/OFF ratio in order to obtain an average output voltage. Because the switch turns off frequently, only a small amount of power is lost during conversion.

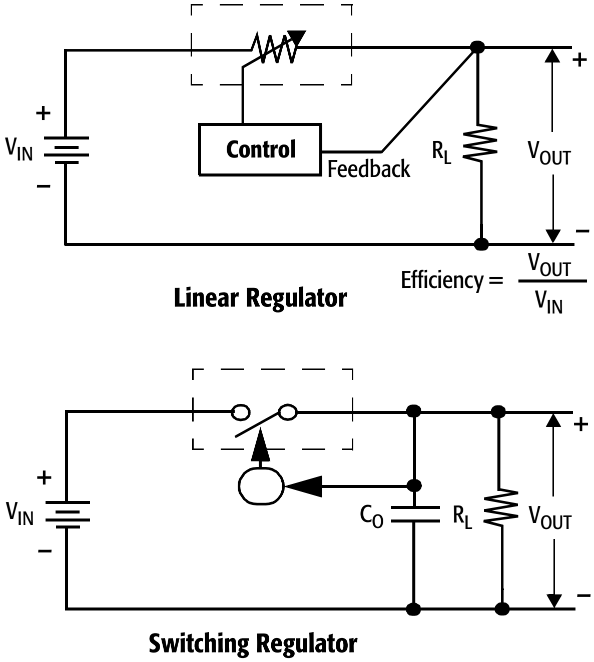


Figure 2. Linear and Switching Voltage Regulators

As the trend toward smaller process geometries continues (0.35-micron to 0.25-micron), the processor core voltage will continue to drop. To provide maximum flexibility for upgrading a motherboard, regulator controllers with the 5-bit VID code are preferable. Using this feature, processors that have not yet been announced can be supported, as long as they do not exceed the current limit of the design. Designing a point solution (such as, 2.9V @ 7.5A) eliminates many design variables, however, this approach limits flexibility and upgradeability.

There are two strategies for extending the life of a motherboard while retaining low cost. The first strategy entails designing the board for the maximum current anticipated. This approach increases the cost because the components used are more expensive and may be physically larger, therefore occupying more room. The second strategy entails the development of two designs—one that operates at 10A and one that operates at 15A. The motherboard can be laid out to accept components for either design. With this approach, a simple bill of material change is all that is necessary to upgrade to a higher-power processor.

One of the key motherboard components is the power transistor. The transistor can be replaced with one that has a lower $R_{DS(ON)}$ (resistance-drain-to-source when the transistor is on) or two transistors can be paralleled. Another important component is the output inductor. Because an inductor that carries 15A is physically larger than an inductor that carries 10A, the layout must allow sufficient space. Finally, a provision should be made to add extra decoupling capacitors. The calculations in the examples starting on page 12 show how many decoupling capacitors are needed for various cases.

Many of the components are common, including the regulator/controller IC and the basic circuitry. Typically, switching transistors and the output inductor need to change. The output filter capacitance needs to be increased for the higher currents.

Linear Regulator

The linear regulator relies on a linear series component to continuously drive the power to a load. The series component is considered a load, and the voltage drop between the input and output represents the power loss. The higher the input-to-output voltage ratio, the lower the conversion efficiency. In order to meet the voltage requirement, output feedback to the control unit is commonly used to obtain an accurate (and adjustable) voltage output.

For a linear regulator, converting a 5-V source to 3.3V results in a 66% conversion efficiency and a 34% power loss (See Figure 2 on page 6). The efficiency of the conversion gets worse if the output voltage is lower than 3.3V. The low dropout (LDO) linear regulator is a reasonable solution for providing the processor core voltage in systems that already support 3.3V from the silver-box power supply or in systems converted from an existing 3.3V design to a lower voltage.

Heat is an additional consideration. The voltage drop between the input and output multiplied by the current supplied is the power that must be dissipated by the regulator. For example, when converting 5V to 2.2V at 6A, the power dissipated is $(5\text{V} - 2.2\text{V}) \bullet 6\text{A} = 16.8\text{W}$. Therefore, linear regulators often have large heat sinks. This heat raises the ambient air temperature, making it more difficult to cool the processor. Consider the example of converting 5V to 2.2V at 10A. In this case, the power dissipated is (5V – 2.2V) • 10A = 28W. This heat makes using linear regulators impractical in many systems with these larger currents. To make a design that accommodates a wide range of processors, a switching design is preferable.

Another consideration for linear supplies involves high-frequency decoupling on the input to the regulator. Noise from a 5-V supply can pass through a linear regulator to the processor. Generally, there is no high-frequency decoupling on the input of a power supply. A switching design seems to be less susceptible to this type of noise.

Although linear regulators are good solutions at 2.2V and 7.5A, AMD does not recommend them as a desktop solution because of their lack of flexibility. Typically, a desktop motherboard should work with all available processors. A linear regulator makes such flexibility difficult to achieve while staying within heat constraints. However, a switching regulator designed for 3.2V at 14A can also accommodate a 2.2V, 7.5A processor.

Switching Regulator

A switching regulator varies the switch duty cycle (ON/OFF ratio) according to the output feedback. A large output capacitor (C_O) is used in the switching design to achieve a constant average output. The switching regulator delivers higher efficiency than a linear regulator, but the tradeoffs are higher ripple voltages (noise) and slower transient current response time. A series inductor is used to supply current to the load during the switch OFF time, adding complexity to the design. In addition, the inductor and the output capacitor increase the overall cost of the switching regulator design relative to a linear regulator design.

The power supply design must account for a low current (I_{CC2} and I_{CC3}) drain when the processor enters the Stop Grant state. The power supply must ensure the minimal current drain does not cause any adverse side effects (drift out of regulation, over-compensation, or shutdown) that could corrupt or damage the functionality of the processor.

The processor voltage tolerance requirement on both core and I/O voltage pins can be handled by commonly available linear and switching regulators. This application note describes several high-accuracy designs that provide the processor with accurate and stable voltage supplies.

In the basic asynchronous circuit design shown in Figure 3, Q1 turns on to charge C_{out} and builds up the magnetic field in L1. When the feedback from the sense input is too high the controller turns Q1 off. Current is supplied to the load by the collapsing magnetic field in L1 and the discharge of C_{out}. When the sense feedback detects a drop in the load voltage, the controller turns on Q1 to recharge the circuit. CR2 supplies a return path for L1 when it is suppling current. The main reason this design is less efficient than a synchronous design is because the power dissipated in CR2 is higher than Q2 in the synchronous design.

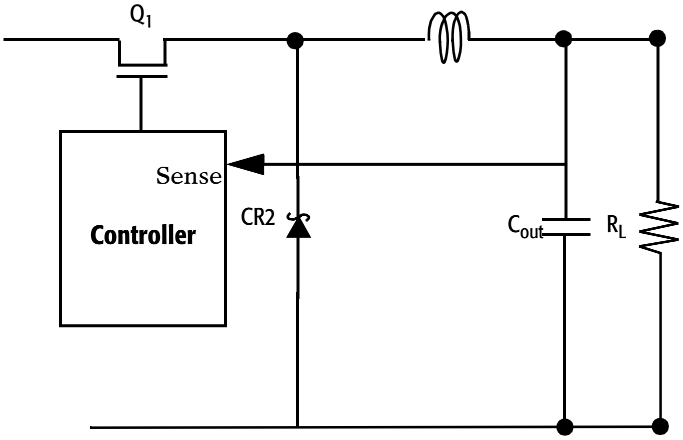


Figure 3. Basic Asynchronous Design

The operation of the basic synchronous circuit design shown in Figure 4 on page 10 is essentially the same as the asynchronous design. Q1 turns on to charge C_{out} and builds up the magnetic field in L1. When the feedback from the sense input is too high, the controller turns Q1 off. Current is supplied to the load by the collapsing magnetic field in L1 and the discharge of C_{out}. When the sense feedback detects a drop in the load voltage, the controller turns on Q1 to recharge the circuit. Q2 supplies a return path for L1 when it is supplying current. When Q1 is on, Q2 is off and when Q1 is off, Q2 is on. The main reason this design is more efficient is because the power dissipated in Q2 is lower than the power in CR2.

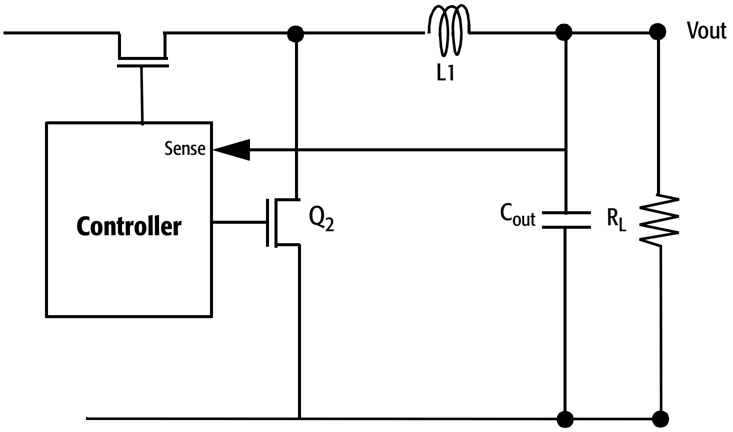


Figure 4. Basic Synchronous Design

Another consideration is power dissipation in the lower MOSFET (synchronous) or diode (asynchronous). As the output voltage decreases the power dissipation in CR2 (Q2) increases. The higher power dissipation may require using a different package type or adding a heat sink to dissipate the additional power.

To determine if the transistors or the diode need a heat sink use the following equation:

$$P = I^2R \bullet \text{duty cycle (Q1)}$$

$$P = I^2R \bullet \text{(1- duty cycle) (Q2)}$$

$$\text{Duty cycle} \sim V_{out}/V_{in}$$

Compare these calculations with the specifications of the device used.

Switching Regulator Layout

Each manufacturer has example layouts. Since the layout is critical for stability and performance, AMD recommends working closely with the manufacturer. For more information on switching regulator layouts, refer to “Board Layout Boost Power-Supply Performance” by Philip Rogers in the Nov. 5, 1998 issue of EDN (www.ednmag.com).

Decoupling and Layout Recommendations

Power Distribution

In order to maintain a stable voltage supply during fast transients, power planes with high frequency and bulk decoupling capacitors are required. Figure 5 shows a power distribution model for the power supply and the processor. The bulk capacitors (C_B) are used to minimize ringing, and the processor decoupling capacitors (C_F) are spread evenly across the circuit to maintain stable power distribution.

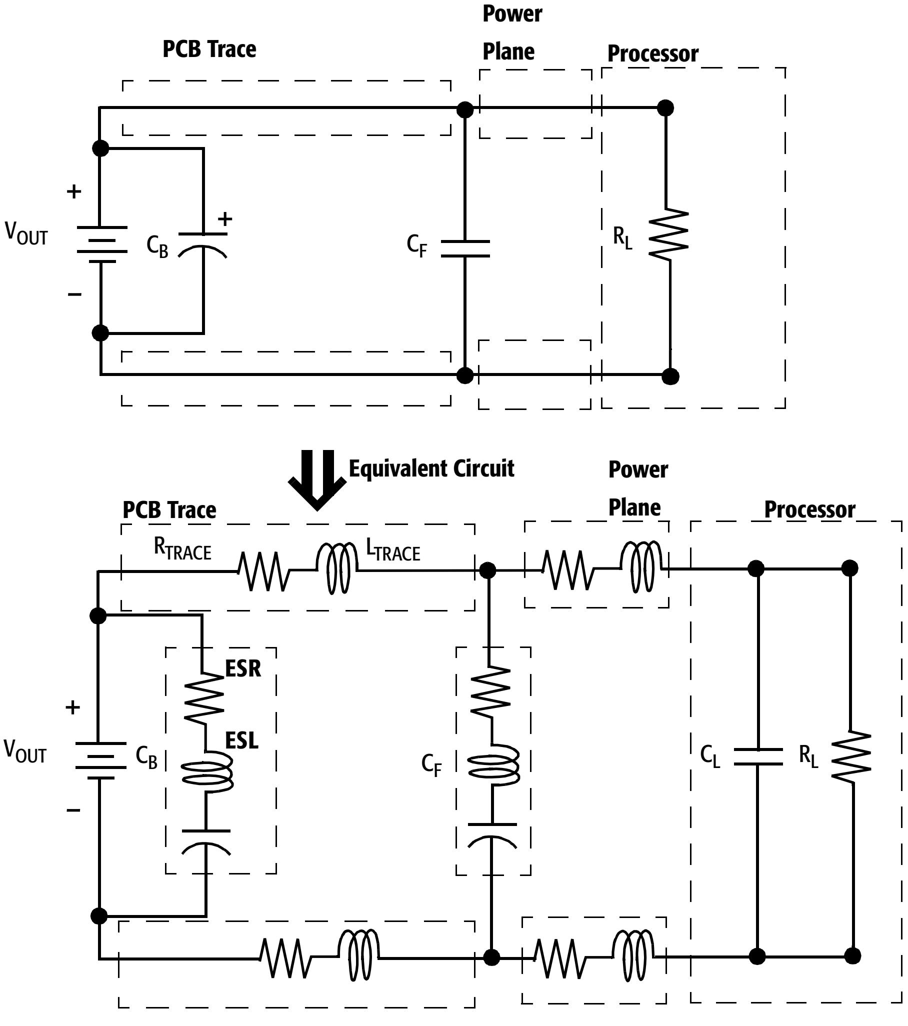


Figure 5. Power Distribution Model

Current Transient Response

In the power distribution model shown in Figure 5 on page 11, C_B represents bulk capacitors for the power supply and C_F represents high-frequency capacitors for processor decoupling. The bulk capacitors supply current to the processor during sudden excessive current demands that cannot be supplied by the voltage regulator (for example, transitioning from the Stop Grant state to normal mode). The required C_B can be calculated by the following equation (ideal case):

$$C \geq \frac{\Delta I}{\Delta V} \bullet \Delta t$$

Where:

- ΔI is the maximum processor current transient
- ΔV is the tolerance times the nominal processor voltage
- Δt is the voltage regulator response time

Examples

The following examples are not the only solutions. Based on the availability of parts and the choice of controller, many correct solutions are possible. The examples, which use tantalum capacitors, are intended to give insight into the requirements, not to specify a particular solution. The use of aluminum electrolytic capacitors are acceptable as long as good quality, low-ESR parts are used.

Example 1 Theoretical 3.2V @ 10A

Assuming the maximum processor current transient is 10A, the voltage tolerance of the processor is less than 100mV (3% of 3.2V), and the voltage regulator response time is 10µs, the minimum capacitance for the bulk decoupling is:

$$C_B \geq (10A/0.100V) \bullet 10\mu s = 1000\mu F$$

ESR (equivalent series resistance) and ESL (equivalent series inductance) are introduced in the model shown in Figure 5. C_B contains ESR and ESL, which cause voltage drop during current transient activity (See Figure 6 on page 15). The resistive and inductive effect of the capacitors must be taken into account when designing processor decoupling. Low ESL and ESR capacitors should be used to obtain better voltage and current output characteristics. The voltage error budget for ESL is shown in Table 1 on page 15. Taking into account the ESR, the following equation is used to calculate C_B:

$$C \geq \frac{\Delta I}{(\Delta V - (\Delta I \bullet ESR))} \bullet \Delta t$$

Example 2
Actual 3.2V @ 10A

This example assumes the maximum processor current transient is 10A, the voltage tolerance of the processor is less than 100mV (3.2V ± 100mV), and the voltage regulator response time is 10µs.

Using ten tantalum capacitors with 80-mΩ ESR (the parallel resistance is 8mΩ) as bulk capacitors, the minimum bulk capacitance is:

$$C_0 \geq ((10A/(0.100V - [10A \bullet 8m\Omega])) \bullet 10\mu s = 5000\mu F$$

In this example, the high current transient combined with the tight regulation specification requires significantly more decoupling capacitance than what is shown in Example 3. Therefore, ten (5000/470=10.6) 470-µF 55-mΩ capacitors are required to satisfy this current transient and voltage requirement. It is possible here to use either 10 or 11 capacitors. For the worst case, the correct approach is to round up giving 11 capacitors. However, experience shows that rounding down may be sufficient as it is extremely unlikely that all capacitors will be at the maximum ESR.

Example 3
Actual 2.9V @ 7.5 A

This example assumes the maximum processor current transient is 7.5A, the voltage tolerance of the processor is less than 145mV (5% of 2.9V), and the voltage regulator response time is 10µs.

Using four tantalum capacitors with 60-mΩ ESR (the parallel resistance is 15mΩ) as bulk capacitors, the minimum bulk capacitance is:

$$C_0 \geq ((7.5A/(0.145V - [7.5A \bullet 15m\Omega])) 10\mu s = 2300\mu F$$

Five 470-µF tantalum capacitors with 55-mΩ ESR meet this requirement. However, if the brand of capacitor is changed to one with a 100-mΩ ESR, the supply is out of tolerance.

Example 4
Actual 2.2 V @ 7.5 A

This example assumes a device with a maximum processor current transient of 7.5 A, the voltage tolerance of the processor is less than 100 mV, and the voltage regulator response time is 10 µs.

Using six tantalum capacitors with 60-mΩ ESR (the parallel resistance is 10 mΩ) as bulk capacitors, the minimum bulk capacitance is:

$$C_0 \geq ((7.5A/(0.100V - [7.5A \bullet 10m\Omega])) \, 10\mu s = 3000\mu F$$

Six 470-µF tantalum capacitors with 55-mΩ ESR meet this requirement. However, if the brand of capacitor is changed to one with a 100-mΩ ESR, the supply is out of tolerance. Therefore, when designing a system that supports only 2.2 V devices, the required bulk decoupling is significantly less than the bulk decoupling for the higher voltage and higher current parts. Note that the voltage tolerance is an important factor. Because of the higher Vcc2 tolerance in example 3 the decoupling requirement is slightly less than the 2.2V case.

Note: *The denominator of the C_0 equation cannot be a negative value, which implies a negative capacitor (such as a battery).*

In order to achieve greater margin, the total error budget should be distributed between set point tolerance, ESL, and ESR as shown in Figure 6 and Table 1 on page 15. Although the drop from ESL is a small factor, it is not negligible. If aluminum electrolytic capacitors are used instead of tantulum capacitors, the ESL drop is larger.

The high-frequency decoupling capacitors (C_F), which are typically smaller in capacitance and ESL, maintain the voltage output during average load change until C_B can react. See "High-Frequency Decoupling" on page 23 for more information.

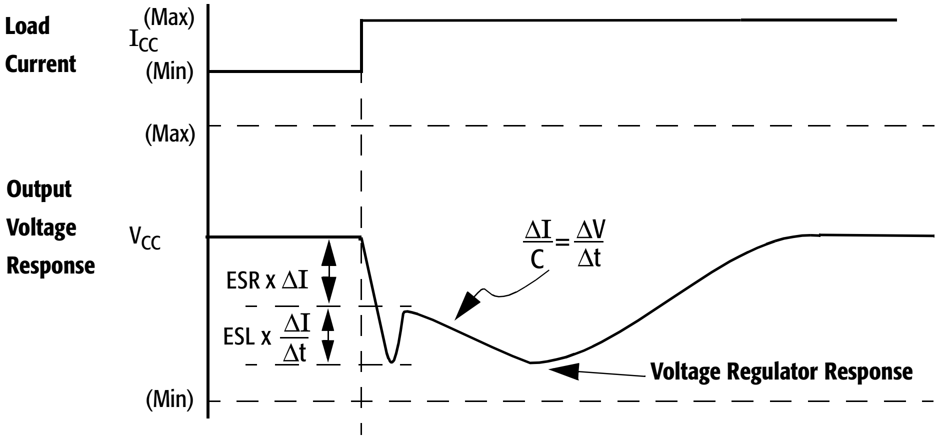


Figure 6. Load Current Step versus Output Voltage Response

Allocation of the voltage error budget can be determined from Figure 6 on page 15. Given a total error budget of 100 mV and using good capacitors (ten 470-µF capacitors with a 55-mΩ ESR are assumed), voltage drops for a 0.35-µm processor can be allocated as shown in Table 1.

Table 1. Voltage Error Budget for 0.35-Micron Processors (Model 6)

Error Budget Component	Calculations*	Budgeted Drop
V (Set Point)	1%	0.032 V
V(ESR)	5.5 mΩ x 10 A (5.5 mΩ = 55mΩ / 10)	0.055 V
V(ESL)	0.12 nH x (10 A/10 nsec) {0.12 nH = (0.6 nH + 0.6 nH via) / 10}	0.012 V
Total		0.099 V

Note:
* *Calculations assume 10 capacitors*

Figure 7 on page 16 shows the voltage drop as a function of bulk decoupling for the 3.2 V case. The graph was calculated using 55-mΩ ESR, 470-µF capacitors, and gives the designer a visual representation of how much bulk decoupling is needed. For example, at 2820 µF, the voltage is 3.1 V (10 A current transient), leaving no margin for DC-tolerance errors. At 4700 µF, the voltage is 3.144 V, allowing 0.058 mV for set point tolerance, ESR, and ESL drop.

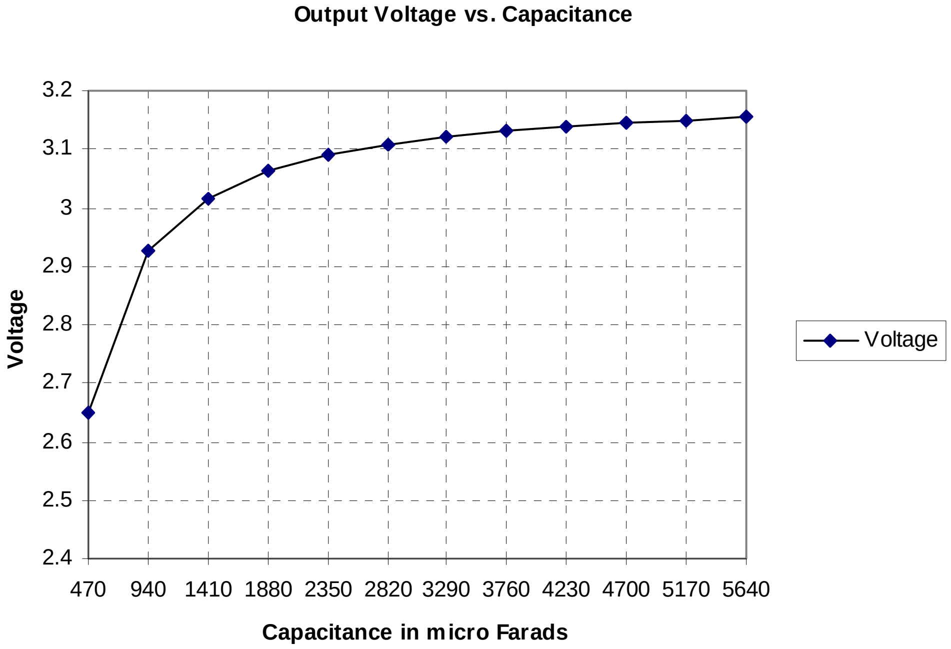


Figure 7. Bulk Decoupling versus Output Voltage Response for 3.2 V @10 A

Table 2 shows an error budget calculation for a 0.25-µm processor. The example uses seven, 470-µF capacitors.

Table 2. Voltage Error Budget for 0.25-Micron Processors (Models 7, 8, 9)

Error Budget Component	Calculations*	Budgeted Drop
V (Set Point)	1%	0.022 V
V(ESR)	7.86 mΩ x 7.5A (7.86 mΩ = 55mΩ / 7)	0.059 V
V(ESL)	0.2 nH x (7.5 A/10 nsec) {0.2 nH = (0.7 nH + 0.7 nH via) / 7}	0.015 V
Total		0.096 V

Note:
* *Calculations assume 7 capacitors*

Figure 8 on page 17 shows the voltage drop as a function of bulk decoupling for the 2.2V case. The graph was calculated using 55-mΩ ESR, 470-µF capacitors.

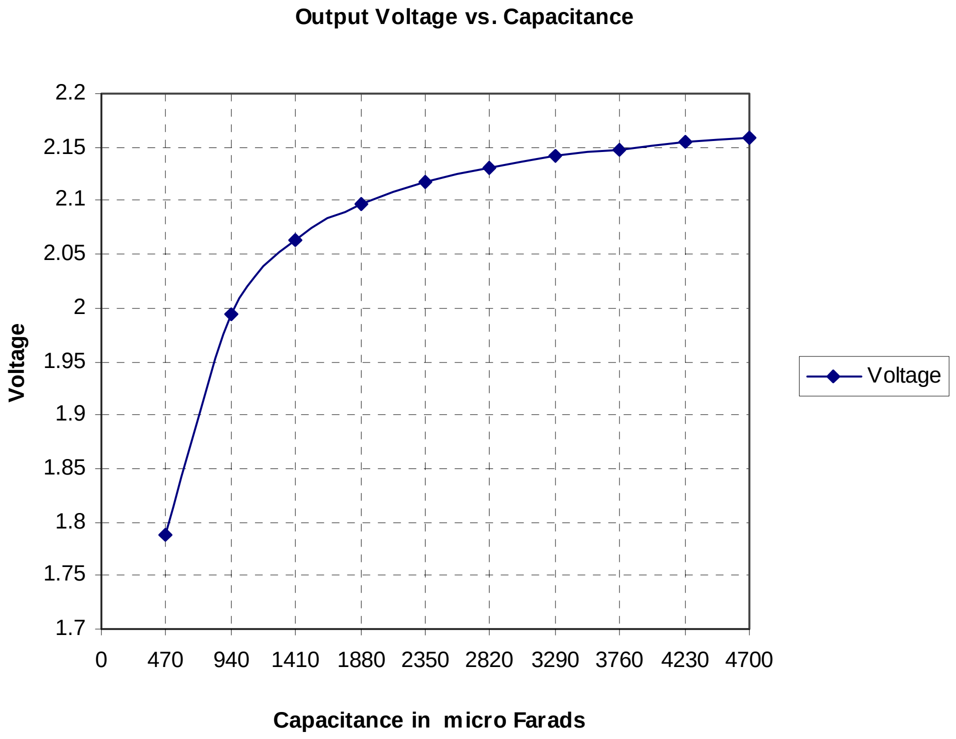


Figure 8. Bulk Decoupling versus Output Voltage Response for 2.2 V @7.5 A

Example 5 Hypothetical 2.4 V @ 15 A

This example assumes a device with a maximum processor current transient of 15 A, the voltage tolerance of the processor is less than 100 mV, and the voltage regulator response time is 10µs.

Using twelve tantalum capacitors with 60-mΩ ESR (the parallel resistance is 5 mΩ) as bulk capacitors, the minimum bulk capacitance is:

$$C_0 \geq ((15A/(0.100V - [15A \bullet 5m\Omega])) \; 10\mu s = 6000\mu F$$

Twelve 470-µF tantalum capacitors with 55-mΩ ESR meet this requirement. Figure 9 on page 18 shows the voltage curve for this case.

Note: *The denominator of the* C_0 *equation cannot be a negative value, which implies a negative capacitor (such as a battery).*

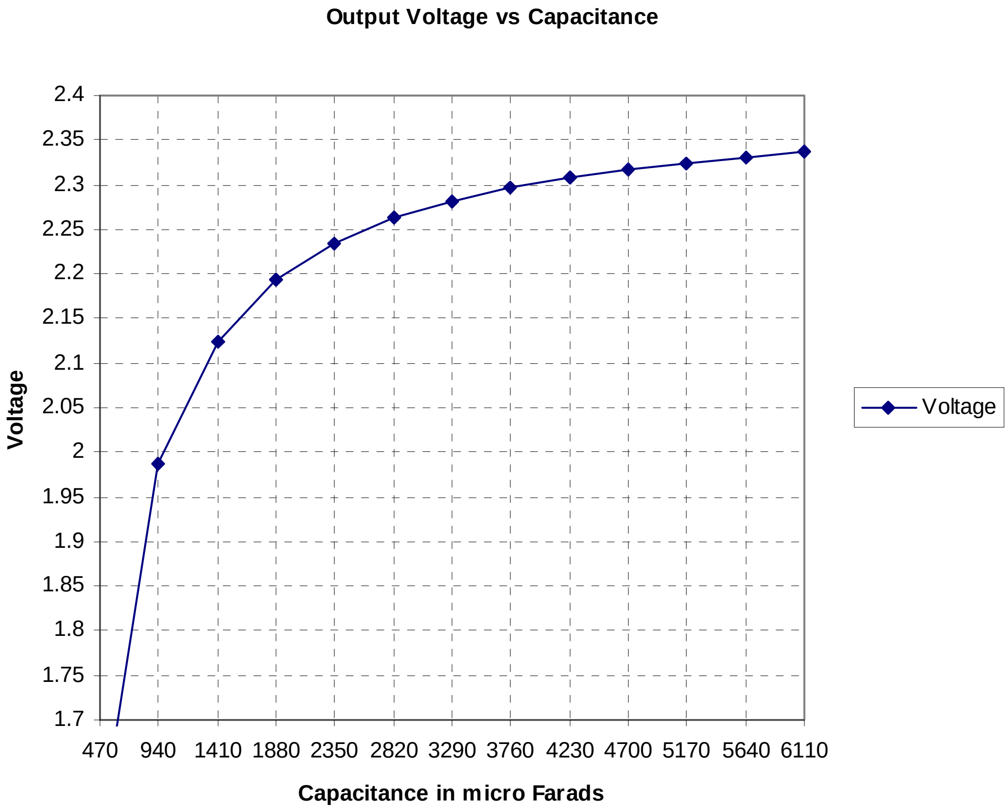


Figure 9. Bulk Decoupling versus Output Voltage Response for 2.4 V @15 A

Output Voltage Response Measurement Techniques

To measure output voltage response, run a program such as DOS EDIT and toggle STPCLK# every 40 µsec or slower. (AMD has developed the Maxpwr99.exe utility. See "Output Voltage Response Measurement Utility" on page 19 for more information.) Measure the voltage at the back of the board right under the processor. Use a scope probe with a ground connection next to the tip. The 3 inch to 6 inch ground leads that come off the side of a scope probe have too much inductance for this type of measurement. The scope bandwidth can be limited to 20MHz, giving a clear indication of the power supplied. While limiting the scope bandwidth for bulk decoupling verification gives a clear indication of the low-frequency issues, AMD recommends rechecking with at least a 250MHz bandwidth for verifying the high-frequency decoupling.

AMD used a Tektronix 684B scope with 6245 probes and an HP54720 with 54701 probes. (There was no significant difference between these two instruments.) The data was taken over a 40-second window with the scope set to infinite persistence. For a good starting point, use a horizontal sweep rate of 500nsec per division and a vertical scale of 0.1V per division. AMD made measurements while running Winstone® 96 under the Windows® 95 operating system, running DOS EDIT pull down, and running Maxpwr99.exe while toggling STPCLK#. The latter case created the worst-case current transient in the measurements conducted by AMD. In addition, this is the case that requires the maximum decoupling capacitance.

Those regulators that AMD believes can meet the processor requirements (with proper decoupling) are marked as tested in the tables shown in “Voltage Regulator Vendor Information” on page 53. The other listed regulators are expected to work, but were not tested in time for the printing of this document.

Output Voltage Response Measurement Utility

AMD has developed a software utility to assist in designing systems that comply with the processor power and thermal requirements. This utility can verify that the supply voltage remains stable during a transition to a higher power/current consumption level.

This utility is DOS based. For systems based on the Windows 95 or Windows 98 operating system, re-boot in DOS mode or boot from a bootable DOS floppy disk that contains the utility. For systems based on the Windows NT® and OS/2 operating systems, boot from a bootable DOS floppy disk that contains the utility.

The command line for this utility is as follows: (***Note:*** *Do not execute the utility in a DOS window or with a memory manager loaded.*)

```
c:\>Maxpwr99.exe
```

The Maxpwr99.exe utility is available under a nondisclosure agreement. Contact your local AMD sales office for information.

Decoupling Capacitance and Component Placement

The high-frequency decoupling capacitors (C5–C31 in Figure 11 on page 22) should be located as close to the processor power and ground pins as possible. To minimize resistance and inductance in the lead length, the use of surface mounted capacitors is recommended. When possible, use traces to connect capacitors directly to the processor's power and ground pins. In most cases, the decoupling capacitors can be placed in the Socket 7 cavity on the same side of the processor (component side) or the opposite side (bottom side).

Figure 11 on page 22 shows a suggested component placement for the decoupling capacitors. The values of the capacitors are specified in Table 5 on page 22. The split voltage planes should be isolated if they are in the same layer of the circuit board. To separate the two power planes, an isolation region with a minimum width of 0.254 mm is recommended. The ground plane should never be split.

These recommendations are based on single-sided component assembly and general space constraints. The designer should assume these are minimum requirements. If double-sided component assembly is used, it is preferable to use more capacitors of a smaller value, which reduces the total ESR and total ESL of the capacitors. For example, instead of four 470-µF capacitors, use ten 47-µF capacitors. (Check the device specifications shown in Table 3. Occasionally a lower value capacitance has a higher ESR.) As the effective ESR is lowered, the total required capacitance is reduced. The breakdown voltage and case size both affect the ESR value.

Table 3. Representative ESR Values

Capacitance	Device 1	Device 2
470 µF	55 mΩ	100 mΩ
270 µF	70 mΩ	100 mΩ
100 µF	90 mΩ	100 mΩ
68 µF	95 mΩ	100 mΩ
47 µF	120 mΩ	250 mΩ

Via inductance can be reduced when using double-sided component assembly. Components can share vias on the top side and bottom side. This technique reduces the effective via inductance. Because double-sided assembly is rarely used in desktop systems, the most likely use for this technique is in portable systems.

Figure 10 on page 21 shows another way to reduce via inductance— parallel vias. This technique is usually used on bulk decoupling capacitors. The inductance contribution numbers shown in Table 4 indicate that a poor layout can negate a good component.

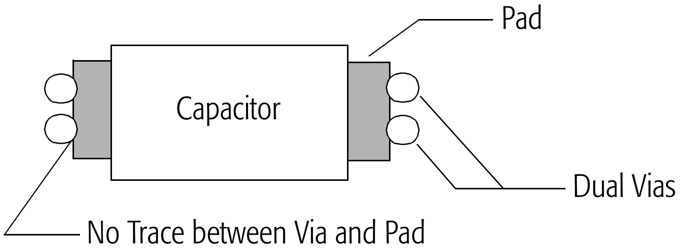


Figure 10. Via Layout For Low Inductance

Table 4. Inductance Contributions of Components

Component	Induction	Comment
Capacitor	0.6 nH (approximately)	ESL
Via	0.7 nH (approximately)	–
100 mil Trace	1.6 nH (approximately)	10 mil wide trace

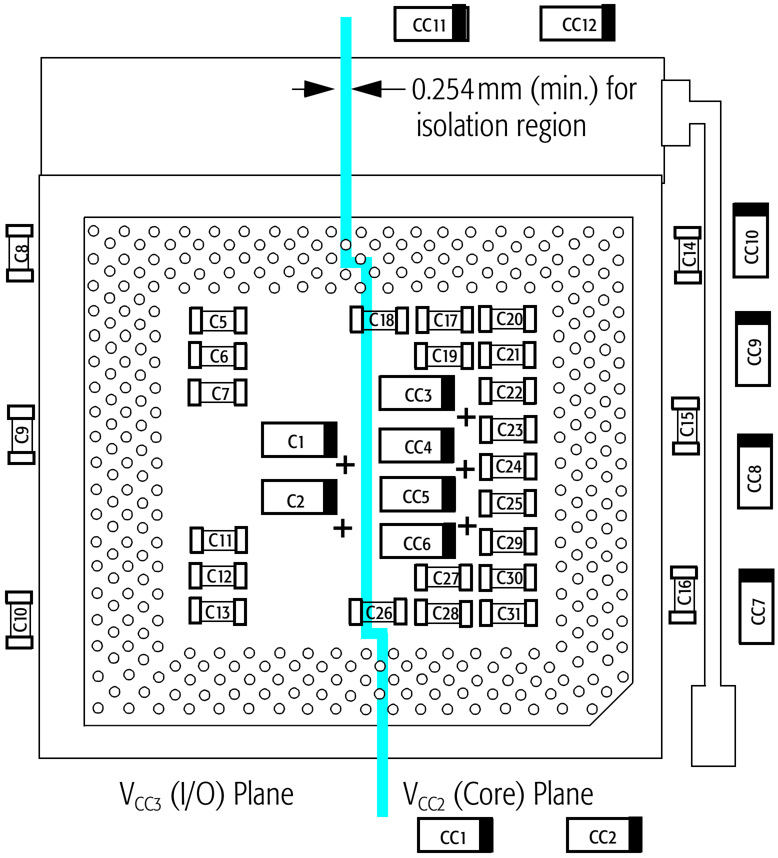


Figure 11. Suggested Component Placement

Table 5 lists the recommended capacitor values.

Table 5. Decoupling Capacitor Values

Item	Qty	Location	Value	Footprint	Description	Note
1	2	C1, C2	47 µF	AVX Size V	Surface tantalum capacitor, AVX part number TPSV476*025R0300 or equivalent	V_{CC3} Decoupling
2	12	CC1–CC12	470 µF	AVX Size V	Surface tantalum capacitor, AVX part number TPSV477*006R0100 or equivalent	V_{CC2} Decoupling
3	27	C5–C31	0.1 µF	0805	–	C5–C13 for V_{CC3} C14–C31 for V_{CC2}

Table 6 lists recommended capacitor types.

Table 6. Capacitor Recommendations

Manufacturer	Type	Comment	Web
AVX	TPS	exceptional	/www.avxcorp.com
Vishay Sprague	594D	exceptional	/vishay.com/vishay/sprague
Kemet	T510	excellent	/www.kemet.com
Sanyo	SA/SG / OS-CON 4SP560M	excellent	/www.sanyovideo.com
Vishay Sprague	593D	good	/vishay.com/vishay/sprague
Mallory	T495	good	/www.nacc-mallory.com
Nemco	SLR series	good	/www.nemcocaps.com
Panasonic	FA	good	/www.panasonic.com/pic
Elna	RJH/RJJ	good	/www.elna-america.com

The recommendations in Table 6 are not the only solutions. Based on the availability of parts and the choice of controller, many correct solutions are possible. The information in Table 6 is intended to give insight into the requirements, and not to specify a particular solution. In addition, aluminum electrolytics can be used instead of tantulum capacitors. This approach is acceptable as long as good quality, low-ESR parts are used. The biggest problem with aluminum electrolytics is the large decrease in capacitance as they age.

High-Frequency Decoupling

Inductance is also a concern for the high-frequency decoupling capacitors. Case size can be a significant factor affecting capacitor inductance. For example, a 0603 case has significantly more inductance than a 0612 case. AMD recommends the 0612, 1206, 0805, and 0603 case in order of best to worst. Inductance can also be reduced by directly connecting the capacitor to the power pin of the processor. In order to minimize its inductance, this trace must be short and as wide as possible. This technique effectively removes two via inductances between the capacitor and the processor as shown in Figure 13 on page 26. The dotted line shows that connecting the capacitor directly to the processor eliminates two series inductances. However, this trace also has inductance—if it is too long or too narrow it can be worse than the vias.

Figure 12 on page 25 shows the effect of inductance at higher frequencies. (The numbers outside the X and Y axis indicate the minimum and maximum values plotted). The inductance used is 1.8nH (two 0.7nH for the vias and 0.4nH for the capacitor itself). The capacitor is a 0.1-µF X7R multilayer Ceramic MLC. The inductance of a capacitor is a function of the case type. An 0612 case is assumed here.

The following steps show how the number of required capacitors is calculated:

1. Decide what to allow as a ripple voltage budget. In this example calculation the ripple-voltage budget = 30mV.
2. The measured AC transient current is 0.75A. This transient current has a typical duration of 2.5 nsec. The amount of capacitance required can now be determined using the following equation:

   $I = C\ (dv/dt)$

   $C = I\ (dt/dv) = 0.75A\ (2.5nsec/30mV) = 0.625\mu F$

   This equation indicates that if the capacitors didn't have inductance, only six 0.1-µF capacitors would be needed.
3. Determine the number of capacitors required based on the inductance of the capacitor. Use the following formula:

   $V = L\ (di/dt) = L \bullet (0.75A/2.5nsec) = 30mV$

   Solving for L, the allowed budget is 100pH
4. The inductance of the capacitor and via = 1.8nH (two 0.7nH for the vias and 0.4nH from the capacitor itself). Because each capacitor usually has two vias (one on each end), the effective via inductance must be:

   $2 \bullet 0.7nH + 0.4nH = 1.8nH$
5. Solving the following equations for N:

   $1.8nH/N = 100pH$

   $N = 1.8nH/100pH = 18$

   The number of capacitors required is 18.

The following steps repeat the calculation for I/O decoupling:

1. Determine the amount of capacitance required using the following equation:

   `I= C (dv/dt)`

   `C = I (dt/dv) = 0.5 (2.5nsec/145mV) = 0.0086µF`

   This equation indicates that if the capacitors didn't have inductance, only one 0.1-µF capacitors would be needed.

2. Using 0.5A as a typical I_{CC3} value, repeat the calculations to account for inductance:

   Note: *The ripple budget is 145mV because the I/O drivers are not as sensitive to supply variations as the core and the current transient is smaller.*

   `L = V (dt/di) = 0.145 (2.5nsec/.5A) = 725pH`

   Solving for L, the allowed budget is 725pH.

   The number of capacitors = 1.8nH/725pH = 2.5. Therefore, only three capacitors are needed on the I/O. AMD recommends a minimum of six capacitors.

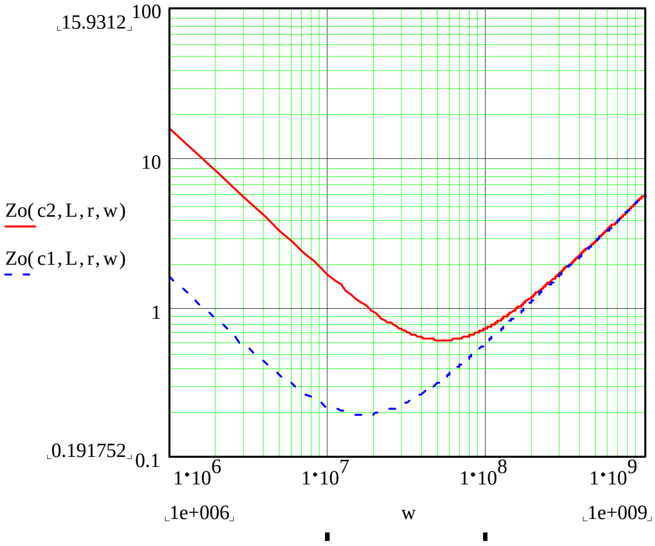


Figure 12. 0.1 µF (c1) and 0.01 µF (c2) X7R Capacitor Impedance versus Frequency

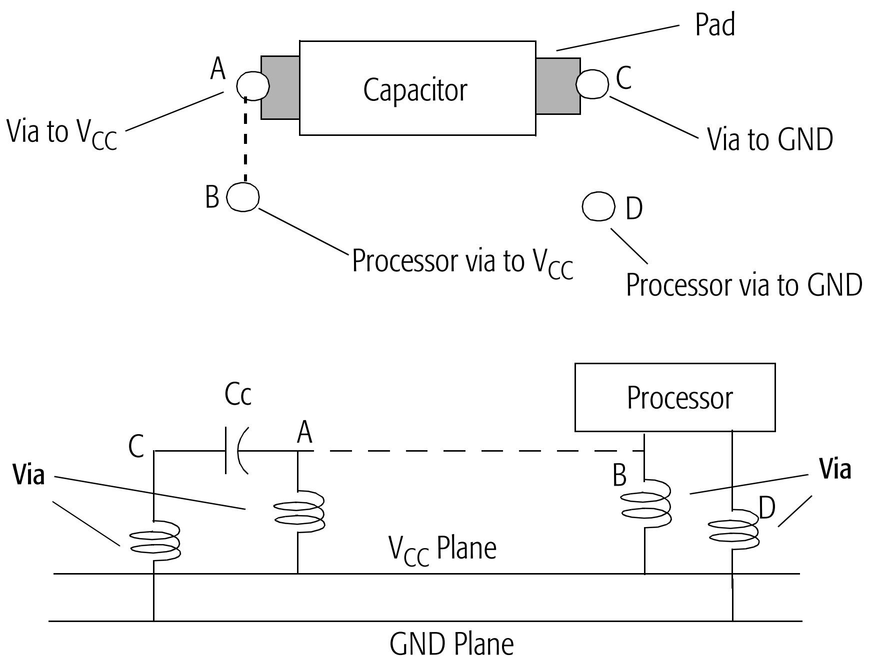


Figure 13. Decoupling Inductance

Power Sequencing

Although the processor requires dual power supply voltages, there are no special power sequencing requirements. The best procedure is to minimize the time between which V_{CC2} and V_{CC3} are either both on or both off (See Figure 14). However, a good design practice ensures V_{CC3} is always greater than V_{CC2}.

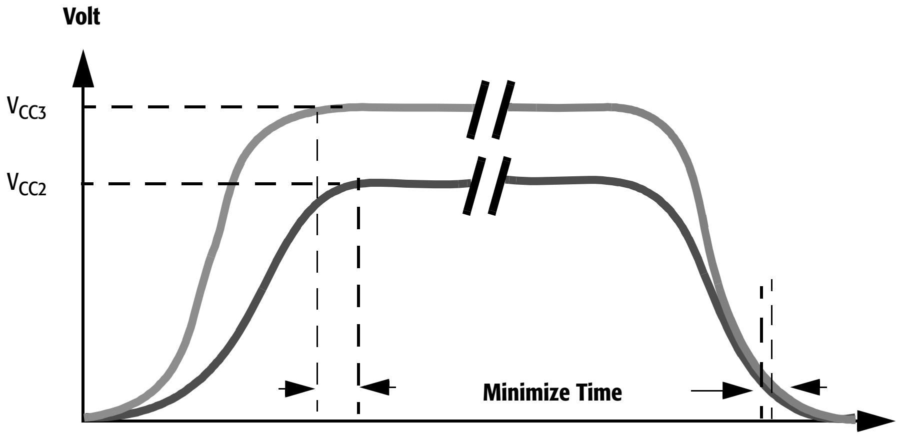


Figure 14. Power Sequencing

Power Supply Solutions

The solutions provided in this section are not all-inclusive. Obtain additional circuit diagrams and application assistance from the manufacturers. The manufacturers may customize designs to an OEM's requirements. The schematics shown in this document have not been tested by AMD and are provided as examples.

Digital-to-Analog Converter (DAC)

Voltage Identification (VID) codes provide a way to program the Digital-to-Analog Converter (DAC) to supply a reference for different output voltages. Many manufacturers have DAC-controlled devices, however, some do not follow the defined VID codes (designated as DAC in the Remarks column of the vendor table in "Voltage Regulator Vendor Information" on page 53). Table 7 shows the codes and corresponding voltage.

Table 7. Voltage Output VID Codes

D4	D3	D2	D1	D0	Output Voltage		D4	D3	D2	D1	D0	Output Voltage
1	0	0	0	0	3.50V		0	0	0	0	0	2.05V
1	0	0	0	1	3.40V		0	0	0	0	1	2.00V
1	0	0	1	0	3.30V		0	0	0	1	0	1.95V
1	0	0	1	1	3.20V		0	0	0	1	1	1.90V
1	0	1	0	0	3.10V		0	0	1	0	0	1.85V
1	0	1	0	1	3.00V		0	0	1	0	1	1.80V
1	0	1	1	0	2.90V		0	0	1	1	0	1.75V
1	0	1	1	1	2.80V		0	0	1	1	1	1.70V
1	1	0	0	0	2.70V		0	1	0	0	0	1.65V
1	1	0	0	1	2.60V		0	1	0	0	1	1.60V
1	1	0	1	0	2.50V		0	1	0	1	0	1.55V
1	1	0	1	1	2.40V		0	1	0	1	1	1.50V
1	1	1	0	0	2.30V		0	1	1	0	0	1.45V
1	1	1	0	1	2.20V		0	1	1	0	1	1.40V
1	1	1	1	0	2.10V		0	1	1	1	0	1.35V
1	1	1	1	1	OFF		0	1	1	1	1	1.30V

Cherry CS5166

The CS5166 shown in Figure 15 on page 29 is a synchronous dual NFET buck regulator controller. It is designed to power the core logic of the processors in the AMD-K6 family. It uses the V2 control method to achieve fast transient response and good overall regulation. This proprietary control architecture makes use of the ramp signal developed across the ESR of the output capacitors. This signal is fed back to the CS5166 through two feedback loops. The CS5166 features a 5-bit DAC with 1% tolerance, programmable hiccup mode current limiting, adaptive voltage positioning, and over-voltage protection. The CS5166 buck regulators can deliver 14 A at 88% efficiency.

The CS5166 minimizes external component count, total solution size, and cost. It operates over a 4.05V to 20V range using either single or dual input voltage. Table 8 on page 28 shows the bill of materials for the CS5166.

Contact Information

Cherry Semiconductor Corporation
2000 South County Trail
East Greenwich, RI 02818-1530
Tel: (401) 885-3600 Fax: (401) 885-5786

www.cherry-semi.com

Table 8. Cherry CS5166 Bill of Materials

Reference	Description	Part Number	Manufacturer
C1	1 µF	499-717	Farnell/Newark
C3, C4, C5	0.1 µF	1206B104K500NT	Novacap
C2	330 pF	0805N391J500NT	Novacap
C7–C14	1200 µF/10 V	10MV1200GX	Sanyo
R1	3.3K, 5%, 1/8 W	RM73B2AT332J	KOA
R2	510 W, 1/8 W	P-510-ECT-ND	Digi-Key
C6	1000 pF	0805N102J500NT	Novacap
Q1, Q2 (10 amp)	N-Channel FET	IRL3103	Intern.Rectifier
Q1, Q2 (19 amp)	N-Channel FET	FS70VSJ-03	Mitsubishi
L1 (10 amps)	2 µH/10 A	S26-10006	Xformers
L1 (10 amps)	2 µH/10 A	S26-10006	Xformers
L1 (19 amps)	1.2 µH/19 A	XF0016-V04	Xformers
U1	CS5166	CS5166DW16	Cherry

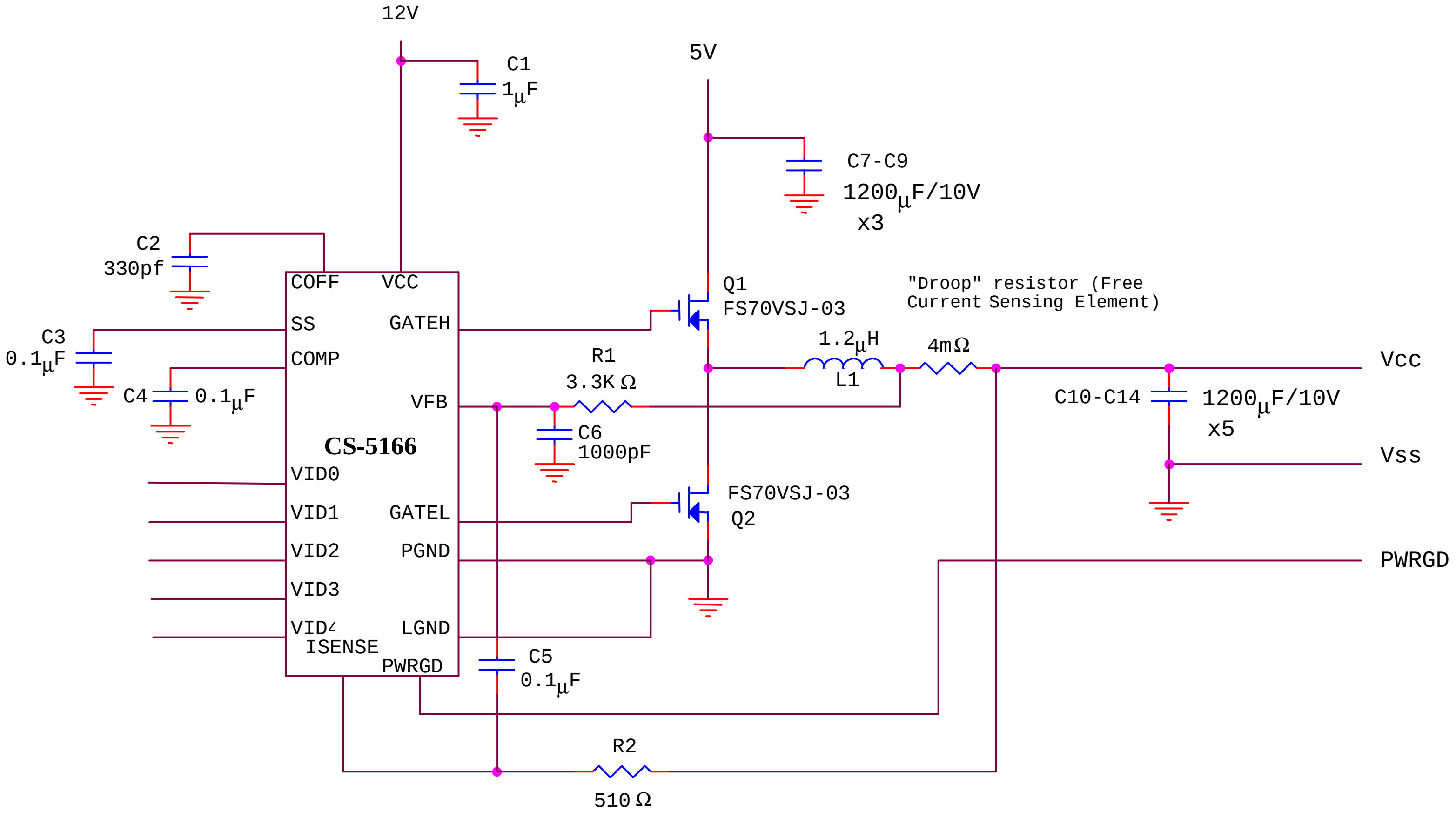


Figure 15. Cherry CS5166 Switching Power Supply Design

Elantech EL7571

The EL7571 switching regulator is a flexible, high-efficiency, PWM controller that includes a five bit DAC adjustable output. This regulator employs synchronous rectification to deliver up to 15A at efficiencies greater than 85% over a wide range of supply voltages. (Efficiencies up to 92% can be achieved at 10A.) Figure 16 shows an EL7571 reference design. The VID code allows the output to be set between 1.3V and 2.05V (in 50mV increments) and 2.1V and 3.5V (in 100mV increments) with a 1% accuracy. The VID code should be set to 00011 for 3.2V output. Table 9 on page 31 shows the bill of materials for the EL7571.

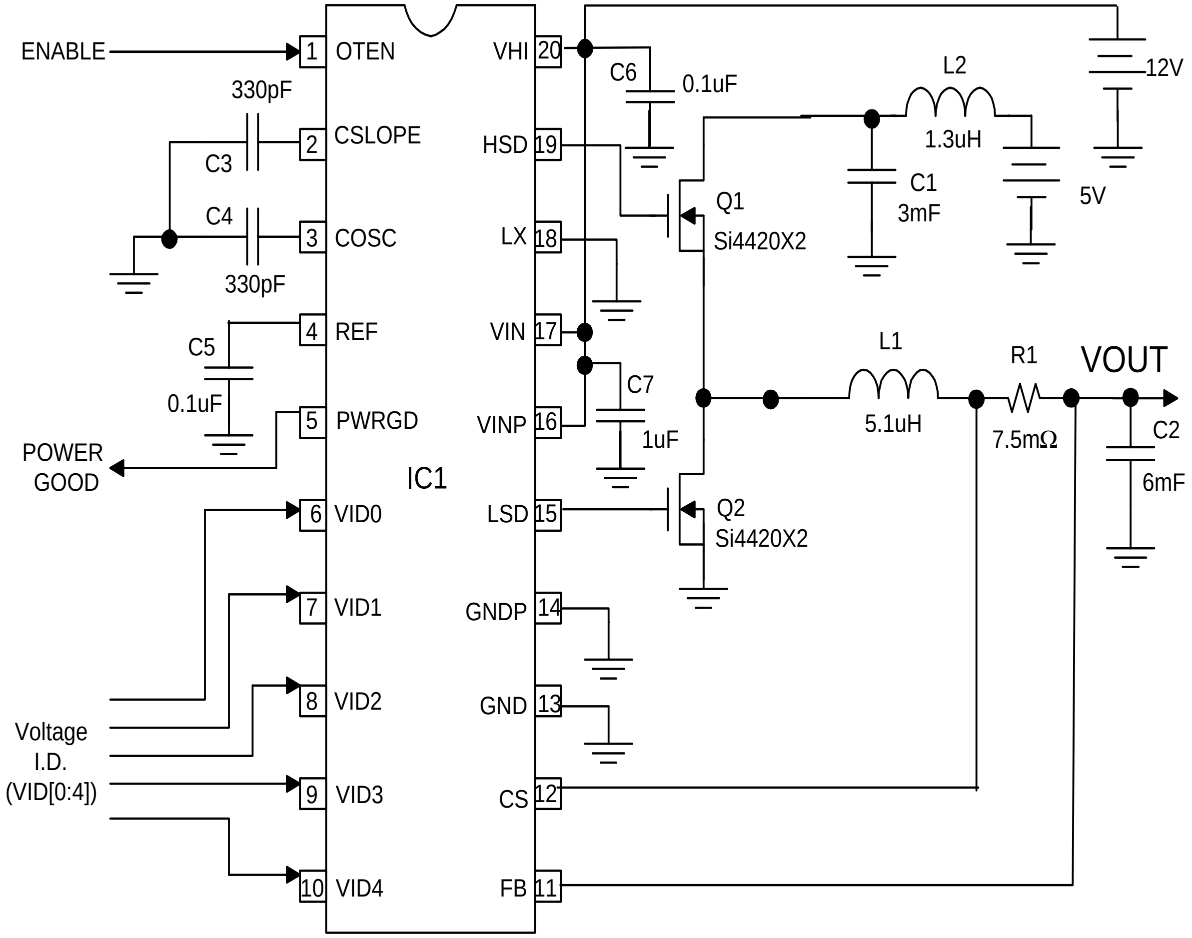


Figure 16. Elantec EL7571 Switching Power Supply Design

Contact Information

Elantec Corporation
675 Trade Zone Blvd.
Milpitas, CA 95035-1323
Tel: (408) 945-1323
Fax: (408) 945-9305

www.elantec.com

Table 9. Elantec EL7571 Bill of Materials

Reference	Description	Part Number	Manufacturer
C1, C2	680 µF	LXF16VB681M10X20LL	United Chem-Con
C3,C4	330 pF	08055A331JAT2A	AVX
C5, C6	0.1 µF	08053C104MAT2A	AVX
C7	1 µF	TAJA105K025R	AVX
D1	Diode	BAV99	Motorola, Siemens, et-al
D2	Diode	32CTQ030	International Rectifier
IC1	Controller	EL7571CM	Elantec
L1	5.1 µH	PE-53700	Pulse Engineering
L2 (optional)	1.5 µH	T30-26 7T AWG #20	Micro Metals
R1	15 mΩ	WSL-2512	Dale
R2	5 Ω	RK73H2ATE05RoF	KOA
2xQ1, 2xQ2	MOSFET	Si4420	Siliconix
Q1, Q2	MOSFET	Si4410	Siliconix

Harris Semiconductor HIP6004 and HIP6005

The Harris HIP6004 and HIP6005 are voltage-mode controllers with many functions pertinent to the processors in the AMD-K6 family. The HIP6004 is the heart of a standard step-down, or buck converter. It contains a high-performance error amplifier, a high-resolution, 5-bit digital-to-analog converter (DAC), a programmable free-running oscillator, and a floating MOSFET driver. This regulator can deliver up to 15A at efficiencies greater than 80%. The VID code allows the output to be set between 1.3 V and 2.05 V (in 50 mV increments) and between 2.1 V and 3.5 V (in 100 mV increments) with a 1% accuracy. The HIP6004 is very similar to the HIP6005, but is targeted for buck converters with a synchronous rectifier design. Figure 17 shows the reference design and Table 10 on page 33 shows the bill of materials for the HIP6004.

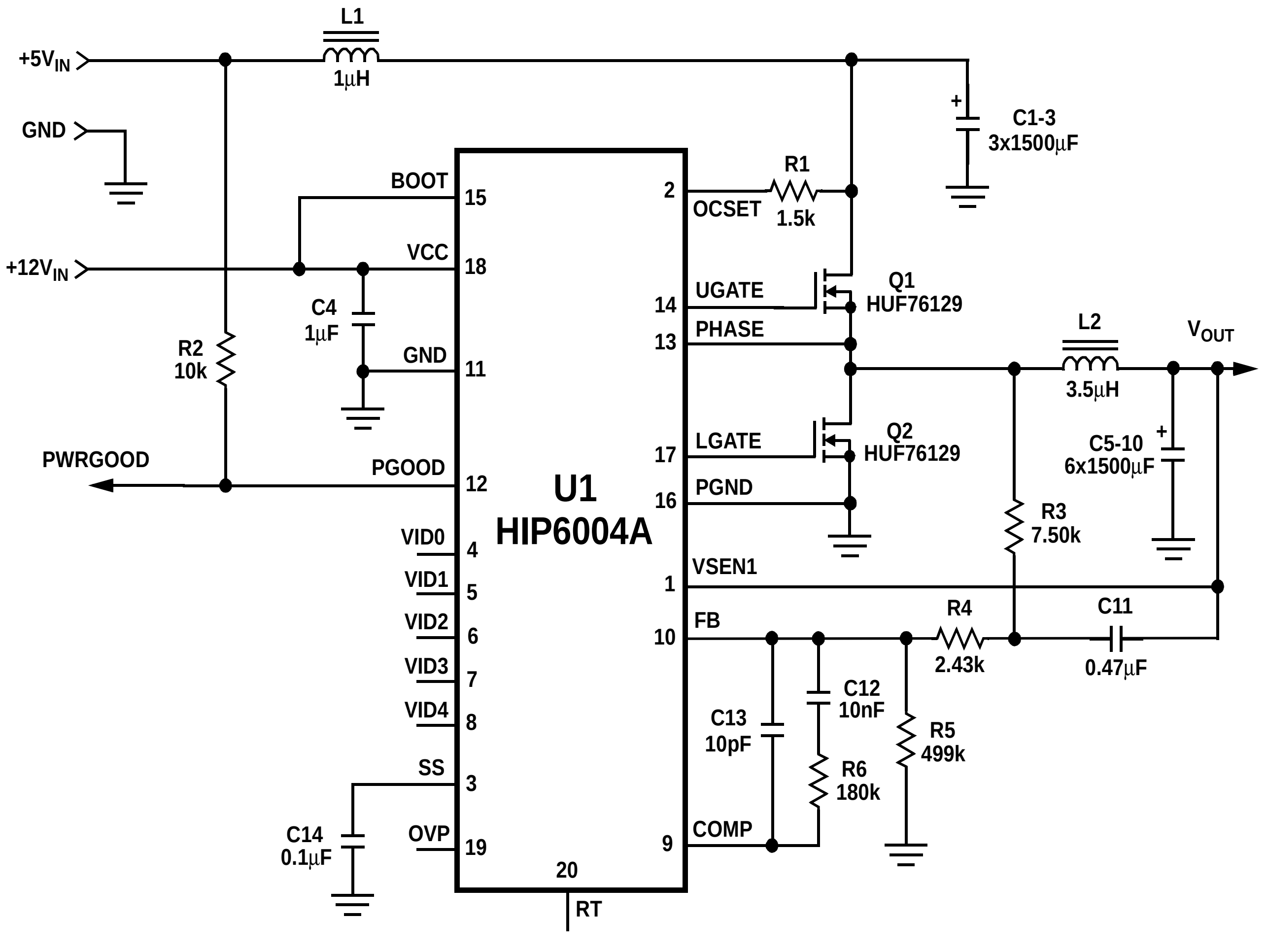


Figure 17. Harris HIP6004 1.3V–3.5V Switching Power Supply Design

Contact Information

Harris Semiconductor
P.O. Box 883, MS 53-210
Melbourne, FL 32902
Tel: (407) 729-4984 Fax: (407) 729-5321

www.semi.harris.com

Table 10. Harris HIP6004 Bill of Materials

Reference	Description	Part Number	Manufacturer
C1–C3, C5–C10	Aluminum Capacitor, 6.3 V, 1500 µF	6MV1500GX	Sanyo
C4	1.0 µF Ceramic Capacitor, X7S, 16 V	1206YZ105MAT1A	AVX
C11	0.47 µF Ceramic Capacitor, X7R, 16 V	0805YC474JAT2A	AVX
C12	0.01 µF Ceramic Capacitor, X7R, 16 V		Various
C13	10 pF Ceramic Capacitor, X7R, 25 V		Various
C14	0.1 µF Ceramic Capacitor, X7R, 16 V		Various
L1	1 µH Inductor, 7T of 16AWG on T50-52 core	PO720	Pulse
L2	3.5 µH Inductor, 7T of 17AWG on T68A-52 core	PO718	Pulse
Q1, Q2	UltraFET MOSFET, 30 V, 16 mΩ	HUF76139S3S	Harris
R1	1.5 kΩ Resistor, 5%, 0.1 W		Various
R2	10 kΩ Resistor, 5%, 0.1 W		Various
R3	7.50 kΩ Resistor, 1%, 0.1 W		Various
R4	2.43 kΩ Resistor, 1%, 0.1 W		Various
R5	499 kΩ Resistor, 1%, 0.1 W		Various
R6	18 0kΩ Resistor, 5%, 0.1 W		Various
U1	Synchronous PWM Controller	HIP6004ACB	Harris

Linear Technology LT1553

The LTC1553 is a high-power, high-efficiency (over 95% is possible) switching regulator for 1.8V–3.5V output applications. It features a 5-bit DAC controlled output voltage, a precision internal reference that provides output accuracy of ±1.5% at room temperature, load current, and line voltage shifts. The LTC1553 uses a synchronous switching architecture (that free-runs at 300 kHz) with two external N-channel output devices, providing high efficiency. It senses the output current across the on-resistance of the upper N-channel FET, providing an adjustable current limit up to 19 A without an external sense resistor. Fast transient response minimizes the output decoupling required. The design shown in Figure 18 on page 35 provides 14 A at efficiencies greater than 90%. Table 11 shows the bill of materials.

Contact Information

Linear Technology Corporation
1630 McCarthy Blvd.
Milpitas, CA 95035-7417
Tel: (408) 432-1900
Fax: (408) 434-0507

www.linear.com

Table 11. Linear LT1553 Bill of Materials

Reference	Description	Part Number	Manufacturer
Cin	1200 µF 6.3V 20% aluminum electrolytic capacitor	10MV1200GX	Sanyo
Cout	330 uF 6.3 Volt Tantalum	TPSE337M006R0100	AVX
C1	150 pF 50 V 10% NPO chip capacitor	08055A151KAT1A	AVX
Css, Cs, Cvcc, Cvcc	0.1 µF 50 V 10% Y5V chip capacitor	08055G104KAT1A	AVX
Ccc	0.01 µF 50 V 10% Y5V chip capacitor	08055G103KAT1A	AVX
Cvcc, Cvcc	10 µF 35 V 20% tantalum capacitor	TPSE106M035	AVX
L0	2 µH 18 A inductor	CTX02-13198 12TS-2R5SP	Coiltronics Panasonic
Q1, Q2	N-Channel MOSFET	SUD50N03-10	Siliconix
Rpu	5.6k 1/10W 5% chip resistor	CR21-562J-T	AVX
Rfb	20Ω 1/10W 5% chip resistor	CR21-200J-T	AVX
Rmax	2.7k 1/10W 1% chip resistor	CR21-2701F-T	AVX
Rc	8.2k 1/10W 1% chip resistor	CR21-8201F-T	AVX
U1	20-lead narrow small outline IC	LTC1553CG	LTC

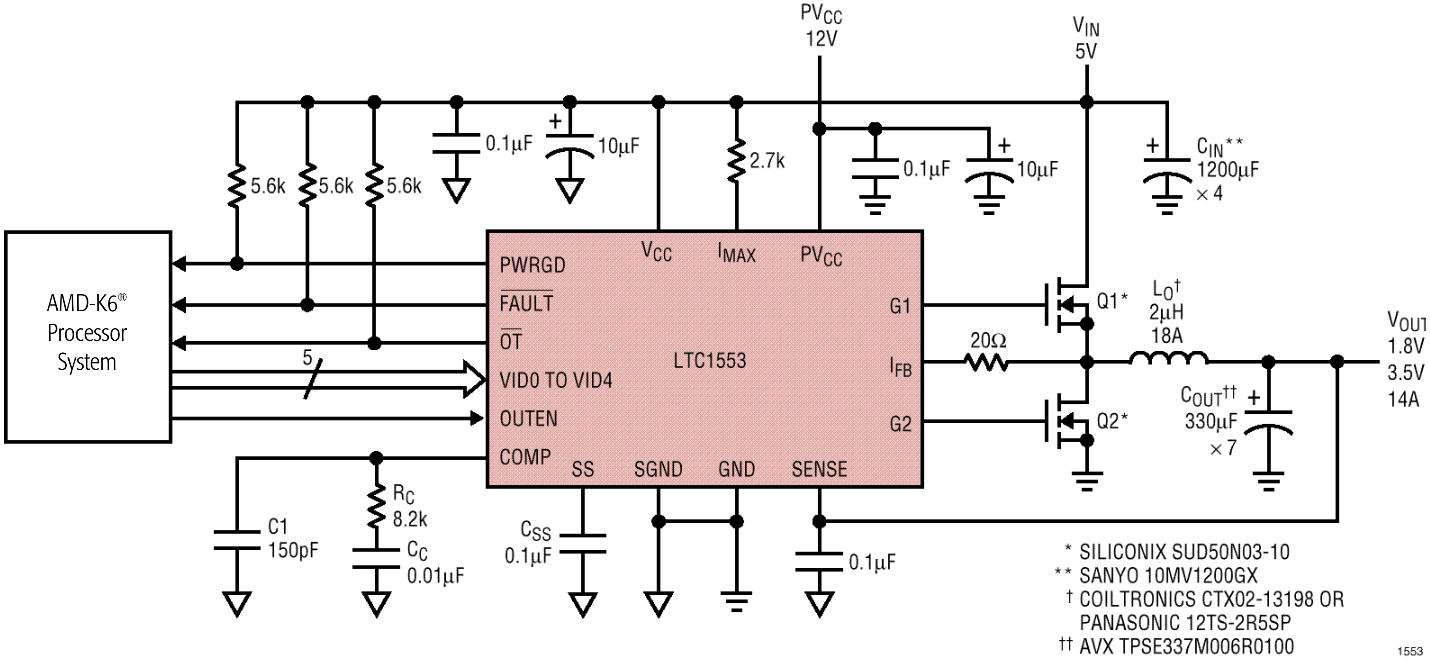


Figure 18. Linear LT1553 1.8V to 3.5V Switching Power Supply Design

LINFINTY LX1664 and LX1665

The LX1664 and LX1665 are dual-output controllers that combine a programmable switch-mode controller with a linear regulator driver. The linear section is adjustable and can supply 5 A–7 A. The switch mode section uses a modulated constant off-time architecture with adaptive voltage positioning to achieve optimal transient response. The circuit offers pulse-by-pulse current limiting, short-circuit protection, and the LX1665 offers a power-good output and a crowbar driver for over-voltage protection. An input inductor is recommended to reduce ripple on the 5 V input. The internal 5-bit DAC provides an adjustable output of 1.3 V to 3.5 V. The circuit shown in Figure 19 on page 37 can deliver more than 15 A, dependent on choice of FETs and current limit set-point. The efficiency of this circuit is around 85–90%, depending on the choice of components. Table 12 shows the bill of materials for the LX1664.

Contact Information

LINFINITY Microelectronics
11861 Western Avenue
Garden Grove, CA 92841
Tel: (714) 372-8383 Fax: (714) 372-3566
www.linfinity.com

Table 12. LINFINITY LX1664 Bill Of Materials

Reference	Description	Mechanical	Part Number	Manufacturer
U1	Dual output PWM controller	SO-18 [LX1664 is SO-16]	LX1665	LINFINITY
Q1, Q2	MOSFET, 26 mΩ, 24 A	TO-263 or TO-220	IRL3303S	International Rectifier
Q4	MOSFET	TO-220	IRLZ44	International Rectifier
L1	Inductor, 5 µH	Thru-hole	-	-
C1, C2	Capacitor, Al-Elec, 1000 µF, 6.3 V, low ESR	Radial, 8x20mm	6MV1000GX	Sanyo
C7	Capacitor, Al-Elec, 330 µF, 6.3 V, low ESR	Radial, 8x20mm	6MV330GX	Sanyo
C3	Capacitor, ceramic, 0.1 µF, X7R	0805	-	-
C4, C6	Capacitor, ceramic, 390 pF, X7R	0805	-	-
C8	Capacitor, ceramic, 680 pF, X7R	0805	-	-
C5	Capacitor, ceramic, 1 µF, Y5V	1206	-	-
R3, R4	Resistor, 1k, 5%	0805	-	-
R6	Resistor, 10k, 1%	0805	-	-
R6	Resistor, 10k, 1%	0805	-	-
R1	Power Resistor, 5 mΩ 1 %	OARS-1	-	-

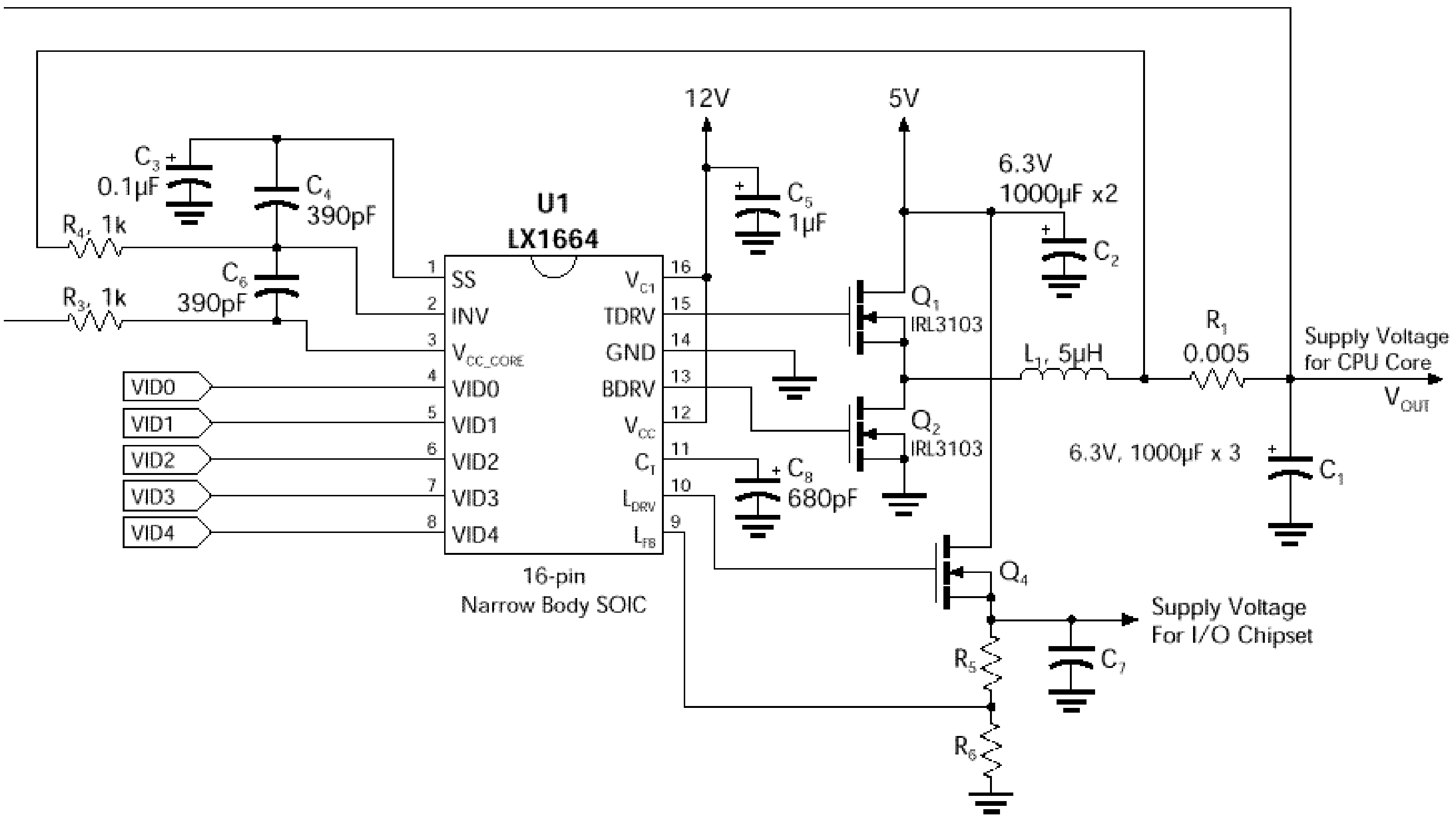


Figure 19. LINFINITY LX1664 Switch-Mode Power Supply Design

Maxim MAX1638

The MAX1638 is an ultra-high-performance, step-down DC-to-DC controller for processor power in high-end computer systems. It delivers over 35 A from 1.3 V to 3.5 V with ±1% total accuracy from a +5V ±10% supply. Excellent dynamic response corrects for output transient. This controller achieves over 90% efficiency by using synchronous rectification.

The switching frequency is pin-selectable for 300 kHz, 600 kHz, or 1 MHz. Fast recovery from load transients is ensured by a GlitchCatcher current-boost circuit that eliminates delays caused by the buck inductor. Other features include over-voltage protection, internal digital soft-start, a power-good output, and a 3.5 V ±1% reference output.

Figure 20 on page 40 shows a 14 A reference design and Table 13 on page 39 shows the bill of materials. By changing the components as listed in the BOM, the circuit can be designed to supply up to 19 A.

Contact Information

Maxim Integrated Products
120 San Gabriel Drive
Sunnyvale, CA 92841
Tel: (408) 737-7600 Fax: (408) 737-7194

www.maxim-ic.com

Table 13. Maxim MAX1638 Bill of Materials

Reference	2.2V 12A Load	2.2V 14A Load	2.2V 19A Load	1.3 V 19 A Load
C1	(x2) Sanyo OS-CON 10SA220M (220 µF)	(x3) Sanyo OS-CON 10SA220M (220 µF)	(x4) Sanyo/OS-CON 10SA220M (220 µF)	(x4) Sanyo/OS-CON 10SA220M (220 µF)
C2	(x3) Sanyo OS-CON 4SP220M (220 µF)	(x4) Sanyo OS-CON 4SP220M (220 µF)	(x6) Sanyo OS-CON 4SP220M (220 µF)	(x7) Sanyo OS-CON 4SP220M (220 µF)
C4	1 µF ceramic or 2.2 µF TDK C3216X7R1C225M, Taiyo Yuden EMK316BJ225ML			
C5, C8	0.1 µF			
C6	Sprague 595D106X0010A2B (10 uF)			
C7	Sprague 595D475X0016A2T (4.7 uF)			
CC1	1000 pF			
CC2	0.056 µF			
D1 (optional)	Nihon NSQ03A02 Schottky diode or Motorola MBRS340 or Central Semi NSC03A02	Nihon NSQ03A02 Schottky diode or Motorola MBRS340		
D2	Central Semiconductor CMPSH-3			
L1	Coiltronics UP4-R47 (0.47 µH, 19 A, SMD) or Panasonic ETQP1F0R7H (0.70 µH, 19 A, 1.6 mΩ, SMD)	Coiltronics UP4-R47 (0.47µH, 19A, SMD) or Panasonic ETQP1F0R7H (0.70 µH, 19 A, 1.6 mΩ, SMD)	Panasonic ETQP2F1R0S (0.70 µH, 23 A, 0.94 mΩ, SMD)	
N1, N2	Int'l Rectifier IRL3103S	Fairchild FDB7030L (10 mΩ) or Int'l Rectifier IRL3803S (9 mΩ)	(x2) Fairchild FDB7030L (10 mΩ) or (x2) Int'l Rectifier IRL3803S (9 mΩ)	
P1/N3	Int'l Rectifier IRF7107	Int'l Rectifier IRF7105 (0.4 W/0.16 W)	Int'l Rectifier IRF7307 (0.09 W/0.05 W)	
R1	(x2) Dale WSL-2512-R009-F (10 mΩ)	(x2) Dale WSL-2512-R009-F (10 mΩ)	(x2) Dale WSR-20.007 ±1% (7 mΩ)	
R2	Dale WSL-2512-R120-J (120 mΩ)	Dale WSL-2512-R120-J (120 mΩ)		
R3, R4	(Optional) 1-5 Ohms			
RC!	1K 5% resistor			

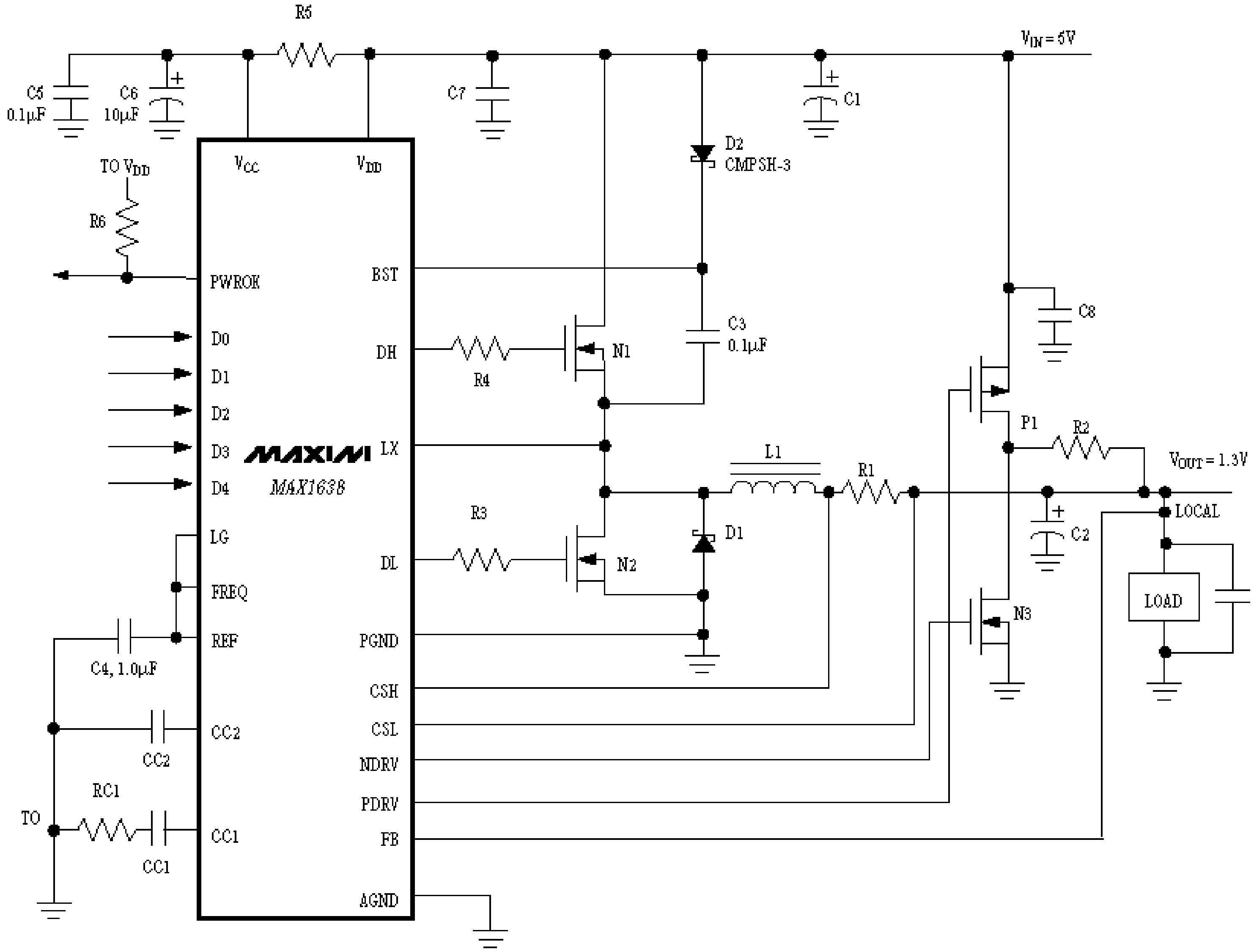


Figure 20. Maxim MAX1638 Switching Power Supply

Micro Linear ML4902

The ML4902 is designed to be configured as a synchronous buck converter with a minimum of external components. The ML4902 can generate voltages between 1.8V and 3.5V from a 5V supply at currents up to 14 A. Figure 21 shows an ML4902 reference design capable of 12 A at 90% efficiency. Table 14 on page 42 shows the bill of materials.

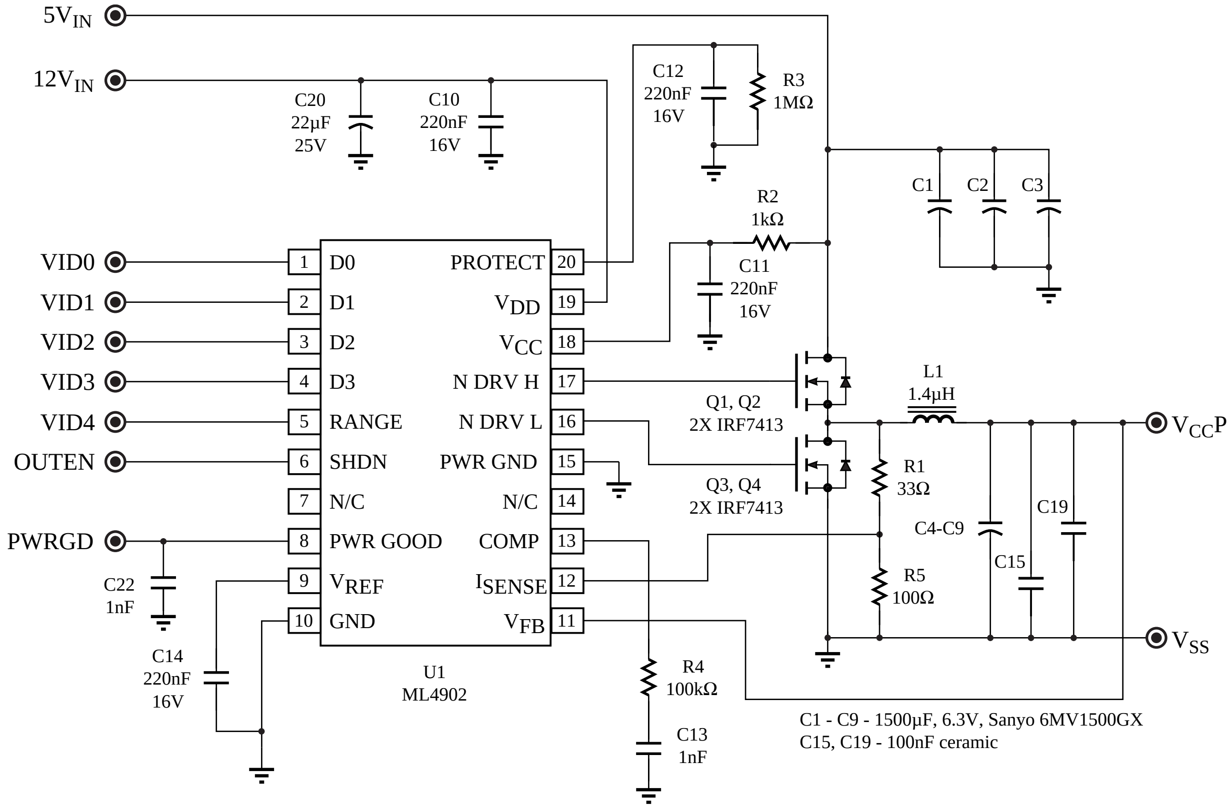


Figure 21. Micro Linear ML4902 Switching Power Supply Design

Contact Information

Micro Linear Corporation
2092 Concourse Dr.
San Jose, CA 95131
Tel: (408) 433-5200
Fax: (408) 432-0295

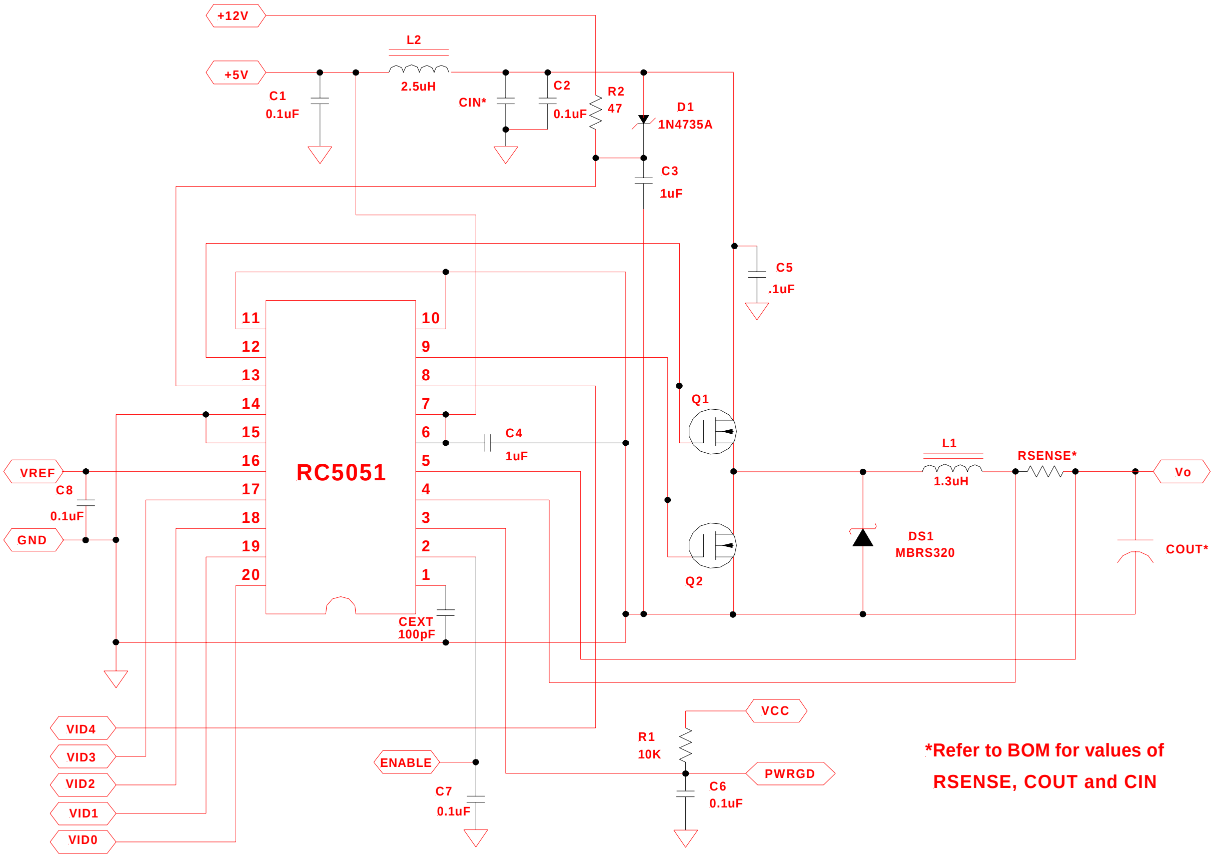
www.microlinear.com

Table 14. Micro Linear ML4902 Bill of Materials

Reference	Description	Part Number	Manufacturer
C1–C9	1500 µF, 6.3 V	6MV1500GX	Sanyo
C10–C12, C14	0.22 µF ceramic	1206Y224Z205NT	Novacap
C13, C22	0.001 µF ceramic	0805N102J500N	Novacap
C15– C19	0.1 µF ceramic	1206B104K500NT	Novacap
C20	22 µF 25 V	TPSE226M025	AVX
L1	1.4 µH on T44-52 core	CTX09-13336	Coiltronics
Q1,Q2	Transistor	IRF7413	International Rectifier
Q3,Q4	Transistor	IRF7413	International Rectifier
R1	33 Ω 1%		
R2	1 KΩ 5%		
R3	1 MΩ 5%		
R4	100 KΩ 5%		
R5	100 Ω 1%		

Fairchild RC5051

The RC5051 shown in Figure 22 combines a switch-mode DC-to-DC controller with a reference DAC in a single package. The DAC provides a mechanism to adjust the DC-to-DC converter output between 1.3V and 3.5V, which allows one motherboard design to accommodate several different processors. Table 15 on page 44 shows the bill of materials for the RC5051. This design provides up to 15A at an 80% efficiency.



*Refer to BOM for values of RSENSE, COUT and CIN

Figure 22. Fairchild RC5051 Power Supply Design

Contact Information

Fairchild Semiconductor (formerly Raytheon Electronics)
350 Ellis Street
Mountain View, CA 94043
Tel: (415) 962-7982
Fax: (415) 966-7742

www.fairchildsemi.com

Table 15. Fairchild RC5051 Bill of Materials

Reference	Part Number and Description for 10 Amp Load	Part Number and Description for 13 Amp Load	Part Number and Description for 15 Amp Load
C1, C2, C5–8	Panasonic ECU-V1H104ZFX Capacitor, ceramic, 0.1 µF, X7R		
C3,C4	Panasonic ECSH1CY105R Capacitor, ceramic, 1 µF, X7R		
CEXT	Panasonic ECU-V1H121JCG Capacitor, ceramic, 100 pF, COG		
Cin	(3x) Sanyo 10MV1200GX, Capacitor, 10 V al-electrolytic, 1200 µF		
Cout	(4x) Sanyo 6MV1500GX Capacitor, 6.3 V al-electrolytic, 1500 µF	(6x) Sanyo 6MV1500GX Capacitor, 6.3 V al-electrolytic, 1500 µF	(8x) Sanyo 6MV1500GX Capacitor, 6.3 V al-electrolytic, 1500 µF
D1	Motorola 1N1545A Zener Diode	Motorola 1N4735A Zener Diode 6.2 V,1 W	Motorola 1N4735A Zener Diode 6.2 V,1 W
DS1	General Instruments 1N5817 Schottky Diode	General Instruments 1N5817 Schottky Diode	Fairchild MBRS320 4 A, 20 V Schottky Diode
L1	Skynet 320-8107 1.3 µH inductor	1.3µH, Isat>15Amp DCR-2.5mΩ	1.3µH, Isat>17Amp DCR-2.5mΩ
L2 (optional)	Skynet 320 6110 Bead Inductor	Input Inductor 2.5µH, toroid, 10 turns 17AWG	2.5µH, Isat>11Amp DCR-6mΩ
R2	47 ohm resistor, 1/8 W, 5%		
Rsense	Copel AWG #18–6 mΩ CUNi Alloy wire Sense resistor, 1 W, 10%	6.3 mΩ CUNi Alloy wire Sense resistor, 1 W, 10%	Fairchild RC10-32, 5.2 mΩ, Wire resistor
R1	Panasonic ERJ-6ENF10.0KV 10 KΩ resistor, 1/8 W, 5%		
Q1, Q2	IRL3103 N-Channel MOSFET	IRL2203 N-channel Power FET	Fairchild FDB6030L 30V, 10mΩ, MOSFET
U1	Fairchild RC5051M PWM Controller		

Semtech SC1182 and SC1183

The SC1182 and SC1183 combine a synchronous voltage-mode controller with two low-dropout linear regulators providing most of the circuitry necessary to implement three DC-to-DC converters for powering advanced processors such as the AMD-K6 family of processors.

The SC1182 and SC1183 feature an integrated 5-bit DAC, pulse-by-pulse current limiting, integrated power-good signaling, and logic-compatible shutdown. The SC1182/3 switching section operates at a fixed frequency of 200 kHz. The integrated DAC provides output voltage programmability from 2.0 V to 3.5 V in 100 mV increments and 1.30 V to 2.05 V in 50 mV increments with no external components.

The SC1182/3 linear sections are low dropout regulators. The LDOs can provide 3.3 V for operation of the I/O, cache, memory etc. The current capability of each LDO is determined by the MOSFET chosen.

The circuit shown in Figure 23 on page 46 provides a current of 15 A at 85% efficiency. Table 16 on page 47 shows the bill of materials for the SC1182.

Contact Information

Semtech Corp
652 Mitchell Road
Newbury Park, CA 91320
Tel: (805) 498-2111 Fax: (805) 498-3804

www.semtech.com

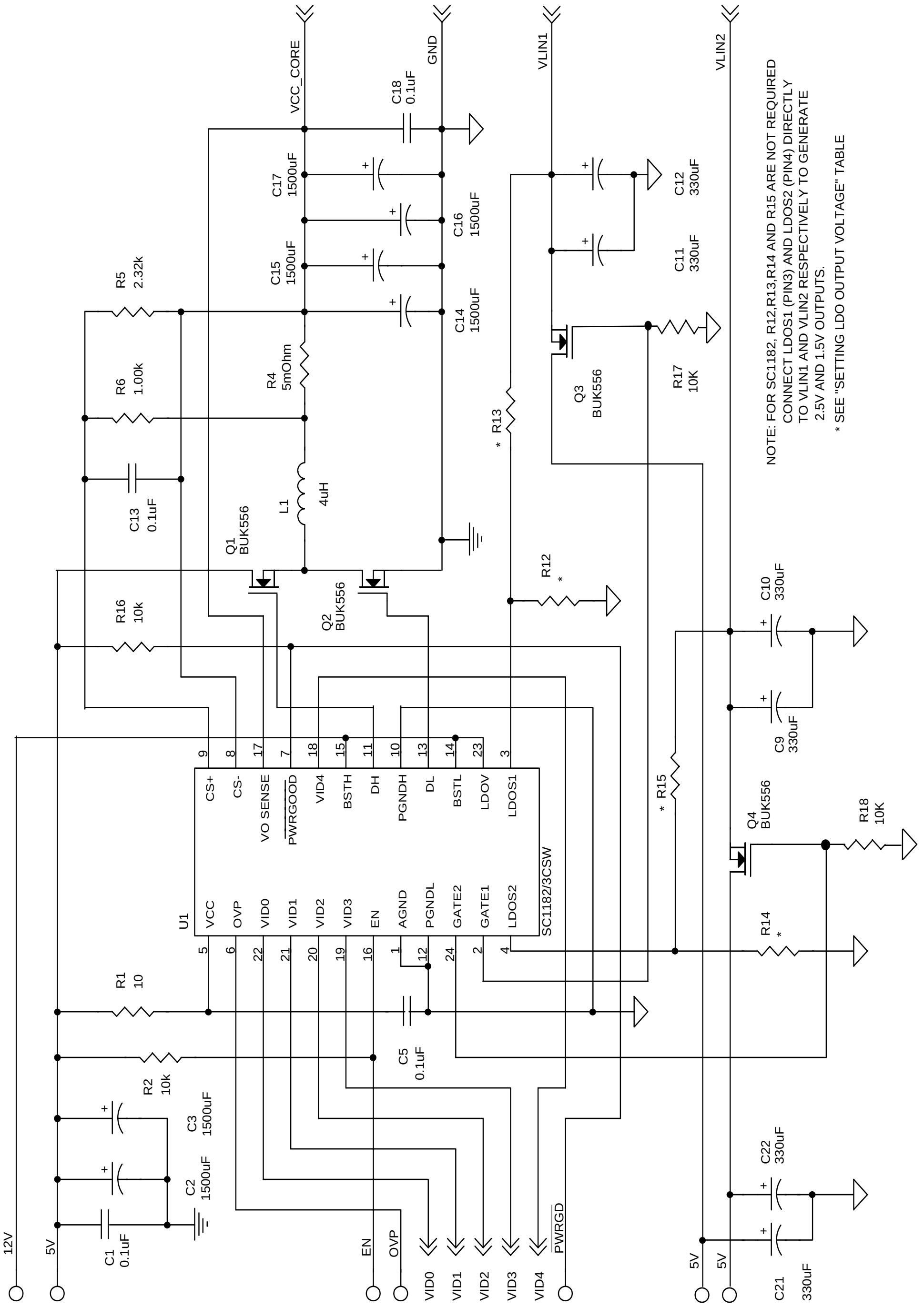


Figure 23. Semtech SC1182 Voltage Power Supply Design

Table 16. Semtech SC1182 Bill Of Materials

Reference	Description	Part Number	Manufacturer	Notes
C1, C5, C13, C18	0.1 µF 50V capacitor	ECU-V1H104ZFX	Panasonic	
C2, C3, C14–C17	Low ESR 1500 µF/6.3 V capacitor	63MV1500GX	Sanyo	
C9–C12, C21, C22	330µF/6.3V			
L1	8 Turns 16AWG on T50–52D core 4 µH	T50–52D	Micro Metals	
Q1, Q2, Q3, Q4		Phillips BUK556 or DIODS Inc MMBT3904 or others	Phillips or DIODS Inc or others	Note 1
R4	IRC OAR-1 Series 5 mΩ	IRC OAR-1 Series 5mΩ	IRC OAR-1 Series 5mΩ	
R2, R17, R18	10 kΩ, 5%, 1/8W			
R5	2.32 kΩ 1% resistor	ERJ-6ENF2.32KV	Panasonic	
R6	1.00 kΩ 1% resistor	ERJ-6ENF1.00KV	Panasonic	
R1	10 Ω, 5%, 1/8W			
R12	1%, 1/8W			Note 2
R13	1%, 1/8W			Note 2
R14	1%, 1/8W			Note 2
R15	1%, 1/8W			Note 2
U1		SC1182/3CSW	Semtech	

Notes:

1) *FET selection requires a trade-off between efficiency and cost. Absolute maximum* $R_{DS(ON)}$ *= 22 mΩ for Q1,Q2*
2) *See Table 17 (Not required for SC1182)*

Table 17. LDO Voltage Selection

VOUT LDO1 (LDO2)	R12 (R14)	R13 (R15)
3.45V	105Ω	182Ω
3.30V	105Ω	169Ω
3.10V	102Ω	147Ω
2.90V	100Ω	130Ω
2.80V	100Ω	121Ω
2.50V	100Ω	97.6Ω
1.50V	100Ω	18.7Ω

Unisem US3004

The US3004A controller shown in Figure 24 on page 50 is a high-efficiency synchronous pulse width modulated (PWM) controller that provides in excess of 16 A of output current. The output voltage is selected by the 5-bit internal DAC. In addition, the US3004A features two uncommitted linear controllers that can provide a second regulated voltage of 3.3 V. The switcher also employs current sensing by using the $R_{DS(ON)}$ of the high-side power MOSFET as the sensing resistor. Other features include a power-good signal, under-voltage lockout for both 5 V and 12 V supplies, an external programmable soft-start function, and use of an external capacitor for programming the oscillator frequency. Table 18 shows the bill of materials for the US2075.

Contact Information

Unisem Corp.
32C Mauchly
Irvine, CA 92618
Tel: (949) 453-1008 Fax: (949) 453-8748

www.unisem.com

Table 18. Unisem US3004 Bill of Materials

Reference	Description	Part Number	Manufacturer
Q1, Q2	MOSFET	IRL3103 IRL3103S (Note 1)	IR
Q3	MOSFET	MTP3055VL	Motorola
Q4	MOSFET	NDP603AL	National
D1	Diode, GP	1N4148	Motorola
L1	Inductor	L=1 µH	
L2	Inductor	Core: L=4 µH R=2 mΩ	Micro Metal
C3, C10	Capacitor, Electrolytic	6 MV1500GX, 1500 uF, 6.3 V,	Sanyo
C11	Capacitor, Electrolytic	220 µF, 6.3 V, ECAOJFQ221	Panasonic
C9, C12, C13	Capacitor, Electrolytic	680 µF, 10 V, EEUFA1A681L	Panasonic
C2	Capacitor, Ceramic	0805Z105P250NT 1 µF, 25V, Z5U, SMT 0805	Novacap
C4, C6	Capacitor, Ceramic	0805Z104P250NT 1 µF, 25V, Z5U, SMT 0805	Novacap

Notes:

1) *For the applications where it is desirable not to use the Heatsink, the IRL3103S MOSFET in the TO263 SMT package with 1 inch square of pad area using top and bottom layers of the board as a minimum is required.*
2) *R13 sets the Vcore, approximately 1% higher to account for the trace resistance drop.*

Table 18. Unisem US3004 Bill of Materials (continued)

Reference	Description	Part Number	Manufacturer
C8	Capacitor, Ceramic	0.1 µF, SMT 0805 size	
C1	Capacitor, Ceramic	150 pF, X7R, SMT 0805 size	
C5	Capacitor, Ceramic	220 pF, SMT 0805 size	
C7	Capacitor, Ceramic	470 pF, SMT 0805 size	
C14, C15	Capacitor, Ceramic	0.01 µF, SMT 0805 size	
R1	Resistor	2.21 kΩ,1%, SMT 0805 size	
R2, R4	Resistor	10 Ω, 5%, SMT 1206 size	
R3	Resistor	Short or 5 Ω, 5%, SMT 1206 size	
R5	Resistor	10 kΩ, 5%, SMT 0805 size	
R7	Resistor	267 Ω, 1%, SMT 0805 size	
R14	Resistor	180 Ω, 1%, SMT 0805 size	
R8, R15	Resistor	150 Ω, 1%, SMT 0805 size	
R6, R10	Resistor	1 kΩ, 5%, SMT 0808 size	
R9, R11	Resistor	100 Ω, 5%, SMT 0805 size	
R12	Resistor	100 Ω, 1%, SMT 0805 size	
R13	Resistor (Note 2)	10 kΩ, 1%, SMT 0805 size	
HS1	Q1 Heatsink	6270	Thermalloy
HS2	Q2 Heatsink	6270	Thermalloy

Notes:

1) *For the applications where it is desirable not to use the Heatsink, the IRL3103S MOSFET in the TO263 SMT package with 1 inch square of pad area using top and bottom layers of the board as a minimum is required.*
2) *R13 sets the Vcore, approximately 1% higher to account for the trace resistance drop.*

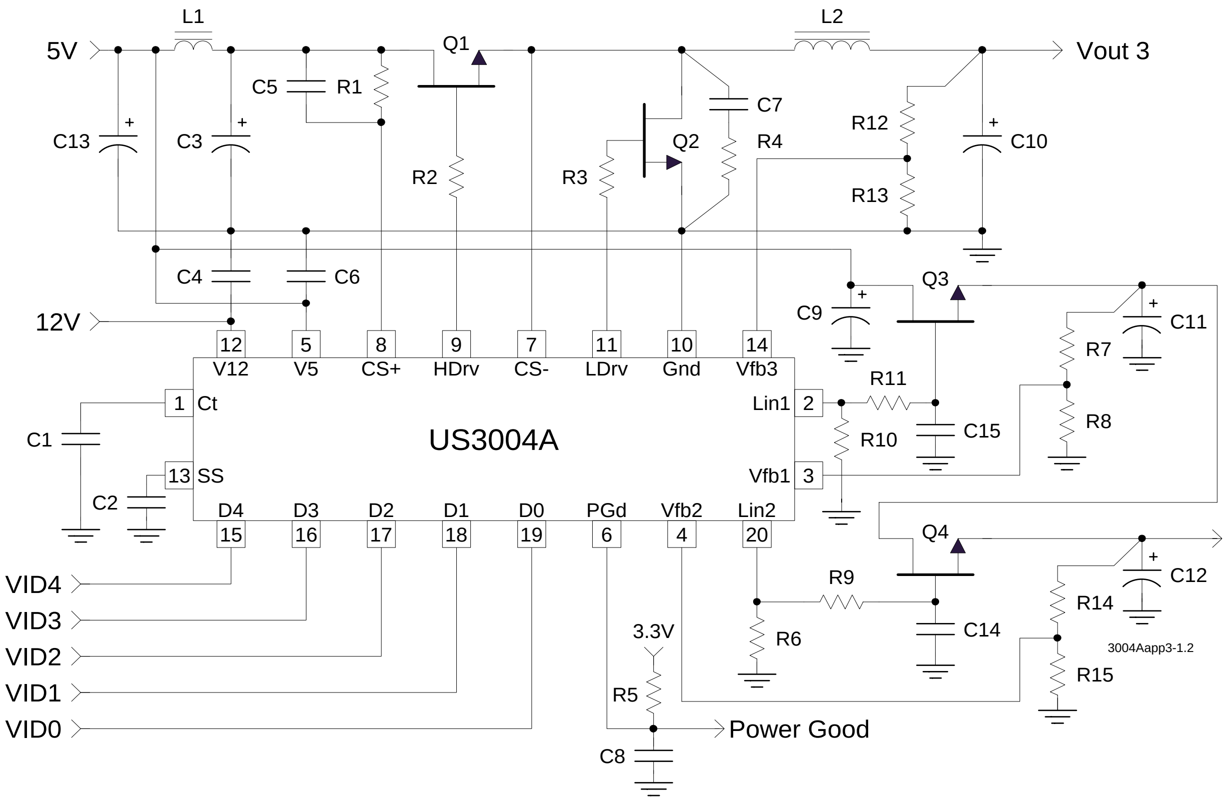


Figure 24. Unisem US3004 Dual Supply Design

Unitrode UCC3880

The UCC3880 PWM controller shown in Figure 25 combines a switch-mode DC-to-DC controller with a reference DAC, and a precision reference in a single package. The accuracy of the DAC/reference combination is 1.0%. Typical efficiency is greater than 83% at 11.2A. The DAC provides a mechanism to adjust the DC-to-DC converter output between 2.1V and 3.5V in 100 mV steps. Over-voltage and under-voltage monitors are also included. Table 19 on page 52 shows the bill of materials for the UCC3880 capable of up to 16 A.

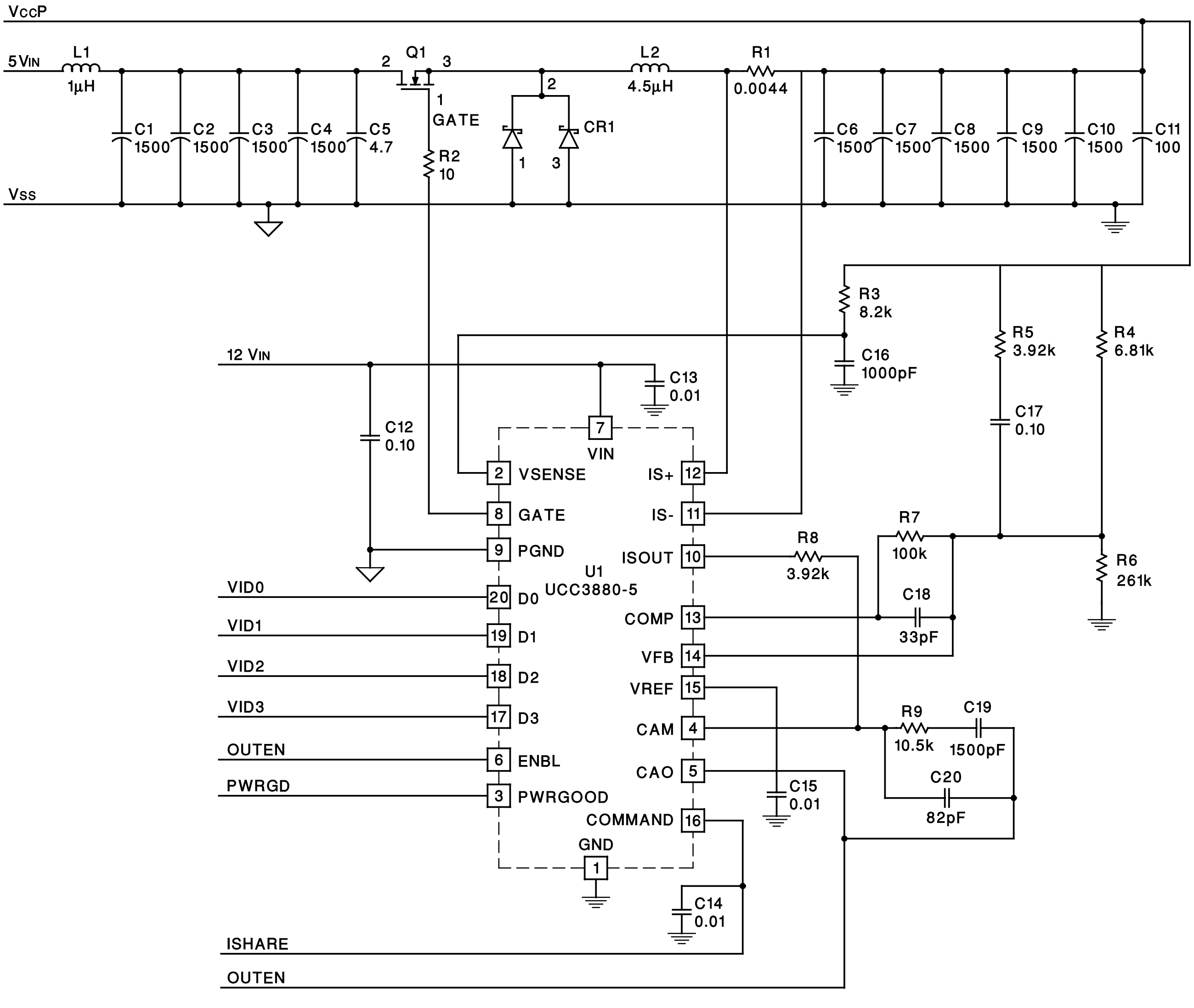


Figure 25. Unitrode UCC3880 Switching Power Supply

Contact Information

Unitrode Integrated Circuits
7 Continental Blvd.
Merrimack, NH 03054
Tel: (603) 424-2410 Fax: (603) 424-3460

www.unitrode.com

Table 19. Unitrode UCC3880 Bill of Materials

Reference	Description	Part Number	Manufacturer
C12, C17, C21, C22	0.1 µF 50V capacitor	ECU-V1H104ZFX	Panasonic
C5	4.7µF 16V capacitor	595D475X0016A2B	Sprague
C_{11}	100µF capacitor, 6.3 V tantalum	593D107X9010D2	Sprague
C1- C4, C6 - C10	1500µF 6.3V electrolytic capacitor	6MV1500GX	Sanyo
C13, C14, C15	0.01 µF 50V capacitor	any	any
C16	1000pF ceramic	any	any
C18	33pF NPO ceramic	any	any
C19	1500pF ceramic	any	any
C20	82pF NPO ceramic	any	any
CR1	30V, 30A, Schottky Diode	32CTQ030	International Rectifier
L1*	2 Turns #16 AWG, 1µH	any (optional)	any (optional)
L2	10 Turns #16 AWG, 4.5µH	T50-52B	Micrometals
Q1	N-Channel Logic Level Enhancement Mode MOSFET 30V, 56 A	RL3103	International Rectifier
R1	0.005Ω 1% power resistor	WSR-2	Dale/Vishay
R2	10Ω 5% 1/16 watt resistor	any	any
R3	8.2kΩ 5% 1/16W resistor	any	any
R4	6.81 kΩ 1% 1/16W resistor	any	any
R5, R8	3.92kΩ 1% 1/16W resistor	any	any
R6	261 kΩ 5% 1/16W resistor	any	any
R7	100 kΩ 5% 1/16W resistor	any	any
R9	10.5 kΩ 5% 1/16W resistor	any	any
Q1-HS	TO-220 heat sink	576802	AAVID
CR1–HS	TO-220 heat sink	577002	AAVID

Note:

* *The L1 inductor is recommended for isolating the 5V input supply from current surges caused by MOSFET switching. L1 is not required for normal operation and may be omitted.*

Voltage Regulator Vendor Information

Company Name and Contact	Part Number	Type	Remarks
Cherry Contact: George Shuline (401)886-3821	CS5150 CS5151 CS5166	Switching Regulator Switching Regulator Switching Regulator	a) Synchronous 4-bit DAC, 2.14 V min. b) Asynchronous 4-bit DAC, 2.14 V min. c) 5-bit VID, 1.3 V min.
Corsair Microsystem Contact: John Beekley (408) 559-1777	SP52P6TS SP520P6CS SPX525P6TS	Switching VRM Switching VRM Switching VRM	a) 4-bit VID, 2.1 V min. b) 4-bit VID, 2.1 V min. c) 4-bit VID, 2.1 V min.
Elantech Contact: Steve Sacarisen (408) 945-1323	EL7571 EL7556	Switching Regulator Switching Regulator	a) Tested/ 5-bit VID DAC, 1.3 V min. b) 5-bit DAC, 1.3 V min. VRM designs are available
Harris Contact: Steve River (407) 729-5949	HIP6002/3 HIP6004/5/14 HIP6019	Switching Regulator Switching Regulator 2 Switchers + 2 Linear	a) 4-bit DAC, 2.0 V min. b) 5-bit VID, 1.3 V min. VRM designs are available
Linear Technology Corporation Contact: Mike Gillespie (408) 428-2060	LT1430/35 LT1552/53	Switching Regulator Switching Regulator	a) Voltage set by resistor b) 5-bit VID, 1.8 V min.
Linfinity Microelectronics Inc. Contact: Andrew Stewart (714) 372-8383	LX1660/61 LX1662/63 LX1664/65	Switching Regulator Switching Regulator Linear and Switcher	a) External DAC or resistors b) 5-bit VID, 1.3 V min. c) 5-bit VID, 1.3 V min.
Maxim Integrated Products Contact: Nancie George-Adeh (408) 737-7600	MAX1624 MAX1638 MAX1710	Switching Regulator Switching Regulator Switching Regulator	a) 5-bit DAC, 1.1 V min. b) 5-bit VID, 1.3 V min c) 5-bit DAC, 1.1 V min.
Micro Linear Contact: Doyle Slack (408) 433-5200	ML4900 ML4902	Switching Regulator Switching Regulator	a) 4-bit DAC, 2.1 V min. b) 5-bit DAC, 1.8 V min.
National Semiconductor http://www.national.com/pf/LM/LM2635.html	LM2635	Switching Regulator	a) 5-bit VID, 1.8 V min. (1.3V available)
Fairchild Semiconductor Contact: David McIntyre (415) 966-7734	RC5041/42 RC5051/53/54	Switching Regulator Switching Regulator	a) 4-bit VID 2.1 V min. b) 5-bit VID, 1.3 V min.
Semtech Corporation Contact: Alan Moore (805) 498-2111	SC1172/73 SC1151/52 SC1182/83	Switching Regulator Switching Regulator Switching Regulator	a) 5-bit VID, 1.3 V min b) 5-bit VID, 1.3 V min. c) 5-bit VID, 1.3 V min.

Notes:

1) *The lower value of the output voltage setting can vary between the parts listed in this table.*
2) *Parts with a DAC designation in the Remarks column do not follow the defined VID codes. For more information, see "Digital-to-Analog Converter (DAC)" on page 27.*

Company Name and Contact	**Part Number**	**Type**	**Remarks**
Texas Instruments http://wwws.ti.com/sc/psheets/slvs171/slvs171.pdf	TPS5210	Switching Regulator	a) 5-bit VID, 1.3 V min.
Unisem Contact:Reza Amiranir (949) 453-1008	US2050 US3004	Switching Regulator Switching Regulator	a) Voltage set by resistor b) 5-bit VID
Unitrode Contact: John O'Connor (603) 429-8504 VXI –503-652-7300	UCC3882 UCC3881 VID073-2071-01	Switching Regulator Switching Regulator VXI VRM's	a) 5-bit VID, 1.8 V min. b) Voltage set by resistor VXI Contact: Joseph Chang

Notes:

1) *The lower value of the output voltage setting can vary between the parts listed in this table.*
2) *Parts with a DAC designation in the Remarks column do not follow the defined VID codes. For more information, see "Digital-to-Analog Converter (DAC)" on page 27.*