

RC5037

Adjustable Switching Regulator Controller

Features

- High power switched-mode DC-DC controller can control in excess of 13A
- Output voltage adjustable from 1.5V to 3.6V
- 85% efficiency
- Cumulative accuracy < 3% over line, load, and temperature variations
- Overvoltage and short circuit protection
- Built-in soft start

Applications

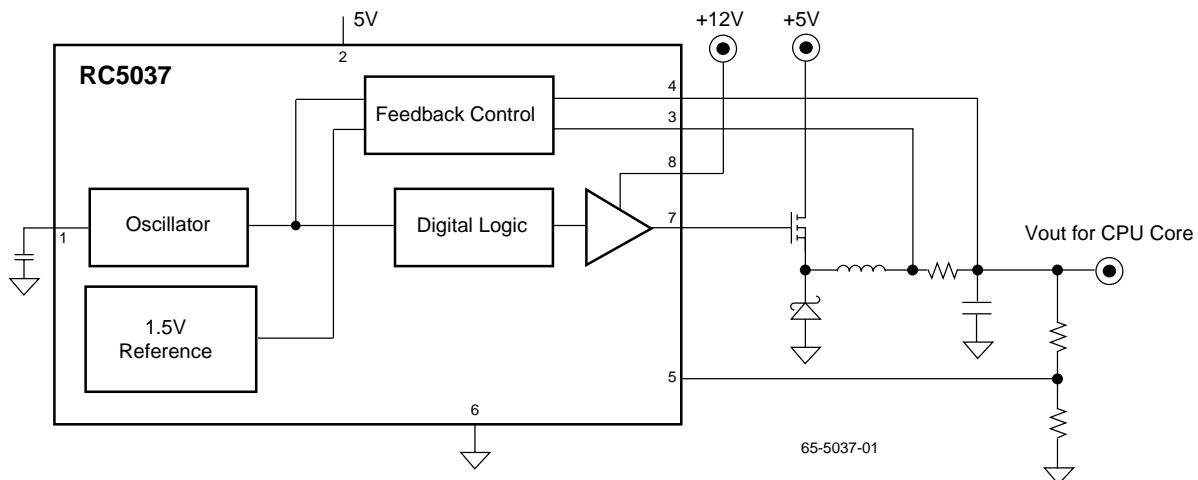
- Precision 2.xV CPU core regulator for Pentium® MMX™ processes
- Precision 2.xV or 3.xV CPU core regulator for AMD-K6™ MMX and Cyrix 6x86MX™ (M2) processors

Description

The RC5037 is a high power, switch-mode DC-DC controller that provides an accurate output for high-end microprocessors CPU voltage. This controller has a built-in Soft Start feature which offers system protection during power-up by reducing both inrush current and output overshoot. When combined with the appropriate external circuitry, the RC5037 can deliver load currents as high as 13A at efficiencies as high as 88%. The RC5037 can generate output voltages from 1.5V up to 3.6V using external resistors.

The RC5037 is designed to operate in a “constant on-time” (patent pending) control mode under all load conditions. Its accurate low TC reference eliminates the need for precision external components in order to achieve the tight tolerance voltage regulation required by most CPU-based applications. Short circuit current protection is provided through the use of a current sense resistor, while overvoltage protection is provided internally.

Block Diagram



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Functional Description

The RC5037 contains a precision trimmed zero TC voltage reference, a constant-on-time architecture controller, a high current output driver, and a low offset op-amp. The detailed block diagram in Figure 1 shows how the RC5037 works together with external components to achieve a high-performance switching power supply.

Switch-Mode Control Loop

The main control loop for the switch-mode converter consists of a current conditioning amplifier and a voltage conditioning amplifier. The voltage amplifier compares the voltage from the internal reference with the converter's output voltage divided by an internal resistor divider. The current amplifier senses the current by comparing the voltages at the IFBH and IFBL pins, which are attached to either side of the current sense resistor. The signals from the voltage and current amplifiers are summed together, the result being used to control the off-time of the oscillator. The current feedback signal is also used as part of the RC5037 short-circuit protection.

High Current Output Drivers

The RC5037 high current output driver (SDRV) contains high speed bipolar power transistors configured in a push-pull configuration. The output driver is capable of supplying 0.5A of current in less than 100ns. The driver's power and ground are separated from the overall chip power and ground for added switching noise immunity.

Internal Reference

The reference in the RC5037 is a precision band-gap type reference. Its temperature coefficient is trimmed to provide a near zero TC.

Constant-On-Time Oscillator

The RC5037 switch-mode oscillator is designed as a fixed on-time, variable off-time oscillator. The constant-on-time oscillator consists of a comparator, an external capacitor, a fixed current source, a variable current source, and an analog switch that selects between two threshold voltages for the comparator. The external timing capacitor is alternately charged and discharged through the enabling and disabling of the fixed current source. The variable current source is controlled from the error inputs that are received from the current and voltage feedback signals. The oscillator off-time is controlled by the amount of current that is available from the variable current source to charge the external capacitor up to the high threshold level of the comparator. The on-time is set by the constant current source that discharges the external capacitor voltage down to the lower comparator threshold.

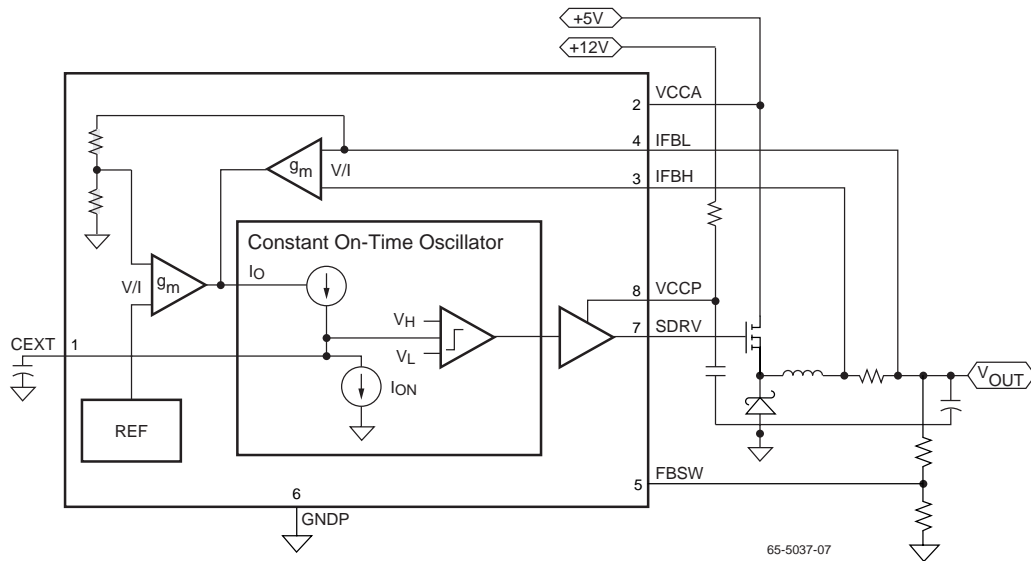
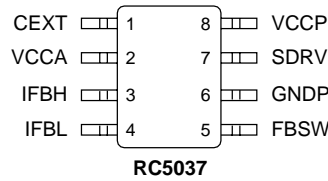


Figure 1. RC5037 Detailed Block Diagram

Pin Assignments



Pin Descriptions

Pin Name	Pin Number	Pin Function Description
CEXT	1	External capacitor. A 180pF capacitor is connected to this pin as part of the constant on-time pulse width circuit. Careful layout of this pin is critical to system performance. See Applications Information for details.
VCCA	2	Switching Regulator V_{cc}. Power supply for switching regulator control circuitry and voltage reference. Connect to system 5V supply and decouple to ground with 0.1μF ceramic capacitor.
IFBH	3	High side current feedback for switching regulator. Pins 3 and 4 are used as the inputs for the current feedback control loop and as the short circuit current sense points. Careful layout of the traces from these pins to the current sense resistor is critical for optimal performance of the short circuit protection scheme. See Applications Information for details.
IFBL	4	Low side current feedback for switching regulator. See Applications Information for details.
FBSW	5	Voltage feedback for switching regulator. Using two external resistors, this pin sets the output voltage level for the switching regulator.
GNDP	6	Power Ground. Connect to a low impedance ground. See Application Information for details.
SDRV	7	MOSFET driver output for switching regulator. Connect this pin to the gate of the N-channel MOSFET Q1 as shown in Figure 12. The trace from this pin to the MOSFET gate should be kept as short as possible (less than 0.5"). See Applications Information for details.
VCCP	8	Switching regulator gate drive V_{cc}. Power supply for SDRV output driver. Connect to system 12V supply with R-C filter shown in Figure 12. See Applications Information for details.

Preliminary Information

Absolute Maximum Ratings

Supply Voltages, VCCA	7V
Supply Voltages, VCCP	13V
Junction Temperature, T _J	+150°C
Storage Temperature, T _S	-65 to +150°C
Lead Soldering Temperature, 10 seconds	300°C

Note:

- Functional operation under any of these conditions is not implied. Performance is guaranteed only if Operating Conditions are not exceeded.

Operating Conditions

Parameter	Conditions	Min.	Typ.	Max.	Units
Switching Regulator Supply, VCCA		4.75	5	5.25	V
Ambient Operating Temperature, T _A		0		70	°C
Gate Drive Supply, VCCP		9.5	12	12.6	V

Electrical Characteristics

(VCCA = 5V, VCCP = 12V, T_A = 25°C using circuit of Figure 10, unless otherwise noted)

The • denotes specifications which apply over the full ambient operating temperature range.

Parameter	Conditions	Min.	Typ.	Max.	Units	
Initial Accuracy ¹	I _{LOAD} = 13A	1.5		3.6	V	
Output Temperature Drift	T _A = 0°C–70°C		40		ppm/°C	
Line Regulation	VCCA = 4.75 to 5.25V, I _{LOAD} = 13A		3	5	mV	
Load Regulation	I _{LOAD} = 0 to 5A or 5A to 13A		30	43	mV	
V _{OUT} PSRR		60			dB	
Output Ripple, peak-peak	20MHz BW, I _{LOAD} = 13A		15		mV	
Cumulative DC Accuracy ²		•	±55	±100	mV	
Efficiency	I _{LOAD} = 5A	•	80	85	%	
Output Driver Current	Open Loop	•	0.5		A	
Short Circuit Threshold Voltage		•	80	90	100	mV
On Time Pulse Width ³	C _{EXT} = 180pF		3.5		μs	
Thermal Impedance, θ _{JA}		•	140		°C/W	
VCCA Supply Current	Independent of load	•	5	10	mA	
VCCP Supply Current	I _{LOAD} = 13A	•	20	25	mA	
Internal Power Dissipation	I _{LOAD} = 13A	•	125		mW	

Notes:

1. Initial accuracy is the initial output voltage variability under the specified conditions.
2. Cumulative DC accuracy includes setpoint accuracy, temperature drift, line and load regulation.
3. The on-time pulse width of the oscillator is set via external capacitor C_{EXT}.

Typical Operating Characteristics

(VCCA = 5V, and TA = +25°C using circuit in Figure 10, unless otherwise noted)

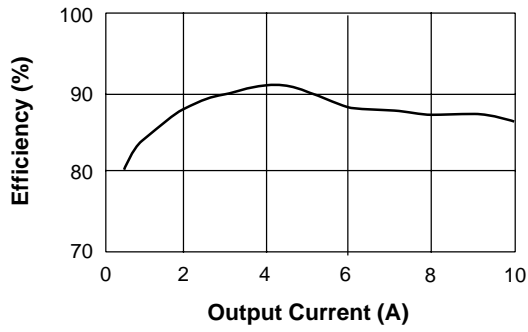


Figure 2. Switcher Efficiency vs. Output Current

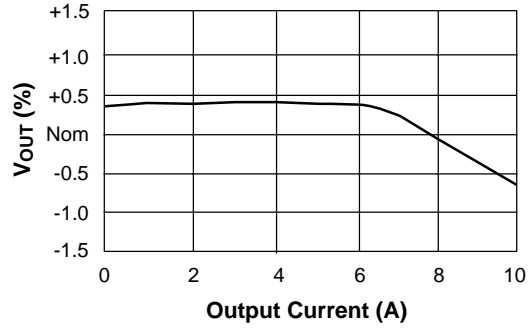


Figure 3. Switcher Output Voltage vs. Load

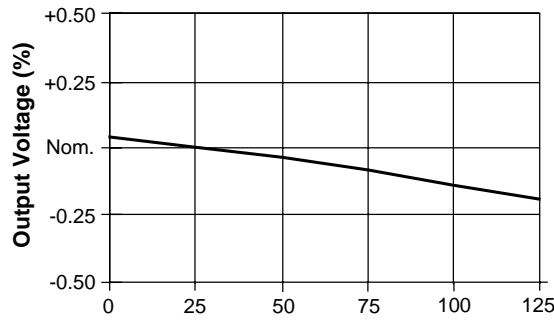


Figure 4. Output Voltage vs. Temperature (I/IO = 10A)

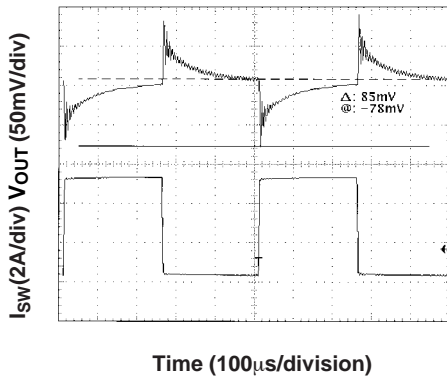


Figure 5. Switcher Transient Response (0.5 to 5.5A Load Step)

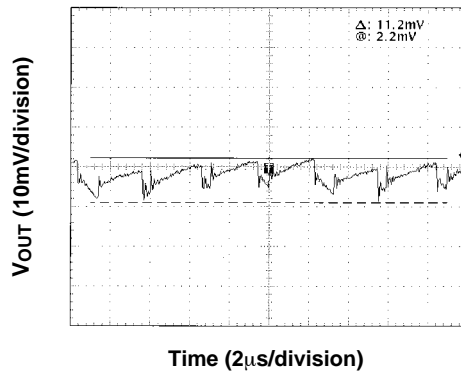


Figure 6. Switcher Output Ripple (BW = 20MHz, I/IO = 10A)

Preliminary Information

Typical Operating Characteristics (continued)

Preliminary Information

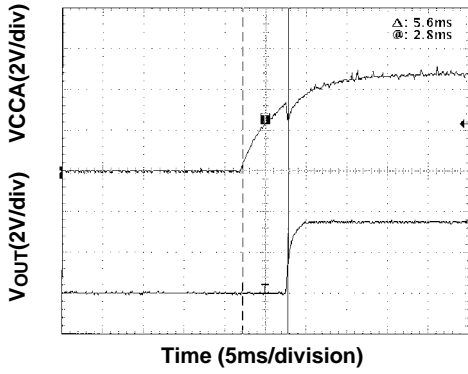


Figure 7. Switcher Turn-on Response

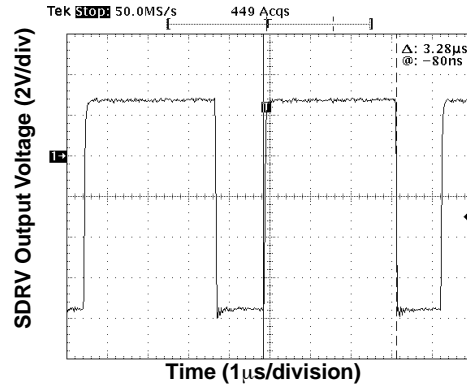


Figure 8. Pin 7 (SDRV) at a 10 Amp Load

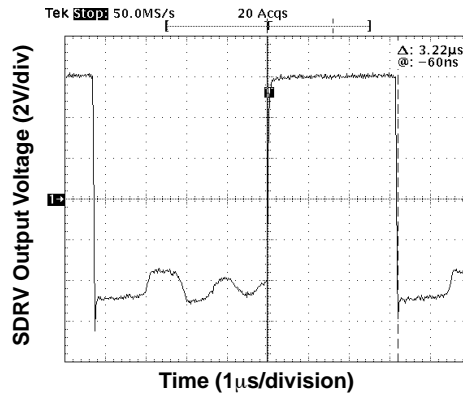


Figure 9. Pin 7 (SDRV) at a 0.1 Amp Load

Test Circuit Configurations

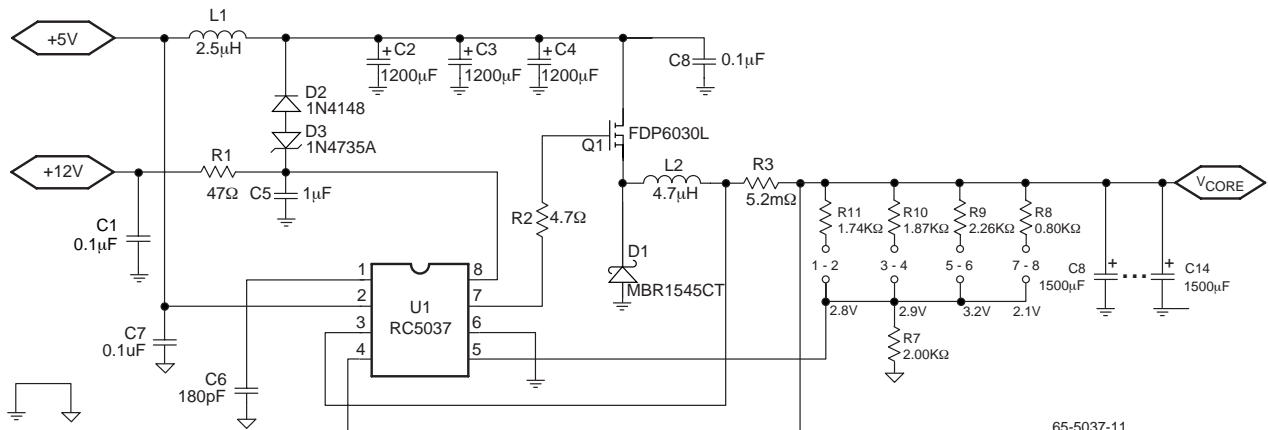


Figure 10. 13A Application Schematic

65-5037-11

Table 1. Bill of Materials for a RC5037 13A Application

Qty.	Reference	Manufacturer	Part Number	Description
3	C1, C7, C8	Rohm	MCH212F104ZP	100nF +80/-20%, 25V Z5U Ceramic Capacitor
2	C2, C3, C4	Sanyo	10MV1200GX	1200µF, 10V 44mΩ Aluminum Capacitor
1	C5	Rohm	MCH312F105ZP	1µF +80/-20%, 25V Z5U Ceramic Capacitor
1	C6	Rohm	MCH215A181JK	180pF ± 5%, 50V COG Ceramic Capacitor
2	C9, C10, C11, C12, C13, C14	Sanyo	6MV1500GX	1500µF, 6.3V, 44mΩ Aluminum Capacitor
1	R1	Panasonic	ERJ-6GEYJ470	47Ω ± 5%, 1/10W Resistor
1	R2	Panasonic	ERJ-6GEYJ4R7	4.7Ω ± 5%, 1/10W Resistor
1	R3	Fairchild Semiconductor	RC10-52	5.2mΩ, 1W Resistor
1	R7	Panasonic	ERJ-ENF 2.0 0KV	0.1% resistor desirable for accuracy
1	R8	Panasonic	ERJ-ENF 0.80KV	0.1% resistor desirable for accuracy
1	R9	Panasonic	ERJ-ENF 2.26KV	0.1% resistor desirable for accuracy
1	R10	Panasonic	ERJ-ENF 1.87KV	0.1% resistor desirable for accuracy
1	R11	Panasonic	ERJ-ENF 1.74KV	0.1% resistor desirable for accuracy
1	D1	Motorola	MBR1545CT	15A, 45V Schottky Diode
1	D2	Any	1N4148	Small Signal Diode
1	D3	Motorola	1N4735A	6.2V ± 5%, 1W, Zener Diode
1	Q1	Fairchild	FDP6030L	30V, 14mΩ Logic Level MOSFET
1	L1	Panasonic	EXC-ELDR35V	2.5µH Bead Inductor
1	L2	Pulse	PE-53682	4.7µH, ISAT > 10A Inductor
1	U1	Fairchild Semiconductor	RC5037M	Adjustable Switching Regulator

Table 2. Switching Regulator Components Selection Table

Output Voltage	Output Current	CIN Sanyo 10MV1200GX	COUT Sanyo 6M1500GX	Power MOSFET (M1)
3.5	8	1x	2x	IRL3103
2.8	6	1x	2x	IRL3103
2.9	6.25	1x	2x	IRL3103
2.9	7.5	1x	2x	IRL3103
3.2	9.5	2x	4x	IRL3103
3.2	13	3x	6x	IRL3103
2.1	5.6	1x	2x	IRL3103
3.3	3	N/A	1x	Si9936

Applications Information

The following discussion is intended to be an abbreviated list of design considerations regarding the RC5037 as used in a typical processor motherboard application. For a more thorough discussion of applicable specifications and layout considerations relating to the Intel Pentium P55C processor, please refer to Application Note 48.

Output Voltage Selection

Feedback Voltage Divider

The RC5037 precision reference is trimmed to be 1.5V nominally. When using the RC5037, the system designer has complete flexibility in choosing the output voltage for each regulator from 1.5V to 3.6V. This is done by appropriately selecting the feedback resistors. These should be 0.1% resistors to realize optimum output accuracy. The following equations determine the output voltages of the two regulators:

Preliminary Information

Switching Regulator

$$V_{OUT} = 1.5 \times \left(\frac{R_X + R7}{R7} \right)$$

where Rx: R8, R9, R10, and R11.

For example, for 2.8V:

$$V_{OUT} = 1.5 \times \left(\frac{R11 + R7}{R7} \right) = 1.5 \times \left(\frac{1.74k + 2.0k}{2.0k} \right) = 2.8V$$

Short Circuit Considerations

The RC5037 uses a current sensing scheme to limit the load current if an output fault condition occurs. The current sense resistor carries the peak current of the inductor, which is greater than the maximum load current due to ripple current flowing in the inductor. The RC5037 will begin to limit the output current to the load by reducing the duty cycle of the top-side MOSFET driver when the voltage across the current-sense resistor exceeds the short circuit comparator threshold voltage (V_{th}). When this happens the output voltage will temporarily go out of regulation. As the voltage across the sense resistor becomes larger, the duty cycle of the top-side MOSFET will continue to be reduced until the current limit value is reached. At this point, the RC5037 will continuously deliver the limit current at a reduced output voltage level. The short circuit comparator threshold voltage is typically 90mV, with a tolerance of ± 10 mV. The ripple current flowing through the inductor in Figure 10 is 0.6A. There needs to be a 29% margin for the sense resistor when using a motherboard PC trace resistor. Refer to Application Note 48 for detailed discussions. The sense resistor value can be approximated as follows:

$$R_{SENSE} = \frac{V_{th,min}}{I_{PK}} \times (1 - TF) = \frac{V_{th,min}}{0.6A + I_{LOAD,MAX}} \times (1 - TF)$$

Where TF = Tolerance Factor for the sense resistor and 0.6A accounts for the inductor ripple current.

There are several different types of sense resistors. Table 3 describes the tolerance, size, power capability, temperature coefficient and cost of various types of sense resistors.

Based on the Tolerance in Table 3:

For an embedded PC trace resistor:

$$R_{SENSE} = \frac{0.08}{0.6 + I_{LOAD,MAX}} \times .71$$

For a discrete Copel resistor:

$$R_{SENSE} = \frac{0.08}{0.6 + I_{LOAD,MAX}} \times .90$$

Table 4 lists recommended values for sense resistors for various load currents using an embedded PC trace resistor or a discrete resistor. If the calculated value is not available, round down.

Table 4. RSENSE for Various Load Currents, Switching Regulator

I _{LOAD, MAX} (A)	RSENSE PC Trace Resistor (mΩ)	RSENSE Discrete Resistor (mΩ)
3	15.8	20.0

Table 3. Comparison of Sense Resistors

	Motherboard Trace Resistor	Discrete Iron Alloy resistor (IRC)	Discrete Metal Strip surface mount resistor (Dale)	Discrete MnCu Alloy wire resistor	Discrete CuNi Alloy wire resistor (Copel)
Tolerance Factor (TF)	$\pm 29\%$	$\pm 5\%$ ($\pm 1\%$ available)	$\pm 1\%$	$\pm 10\%$	$\pm 10\%$
Size (L x W x H)	2" x 0.2" x 0.001" (1 oz Cu trace)	0.45" x 0.065" x 0.2"	0.25" x 0.125" x 0.025"	0.2" x 0.04" x 0.16"	0.2" x 0.04" x 0.1"
Power capability	>50A/in	1 watt (3 and 5 watts available)	1 watt (3 and 5 watts available)	1 watt	1 watt
Temperature Coefficient	+4,000 ppm	+30 ppm	± 75 ppm	± 30 ppm	± 20 ppm
Cost@10,000 piece quantity	Low; included in motherboard	\$0.31	\$0.47	\$0.09	\$0.09

5	10.1	12.9
6	8.6	10.9
7	7.5	9.5
8	6.6	8.4
9	5.9	7.5
10	5.4	6.8
13	4.2	5.3

Since the value of the sense resistor is often less than 10mΩ, care should be taken in the layout of the PCB. Trace resistance can contribute significant errors. The traces to the IFBH and IFBL pins of the RC5037 should be Kelvin connected to the pads of the current-sense resistor. To minimize the influence of noise, the two traces should be run next to each other.

Thermal Design Considerations

Good thermal management is critical in the design of high current regulators. System reliability will be degraded if the component temperatures become excessive. The following guide should serve as a reference for proper thermal management.

MOSFET Temperature

The maximum power dissipation of the MOSFET can be calculated by using the following formula:

$$P_D = \frac{T_{J(MAX)} - T_A}{\Theta_{JA}}$$

For IRL3103, Θ_{JA} is 62°C/W. For reliability the junction temperature of the MOSFET should not exceed 120°C. Assuming that the ambient temperature is 40°C, then the maximum power dissipation without heat sink is calculated as:

$$P_D = \frac{120 - 40}{62} = 1.29W$$

The power that the MOSFET dissipates at 10A load is calculated as follows:

$$P_{MOSFET} = I_{LOAD}^2 \times R_{DS(ON)} \times (Duty\ Cycle) + \frac{V_{IN} \times I_{LOAD}}{2} \times (t_r + t_f) \times f$$

$$Duty\ Cycle = \frac{V_{OUT} + V_D}{V_{IN} + V_D - (I_{LOAD} \times R_{DS(ON)})}$$

where V_D is the forward voltage of the Schottky diode used.

Using the above formula, for $V_{out} = 3.3V$, $I_{LOAD} = 10A$

$$Duty\ Cycle = \frac{3.3 + 0.65}{5 + 0.65 - (10 \times 0.023)} = 73.1\%$$

$$P_{MOSFET} = (10A)^2 \times 0.025\Omega \times 73.1\% + \frac{5V \times 10A}{2} \times (210ns + 54ns) \times 300KHz$$

$$P_{MOSFET} = 3.81W$$

Since the power at 10A is higher than the thermal guideline, a heat sink is required.

Schottky Diode

In Figure 10, MOSFET Q1 and flyback diode D1 are used as complementary switches in order to maintain a constant current through the output inductor L2. As a result, D1 will have to carry the full current of the output load when the power MOSFET is turned off. The power in the diode is a direct function of the forward voltage at the rated load current during the off time of the FET. The following equation can be used to estimate the diode power:

$$P_{DIODE} = I_D \times V_D \times (1 - DutyCycle)$$

where I_D is the forward current of the diode, V_D is the forward voltage of the diode, and DutyCycle is defined the same as above.

For the Motorola MBR1545CT Rectifier in Figure 10,

$$P_{DIODE} = 10A \times 0.65 \times (1 - 73.1\%) = 1.75W$$

It is recommended that the diode T0-220 package be attached to a heatsink.

Board Design Considerations

MOSFET Placement

Placement of the power MOSFET is critical in the design of the switch-mode regulator. The MOSFET should be placed in such a way as to minimize the length of the gate drive path from the RC5037 SDRV pin. This trace should be kept under 0.5" for optimal performance. Excessive lead length on this trace will cause high frequency noise resulting from the parasitic inductance and capacitance of the trace. Since this voltage can transition nearly 12V in around 100nsec, the resultant ringing and noise would be very difficult to suppress. This trace should be routed on one layer only and kept well away from the "quiet" analog pins of the device: CEXT, IFBH, IFBL, and GND. A 4.7Ω resistor in series with the MOSFET gate can decrease this layout criticality. Refer to Figure 10.

Inductor and Schottky Diode Placement

The inductor and fly-back Schottky diode need to be placed close to the source of the power MOSFET for the same reasons stated above. The node connecting the inductor and Schottky diode will swing between the drain voltage of the FET and the forward voltage of the Schottky diode. It is recommended that this node be converted to a plane if possible. This node will be part of the high current path in the design, and as such it is best treated as a plane in order to minimize the parasitic resistance and inductance on that node. Since most PC board manufacturers utilize 1/2 oz copper on the

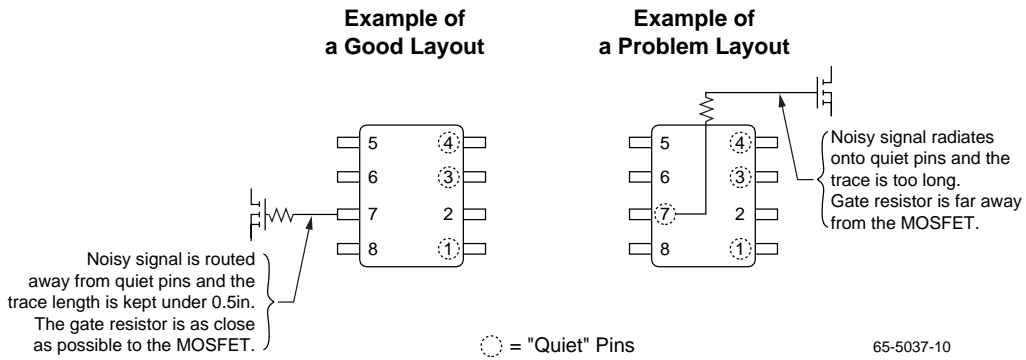


Figure 11. Examples of good and poor layouts

top and bottom signal layers of the PCB, it is not recommended to use these layers to route the high current portions of the regulator design. Since it is more common to use 1 oz. copper on the PCB inner layers, it is recommended to use those layers to route the high current paths in the design.

Power and Ground Connections

The connection of VCCA to the 5V power supply plane should be short and bypassed with a 0.1µF directly at the VCCA pin of the RC5037. The ideal connection would be a via down to the 5V power plane. A similar arrangement should be made for the VCCP pin that connects to +12V. Each ground should have a separate via connection to the ground plane below.

A 12V power supply is used to bias the VCCP. A 47Ω resistor is used to limit the transient current into VCCP. A 1µF capacitor filter is used to filter the VCCP supply and source the transient current required to charge the MOSFET gate capacitance. This method provides sufficiently high gate bias voltage to the MOSFET (V_{GS}), and therefore reduces R_{DS(ON)} of the MOSFET and its power loss.

Figure 12 provides about 5V of gate bias which works well when using typical logic-level MOSFETs, as shown in Figure 13. Non-logic-level MOSFETs should not be used because of their higher R_{DS(ON)}.

MOSFET Gate Bias

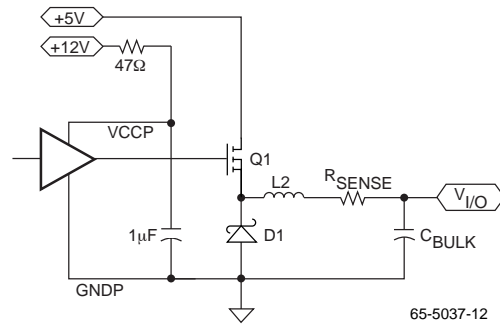


Figure 12. 12V Gate Bias Configuration

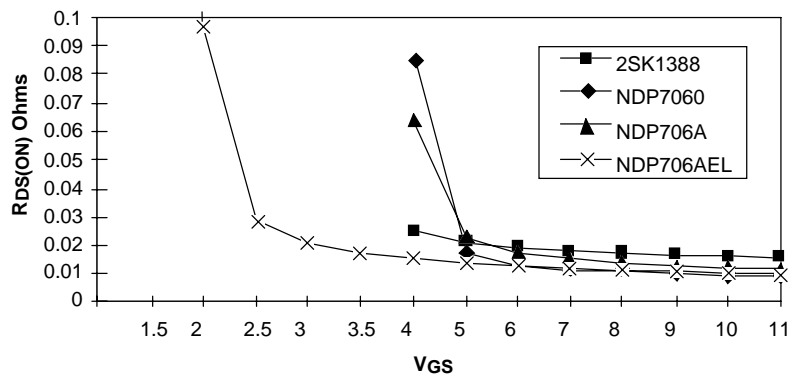


Figure 13. R_{DS(ON)} vs. V_{GS} for Selected Logic-Level MOSFETs

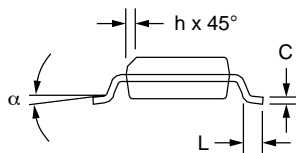
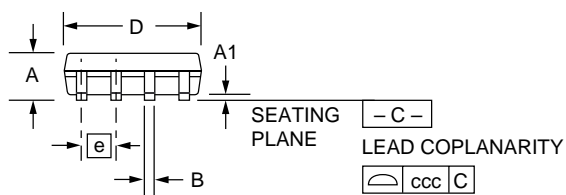
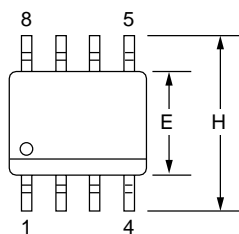
Mechanical Dimensions

8 Lead SOIC Package

Symbol	Inches		Millimeters		Notes
	Min.	Max.	Min.	Max.	
A	.053	.069	1.35	1.75	
A1	.004	.010	0.10	0.25	
B	.013	.020	0.33	0.51	
C	.008	.010	0.20	0.25	5
D	.189	.197	4.80	5.00	2
E	.150	.158	3.81	4.01	2
e	.050 BSC		1.27 BSC		
H	.228	.244	5.79	6.20	
h	.010	.020	0.25	0.50	
L	.016	.050	0.40	1.27	3
N	8		8		6
α	0°	8°	0°	8°	
ccc	—	.004	—	0.10	

Notes:

1. Dimensioning and tolerancing per ANSI Y14.5M-1982.
2. "D" and "E" do not include mold flash. Mold flash or protrusions shall not exceed .010 inch (0.25mm).
3. "L" is the length of terminal for soldering to a substrate.
4. Terminal numbers are shown for reference only.
5. "C" dimension does not include solder finish thickness.
6. Symbol "N" is the maximum number of terminals.



Preliminary Information

Ordering Information

Product Number	Package
RC5037M	8 pin SOIC

Preliminary Information

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2. A critical component in any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.