Application Note 13

52kHz LM2574/5/6 Family Design Guide

by Kevin Lynn

Introduction

Micrel's LM257x family of BiCMOS simple buck voltage regulators feature faster rise/fall time, faster response to fault conditions, and improved efficiency at light loads.

Description

The LM257x switching regulator is basically a PWM (pulse width modulation) controller IC with a fixed gain error amplifier, a 52kHz oscillator, and internal compensation network. The non-inverting side of the error amplifier is tied to a 1.23V bandgap reference.

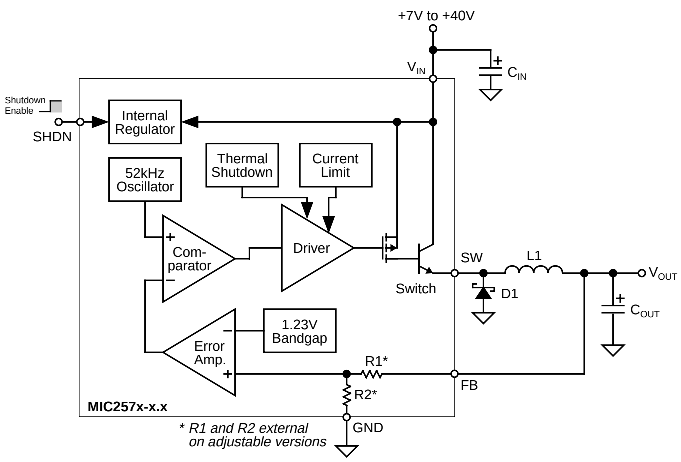

Figure 1. Block Diagram (Fixed Version)

Buck Regulator Design Procedure

Select the LM2574 (0.5A), LM2575 (1A), or LM2576 (3A) based on the required output current. If higher current rated regulators are chosen for low current applications, make sure the current limit range is appropriate for that application.

Output Voltage

For fixed output voltages, 3.3V, 5.0V, 12V, or 15V versions are available.

The output voltage of the adjustable regulators is configured using an external resistive divider.

$$V_{OUT} = 1.23V\left(1 + \frac{R2}{R1}\right)$$

For best performance, R1 should be between 1k and 10k.

Inductor Selection Criteria

The following criteria is used for inductor selection:

Mode of operation (continuous or discontinuous).

Peak inductor current

Volt-seconds (V·s) applied to the inductor

Definitions

Critical Inductance Condition The critical inductance condition is when the current through the inductor decays to zero just prior to the next "on" time of the regulator switch. This occurs at the boundary between continuous and discontinuous operation.

Discontinuous Operation Discontinuous operation occurs when, for any condition of input voltage or output current, the inductor current decays to zero before the next "on" time of the regulator switch.

Continuous Operation Continuous operation occurs when, for any condition of input voltage or output current, the inductor current does not decay to zero before the next "on" time of the regulator switch.

Continuous Conduction Operation

Critical Inductance

Compute the value of critical inductance required for the application at the worst case combination of input voltage and output load current. This will be the minimum value of inductance that will guarantee continuous conduction operation over all input voltage and output load conditions.

At the critical inductance condition, the peak inductor current is twice the average current. The average current is the current delivered to the load. The peak current at the critical inductance condition is:

$$(1) \quad I_{PEAK} = \frac{D\left(V_{IN} - V_{OUT}\right)}{L\, f_S}$$

Where:

D = duty cycle

D = switch on time/switch cycle time, T_{ON} / τ

τ = switch cycle time, $1 / f_S$, (s)

V_{IN} = input (supply) voltage (V)

V_{OUT} = regulator output voltage (V)

L = inductance of filter inductor (H)

f_S = switching frequency (Hz)

The input power will be assumed to be equal to the output power.

$$(2) \quad E_{FF}\, V_{IN}\, I_L\, D = \frac{V_{OUT}^{\,2}}{R_{LOAD}}$$

Where:

E_{FF} = estimated efficiency
reasonable initial estimate 80% (0.8)

R_{LOAD} = load resistance (Ω)

and,

$$\text{(3)} \quad L_{CRITICAL} = \frac{R_{LOAD}\,(1 - D)}{2\,f_S}$$

Duty Cycle

Compute the duty cycle required at the maximum required input voltage and minimum load current. If your cannot guarantee a minimum load current, an additional resistive load may be required at the regulator output.

$$D_{MIN} = \frac{V_{OUT}}{V_{IN(max)}}$$

Use this value of D_{MIN} and the minimum value of R_{LOAD} in equation (3) to determine the value of critical inductance. This is the minimum value of inductance required. Changing the minimum load and/or the maximum input voltage requirement changes the minimum required critical inductance.

The value of inductance can be chosen to allow the regulator to operate in discontinuous mode under certain conditions. Discontinuous mode typically occurs at maximum input and minium load current. In many cases this may not present a problem, however, it should be verified that operation in discontinuous mode still allows the circuit to satisfy the load regulation requirement.

Maximum V·s

Compute the maximum volt-microseconds applied to the inductor:

$$V \cdot s = \left(V_{IN} - V_{OUT}\right) \frac{V_{OUT}}{V_{IN(max)}}\,\tau$$

Inductor Peak Current

Compute the peak current through the inductor. This is the sum of the maximum load current and peak ripple current though the inductor.

$$I_{PEAK} = \frac{1}{2}\left(\frac{V_{IN(max)} - V_{OUT}}{L}\right)\tau\,\frac{V_{OUT}}{V_{IN(max)}} + \frac{V_{OUT}}{R_{LOAD}}$$

Inductor Selection

Refer to the “Inductor Selection and Cross Reference” table to select the appropriate inductor for your application. The selection should satisfy the following:

Inductance > Calculated Critical Inductance

Volt-second Capability > Calculated V·µs (if applicable)

I_{DC} > Calculated I_{PEAK} Current × 0.85

Output Capacitor Selection

For stable operation, the output capacitor must satisfy the following:

$$C_{OUT} \geq 13300 \left(\frac{V_{IN(max)}}{V_{OUT}\,L}\right)$$

Where:

C_{OUT} = output capacitance (µF)

L = inductance (µH)

This guarantees that the dominant pole pair of the LC filter does not occur at a frequency that is too high for the regulator’s internal loop compensation circuitry. This computation may result in a capacitor value that is too small to provide adequate peak-to-peak output ripple reduction.

Peak-to-peak ripple voltage is a function of the capacitor value and type. A low ESR/ESL (equivalent series resistance/equivalent series inductance) capacitor should be used for lower ripple voltage. (Standard capacitors may be paralleled to reduce the effective ESR/ESL value.) Low ESR electrolytic capacitors are available from Panasonic, Nichicon, and United Chemicon.

Maximum peak-to-peak ripple voltage (assuming no ESR or ESL in the filter capacitor) can be estimated as follows:

$$V_{P\text{-}P} = \frac{1}{C}\,\frac{\left(V_{IN(max)} - V_{OUT}\right)}{L}\,\frac{1}{2}\,\frac{V_{OUT}^{\;2}}{V_{IN}^{\;2}}\,\tau^2$$

Input Capacitor Selection

The input bypass capacitor must be at least 47µF to maintain stability. Low ESR capacitors are recommended. If the operating temperature range is below –25°C, the value of this capacitor should be increased. Adding a ceramic or solid tantalum capacitor near the input pin will also increase regulator stability at low temperatures. The capacitor’s ripple current rating should be more than the ripple component of the inductor current:

$$I_{RIPPLE} = \frac{\tau}{2}\left(\frac{V_{IN(max)} - V_{OUT}}{L}\right)$$

Catch Diode Selection

Although either a Schottky or a fast recovery diode can be used, a Schottky diode will provide the best performance because its lower voltage drop and faster switching speed will result in higher efficiency. Fast recovery diodes with abrupt turn-off characteristics may cause EMI problems and/or instabilities.

The reverse voltage rating of the catch diode should be at least 1.25 × the maximum input voltage.

Standard 1N400x series diodes should not be used. The reverse recovery time of this type of diode is excessive which will cause additional noise and heat dissipation in the diode and the regulator’s internal power switch.

Typical Applications

Fixed 3.3V Buck Regulator

Figure 2 shows a 3.3V buck regulator using inexpensive standard components.

The high efficiency (~80%) and low form factor afforded by the use of a new TO-263 surface mount package makes this ideal for battery operated designs.

If lower ripple voltage is desired, the standard 220µF capacitor can be replaced with a standard 330µF. For lower ripple at a small size, an Oscon 105A220M capacitor (220µF, 35mΩ ESR) can be used.

Isolated 24V to 5V Flyback Regulator

When isolation is desired (required for many telecommunications applications), an isolated flyback scheme can be used. See figure 4.

Isolation between the input and load is provided by a 4N35 optoisolator and a 1:1 transformer.

A TL431 shunt regulator creates the feedback signal which is sent through the optical isolator to the regulator IC.

To prevent the output pin from being forced much below ground (and forward biasing the substrate diode), a floating ground scheme is used.

The Schottky, resistor, and diode combination also serves as a snubber for the flyback transformer.

Both the pseudo-ground and the system ground are bypassed to remove noise.

Discontinuous mode operation avoids conditions that would otherwise require phase and gain compensation (The LM257x family does not support external compensation.) Specifically, this avoids the right half-plane zero that occurs in the open loop gain and phase when operated in the continuous conduction mode.

External compensation is required in this application because the additional elements in the feedback loop (optoisolator and shunt regulator) have changed the overall open-loop gain and phase. A simple RC compensation network is added around the shunt regulator.

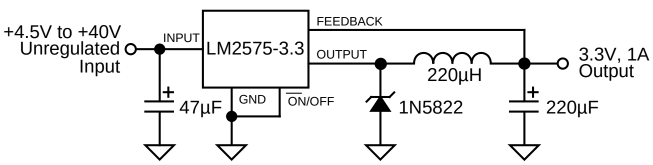

Figure 2. 3.3V Buck Regulator

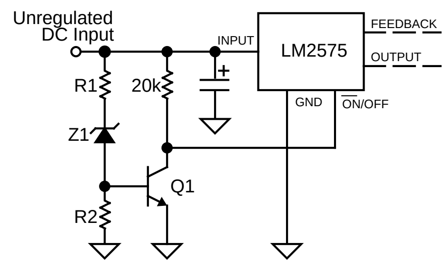

Figure 3. Undervoltage Lockout

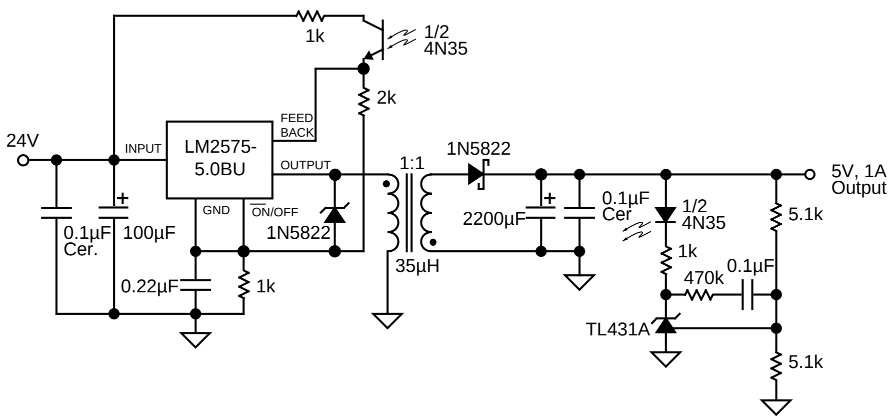

Figure 4. Isolated Flyback DC-DC Converter

Inductor Selection and Cross Reference

Custom Coils[1] Part No.	Renco Part[2] Part No.	I_{OC} (A)	V·µs (V·µs)	L (µH)	Description	
CCI-5023	RL5022	1.2	*	68	power line choke	
CCI-5024	RL5023	0.9	*	100		
CCI-4929	RL5024	0.75	*	150		
CCI-5025	RL5025	0.65	*	220		
CCI-5026	RL5026	0.5	*	330		
CCI-5027	RL5027	0.45	*	470		
CCI-4930	RL5028	0.9	*	220	power line choke	
CCI-4931	RL5029	0.75	*	330		
CCI-4932	RL5030	0.6	*	470		
CCI-4933	RL5031	0.5	*	680		
CCI-5028	RL5032	0.65	*	1000	power line choke	
CCI-5029	RL5033	0.5	*	1500		
CCI-5030	RL5034	0.45	*	2200		
CCI-4926	RL5035	12.0	*	47	cylindrical bobbin choke	
CCI-4927	RL5036	9.0	*	68		
CCI-4928	RL5037	7.5	*	100		
CCI-4934	RL5038	6.0	*	150		
CCI-4938	RL5039	2.5	*	680	cylindrical bobbin choke	
CCI-4939	RL5040	2.25	*	100		
CCI-4940	RL5041	TBD	*	TBD		
CCI-4941	RL5042	1	*	2200	cylindrical bobbin choke	
CCI-4935	RL5043	5	*	220		
CCI-4936	RL5044	4	*	330		
CCI-4937	RL5045	4	*	470	cylindrical bobbin choke	
CCI-4948	RL5046	1	44	20	powdered iron toroid	
CCI-5031	RL5047	3	38	20		
CCI-4949	RL5048	1	40	48		
CCI-4967	RL5049	3	105	48		
CCI-4951	RL5050	1	83	68		
CCI-4968	RL5051	3	130	68		
CCI-4952	RL5052	1	102	100		
CCI-4969	RL5053	3	165	100		
CCI-4953	RL5054	1	166	220		
CCI-4970	RL5055	3	342	220		
CCI-4954	RL5056	1	208	330		
CCI-4971	RL5057	3	437	330		
CCI-4942	RL5058	1	*	20	MPP toroid	
CCI-4961	RL5059	3	*	20		
CCI-4943	RL5060	1	*	48		
CCI-4962	RL5061	3	*	48		
CCI-4944	RL5062	1	*	68		
CCI-4963	RL5063	3	*	68		
CCI-4945	RL5064	1	*	100		
CCI-4964	RL5065	3	*	100		
CCI-4946	RL5066	1	*	220		
CCI-4965	RL5067	3	*	220		
CCI-4947	RL5068	1	*	330		
CCI-4966	RL5069	3	*	330		

1. Custom Coils, Alcester, South Dakota; tel: (605) 934-2460

2. Renco Electronics Inc., Deer Park, New York; tel: (516) 586-5566