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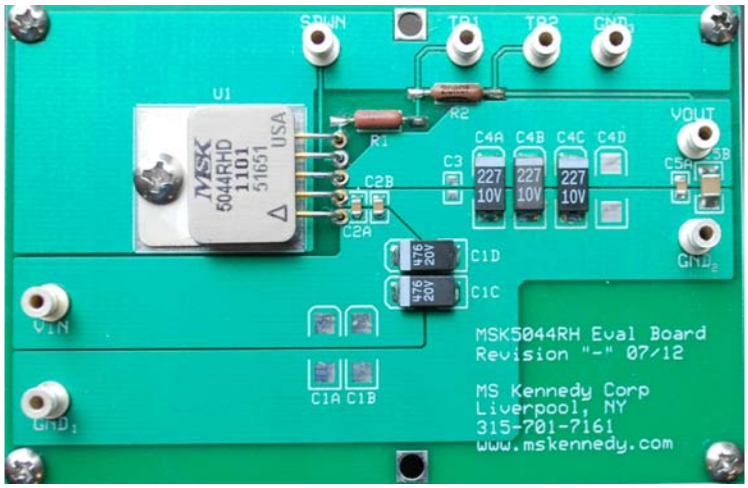
Application Note 014

MSK5044RH Evaluation Board User's Guide

By Bob Abel & Paul Musil, MS Kennedy Corp.; Revised 9/19/2013



Introduction

The MSK5044RH is an adjustable radiation hardened 500 kHz step down switching regulator capable of delivering up to 3.5A of current to the load. The 3.5A integrated switch, catch diode, boost components, and inductor leaves only a few application specific components to be selected by the designer. The MSK 5044RH simplifies design of high efficiency radiation hardened switching regulators that use a minimum amount of board space. The MSK5044RH is packaged in a hermetically sealed 5 pin TO-258, and is available with straight, bent up, bent down, or gull wing lead forms.

The evaluation board provides a platform from which to evaluate new designs with ample real estate to make changes and evaluate results. Evaluation early in the design phase reduces the likelihood of excess ripple, instability, or other issues, from becoming a problem at the application PCB level.

This application note is intended to be used in conjunction with the MSK5044RH and Linear Technology's LT1959 data sheet. Reference those documents for additional application information and specifications.

Setup

Use the standard turret terminals to connect to your power supply and test equipment. Connect a power supply across the Vin and GND_1 terminals (see note 1). Connect the output load between the VOUT and GND_2 terminals. Use separate or Kelvin connections to connect input and output monitoring equipment. When measuring output ripple voltage with an oscilloscope probe, the wire from the probe to the ground clip will act as an antenna, picking up excessive noise. For improved results, the test hook should be removed from the tip of the probe. The tip should be touched against the output turret, with the bare ground shield pressed against the ground turret. This reduces the noise seen on the waveform.

Note 1: *The MSK5044RH has a typical minimum on time requirement of 300nS corresponding to a minimum duty cycle of 15% at 500kHz switching frequency. Forcing the device to operate at less than the minimum on time may result in irregular switching waveforms and present the appearance of instability. The default configuration for this evaluation card is 1.8V out and it may present irregular switching waveforms at input voltages greater than 12V. When configured for an output voltage of 2.5V or greater the MSK5044RH will function normally with input voltages up to the maximum rating of 15V.*

Output Voltage Programming

$V_{OUT} = V_{FB} * (1+R_{FB}/2490)$
$R_{FB} = 2490 * ((V_{OUT}/V_{FB})-1)$

Given: $V_{FB} = 1.21V$ Typ.
Factory Configuration: $R_{FB} = 1.21K$
$V_{OUT} = 1.21 * (1+1.21/2.49) = 1.8V$

Efficiency

Typical efficiency curves for 1.8V and 3.3V output voltages with $5V_{IN}$ are shown in Figure 1.

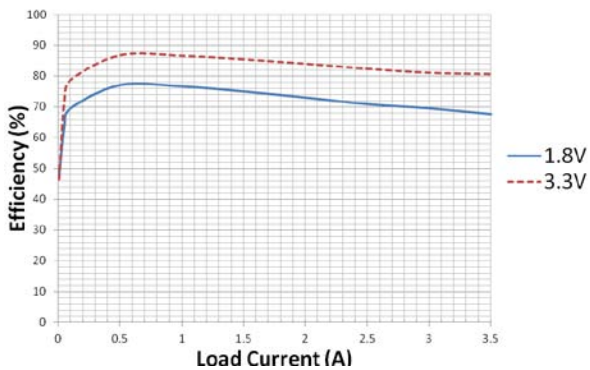


Figure 1

Loop Stability

The compensation for MSK5044RH is an internal 1,500pF capacitor. The values for loop compensation components depend on parameters which are not always well controlled. These include inductor value (±30% due to production tolerance, load current and ripple current variations), output capacitance (±20% to ±50% due to production tolerance, temperature, aging and changes at the load), output capacitor ESR (±200% due to production tolerance, temperature and aging), and finally, DC input voltage and output load current. This makes it important to check out the final design to ensure that it is stable and tolerant of all these variations.

Phase margin and gain margin are measures of stability in closed loop systems. Phase margin indicates relative stability, the tendency to oscillate during its damped response to an input change such as a line voltage step or a load step. Additionally, the phase margin measures how much phase variation is needed at the gain crossover frequency to lose stability. Gain margin is also an indication of relative stability. Gain margin measures how much the gain of the system can increase before the system becomes unstable. Together, these two numbers give an estimate of the safety margin for closed-loop stability. The smaller the stability margins, the more likely the circuit will become unstable.

One method for measuring the stability of a feedback circuit employs a network analyzer. Use an isolation transformer / adapter to isolate the grounded output analyzer from the feedback network. Remove the jumper across R2 and connect the output of the isolation transformer across R2 using TP1 and TP2 terminals. Use 1M-ohm or greater probes to connect the inputs of the analyzer to TP1 and TP2. Use GND_3 for the ground reference for the network analyzer inputs. Inject a swept frequency signal into the feedback loop, and plot the loop's gain and phase response between 100 Hz and 1 MHz. This provides a full picture of the frequency response on both sides of the unity gain frequency (26 kHz in this case). Figure 2 illustrates typical results for 5.0V in, 1.8V out, and 1A Iout. The phase margin is the phase value at the unity gain frequency, or about 63.2 Deg. The gain margin is the gain at the 0° phase frequency, or approximately 21.4dB.

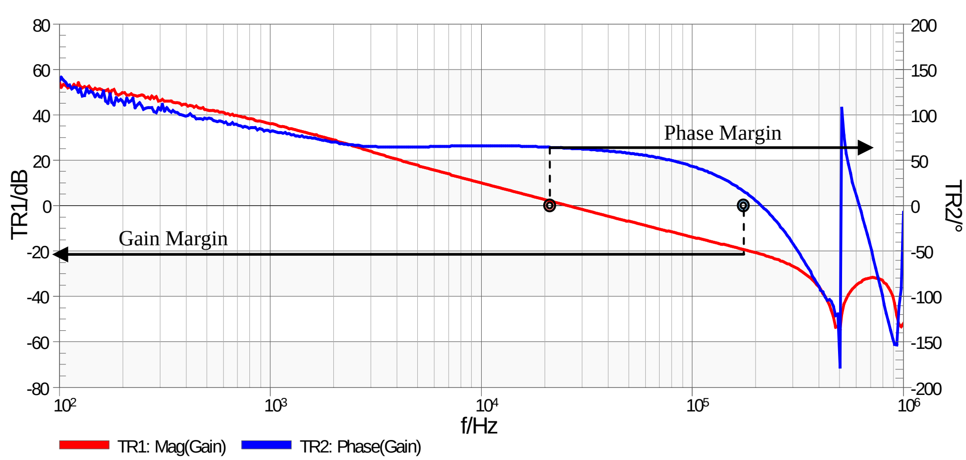


Figure 2

An alternate method to look at phase margin is to step the output load and monitor the response of the system to the transient. Filtering may be required to remove switching frequency components of the signal to make the small transients more visible. Any filter used for this measurement must be carefully designed such that it will not alter the signal of interest. A well behaved loop will settle back quickly and smoothly (Figure 3-C) and is termed critically damped, whereas a loop with poor phase or gain margin will either ring as it settles (Figure 3-B) under damped, or take too long to achieve the setpoint (Figure 3-A) over damped. The number of rings indicates the degree of stability, and the frequency of the ringing shows the approximate unity-gain frequency of the loop. The amplitude of the signal is not particularly important, as long as the amplitude is not so high that the loop behaves nonlinearly. This method is easy to implement in labs not equipped with network analyzers, but it does not indicate gain margin or evidence of conditional stability. In these situations, a small shift in gain or phase caused by production tolerances or temperature could cause instability even though the circuit functioned properly in development.

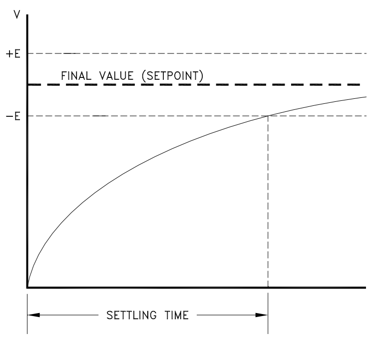


Figure 3-A

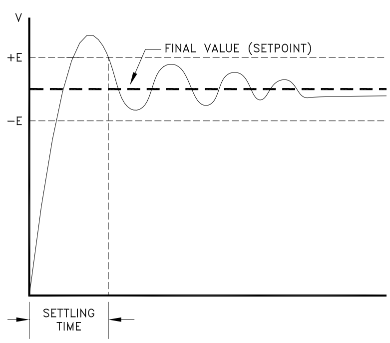


Figure 3-B

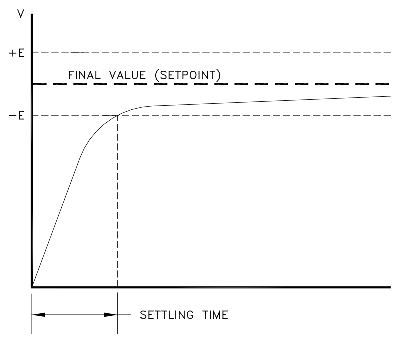


Figure 3-C

Figure 4 illustrates typical results for a step load response between 500ma and 1.5A.

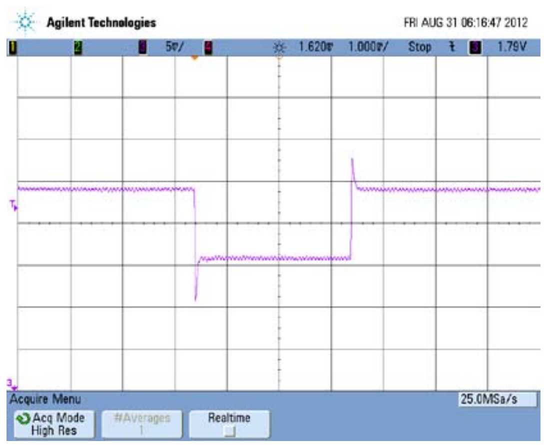


Figure 4

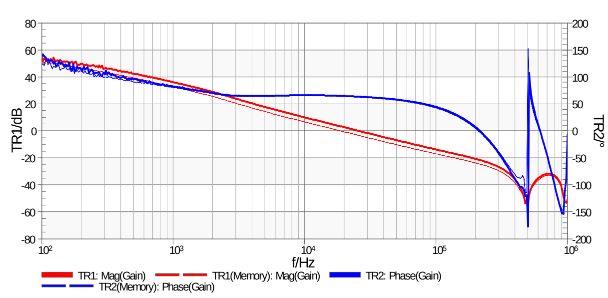
Shutdown

For normal operation, the SHDN pin can be left floating. SHDN has two output-disable modes: lockout and shutdown. When the pin is taken below the lockout threshold, switching is disabled. This is typically used for input undervoltage lockout. Grounding the SHDN pin places the RH1959 in shutdown mode. This reduces total board supply current to 20µA.

Input/Output Capacitors

The input capacitors C1C and D are AVX TAZ Series 47µF tantalum capacitors and were chosen due to their low ESR, and effective low frequency filtering. See BOM for specific part number. The input ripple current for a buck converter is high, typically $I_{OUT}/2$. Tantalum capacitors become resistive at higher frequencies, requiring careful ripple-rating selection to prevent excessive heating. Measure the capacitor case rise above ambient in the worst case thermal environment of the application, and if it exceeds 10°C, increase the voltage rating or lower the ESR rating. Ceramic capacitors' ESL (effective series inductance) tends to dominate their ESR, making them less susceptible to ripple-induced heating. Ceramic capacitors filter high frequencies well, and C2A and B were chosen for that purpose, and it is important to note that they should be placed as close as possible to the device pins for optimal performce.

The output capacitors C4A and B are AVX TAZ series 220µF tantalum capacitors. See BOM for specific part number. AVX TAZ series capacitors were chosen to provide a design starting point using high reliability MIL-PFR-55365/4 qualified capacitors. Ceramic capacitance is not recommended as the main output capacitor, since loop stability relies on a resistive characteristic at higher frequencies to form a zero. At switching frequencies, ripple voltage is more a function of ESR than of absolute capacitance value. If lower output ripple voltage is required, reduce the ESR by choosing a different capacitor or place more capacitors in parallel. For very low ripple, an additional LC filter on the output may be a more suitable solution. The output contains very narrow voltage spikes caused by the parasitic inductance of C4. Ceramic capacitors C5A and B remove these spikes on the demo board. In application, trace impedance and local bypass capacitors will perform this function. Increasing the output capacitance from two 220µF tantalum capacitors to three decreased the output ripple from 15.8mV to 9.9mV. It also improved the margins from 21.4 dB to 24.7 dB of gain margin, and from 63.2° to 65.2 ° of phase margin. Increasing the output capacitance did lower the zero crossover from 26kHz to 19kHz however. Other performance metrics were negligibly affected by the change.

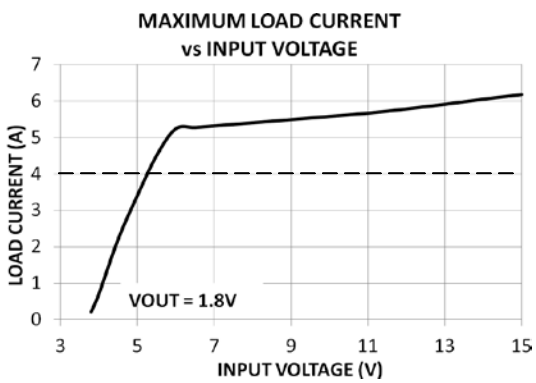


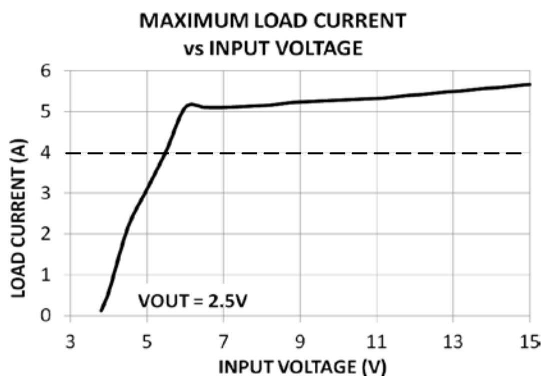
2X (Solid) vs.
3X (Dashed)
220µF Cout

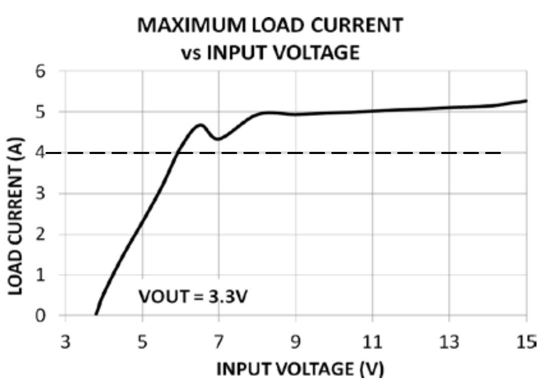
Current Limitations

Peak current for a buck converter is limited by the maximum switch current rating. This current rating is 4.5A minimum up to 50% duty cycle (DC), decreasing to 3.7A at 80% duty cycle for the MSK5044RH. Current rating decreases with duty cycle because the RH1959 has internal slope compensation to prevent current mode subharmonic switching. The RH1959 has nonlinear slope compensation, which gives better compensation with less reduction in current limit.

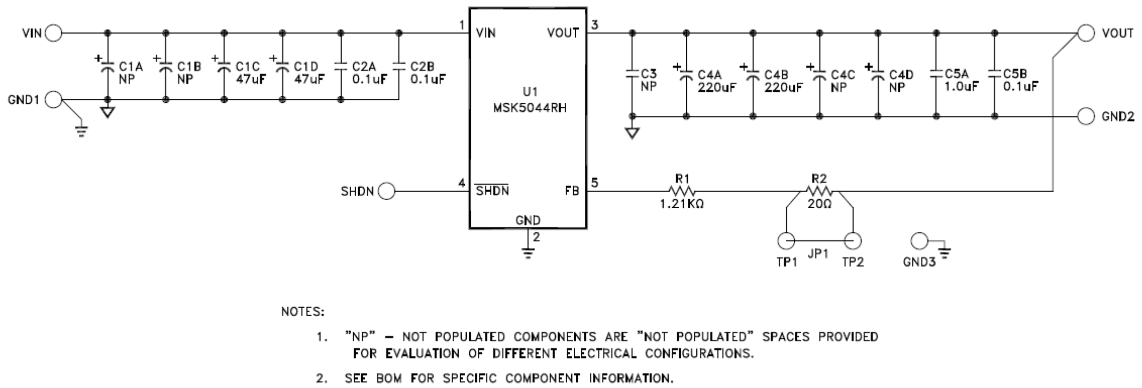
Typical switch current ratings and current limit thresholds are higher than 4.5A, and are illustrated in the typical performance curves below for several input and output voltage combinations. The output current limit function provides protection from transient overloads but it may exceed the maximum continuous rating. Continuous operation beyond the maximum continuous rating of 4A may damage the device.







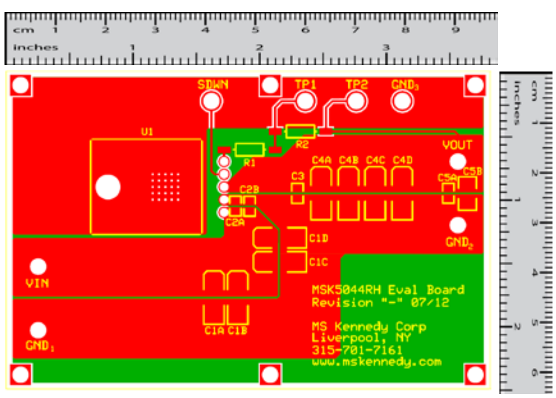
Schematic



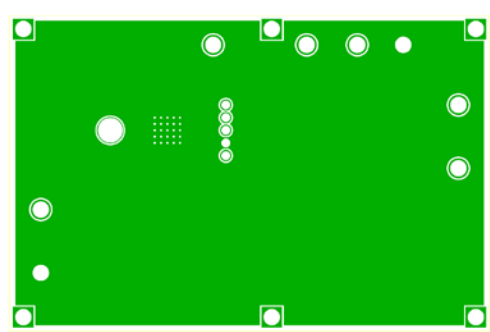
Typical Performance

Parameter	Conditions	Units	Typical
Output Voltage	V_{in} = 5.0V, I_{OUT} = 1.0A	V	1.8V (Factory Default)
Switching Frequency	V_{in} = 5.0V, I_{OUT} = 1.0A	kHz	500
Output Ripple Voltage	V_{in} = 5.0V, I_{OUT} = 1.0A	mVp-p	15.8
Line Regulation	$4.3V \leq V_{in} \leq 15V$, I_{OUT} = 1.0A	%	-0.17
Load Regulation	V_{in} = 5.0V, I_{OUT} = 50mA to 1.0A	%	-0.49
Efficiency	V_{in} = 5.0V, I_{OUT} = 1.0A	%	76.6
Current Limit	V_{in} = 5.0V	A	3.4
Gain Margin	V_{in} = 5.0V, I_{OUT} = 1.0A	dB	21.4
Phase Margin	V_{in} = 5.0V, I_{OUT} = 1.0A	Deg	63.2

PCB Artwork



Top Side



Bottom Side

Bill of Materials

Ref Des	Description	Manufacturer	Part Number
U1	Switching Regulator	MS Kennedy Corp.	MSK5044RHD
C1A	N/A		
C1B	N/A		
C1C	47 uF Low ESR tantalum	AVX	TAZH476K020L (CWR29JC476K)
C1D	47 uF Low ESR tantalum	AVX	TAZH476K020L (CWR29JC476K)
C2A	8050 Ceramic cap 0.1uF	AVX	08053C104K
C2B	8050 Ceramic cap 0.1uF	AVX	08053C104K
C3	N/A		
C4A	220 uF Low ESR tantalum	AVX	TAZH227K010L (CWR29FC227K)
C4B	220 uF Low ESR tantalum	AVX	TAZH227K010L (CWR29FC227K)
C4C	N/A		
C4D	N/A		
C5A	8050 Ceramic cap 0.1uF	AVX	08053C104K
C5B	1210 Ceramic cap 1.0uF	AVX	12103C105K
R1	Resistor 1.21K, 1/8W		
R2	Resistor 20.0 Ohm, 1/8W		