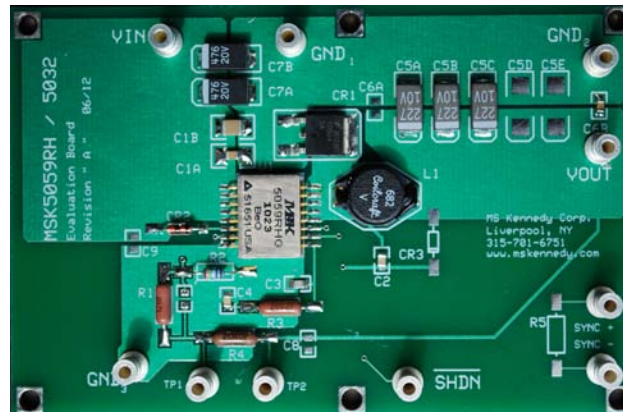


MSK5059RH and MSK5032 Evaluation Board User's Guide

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

**Introduction**

The MSK5059RH is a radiation hardened 500 kHz switching regulator controller capable of delivering up to 4.5A of current to the load. A fixed 500 kHz switching frequency allows the use of smaller inductors reducing required board space for a given design. The 4.5A integrated switch leaves only a few application specific components to be selected by the designer. The MSK 5059RH simplifies design of high efficiency radiation hardened switching regulators that use a minimum amount of board space. The MSK5032 is the non Rad-Hard version of the same device, which is functionally identical to the MSK5059RH. Both devices are packaged in a hermetically sealed 16 pin flatpack, and are available with a straight or gull wing lead form.

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 MSK5059RH or the MSK5032 data sheet, and Linear Technology's LT1959 data sheet. Reference those documents for additional application information and specifications. The MSK5032 device will not be mentioned from this point forward for simplicity, but the information still applies to both devices.

Setup

Use the standard turret terminals to connect to your power supply and test equipment. Connect a power supply across the Vin and GND₁ terminals (see note 1). Connect the output load between the VOUT and GND₂ 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 MSK5059RH 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 MSK5059RH will function normally with input voltages up to the maximum rating of 15V. If operating the MSK5059RH at less than the minimum on time is required greater than typical compensation can reduce the irregular switching.

Output Voltage Programming

$$V_{OUT} = V_{FB} * (1+R1/R2)$$

$$R1 = R2 * (V_{OUT}/V_{FB}-1)$$

Given: $V_{REF} = 1.21V$ Typ.

Factory Configuration: $R1 = 1.21K$, $R2 = 2.49K$

$$V_{OUT} = 1.21 * (1+1.21/2.49) = 1.8V$$

Efficiency

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

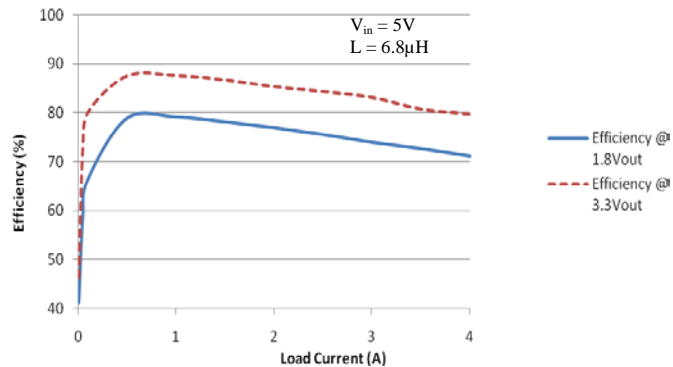


Figure 1

Boost Pin

The Boost pin provides drive voltage greater than V_{IN} to the base of the power transistor. Using a voltage greater than V_{IN} ensures hard saturation of the power switch significantly improving overall efficiency. Connect a capacitor between Boost and SW to store a charge. Connect a diode between V_{IN} and Boost to charge the capacitor during the off time of the power switch. A boost voltage of at least 2.8V is required throughout the on-time of the

switch to guarantee that it remains saturated. The boost components chosen for the evaluation board are a 0.33 μ F capacitor (C2), and a 1N914 or 1N4148 diode (CR2). The anode is connected to the unregulated input voltage. This generates a voltage across the boost capacitor nearly identical to the input. In applications having output voltages greater than 2.8V and significantly higher input voltages, the anode may be connected to the output voltage to further improve efficiency. The default configuration is with the anode on the input. Remove CR2 and install CR3 to connect the boost diode to the output voltage. Efficiency is not affected by the capacitor value, but the capacitor should have an ESR of less than 1 Ω to ensure that it can be recharged fully under the worst-case condition of minimum input voltage. Almost any type of film or ceramic capacitor will work fine.

For maximum efficiency, switch rise and fall times are made as short as possible. To prevent radiation and high frequency resonance problems, proper layout of the components connected to the switch node is essential.

Loop Stability

The compensation for MSK5059RH evaluation board is a 1,000pF capacitor in parallel with a series RC consisting of a 10,000pF capacitor and a 20k Ω resistor. This compensation was selected for use with the default components on this evaluation board. New values may have to be selected if different components are used. The values for loop compensation components depend on parameters which are not always well controlled. These include inductor value ($\pm 30\%$ due to production tolerance, load current and ripple current variations), output capacitance ($\pm 20\%$ to $\pm 50\%$ due to production tolerance, temperature, aging and changes at the load), output capacitor ESR ($\pm 200\%$ 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 step function. Moreover, 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 is a network analyzer. Use an isolation transformer / adapter to isolate the grounded output analyzer from the feedback network. Remove the jumper across R4 and connect the output of the isolation transformer across R4 using TP1 and TP2 terminals. Use 1M-ohm or greater probes to connect the inputs of the analyzer to TP1 and TP2. Use GND₃ 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 1 kHz and 1 MHz. This provides a full picture of the frequency response on both sides of the unity gain frequency (22 kHz in this case). Figure 2

illustrates typical results for the default configuration. The phase margin is the phase value at the unity gain frequency, or about 65.9 Deg. The gain margin is the gain at the 0° phase frequency, or approximately 32.1dB.

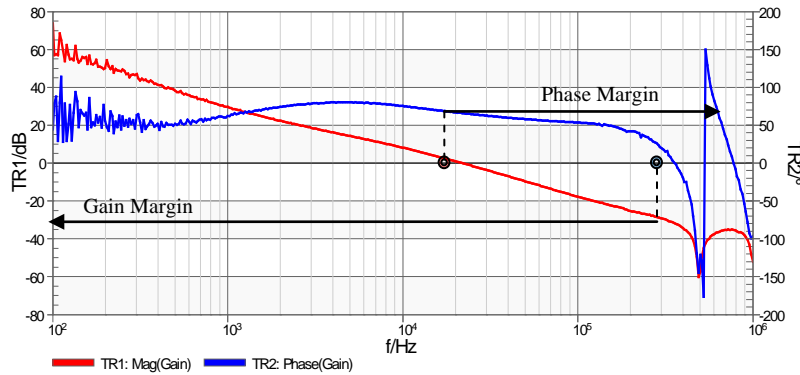


Figure 2

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.

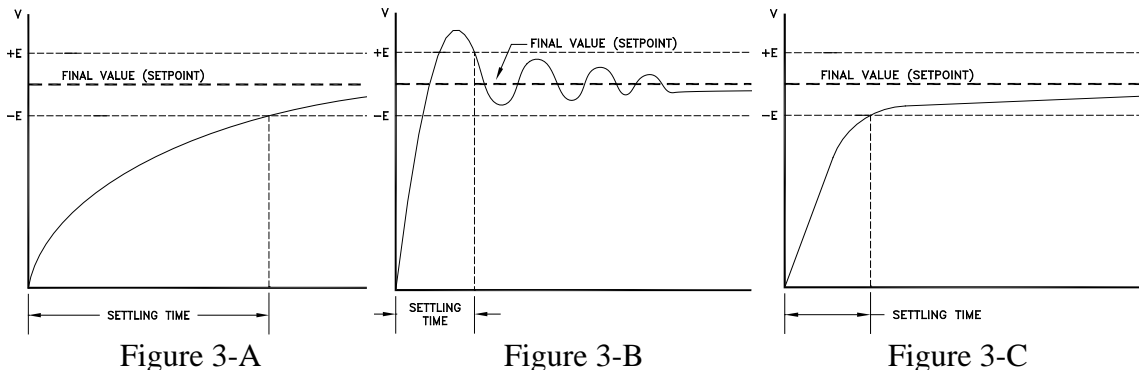


Figure 4 illustrates typical results for a step load response between 500ma and 1.5A.



Figure 4

Current Sharing and Synchronization

There are several advantages to using a multiple switcher approach compared to a single larger switcher. The inductor size is considerably reduced. Three 4A inductors store less energy ($LI^2/2$) than one 12A inductor so are far smaller. In addition, synchronizing three converters 120° out of phase with each other reduces input and output ripple currents. This reduces the ripple rating, size and cost of filter capacitors. If the SYNC pin is not used in the application, tie it to ground. To synchronize switching to an external clock, apply a logic-level signal to the SYNC pin. The amplitude must be from a logic low to greater than 2.2V, with a duty cycle between 10% and 90%. The synchronization frequency must be greater than the free-running oscillator frequency and less than 1 MHz. This means that minimum practical sync frequency is equal to the worst-case high self-oscillating frequency (560 kHz), not the typical operating frequency of 500 kHz. Caution should be used when synchronizing above 700 kHz because at higher sync frequencies the amplitude of the internal slope compensation used to prevent subharmonic switching is reduced. Additional circuitry may be required to prevent subharmonic oscillation.

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 $20\mu\text{A}$.

Input/Output Capacitors

The input capacitors C7A and B are AVX TAZ Series $47\mu\text{F}$ 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 $I_{\text{OUT}}/2$. 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 C1A and B were chosen for that purpose.

The output capacitors C5A,B and C are AVX TAZ series 220uF 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 placing more capacitors in parallel. For very low ripple, an additional LC filter in the output may be a more suitable solution. Re-compensation of the loop may be required if the output capacitance is altered. The output contains very narrow voltage spikes caused by the parasitic inductance of C5. Ceramic capacitors C6A and B remove these spikes on the demo board. In application, trace impedance and local bypass capacitors will perform this function.

Catch Diode CR1 and L1

Use diodes designed for switching applications, with adequate current rating and fast turn-on times, such as Schottky or ultrafast diodes. The parameters of interest are forward voltage, maximum reverse voltage, reverse leakage current, reverse recovery, average operating current, and peak current. Lower forward voltage yields higher circuit efficiency and lowers power dissipation in the diode. The reverse voltage rating must be greater than the input voltage. Average diode current is always less than output current, but under a shorted output condition, diode current can equal the switch current limit. If the application must withstand this condition, the diode must be rated for maximum switch current. There are a number of tradeoffs to consider when selecting an inductor for your application. The inductance value determines the peak to peak ripple current under various operating conditions. A common starting point for the peak to peak current ripple is 20% of the load current. The equation below determines an inductor value based on desired ripple current and circuit parameters.

$$L = D \cdot (V_{in} - V_{out}) / (f_{sw} \cdot I_{pp})$$

Given:

D = Duty cycle, approximately V_{out}/V_{in}

I_{pp} = Peak to peak ripple current, typically $0.2 \cdot I_{out DC}$

f_{sw} = Switching frequency in Hz

L = Inductor value in Henries

Current Limitations

Peak current for a buck converter is limited by the maximum switch current rating. This current rating is 4.5A up to 50% duty cycle (DC), decreasing to 3.7A at 80% duty cycle for the MSK5059.

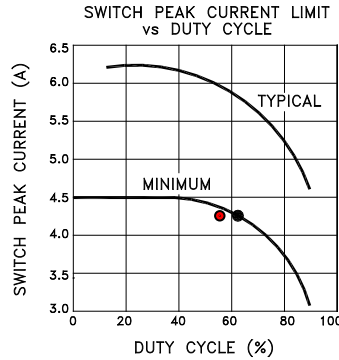


Figure 5

This is shown graphically in Figure 5, and can be calculated using the formula below:

$$I_P = 4.5A \text{ for } DC < 50\%$$

$$I_P = 3.21 + 5.95(DC) - 6.75(DC)^2 \text{ for } 50\% < DC < 90\%$$

$$DC = \text{Duty cycle} = V_{OUT}/V_{IN}$$

Maximum output current is then reduced by one-half peak-to-peak inductor current.

$$I_{MAX} = I_P - (V_{OUT})(V_{IN} - V_{OUT})/2(L)(f)(V_{IN})$$

Example: with $V_{OUT} = 5V$, $V_{IN} = 8V$; $DC = 5/8 = 0.625$, $L = 3.3\mu H$

$$I_P = 3.21 + 5.95(0.625) - 6.75(0.625)^2 = 4.3A$$

$$I_{MAX} = 4.3 - (5)(8-5)/2(3.3\mu H)(500kHz)(8) = 3.73A \text{ (Figure 6)}$$

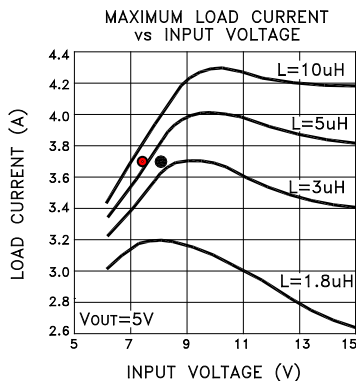
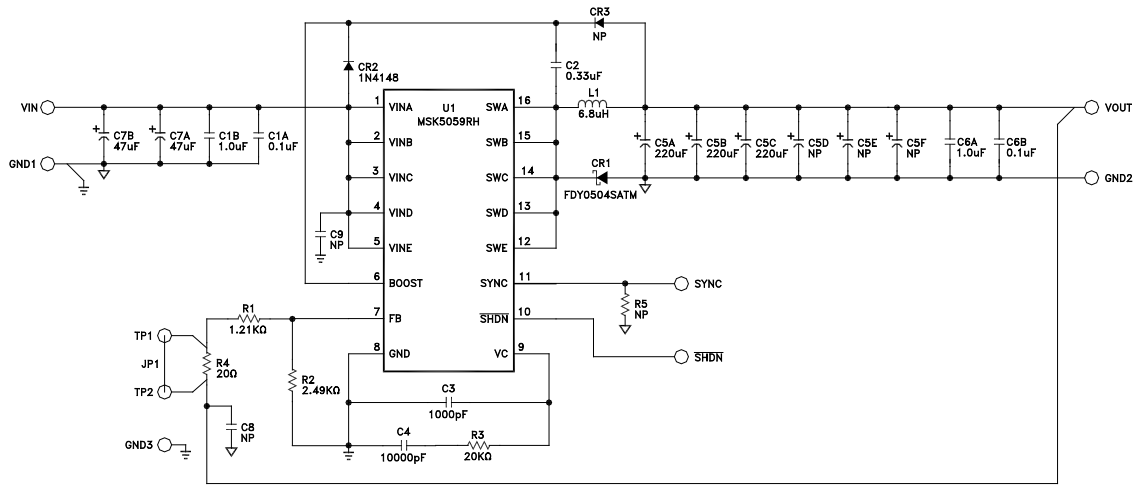


Figure 6

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.

Schematic

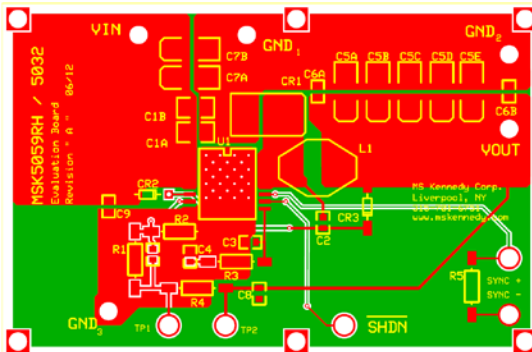


- NOTES:
1. "NP" - NOT POPULATED COMPONENTS ARE "NOT POPULATED" SPACES PROVIDED FOR EVALUATION OF DIFFERENT ELECTRICAL CONFIGURATIONS.
 2. SEE BOM FOR SPECIFIC COMPONENT INFORMATION.

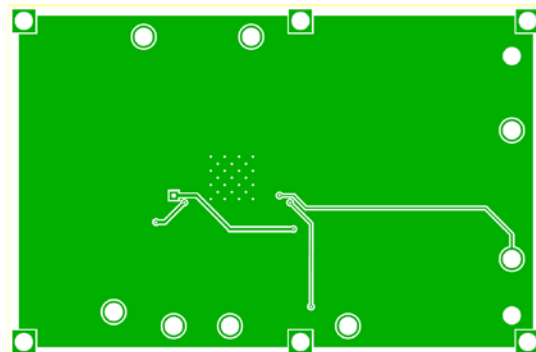
Typical Performance

Parameter	Conditions	Units	Typical
Output Voltage	$V_{in} = 5.0V, I_{OUT} = 2.0A$	V	1.8V (Factory Default)
Switching Frequency	$V_{in} = 5.0V, I_{OUT} = 2.0A$	kHz	500
Output Ripple Voltage	$V_{in} = 5.0V, I_{OUT} = 2.0A$	mVp-p	25
Line Regulation	$4.3V \leq V_{in} \leq 15V, I_{OUT} = 2.0A$	%	-0.1
Load Regulation	$V_{in} = 5.0V, I_{OUT} = 50mA \text{ to } 2.0A$	%	-0.3
Efficiency	$V_{in} = 5.0V, I_{OUT} = 2.0A$	%	75
Current Limit	$V_{in} = 5.0V$	A	5.5
Gain Margin	$V_{in} = 5.0V, I_{OUT} = 2.0A$	dB	32
Phase Margin	$V_{in} = 5.0V, I_{OUT} = 2.0A$	Deg	66

PCB Artwork



Top Side



Bottom Side

Bill Of Materials

Ref Des	Description	Manufacturer	Part Number
U1	Switching Regulator	MS Kennedy Corp.	MSK5059RHG or MSK5032
C1A	1210 Ceramic cap 1.0uF	AVX	12103C105K
C1B	1210 Ceramic cap 1.0uF	AVX	12103C105K
C2	8050 Ceramic Cap .33uF	AVX	08053C334K
C3	8050 Ceramic Cap 1000pF	AVX	08053A102K
C4	8050 Ceramic Cap 10000pF	AVX	08053A103K
C5A	220 uF Low ESR tantalum	AVX	TAZH227K010L (CWR29FC227K)
C5B	220 uF Low ESR tantalum	AVX	TAZH227K010L (CWR29FC227K)
C5C	220 uF Low ESR tantalum	AVX	TAZH227K010L (CWR29FC227K)
C5D	N/A		
C5E	N/A		
C5F	N/A		
C6A	1210 Ceramic cap 1.0uF	AVX	12103C105K
C6B	8050 Ceramic cap 0.1uF	AVX	08053C104K
C7A	47 uF Low ESR tantalum	AVX	TAZH476K020L (CWR29JC476K)
C7B	47 uF Low ESR tantalum	AVX	TAZH476K020L (CWR29JC476K)
C8	N/A		
C9	N/A		
R1	Resistor 1.21K, 1/8W		
R2	Resistor 2.49K, 1/8W		
R3	Resistor 20.0K, 1/8W		
R4	Resistor 20Ω, 1/8W		
R5	N/A		
CR1	Fairchild	Fairchild	FYD0504SATM
CR2	1N4148 or 1N914	ANY	1N4148 or 1N914
CR3	N/A		
L1	6.8uH inductor	Coilcraft	DO3316P-682MLB