Ultralow Noise 15mm×15mm×2.8mm µModule Step-Down Regulators Meet the Class B of CISPR 22 and Yield High Efficiency at up to 36V_{IN}

by Judy Sun, Jian Yin, Sam Young and Henry Zhang

Introduction

Power supply designers face many tradeoffs. Need high efficiency, large conversion ratios, high power and good thermal performance? Choose a switching regulator. Need low noise? Choose a linear regulator. Need it all? Compromise. One compromise is to follow a switcher with a linear regulator (or regulators). Although this cleans up the output noise relative to a switcher-only solution, a good portion of the conducted and radiated EMI remains—even if ferrite beads, π filters, and LC filters are used. The problem can always be traced back to the switcher, where fast dI/dt transitions and high switching frequencies lead to high frequency EMI, but some applications, especially those with large conversion ratios, *require* a switcher.

These µModule step-down regulators are designed to achieve both high power density and meet EMC (electromagnetic compatibility) standards. The integrated ultralow noise feature allows both devices to pass the Class B of CISPR 22 radiated emission limit, thus eliminating expensive EMI design and lab testing.

Fortunately, the LTM4606 and LTM4612 µModule regulators offer the advantages of a switching regulator while maintaining ultralow conducted and radiated noise. These µModule step-down regulators are designed to achieve both high power density and meet EMC (electromagnetic compatibility) standards. The integrated ultralow noise feature allows both devices to pass the Class B of CISPR 22 radiated emission limit, thus eliminating expensive EMI design and

Table 1. Feature comparison of ultralow noise µModule regulators

Feature	LTM4606	LTM4612
V_{IN}	4.5V to 28V	5V to 36V
V_{OUT}	0.6V to 5V	3.3V to 15V
I_{OUT}	6A DC Typical, 8A Peak	5A DC Typical, 7A Peak
CISPR 22 Class B Compliant	✓	✓
Output Voltage Tracking and Margining	✓	✓
PLL Frequency Synchronization	✓	✓
±1.5% Total DC Error	✓	✓
Power Good Output	✓	✓
Current Foldback Protection	✓	✓
Parallel/Current Sharing	✓	✓
Low Input and Output Referred Noise	✓	✓
Ultrafast Transient Response	✓	✓
Current Mode Control	✓	✓
Programmable Soft-Start	✓	✓
Output Overvoltage Protection	✓	✓
Package	15mm × 15mm × 2.8mm	15mm × 15mm × 2.8mm

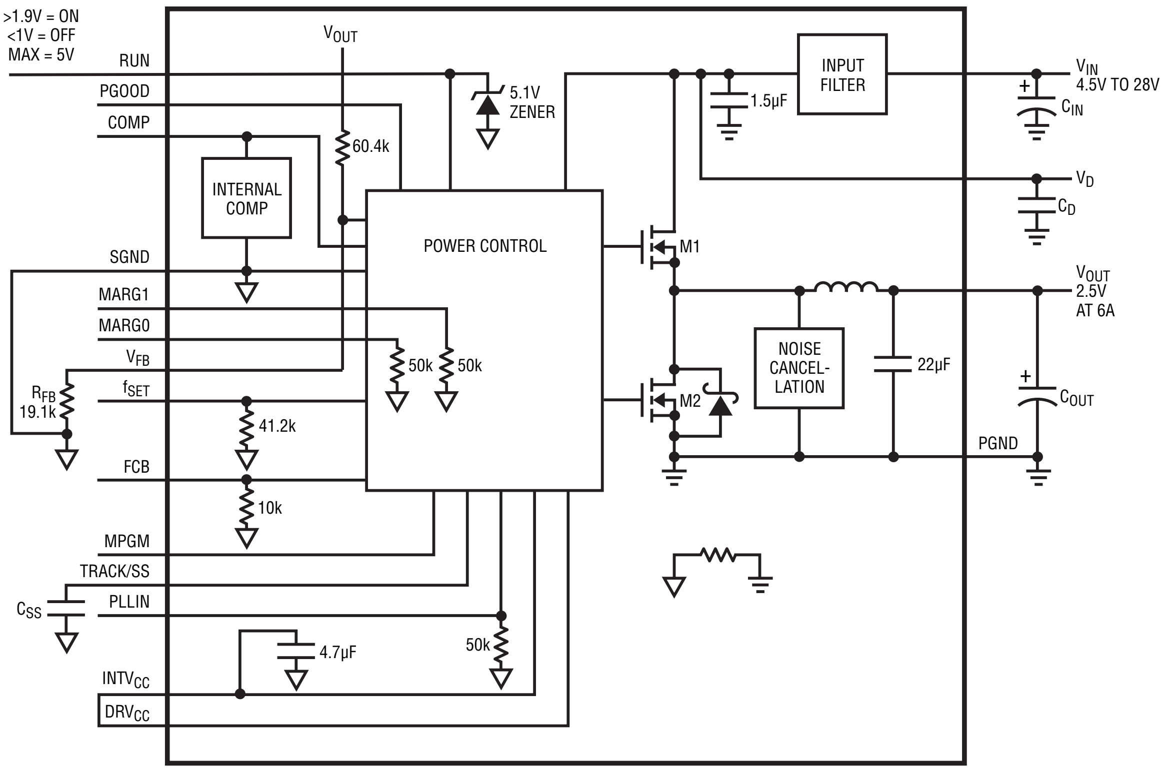

Figure 1. Simplified block diagram of the LTM4606 (LTM4612 is similar). Only a few capacitors and resistors are required to build a complete wide-input-range regulator.

lab testing. See Table 1 for a feature comparison of these two parts.

Both µModule regulators are offered in space saving, low profile and thermally enhanced 15mm × 15mm × 2.8mm LGA packages, so they can be placed on the otherwise unused space at the bottom of PC boards for high-accuracy point-of-load regulation. This is not possible with linear regulators that require a bulky cooling system. Almost all support components are integrated into the µModule package, so layout design is relatively simple, requiring only a few input and output capacitors.

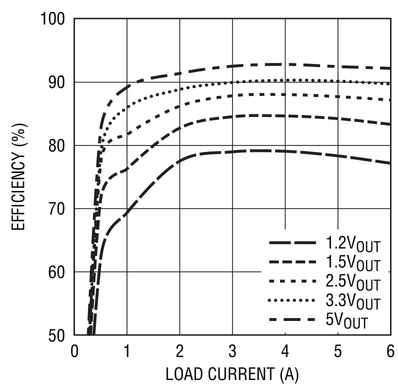

Figure 2. Efficiency of the LTM4606 with a 12V input.

For more output power, both parts can be easily paralleled, where output currents are automatically shared due to the current mode control structure.

Easy Power Supply Design with Ultralow Noise µModule Regulators

With a few external input and output capacitors, the LTM4612 can deliver 4.5A of DC output current

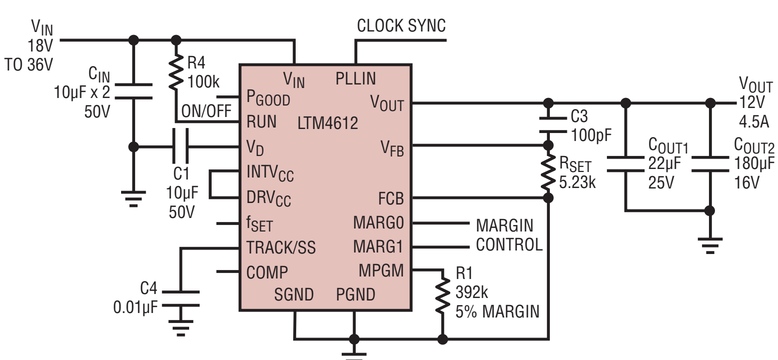

Figure 3. A few capacitors and resistors complete an 18V–36V input, 12V/4.5A output design.

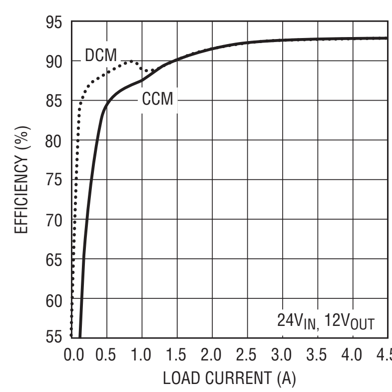

Figure 4. Efficiency for the circuit in Figure 3.

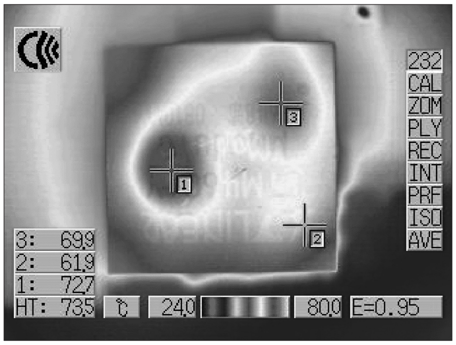

Figure 5. Thermal image of an LTM4606 with 24V input and 3.3V output at 6A

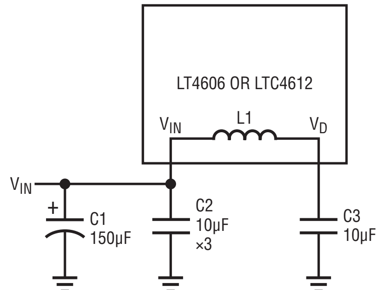

Figure 6. Input π filter reduces high frequency input noise.

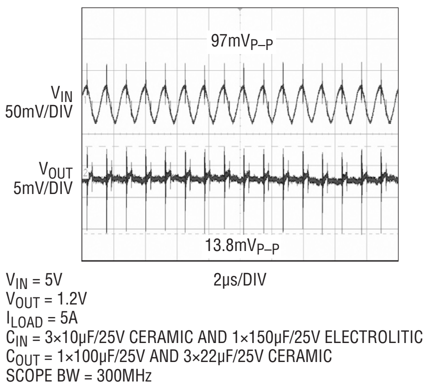

Figure 7. Input and output noise of comparable µModule regulator without low noise feature

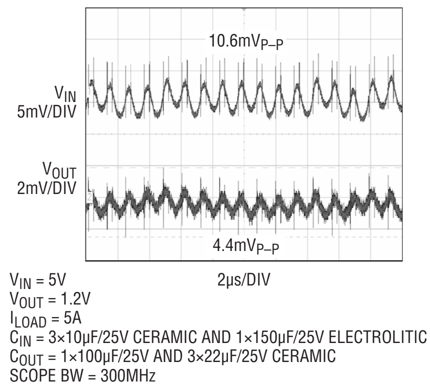

Figure 8. Input and output noise of LTM4606 µModule regulator is significantly lower than the regulator in Figure 7.

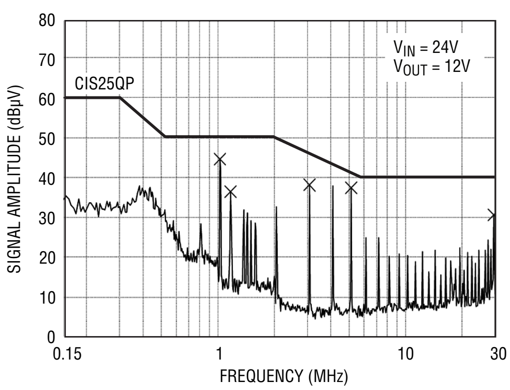

Figure 9. The conducted EMI test of the LTM4612 passes EMI standard CISPR 25 level 5.

and the LTM4606 can deliver 6A. The LTM4612's programmable output can be precisely regulated in a 3.3V-to-15V range from a 4.5V-to-36V input; the LTM4606 can produce 0.6V to 5V from a 4.5V-to-28V range. With current mode control and optimized internal compensations, both offer stable output even in the face of significant load transients.

Figure 1 shows the simplified block diagram of the LTM4606 with an input from 4.5V to 28V and 2.5V/6A output. Figure 2 shows the efficiency test curves with 12V input voltage under CCM mode. About 92% efficiency is achieved at full load with LTM4606, running at 900kHz switching frequency.

Figure 3 shows a complete 18V–36V V_{IN}, 12V/4.5A V_{OUT} design with the LTM4612. Figure 4 shows the efficiency.

Both parts offer good thermal performance with a large output load current. Figure 5 shows the LTM4606 thermal image with 24V input and 3.3V output at 6A load current. The maximum case temperature is only 73.5ºC with the 20W output power.

Both include a number of built-in features, such as controllable soft-start, RUN pin control, output voltage tracking and margining, PGOOD indicator, frequency adjustment and external clock synchronization. Efficiency can be further improved by applying an external gate driver voltage to the DRV_{CC} pin, especially in high V_{IN} applications. Discontinuous mode operation can be enabled to increase the light load efficiency.

Reduce Conducted EMI

Conducted input and output noise of switching regulators (aka ripple) is usually a problem when the regulator operates at high frequency, which is common in space-constrained applications. The LTM4606 and LTM4612 reduce peak-to-peak ripple at the input by integrating a high frequency inductor as shown in Figure 6. The external input capacitors at the V_D and V_{IN} pins form a high frequency input π filter. This effectively reduces conductive EMI coupling between the module and the main input bus.

Since most input RMS current flows into capacitor C3 at the V_D pin, C3 should have enough capacity to handle the RMS current. A 10µF ceramic capacitor is recommended. To effectively attenuate EMI, place C3 as close as possible to the V_D pin. The ceramic capacitors C2 mainly determine the ripple noise attenuation, so the capacitor value can be varied to meet the different input ripple requirements. C1 is only needed if the input source impedance is compromised by long inductive leads or traces.

Since these µModule regulators are used in a buck circuit topology, the lowpass filter formed by the output inductor L and capacitor C_{OUT}

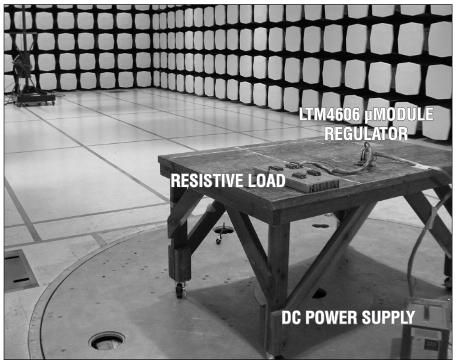

Figure 10. Setup of the radiated emission scan

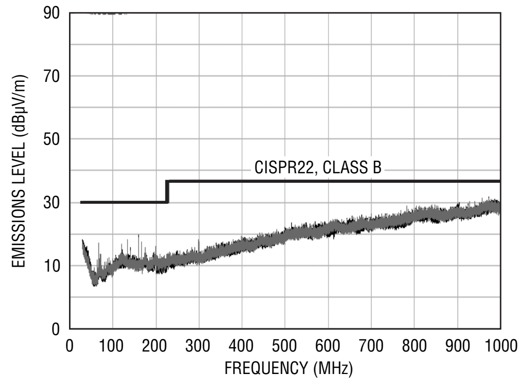

Figure 11. Radiated emission scan of baseline noise (no switching regulator module)

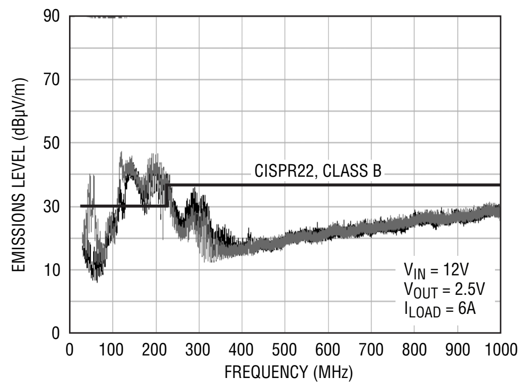

Figure 12. Radiated emission peak scan of a typical module without the low noise features.

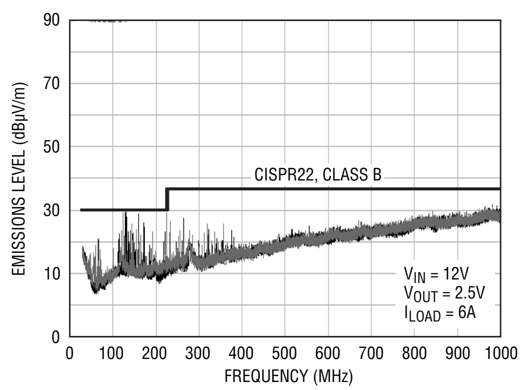

Figure 13. The radiated EMI test of the LTM4606 passes EMI standard CISPR 22 Class B.

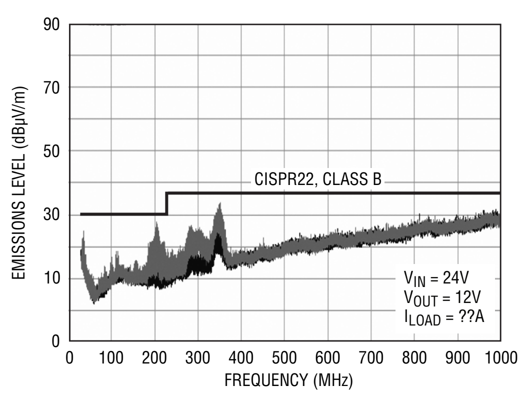

Figure 14. The radiated EMI test of the LTM4612 passes EMI standard CISPR 22 Class B.

can similarly reduce the conducted output EMI.

To show the relative noise attenuation of these µModule regulators, a similar module without the low noise feature is compared to the LTM4606 for input and output noise, as shown in Figure 7 and Figure 8. Both modules are tested from 5V input to 1.2V output at 5A with resistive loads. The same board layout and I/O capacitors are used in the comparison. The results show that the LTM4606 produces much lower input and output noise, with a nearly 10× reduction of the peak-to-peak input noise and better than 3× reduction of the output noise compared to the similar module in Figure 7.

Figure 9 shows the conducted EMI testing results for the LTM4612 with a 24V V_{IN}, 12V/5A V_{OUT}, which accommodates the EMI standard CISPR 25 level 5. The input capacitance for this test comes from 4 × 10µF/50V ceramics plus a single 150µF/50V electrolytic.

Reduce Radiated EMI

Switching regulators also produce *radiated* EMI, caused by the high dI/dt signals inherent in high efficiency regulators. The input π filter helps to limit radiated EMI caused by high dI/dt loops in the immediate module area, but to further attenuate radiated EMI, the LTM4606 and LTM4612 include an optimized gate driver for the MOSFET and a noise cancellation network.

To test radiated EMI, several setups are tested in a 10-meter shielded chamber as shown in Figure 10. To ensure a low baseline radiated noise,

Table 2. Noise margins are good for radiated emission results shown in Figure 13

Frequency (MHz)	Antenna Polarization	EUT Azimuth (Degrees)	Antenna Height (cm)	Uncorrected Amplitude (dBμV)	ACF (dB/m)	Pre-Amp Gain (dB)	CBL (dB)	DCF (dB)	Corrected Amplitude (dBμV)	Limit (dBμV)	Margin (dB)
134.31	H	354	364	1.3	11.428	0	1.532	0	14.26	30	15.74
119.96	V	184	110	3.5	12.694	0	1.456	0	17.65	30	12.35
160.02	H	0	354	0.5	10.499	0	1.793	0	12.792	30	17.208
174.37	H	0	100	1.2	9.638	0	1.944	0	12.782	30	17.218
224.28	V	0	100	–1.87	10.586	0	2.044	0	10.76	30	19.24
263.63	H	0	371	–4.72	12.6	0	2.385	0	10.265	37	26.735

a linear DC power supply is used for the input, and a resistive load is employed on the output. The baseline noise is checked with the power supply providing a DC current directly to the resistive load. The baseline emission scan results are shown in Figure 11. There are two traces in the plot, one for the vertical and horizontal orientations of the receiver antenna.

Figure 12 shows the peak scan results of a μModule buck regulator—not the LTM4606 or LTM4612—without the integrated low noise feature. The scan results show that the noise below 350MHz is produced by the μModule switching regulator, when compared to the baseline noise level. Radiated EMI here does not meet the Class B of CISPR 22 (quasi-peak) radiated emission limit.

In contrast, Figure 13 shows the peak scan results of the low noise LTM4606 module. To ensure enough margin to the quasi-peak limit for different operation conditions, the six highest noise points are checked as shown in the table of Figure 13 using the quasi-peak measurement. The results show that it has more than 12dBμV margin below the Class B of CISPR 22(quasi-peak) radiated emission limit.

Figure 14 shows the results for the LTM4612 meeting the Class B of CISPR 22 radiated emission limit at 24V V_{IN}, 12V/5A V_{OUT}.

Conclusion

The LTM4606 and LTM4612 μModule regulators offer all of the high performance benefits of switching regulators minus the noise issues. The ultralow noise optimized design produces radiated EMI performance with enough margin below the Class B of CISPR 22 limit to simplify application in noise-sensitive environments.

Design is further simplified by exceptional thermal performance, which allows them to achieve high efficiency and a compact form factor. A low profile 15mm × 15mm × 2.8mm package contains almost all of the support components—only a few input and output capacitors are required to complete a design. Several μModule regulators can be easily run in parallel for more output power. The versatility of these parts is rounded out by optional features such as soft-start, RUN pin control, output voltage tracking and margining, PGOOD indicator, frequency adjustment and external clock synchronization.

LTC6652, continued from page 9

output headroom while fully loaded, and they require less headroom with a reduced load or while sinking current. Popular application requirements, such as a 2.5V reference operating on a 3V supply, or a 4.096V reference operating on a 5V supply, are easily accommodated. For high input voltage requirements, all voltage options work up to 13.2V. Regardless of input voltage the LTC6652 maintains its excellent accuracy as shown in the line regulation plot in Figure 6. A plot of the dropout voltage for both sourcing and sinking current is shown in Figures 7a and 7b, respectively.

Superior Performance

While many references share some features of the LTC6652, it's difficult to find any that include all the features at the same level of performance and reliability. Additional features include low noise, good AC PSRR, and excellent load regulation (both sourcing and sinking current). Low power consumption and a shutdown mode round out the feature list.

Conclusion

The LTC6652 reference family is designed and factory trimmed to yield exceptional drift and accuracy performance. The entire family is guaranteed and production tested at –40°C, 25°C and 125°C to ensure dependable performance in demanding applications. Low thermal hysteresis and low long-term drift reduce or eliminate the need for field calibration. The small 8-lead MSOP package and sparse capacitor requirements minimize required board space. The wide input range from 2.7V to 13.2V and seven output voltage options will tackle the needs of most precision reference users.