2MHz Dual Buck Regulator Operates Outside of AM Radio Band When Delivering 3.3V and 1.8V from 16V Input

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The number of microprocessor-based control units continues to grow in both automobiles and industrial systems. Because the amount of required processing power is also increasing, even modest processors require a low voltage core supply in addition to 3.3V or 5V memory, I/O and analog supplies.

In automotive systems, power comes from the battery, with its voltage typically between 9V and 16V. Including cold crank and double battery jump-starts, the minimum input voltage may be as low as 4V and the maximum up to 36V, with even higher transient voltages. Likewise, a 24V industrial supply may be as high as 32V. With these high input voltages, linear regulators cannot be used for supply currents greater than 200mA without overheating the regulator. Instead, high efficiency switching regulators must be used to minimize thermal dissipation.

There are challenges in applying switching regulators in these systems. A small circuit is desired, and certain operating frequencies may be unacceptable. At high step-down ratios, switching regulators typically operate at frequencies in the AM radio band. One solution is to dynamically move the power converter switching frequency (and harmonics) away from the tuned AM frequency, but moving the switching frequency can lead to unexpected EMI problems.

A cleaner solution is to simply set the switching frequency higher than the top of the AM radio band, which is at 1.8MHz. This is easier said than done, since most existing buck converters cannot meet the low (<100ns over temperature) minimum on-time required to produce the step-down ratio from a 16V input to a 3.3V output.

The LT3640 solves this problem with a fast non-synchronous high voltage buck converter and a high efficiency synchronous low voltage buck converter. With a typical minimum on time of about 60ns over temperature, the high voltage channel in the LT3640 can deliver 3.3V from $16V_{IN}$ at 2MHz with comfortable margin. The synchronous low voltage channel in the LT3640 can be cascaded from the 3.3V channel to generate the other lower voltage buses such as 2.5V, 1.8V or 1.2V.

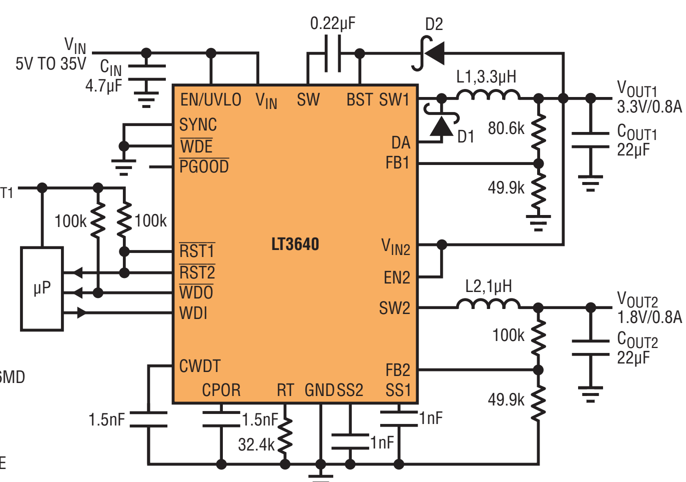
The LT3640 also includes a programmable power-on reset timer and watchdog timer to supervise microprocessors. The LT3640 is offered in 4mm × 5mm QFN and 28-lead FE packages.

DUAL BUCK REGULATOR

The LT3640 is a dual channel, constant frequency, current mode monolithic buck switching regulator with power-on reset and watchdog timer. Both channels are synchronized to a single oscillator with frequency set by R_T. The adjustable frequency ranges from 350kHz to 2.5MHz. The internal oscillator of the LT3640 can be synchronized to an external clock signal on the SYNC pin.

The high voltage channel is a non-synchronous buck with an internal 1.7A NPN top switch that operates from an input of 4V to 35V. Above 35V, an internal overvoltage lockout circuit suspends switching, protecting the LT3640 and downstream circuits from input faults as high as 55V. The low voltage channel is a synchronous buck with internal CMOS power switches

Figure 1. 2MHz 3.3V/0.8A and 1.8V/0.8A step-down regulators



CIN: TAIYO YUDEN UMK316BJ475KL
COUT1, COUT2: TAIYO YUDEN JMK212BJ226MD
L1: VISHAY IHLP2020BZER3R3
L2: VISHAY IHLP1616BZER1R0
D1, D2: DIODES INC. B240A
D2: CENTRAL SEMICONDUCTOR CMDSH-4E

The high voltage buck regulator in the LT3640 has a very fast minimum on time of about 60ns. This enables the LT3640 to operate at a high step-down ratio while maintaining high switching frequency.

providing high efficiency without the need of an external Schottky diode and accepts an input of 2.5V to 5.5V. Typically, the low voltage channel can operate from the output of the high voltage channel to form a cascaded structure as shown in Figure 1, but it can also operate from a separate supply source. The low voltage channel only switches when the high voltage channel output is within regulation.

FAST, HIGH VOLTAGE BUCK REGULATOR

The high voltage buck regulator in the LT3640 has a very fast minimum on time of about 60ns. This enables the LT3640 to operate at a high step down ratio while maintaining high switching frequency. Figure 3 shows the waveform of the LT3640 operating from input voltage of 35V to regulate a 3.3V output at 2MHz. The on time of the top power switch is about 60ns, which is also flat over temperature.

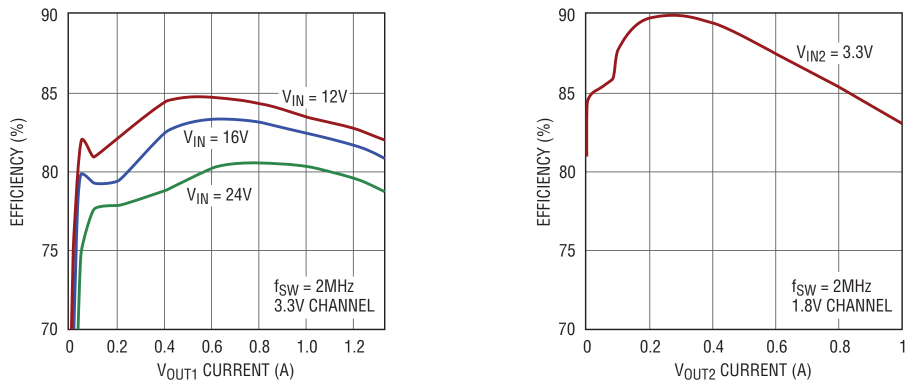


Figure 2. Efficiency of the circuit in Figure 1

Besides the fast minimum on time, the high voltage buck regulator has fast switching edges to minimize switching losses and improve conversion efficiency at high frequency. Figure 4 shows the efficiency of the high voltage buck regulator at 2MHz operation for different input voltages. For 5V output voltage, the high voltage buck maintains an efficiency of higher than 86% for input voltage up to 24V.

OUTPUT SHORT-CIRCUIT ROBUSTNESS

The LT3640 monitors the catch diode current to guarantee the output short-circuit robustness for the high voltage buck converter. The LT3640 waits for the catch diode current to fall below its limit before starting a new cycle. The top NPN does not turn on until the catch diode current is below its limit. This control scheme

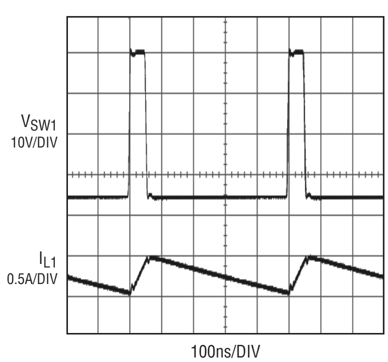


Figure 3. Fast high voltage buck regulator

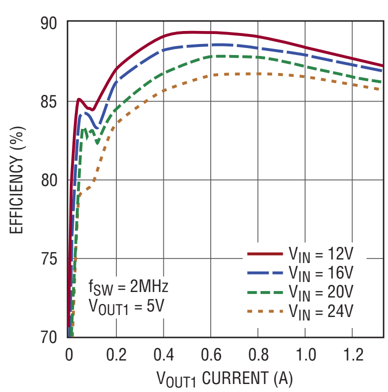


Figure 4. Efficiency of the high voltage buck regulator

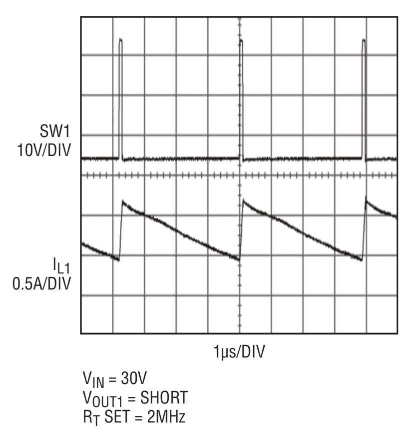


Figure 5. Output shorted robustness, high voltage channel

ensures cycle-by-cycle current limit, providing protection against shorted output. The switching waveform for V_{IN} = 30V and V_{OUT} = 0V is shown in Figure 5.

LOW VOLTAGE SYNCHRONOUS BUCK REGULATORS

The low voltage channel is a synchronous buck with internal CMOS power switches providing high efficiency without the need of external Schottky diode. This channel only switches when the high voltage channel output is within regulation. The output can be programmed as low as 0.6V, covering any core voltage in modern microprocessors.

The low voltage buck has a similar scheme as the high voltage buck of monitoring the current in the bottom NMOS to guarantee shorted output robustness. However, when the bottom NMOS current exceeds its limit, the oscillator frequency is not affected. The low voltage buck simply skips one cycle to avoid interference with the high voltage buck.

At light load the low voltage buck also operates in low ripple Burst Mode operation to minimize output ripple and power loss. Although the two channels in the LT3640 share a common oscillator, they may require different light load operation frequencies to optimize efficiencies at their respective loads. In this case, the oscillator always runs at the higher frequency, with the channel requiring the lower frequency skipping cycles. Figures 6 and 7 show the light load switching waveforms of two channels running at same reduced frequency and at different frequencies, respectively. Output ripple for both channels remains below $10mV_{P-P}$. No-load quiescent current from the input is only 300µA with both outputs in regulation.

BENEFITS OF CASCADING

As described above, there are clear advantages of cascading two switchers to generate I/O and core supplies. The higher operating frequency reduces circuit size

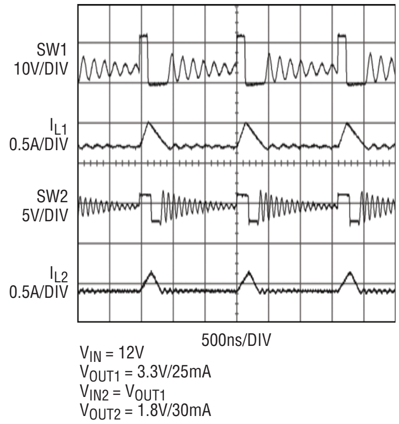


Figure 6. Two channels running in discontinuous mode at light load remain synchronized.

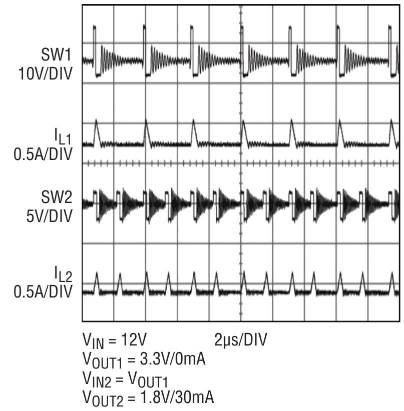


Figure 7. At still lighter loads, the two channels switch at different frequencies to maintain high efficiency and low output ripple.

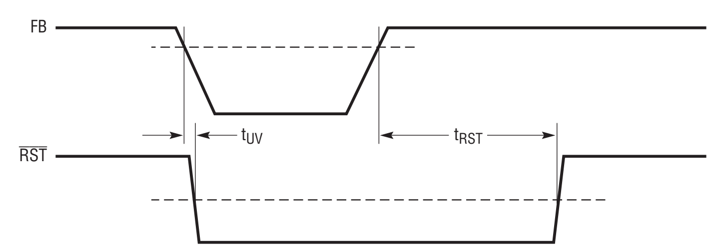
and provides faster transient response for better regulation. The low voltage technology used for the core supply switcher further reduces solution size.

Although the core supply is generated via two conversions, with two efficiency hits, keep in mind that the core supply is often low power, even if it is high current, so total power loss is minimal. Also, a buck converter generating the core voltage directly from the input does not typically operate in an efficient region anyway, and it would be larger and slower. Comparing the circuit in Figure 1 against two non-synchronous bucks operating from V_{IN}, the overall efficiency is nearly identical. If the core voltage is reduced from 1.8V to 1.2V, the LT3640 circuit is actually more efficient.

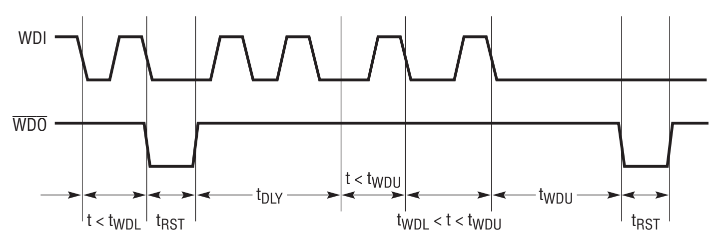
POWER-ON RESET AND WATCHDOG TIMER

In high reliability systems, a supervisor monitors the activity of the microprocessor. If the processor appears to stop, due to either hardware or software faults, the supervisor resets the microprocessor in an attempt to restore the system to a functional state. While some

Figure 8. Power-on reset and watchdog timing



a. Power-on reset timing



b. Watchdog timing

modern processors include internal supervisor functions, it is better practice to separate the two. Typical supervisor functions are voltage monitors with power-on resets to qualify supply voltages and watchdog timers to monitor software and hardware functions.

The LT3640 includes one power-on reset timer for each buck regulator and one common watchdog timer. Power-on reset and watchdog timers are both adjustable using external capacitors.

Once the high voltage buck output voltage reaches 90% of its regulation target, the high voltage channel reset timer is started and the $\overline{\text{RST1}}$ pin is released after the reset timeout period. The low voltage channel reset timer is started once the low voltage buck output voltage reaches 92% of its regulation voltage, and releases $\overline{\text{RST2}}$ after the reset timeout period.

The watchdog circuit monitors a microprocessor's activity. As soon as both $\overline{\text{RST1}}$ and $\overline{\text{RST2}}$ are released and an additional delay has expired, the watchdog starts monitoring the signal at the WDI pin. The LT3640 implements windowed watchdog function for higher reliability. If the falling edges on the WDI pin are grouped too close together or too far apart, the $\overline{\text{WDO}}$ pin is pulled down for a period the same as the power-on reset timeout period before the watchdog timer is started again. The timing diagrams of the power-on reset and watchdog timer are shown in Figure 8.

LOW NOISE DATA ACQUISITION SUPPLY

Figure 9 shows a 4-output supply that generates low noise 5V and 3.3V rails for analog circuits, along with 3.3V I/O and 1.5V core supplies for digital circuits. The high voltage channel of the LT3640 converts the input to a 5.7V intermediate bus, the low voltage channel bucks to the 1.5V core, and a few LDOs regulate the 5V and 3.3V outputs. The 5.7V bus voltage gives the 5V regulator suitable headroom for good PSSR and transient performance.

Diode D2 performs two functions. First, it lowers the intermediate voltage to a value below the 5.5V maximum operating voltage of the synchronous buck regulator. Second, it isolates high frequency ripple current flowing into the V_{IN2} and BST pins of the LT3640 from the inputs of the LDOs regulating the analog supplies, resulting in quiet analog rails.

Total current draw from the 5.7V rail is 820mA, so about 30% more power is available from this output. $\overline{\text{RST1}}$ and $\overline{\text{RST2}}$ indicate power is good when the 1.5V and 5.7V rails are in regulation. The watchdog function is not used here, and is disabled by tying $\overline{\text{WDE}}$ to V_{IN2}. The associated pins, not shown on this schematic, should be left floating.

CONCLUSION

The LT3640 is a dual channel buck regulator. The high voltage channel buck is capable of converting 16V input voltage to 3.3V output at 2MHz with comfortable margin. The high voltage buck maintains efficiency above 86% for delivering 5V from up to 24V input at 2MHz switching frequency. The low voltage channel buck input ranges from 2.5V to 5.5V. The LT3640 also includes power-on reset and watchdog timer to monitors a microprocessor's activity. The high frequency high efficient buck converters and the programmable timers make the LT3640 ideal for automotive applications. ■

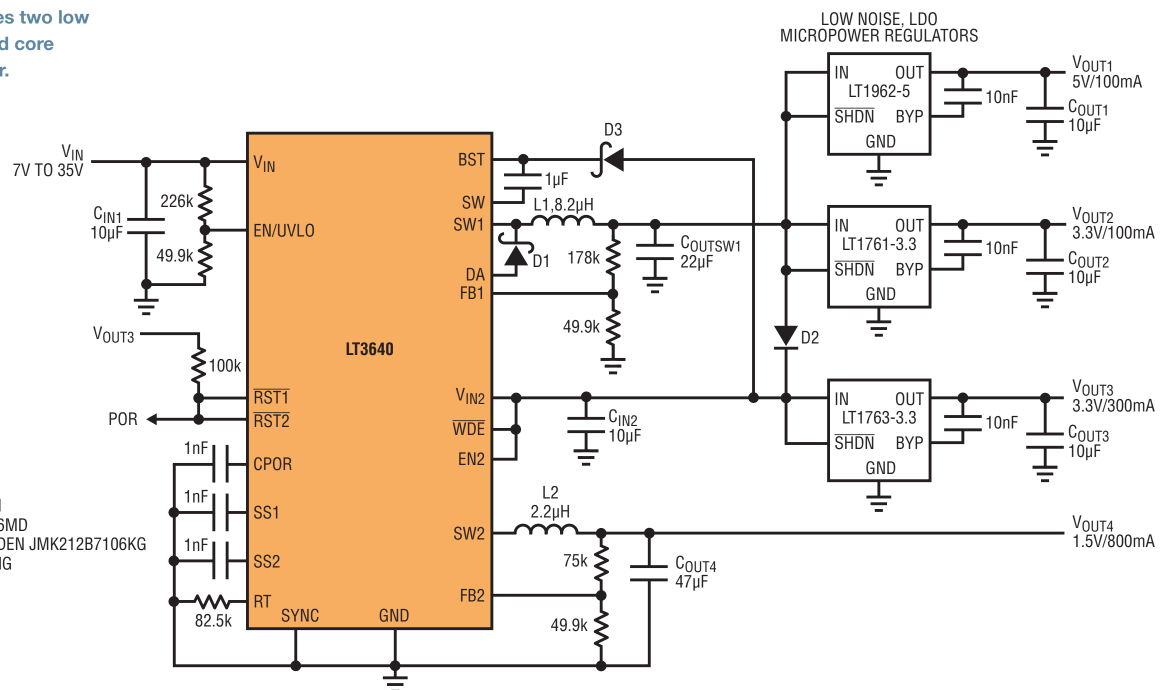


Figure 9. This circuit generates two low noise analog rails plus I/O and core supplies for a microprocessor.

C_{IN1}: TAIYO YUDEN UMK325BJ106MM
C_{OUTSW1}: TAIYO YUDEN JMK212BJ226MD
C_{IN2}, C_{OUT1}, C_{OUT2}, C_{OUT3} : TAIYO YUDEN JMK212B7106KG
C_{OUT4} : TAIYO YUDEN JMK212BJ476MG
L1: VISHAY IHLP2525CZER8R2
L2: VISHAY IHLP1616BZER2R2
D1: UPS140
D2: CMMR1-02
D3: PMEG4005