

2-Phase Controller Makes Small, Fast and Efficient Power Supplies with Output Tracking

by David Chen

Introduction

High efficiency, small size and fast transient response are often at odds in power supply designs. It is generally accepted that any one power supply design can achieve, at best, two of these at the expense of the third. This is no longer true. The LTC3708 2-phase PWM controller makes it possible to simultaneously achieve all three by offering a unique set of powerful features (summarized in Table 1).

The LTC3708 is a dual-output, synchronous step-down DC/DC controller. It uses a constant on-time, valley-current control architecture to regulate each output independently. The on-time of the first output channel is programmed by an external resistor so that the switching frequency is kept relatively constant over input voltage variation. An internal Phase Locked Loop (PLL) locks the frequency of the second output channel to that

of the first channel but with a 180° phase shift—this 2-phase operation reduces the input RMS current and electromagnetic noise.

“High efficiency, small size and fast transient response are often at odds in power supply designs... The LTC3708 2-phase PWM controller makes it possible to simultaneously achieve all three.”

Figure 1 shows the LTC3708 in a compact, high efficiency dual-output power supply that has very fast transient response.

So how does the LTC3708 simultaneously achieve high efficiency, fast response and compact size?

High efficiency results from the combination of several features, including the No R_{SENSE}^{TM} current sensing technique, the 2-phase operation mode, the onboard high current synchronous MOSFET drivers, and a pulse skipping function that reduces the switching and gate driving losses at light loads.

Fast transient response is a result of the current mode control method and the constant on-time architecture, which achieves a very narrow pulse width (minimum $t_{ON} < 85ns$) with no clock latency.

Compact solution size is made possible because of the LTC3708's high frequency capability, minimized input and output capacitance requirements, and high levels of circuit integration—the entire control and gate drive circuit is incorporated within a small 5mm x 5mm QFN package.

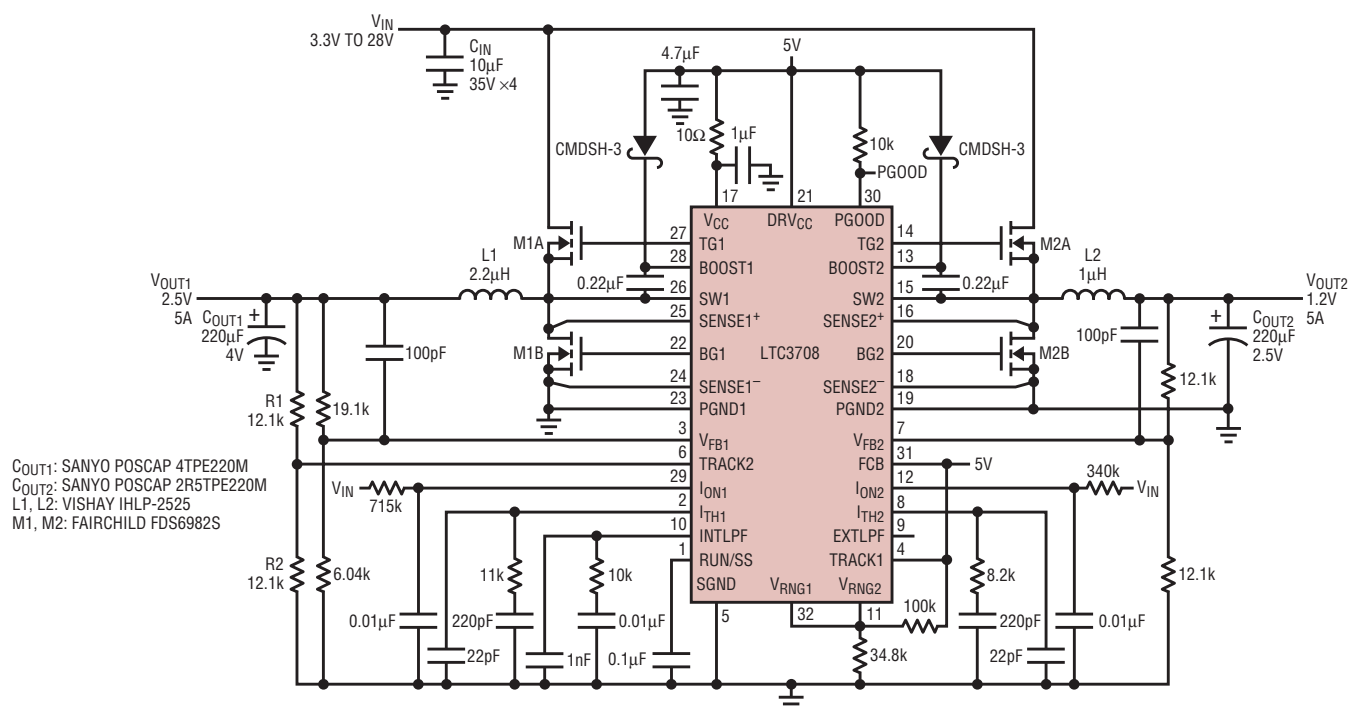


Figure 1. A compact, high efficiency dual-output power supply with fast transient response

Table 1. LTC3708 design features

Features	Functions	Benefits
Output Tracking	Various modes of tracking can be programmed: coincident, ratiometric, etc.	Simplifies the timing design of multiple supply systems
No R_{SENSE}	Output current is sensed through the bottom MOSFET	Improves the efficiency of low output applications ($V_{OUT} \leq 5V$)
2-Phase Operation	Two output channels operate at same frequency with a 180° phase shift	Reduces input RMS current and EMI noises; minimizes input capacitance
Constant On-Time Control Architecture	The top MOSFETs can be turned on immediately without clock latency	Expedites transient response and reduces output capacitance
Minimum $t_{ON} < 85ns$	This is the minimum duration that the top MOSFETs need to be on	Expedites transient response and enables high frequency designs
Frequency Synchronization	The switching frequency can be synchronized to an external clock	Maintains constant frequency operation and synchronizes all switching regulators on a system
Pulse Skipping at Light Loads	The switching period extends at light loads and reverse current is inhibited	Improves light load efficiency with minimum switching and gate driving loss

The LTC3708 also includes features such as output voltage tracking, a wide input voltage range, external frequency synchronization and a 100 μ s Power Good masking. Voltage tracking is accurate over the entire output range at both ramp-up and ramp-down transitions.

Constant On-Time Architecture

Modern digital devices (such as CPUs, FPGAs and DSPs) demand high switching frequencies to achieve fast transient responses. At the same time, the operating voltage of these digital devices continues to decrease. The combination of higher switching frequency and lower output voltage translates to narrower pulse width and a shorter on-time—a requirement that

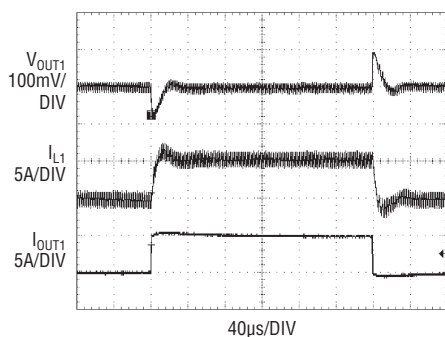
can preclude the use of many constant-frequency controllers where the minimum on-time is hundreds of nanoseconds. Additionally constant-frequency devices possess an inherent clock latency that further delays the power supply from responding to transient load increases.

The LTC3708, on the contrary, employs a constant on-time, valley-current control architecture, which greatly improves the transient response. Its minimum on-time is less than 85ns; a 15V-to-1.5V converter can be designed up to 1MHz without inadvertent pulse skipping. Furthermore, the LTC3708 reacts *immediately* to a load increase. It does not wait for the beginning of the next cycle to respond—there is no clock latency. Fig-

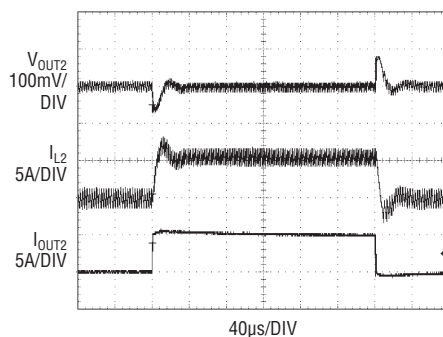
ure 2 shows the transient waveforms of the circuit shown in Figure 1.

External Frequency Synchronization

The constant on-time architecture improves transient response but results in a switching frequency that changes with variations on input voltage and/or output current. While the impact of V_{IN} variation is minimized in the LTC3708 (through its on-time programming), the impact of I_{OUT} variation is more difficult to remove. All parasitic resistance from input to output (battery resistance, MOSFET $R_{DS(ON)}$ and inductor DCR) contributes



a. Load step response of output channel 1



b. Load step response of output channel 2

Figure 2. Load step response of the circuit in Figure 1

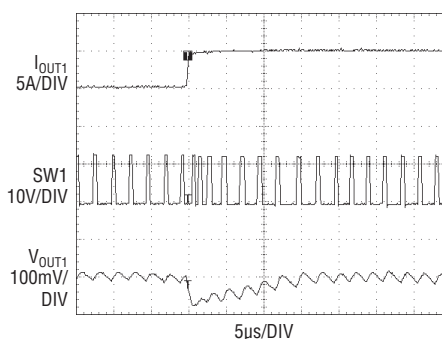


Figure 3. The LTC3708 is able to combine fast transient response with the advantages of constant frequency operation. The switching frequency momentarily increases to expedite the response to transients but returns to nominal at steady state.

to the frequency change, especially at low output voltages.

The LTC3708 offers external frequency synchronization to applications that demand a constant switching frequency. When an external clock signal is connected to the FCB pin, an internal PLL locks the rising edge of TG1 to that of the external clock and generates a fixed switching frequency immune to line and load variations. The PLL loop response time is designed to be much slower than the main PWM loop so that frequency synchronization does not interfere with transient response; in other words, the fast speed of constant on-time control is wholly preserved while the switching frequency is maintained constant at steady state. This combined advantage of constant on-time and constant frequency operations can be seen in Figure 3.

2-Phase Operation

When two outputs are derived from the same input source, a difference in the switching frequencies generates a beat frequency that is difficult to filter. To avoid this, the two output channels must have identical switching frequencies. Furthermore, if both output channels are switched on or off simultaneously, the input RMS current is maximized as each channel concurrently calls for current. A good power supply design aims to minimize input current, because higher input RMS current means larger input capacitors, more power loss along the input supply path (batteries, switches, connectors and protection circuits) as well as excessive radiated and conducted electromagnetic interference (EMI).

The LTC3708 eliminates the beat frequency and minimizes the input RMS current by interleaving the output channels. A second PLL synchronizes the switching frequencies of the two output channels, but maintains 180° phase difference between the rising edges of TG1 and TG2. This 2-phase operation minimizes input RMS current, thus reducing the solution size, increasing the overall efficiency and attenuating EMI. Figure 4 compares

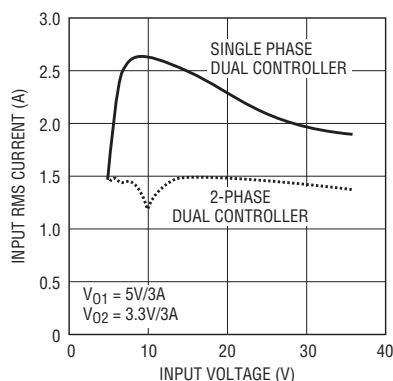


Figure 4. Comparison of the input RMS currents of single and 2-phase designs.

the input RMS current of a single-phase design to that of a 2-phase implementation. The reduction of input RMS current is more than 40% when both converters have an input range from 5V to 36V.

No R_{SENSE} Current Sensing

Current mode control simplifies the compensation design of switching power supplies but usually, adds the cost of an extra current sensing device (most commonly, a sense resistor of several milli-ohms). Low voltage supplies, however, cannot afford the voltage drop across the sense resistor. A 100mV sense voltage, for example, results in about a 10% efficiency loss for a 1V supply.

The LTC3708 solves the above problem by sensing the voltage drop across the synchronous MOSFET. Without a dedicated sense resistor, efficiency is improved, cost is reduced, and overall size is minimized. To accommodate $R_{DS(ON)}$ variation of different power MOSFETs, the LTC3708 allows the user to program the sense voltage range from 50mV to 200mV by applying a DC voltage on the V_{RNG} pin. Since each output channel has its own V_{RNG} pin, different MOSFETs can be used. For applications that require more accurate current sensing and can tolerate the efficiency loss, the LTC3708 still allows the use of a sense resistor between the synchronous MOSFET and the power ground. Figure 5 shows the efficiency of the circuit shown in Figure 1.

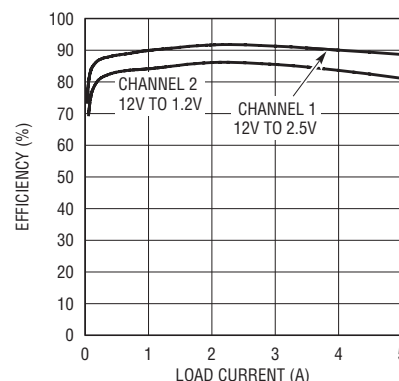


Figure 5. Efficiency of the circuit in Figure 1

Output Tracking

When a digital device is powered from multiple supplies (for example, one for core and another for I/O), voltage tracking between different supplies is often required. Failing to do so can cause circuit malfunction, supply hang-up or even permanent damage to the device.

The TRACK2 pin of the LTC3708 acts as a clamp on the reference voltage and allows the user to program different modes of output tracking. Channel 1 is by default the master channel and is set with a higher output voltage. Channel 2, as a lower-output slave, tracks the first output in a fashion programmed by the resistive divider

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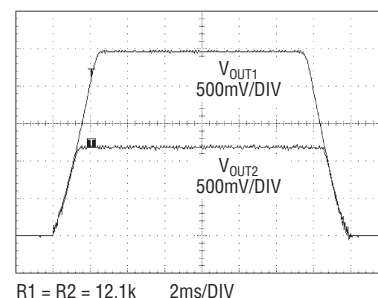


Figure 6a. Coincident tracking

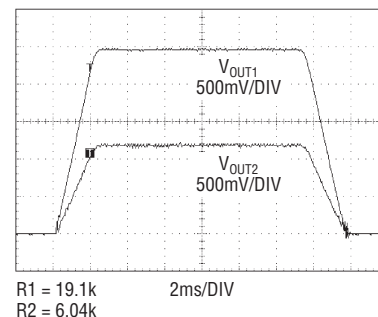


Figure 6b. Ratiometric tracking

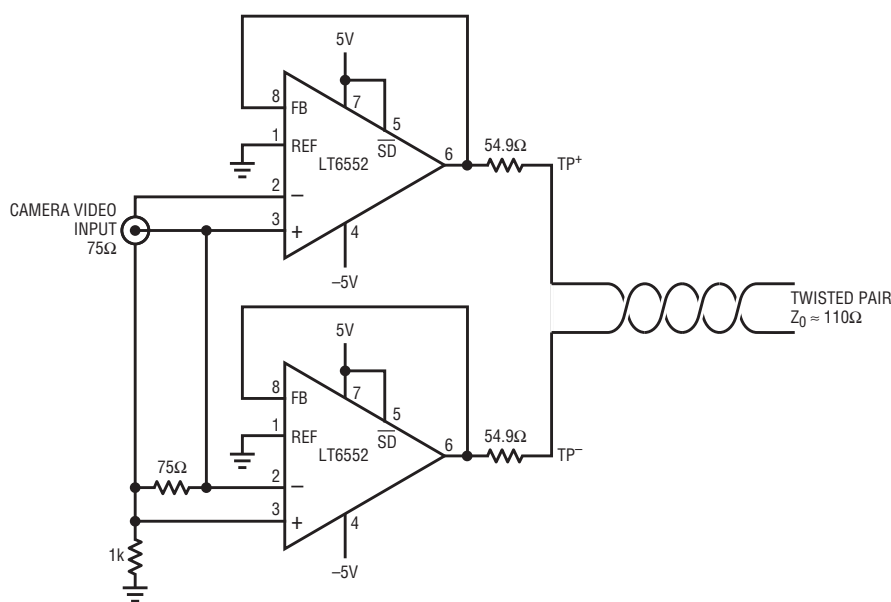


Figure 3. Super-simple coax to twisted-pair adapter

10kΩ resistors so that appropriate circuit bias is assured during input disconnections. For extra ESD robustness, back-biased Schottky diodes may be tied to each I/O connection as shown in Figure 4.

Twisted-Pair Video Adapter/Line-Driver

Figure 3 shows a pair of LT6552s connected as inverting and non-inverting unity-gain stages to form a balanced gain-of-two differential amplifier. The input cable is differentially terminated with 75Ω (as for camera video on coax), and the outputs are each back-terminated in half the characteristic

impedance to form the twisted-pair line driver. The circuit accepts 1V_{P-P} single-ended input and delivers 1V_{P-P} differentially to a 110Ω load.

Since the LT6552 inputs are fully differential, the coax shield could be left ungrounded, thereby eliminating ground-loop induced noise. The input cable shield is actually grounded through a relatively high impedance (1kΩ), which provides appropriate circuit bias during input disconnections but still prevents ground-loop noise.

As with the previous circuit, the exceptional CMRR of the LT6552 eliminates any stray pickup that the floating shield might have. The large

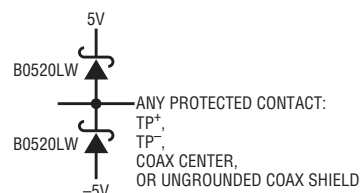


Figure 4. Optional method for enhanced ESD protection

differential common-mode range also permits significant ground-potential differences between the video source and the twisted-pair driver circuit, as is the case in many industrial settings. Here again, each I/O connection may be ruggedized as indicated in Figure 4.

Twisted-Pair Video Repeater

The circuits shown in Figures 1 and 3 could easily be coupled together at the coax connections to form a loss equalized repeater stage. This configuration offers additional 1000ft reach increments to a twisted pair run.

Conclusion

The LT6552's exceptional CMRR makes it possible to transmit high-speed analog signals, like CCTV, over ubiquitous twisted pair cabling. In fact, a twisted-pair video transmission system is remarkably inexpensive, and easy to implement, using LT6552 building blocks and a minimal number of small external passive components.



LTC3708, continued from page 26

connected to the TRACK2 pin. If the ratio of the divider is selected to be same as that on VFB2, coincident tracking is enabled (Figure 6a). If the ratio of the TRACK2 resistor divider is same as VFB1, ratiometric tracking is realized (Figure 6b). In both cases, Channel 2's output voltage and its ramp rate are solely controlled by Channel 1; Channel 2 tracks Channel 1 over its entire output range at both ramp-up and ramp-down transitions.

Similar to TRACK2, the TRACK1 pin offers output tracking between multiple supplies or additional

LTC3708's. When a voltage ramp is present at TRACK1, Channel 1 tracks it either coincidently or ratiometrically and Channel 2 follows Channel 1 accordingly.

Conclusion

The LTC3708 makes it possible to design power supplies with high efficiency, fast transient response and a compact solution size. It possesses the fast speed of constant on-time control and the fixed steady-state frequency of constant frequency control—two features that were, until now, mutu-

ally exclusive. System level timing design is further simplified by the integrated voltage tracking function, which ensures accurate tracking at both ramp-up and ramp-down transitions.

Protection features of the LTC3708 include cycle-by-cycle current limit, over-voltage crowbar, a short-circuit timer and a Power Good indicator with 100μs de-glitch masking. These and other characteristics of the LTC3708 make it well suited for high performance power management applications. 