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FAN23SV04T High-Efficiency Tracking Regulator Provides V_{DDQ} Tracking V_{TT} Supply or Programmable Tracking Ratio

Overview

Fairchild developed the FAN23SV04T switching regulator to simplify the design of DDR4 memory V_{TT} termination power supplies for multi-DIMM applications that require the capability to source and sink several amps of current at low voltages. The FAN23SV04T accepts V_{DDQ} as an input and utilizes an internal 50% resistive voltage divider to provide an accurate reference voltage for the V_{TT} power supply. The IC operates with an input voltage range from 7 V to 15 V in a highly efficient synchronous buck topology, utilizing a constant on time control technique. The tracking functionality can also be combined with an external resistor divider to produce an output voltage that tracks the voltage applied to the VDDQ reference input with a programmable proportionality factor.

Memory Applications

Migration from DDR3 to DDR4 in new computing systems offers significant gains in available memory and access speed, while reducing operational power requirements. DDR4 offers a range of innovative features designed to enable high-speed operation and broad applicability in applications including servers, laptops, desktop PCs, and consumer products.

The JEDEC Solid-State Technology Association published the DDR4 SDRAM specification, JESD79-4, in September 2012. The following list provides a summary of features as memory technology migrates from DDR3 to DDR4:

- Reduction of core voltage from 1.5 V to 1.2 V
- Reduction in references from two to one
- Future lower voltage operation to 1.05 V
- Increased memory densities, up to 16 Gb (DDR4) from 8 Gb (DDR3)
- Data rate range from 800-2133 Mb/s (DDR3) to 1600-3200 Mb/s (DDR4)

The DDR4 architecture is designed to operate with up to 8 stacked memory devices during the lifetime of the technology, presenting a single high-current load that can be supplied from a high-efficiency switching regulator. The simplified system application diagram shown in Figure 1 indicates the V_{DDQ} and V_{TT} supplies are both powered from the 12 V supply rail. The 1.2 V V_{DDQ} output is directly connected to the VDDQ input of the FAN23SV04T to serve as the reference input for the V_{TT} termination supply rail.

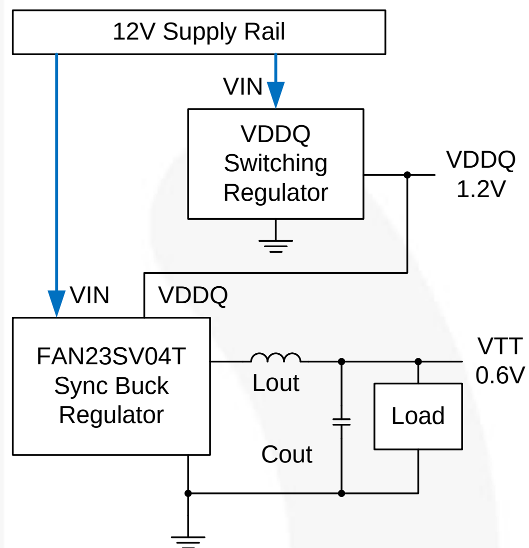

Figure 1. Typical DDR4 Memory Application

The FAN23SV04T supports the DDR4 initial V_{TT} voltage level of 0.6 V and is capable of supporting future requirements down to 0.5 V.

DDR4 Memory Application Requires Tracking Power Supplies

Tracking power supplies are used in applications where one supply rail must remain a fixed percentage of another supply rail during power-up, steady-state, and power-down operation. Tracking performance is especially critical when powering memory systems that require that V_{TT} termination supply remain at half of the V_{DDQ} supply voltage.

Default V_{TT} Tracking Application with 50% Voltage Ratio

Figure 2 illustrates default tracking method as the FAN23SV04T accepts the input from the memory V_{DDQ} power supply at the VDDQ pin. This voltage is divided by two using an internal resistive divider to provide the reference voltage used by the feedback comparator. The internal divider provides an extremely accurate 50% ratio due to the use of matched resistors inside the control IC, eliminating the need for two external tight-tolerance resistors otherwise required to accomplish the same task.

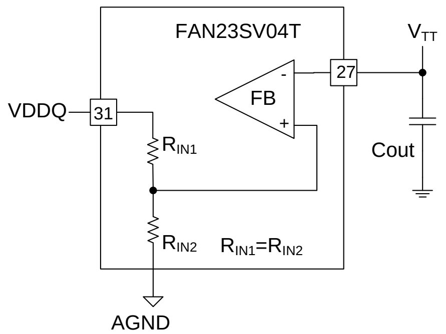

Figure 2. V_{TT} Tracking V_{DDQ} with 50% Ratio

Tracking Operation during Power-Up and Power-Down Operation

Figure 3 illustrates tracking operation when the VDDQ input is driven with an external signal generator with rise and fall times of 1.2 ms. The V_{TT} supply tracks the V_{DDQ} signal during rise, fall, and steady-state operation with an accurate 50% ratio.

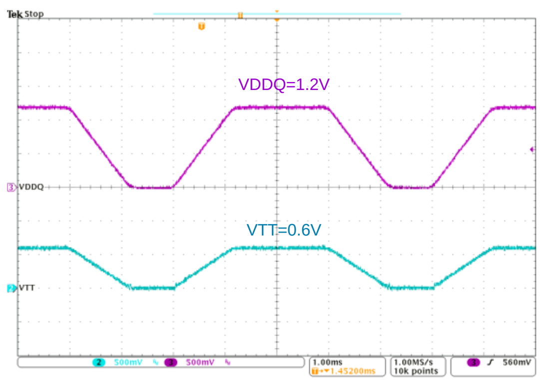

Figure 3. V_{TT} Tracks V_{DDQ} during Startup, Steady-State, and Shutdown

Tracking Operation Requires Output Current Sink and Source

A tracking converter must be able to source and sink current for the output voltage to follow the reference input at VDDQ. In Figure 4, the direction of current flow for the source and sink modes of operation is indicated between VOUT and the load. The source / sink operation is described in the next section; following this, the source-only mode is described to highlight differences between the two modes.

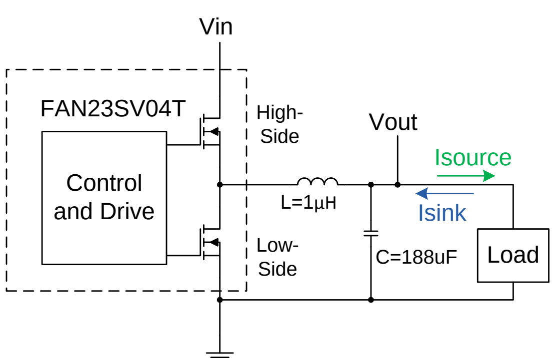

Figure 4. Evaluation Board Power Stage Illustrating Source and Sink Current Flow

Current Source/Sink Operation

The FAN23SV04T synchronous buck regulator is programmed to operate in Forced PWM Mode. In this mode, the high-side MOSFET and low-side MOSFET alternately conduct during each switching cycle in steady-state operation. This forces the power converter to operate in continuous inductor current conduction mode under all conditions, including no load.

Figure 5 illustrates the inductor current waveforms of a source-sink tracking regulator under three different load currents of 4 A, 0 A, and -4 A. In the top trace, the inductor current is centered on 4 A as the converter sources 4 A to the load. In the middle trace, I_{load}=0 A and the inductor is centered around the 0 A level as there is no average source or sink current. In the bottom trace, the load current is centered on -4 A as the converter sinks 4 A from the load. In this instance, energy is being transferred from the load to the input supply of the buck regulator. In all three cases, the high-side MOSFET is ON and the low-side MOSFET is OFF during the interval in which the inductor current rises. In the interval in which the inductor current falls, the high-side MOSFET is OFF and the low-side MOSFET is ON.

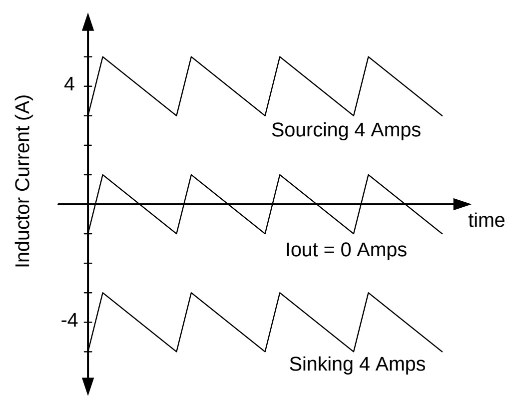

Figure 5. Inductor Current; Source and Sink Operation

Figure 6 illustrates a specific example of current sinking operation using the FAN23SV04T evaluation board. The top trace shows I_{OUT} changing from positive 1 A to negative 1 A in approximately 400 µs, with the resultant transient excursion of 15 mV on the center trace V_{OUT}, representing 2.5% of V_{OUT}=0.6 V.

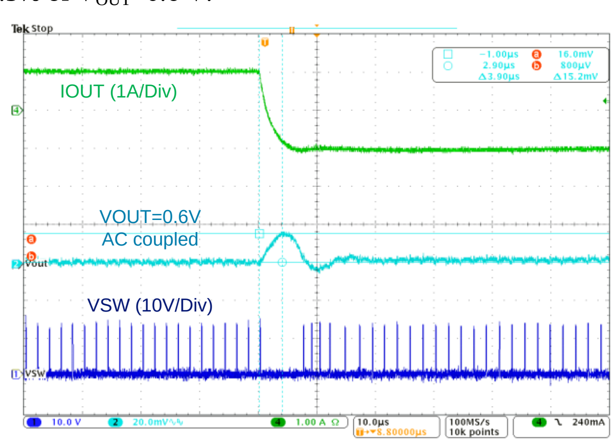

Figure 6. Evaluation Board Sinking Current

Current Source-Only Operation

In contrast to tracking buck regulators, in many DC-DC converter applications, the load only sinks current from the regulator, which operates in source-only mode. Figure 7 illustrates the inductor current of a source-only converter operating under two different operating conditions, with load current of 4 A and 0 A. In the top trace, the inductor current is centered on the load current of 4 A and current flows in the inductor during the complete switching cycle. This operation is the same as in the source/sink example shown in Figure 5.

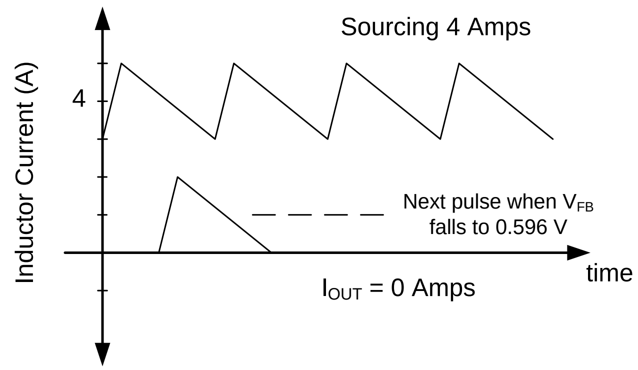

Figure 7. Inductor Current with Source-Only Operation

Operation is significantly different when the load is very small, as indicated in the bottom trace with load current near 0 A. In source-only mode; as the load current falls below one-half of the peak to peak inductor current, the current would normally try to reverse and flow through the low-side MOSFET from drain to source. However, the voltage across the low-side MOSFET is sensed by zero-current-detect comparator inside the FAN23SV04T controller and the low-side MOSFET is turned off when the current reaches zero. This forces the circuit to enter the Discontinuous Conduction Mode (DCM) of operation, in which the repetition frequency of the power pulses is proportional to the load current. This is referred to Pulse Frequency Modulation (PFM) mode of operation. There are no further pulses until the voltage on the feedback pin falls to the trimmed feedback pin voltage of 0.596 V.

Efficiency of V_{TT} Solutions

Linear Regulator V_{TT} Solutions

Historically, it has been common to supply power for the V_{TT} memory termination rail using a linear regulator supplied from the V_{DDQ} rail. With the V_{TT} voltage equal to one-half of V_{DDQ}, the linear supply exhibits an efficiency that is fixed at 50% and the power dissipated by the V_{TT} regulator into the system environment is equal to the power delivered to the load. In addition, the V_{DDQ} voltage is frequently supplied from an upstream converter with typical efficiency of approximately 85-90%, so the cascaded effect of the double conversion for the V_{TT} power rail places the effective efficiency in the vicinity of 45%.

As the current requirements for DDR4 memory increase with several banks of memory, the low efficiency contributes to significant power loss, which is primarily dissipated into the system board. Using linear regulators in this manner provides no viable path for increased efficiency.

Switching Regulators Offer Higher Efficiency Alternatives

For high-capacity memory systems requiring several amperes of termination supply current, a buck switcher solution can increase power conversion efficiency significantly when compared to the linear regulator. In addition, the FAN23SV04T buck regulator can produce V_{TT} from a 12 V supply rail instead of using a linear regulator operating from the V_{DDQ} rail, eliminating the two-stage power conversion for the V_{TT} rail. These two factors combine to deliver a significant reduction in the amount of power that must be dissipated in the system board.

For a specific example, the FAN23SV04T solution operates from a 12 V supply rail to produce an output voltage of 0.6 V, as specified in the initial DDR4 specification. As shown in Figure 8, the solution provides complete power conversion efficiency that exceeds 80% with load current between 2 A to 4 A, as shown in Figure 8, and exceeds 70% for current above 1 A. The phrase "complete power conversion efficiency" is used because the FAN23SV04T includes an internal bias regulator that supplies power for IC operation and MOSFET gate drive, and the bias power is included in the efficiency measurement and calculations.

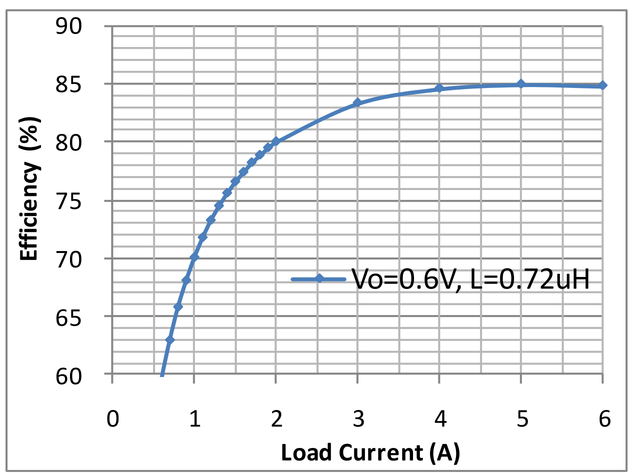

Figure 8. Efficiency of Switching V_{TT} Regulator using FAN23SV04T Evaluation Board

Tracking Application with Voltage Ratio ≠ 50%

The FAN23SV04T can also support applications that require a voltage rail that tracks another voltage rail with a ratio different from the default 50% ratio. In this case, V_{OUT1} is the voltage to be tracked and is applied to the VDDQ pin, which can be a general reference input for tracking. In this case, an external resistor divider is installed from the tracking voltage V_{OUT2} to the FB pin, as shown in Figure 9.

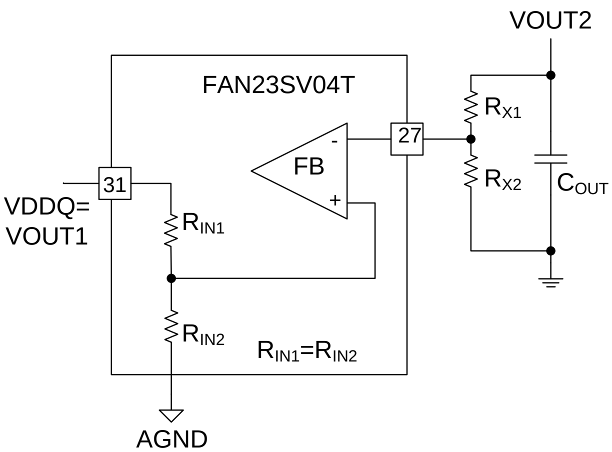

Figure 9. Schematic for V_{OUT2} Tracking V_{OUT1}, 66% Ratio

To find the relationship of V_{OUT2} to the V_{OUT1}=VDDQ pin, the inputs of the feedback comparator can be set equal to each other, as shown in Equation (1):

$$\frac{RX2 * (V_{OUT2})}{RX1 + RX2} = \frac{V_{OUT1}}{2} \tag{1}$$

This can be solved for ratio of RX1/RX2 for desired V_{OUT1} and V_{OUT2}, as shown in Equation (2):

$$\frac{RX1}{RX2} = \frac{2V_{OUT2}}{V_{DDQ}} - 1 \tag{2}$$

This can be solved to find RX1 in Equation (3):

$$RX1 = RX2 \times \left(\frac{(2 \times V_{OUT2})}{V_{DDQ}} - 1\right) \tag{3}$$

Consider an example with a rail V_{OUT1}=1.8 V and requires an additional voltage V_{OUT2}=1.2 V that tracks V_{OUT1} during startup, steady-state, and shutdown. Using Equation (3), with RX2 set to 10 kΩ, RX1 is calculated by:

$$RX1 = 30k\Omega \times \left(\frac{(2 \times 1.2V)}{1.8V} - 1\right) = 10k\Omega \tag{4}$$

Figure 10 shows startup operation where V_{OUT2} tracks V_{OUT1} with the programmed 66% ratio (1.2 V / 1.8 V) during startup and steady state, and Figure 11 shows operation during shutdown.

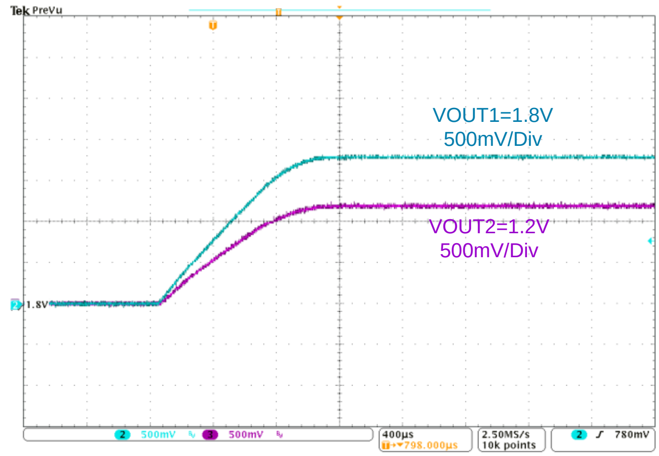

Figure 10. V_{OUT2} Tracks V_{OUT1} during Startup

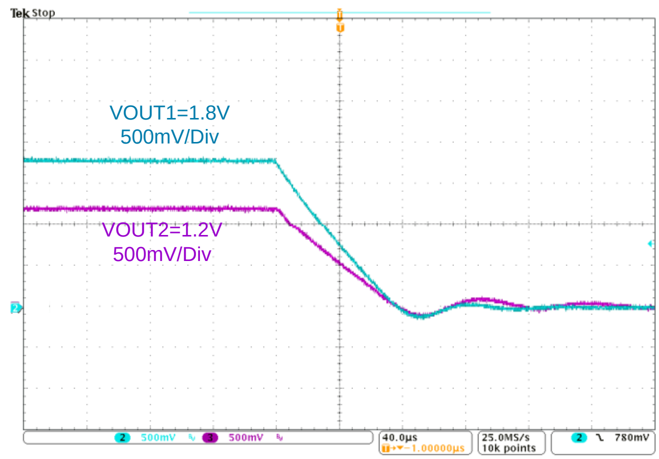

Figure 11. V_{OUT2} Tracks V_{OUT1} during Shutdown

Summary

The FAN23SV04T provides a simple solution for V_{TT} power supplies that contain multiple DIMMS and require several amps of source/sink current capability. The output of the V_{DDQ} supply is directly connected to the VDDQ input and the internal divider programs the desired 50% tracking ratio. In typical applications, the FAN23SV04T operates from a 12 V rail with an efficiency that is higher than that achievable with conventional linear regulators to reduce heat dissipated into the system board.

References

FAN23SV04T — TinyBuck™ 4 A Integrated Synchronous Buck Regulator for DDR Termination

JESD79-4 Standard — JEDEC Solid-State Technology Association