Ultra-low I_Q COT Controlled Synchronous Buck Converter

Abstract

With the proliferation of portable, wearable and IOT devices, the demand for ultra-low energy consumption in idle mode is a major requirement to prolong battery life and reduce maintenance cost. For these applications, systems spend most of the time in standby or idle mode. Minimizing quiescent current (I_Q) is a key factor in reducing power consumption and managing battery life for many applications. Low quiescent current means higher efficiency at ultra-light load, which results in longer battery life. Ways to achieve low-I_Q technologies without compromising system performance based on M3TEK's proprietary COT control architecture are discussed. Methods to measure light load efficiency for ultra-low I_Q system are also explained for M3TEK MT8351 family ultra-low I_Q devices.

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Introduction

The world is becoming battery powered than ever. With the proliferation of portable, wearable and IOT devices, a new class of applications is emerging. The main power source for these applications is either battery or harvested energy from the environment, and most of system's operating life is spent in idle or standby mode. To prolong the battery life and reduce maintenance cost, the system must work with very low energy consumption during idle mode. At the same time, power management systems need to respond to fast load change and provide tightly regulated voltage rail for sensitive circuit like sensors and wireless communication devices.

To achieve these goals, low I_Q is an important design target of DC-DC converters, which can improve the standby time of the device and energy saving. Therefore, I_Q in standby or sleep mode is a limited factor for battery life or other devices. DC-DC devices need to adopt efficient power conversion technology, optimized control architecture and rationalize power management module to achieve low I_Q.

Low I_Q Design Optimization

For a DC-DC converter, I_Q is different from input current in no load and is sometimes misunderstood by engineers. I_Q is defined as the current drawn by the DC-DC converter under no load and non-switching mode with device enabled and output voltage in regulation. "No load" indicates no current flows into output. "Non-switching" means both high-side and low-side power switches are turned off. I_Q usually comes from VIN, VOUT or some other pins which defined in datasheet specification for an IC.

Buck converter draws I_Q only from VIN as specified in a buck converter MT8123 datasheet from M3TEK. For boost or buck-boost converter, I_Q is drawn from VIN and VOUT such as specified for boost converter MT5070 from M3TEK.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Quiescent Current I_Q	V_{FB} = 0.63V, Float OUT and SS pins		18	22	µA

Table1: The specification I_Q of buck converter comes from MT8123 datasheet.

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_Q	Quiescent current	V_{IN}	V_{EN}=V_{IN}=1.2V, V_{OUT}=3.3V		2		µA
		V_{OUT}			10		µA

Table2: The specification I_Q of boost converter comes from MT5070 datasheet.

For a DC-DC converter, all key performance specifications must be met: transient response, noise, output voltage accuracy and efficiency. Now it is also desired to reduce I_Q by several orders of magnitude. To achieve low I_Q while balance the conflicting requirements, DC-DC chips need to adopt a series of techniques and design methods.

PARAMETER	SYMBOL	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Quiescent Current	I_Q	V_{IN} = 3.6V VOS=1.8V, Switching and No-switching			350		nA
		100% Duty-Cycle Mode			500		nA
Shutdown Current	I_{SHDN}	V_{EN} = 0V, V_{IN} = 5.5V			0.1	0.15	μA
VOUT accuracy	$V_{OS\_Accuracy}$			-1		+1	%
VOUT PIN leakage Current I_{OUT}	V_{OS_Leak}	VEN=5V, VSET=10K, VOUT=5V	MT8351ADER MT8351DDER		10		nA
			MT8351QDER		60		
EN Internal Pull Down Current	I_{EN}				15		nA

Table3: The specification of low I_Q device comes from MT8351 datasheet.

The MT8351 is a 1.5MHz, constant on-time (COT) controlled synchronous step-down converter with super-low I_Q of 350nA. It can provide 1A output current with input voltage from 2.0V to 5.5V. The MT8351 family offers a wide range of output voltage from 0.4V to 3.6V with an external selection resistor. The constant on-time control scheme simplifies loop compensation and offers excellent load transient response. MT8351 consumes extremely low quiescent current hence achieves superior light load efficiency. The high gain error amplifier in the control loop provides excellent load and line regulation.

When the input voltage drops to near or below the desired output voltage level, MT8351 will enter 100% duty cycle operation where the HS is kept on continuously to supply the output. In this mode, the MT8351 still can achieve ultra-low I_Q of 500nA under no load. MT8351 has cycle-by-cycle current limit and hiccup mode to protect over-load or short circuit fault conditions.

MT8351 is available in small 6-pin DFN2x2mm package.

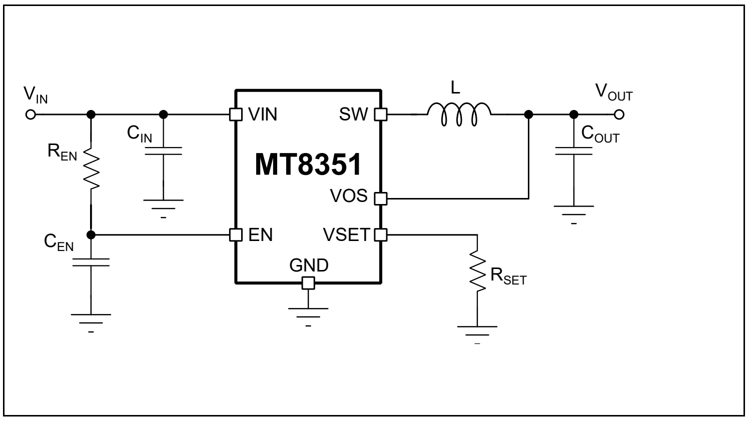

Figure1: MT8351 application circuit

The I_Q does vary tiny changes over input voltage and temperature as showed in figure2.

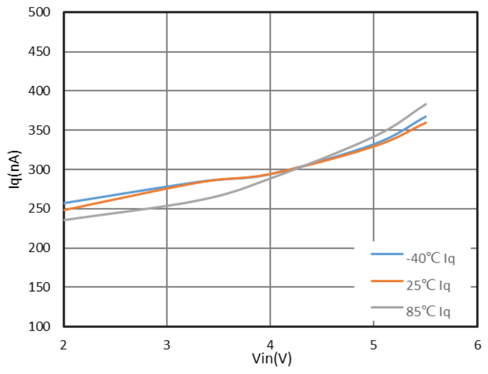

Figure2: Quiescent current vs. VIN and Temp. for MT8351

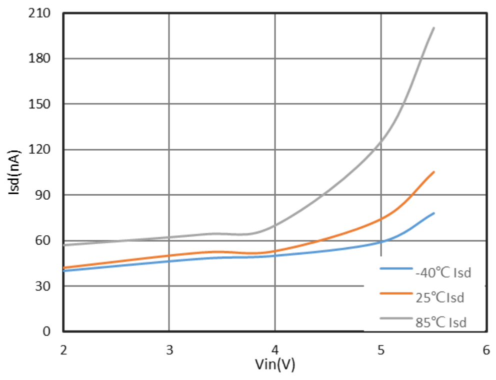

Figure3: Shutdown current vs. VIN and Temp. for MT8351

To achieve these performances, several design techniques are used in MT8351:

1. **COT Control Architecture and Transient Response**

Power converters need to respond to fast input voltage or load change while keeping output voltage regulated. For low I_Q devices, the bias current for analog circuits inside the IC must be reduced, which will affect the response time. MT8351 adopts constant on-time (COT) controlled architecture with dynamic bias current control that achieves superior light load efficiency and excellent load transient response as shown in figure4.

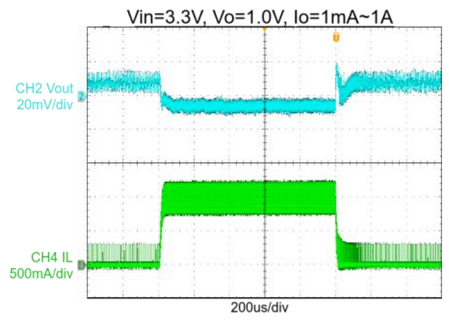

Figure4: Load transient response for MT8351

MT8351 is internally compensated with COT (constant on-time) control. The control circuit turns on HS immediately when FB drops below reference without the need for error amplifier to ramp the compensation voltage. The HS is turned on for a pre-determined period (on-time) of time to ramp up the inductor current, and then the LS will be turned on to ramp down the inductor current. The cycle repeats itself if FB drops below reference again.

Due to its immediate response on FB voltage droop and simplified loop compensation, constant on-time offers a superior transient response compared to competitor COT Ton timer.

2. R2D Conversion

When the load is only uA level, the current consumption of the feedback divider can take a significant portion of the total current consumption. To overcome this, MT8351 integrated feedback network inside and use one resistor to set the output voltage during start-up. This together with other design improvements leads to the extremely low I_Q of only 350nA.

After the device is enabled, an R2D (resistor-to-digital) conversion is started to detect the external resistor RSET value. An internal current source applies current through the external resistor and an internal ADC reads back the resulting voltage level and converts it to corresponding digital code. Then this digital code is stored to select the correct output voltage and the R2D conversion circuit is turned off.

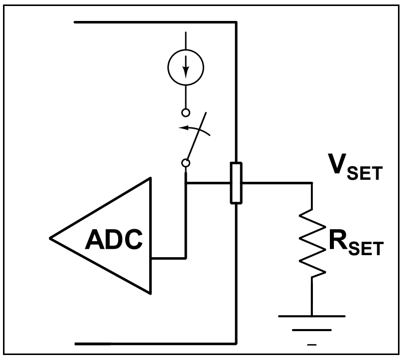

Figure5: R2D Interface

The start-up delay time(t_{Delay})，varies depending on the selected VSET value. The start-up delay is shortest with VSET=0 and longest with VSET=16 as shown in figure6 and figure7.

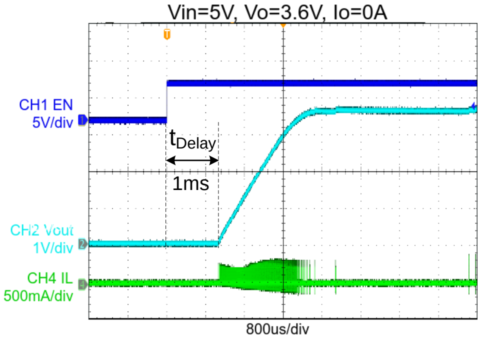

Figure6: Start-up delay 1ms with VSET=0 for MT8351QDER

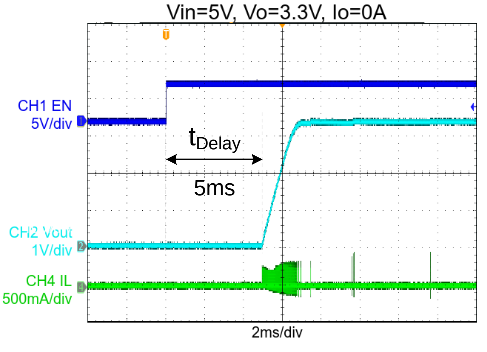

Figure7: Start-up delay 5ms with VSET=16 for MT8351QDER

For a proper R2D conversion, ensure that there is no additional current path or capacitance greater than 30 pF total from VSET pin to GND during R2D conversion. Otherwise, the conversion will result in incorrect code and a wrong output voltage will be selected.

The table4 below lists the correct resistor values for RSET to set the appropriate output voltages for MT8351. The R2D converter is designed to operate with resistor values in the table4 and requires 1% accuracy.

VSET	Output Voltage Setting [V]			R_{SET} [Ω]
	MT8351ADER	MT8351DDER	MT8351QDER	
1	0.4	0.8	1.8	10k
2	0.425	0.85	1.9	12.1k
3	0.45	0.9	2.0	15.4k
4	0.475	0.95	2.1	18.7k
5	0.5	1.0	2.2	23.7k
6	0.525	1.05	2.3	28.7k
7	0.55	1.1	2.4	36.5k
8	0.575	1.15	2.5	44.2k
9	0.6	1.2	2.6	56.2k
10	0.625	1.25	2.7	68.1k
11	0.65	1.3	2.8	86.6k
12	0.675	1.35	2.9	105.0k
13	0.7	1.4	3.0	133k
14	0.725	1.45	3.1	162k
15	0.75	1.5	3.2	205k
16	0.775	1.55	3.3	249k
17	0.8	1.6	3.4	VIN
0	1.0	1.8	3.6	GND

Table4: R2D output voltage setting for MT8351 family series

3. Small 6-pin Package

With internal compensation, integrated high performance power devices and single resistor to program output voltage, MT8351 is available in small 6-pin DFN2x2mm package as below figure8. It only needs several external passive components to realize a high efficiency, fast and robust power conversion solution for applications need ultra-low I_Q and tightly regulated output voltage.

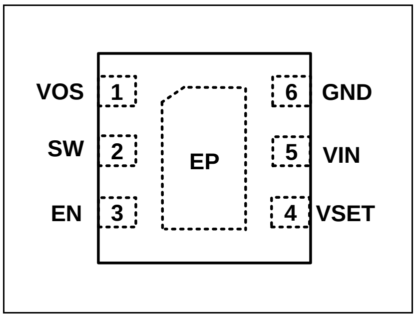

Figure 8: MT8351 package

Accurate Efficiency Measurements for Low I_Q Device

As the quiescent current drops to sub uA range for ultra-low I_Q DC-DC converter, care must be taken when measuring the efficiency. External components or measurement instruments could affect the accuracy of the measuring results.

It is important that the voltage meter and current meter are connected at the proper locations. For example, the setup shown in figure9 can be used to perform efficiency measurements in light load operating. The current flows into input voltmeter should be subtracted from the input current, while the total output current sums with output voltmeter leakage current and load current. Figure10 shows the efficiency measurement data of MT8351, the efficiency is about 85.5% at 5Vin/3.3Vo of 10uA light load, and up to 95% over the entire range load current.

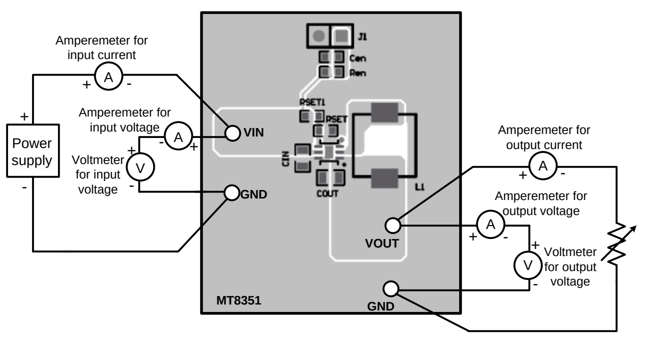

Figure9: Efficiency measurement method for low I_Q of MT8351

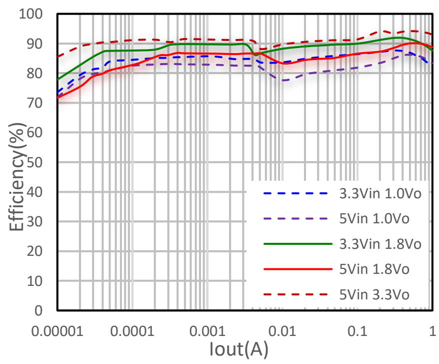

Figure10: Efficiency measurement data for low I_Q of MT8351

Conclusion

With advances in battery, energy harvest, low power SOC, low power wireless communication and sensor technologies, always on battery power devices are proliferating into our homes, office buildings and factories. They promise us a safer, more comfortable and energy efficient working and living environment. Low I_Q is becoming an important requirement in these systems. With low I_Q power management solution, system can realize lower maintenance cost, extended the life of the equipment, and improved user experience. M3TEK MT8351 is an ultra-low I_Q DC-DC device which can achieve superior light load efficiency and other advantages such as below:

- Super-low I_Q of 350nA -- Up to 95% efficiency over the whole range load current.
- 100% duty operation with less than 500nA I_Q.
- Fast COT control and internal compensated high gain error amplifier -- Excellent load transient response and load/line regulation.
- R2D -- 18 selectable output voltage from 0.4V to 3.6V with single resistor.
- Package -- Small DFN2x2mm_6L.

References

1. "MT8351 synchronous step-down converter with super-low I_Q of 350nA" M3TEK Datasheet.

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