High Performance, Single Synchronous Step-Down Controller for Notebook Power Supply

General Description

The uP1537 is a high-efficiency, single synchronous buck controller suitable for low output voltage point-of-load applications in notebook computers and similar digital consumer applications. The proprietary RCOT™ technology provides fast transient response and high noise immunity. It supports ceramic output capacitors. An advantage of this control scheme is that it does not require an external phase compensation network, helping the designer with ease-of-use and realizing low external component count configuration. This combination is ideal for building modern low duty ratio, ultra-fast load step response DC-DC converters. The output voltage ranges from 0.7 V to 2.6V, and the conversion input voltage range is from 3 V to 26V. The switching frequency is selectable from four preset values using a resistor connected from the RF pin to ground. RCOT™ control tracks the preset switching frequency over a wide range of input and output voltages, while it increases the switching frequency at step-up of load.

The RF pin also serves in selecting between auto-skip mode and forced continuous conduction mode for light load conditions. The strong gate drivers of the uP1537 allow low $R_{DS(ON)}$ FETs for high current applications.

Applications

- **Notebook Computers**
- **I/O Supplies**
- **System Power Supplies**

Features

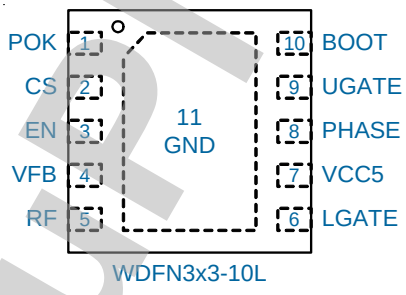
- **Wide Input Voltage Range 3V ~ 26V**
- **Output Voltage Range 0.7V ~ 2.6V**
- **Build-in 1% 0.7V Reference**
- **RCOT™ (Robust Constant On-Time) Control Architecture**
- **4 Selectable Frequency Setting**
- **4700ppm/°C $R_{DS(ON)}$ Currrent Sensing**
- **Internal 1ms Soft-start**
- **Pre-charged Start-up Capability**
- **Built-in Output Discharge**
- **Power OK Indication**
- **Over Voltage, Under Voltage, and Over Temperature Protection**
- **WDFN3x3-10L and WQFN2x2-12L package**
- **RoHS Compliant and Halogen Free**

Ordering Information

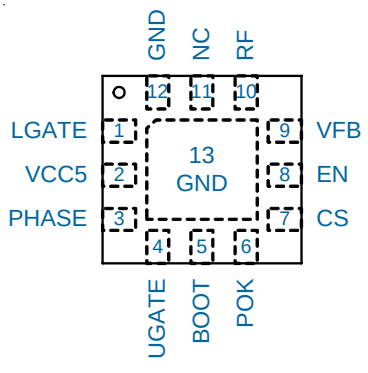
Order Number	Package Type	Top Marking
uP1537PDDA	WDFN3x3-10L	uP1537P
uP1537RQKB	WQFN2x2-12L	uP1537R

Note: uPI products are compatible with the current IPC/JEDEC J-STD-020 requirement. They are halogen-free, RoHS compliant and 100% matte tin (Sn) plating that are suitable for use in SnPb or Pb-free soldering processes.

Pin Configuration



WDFN3x3-10L

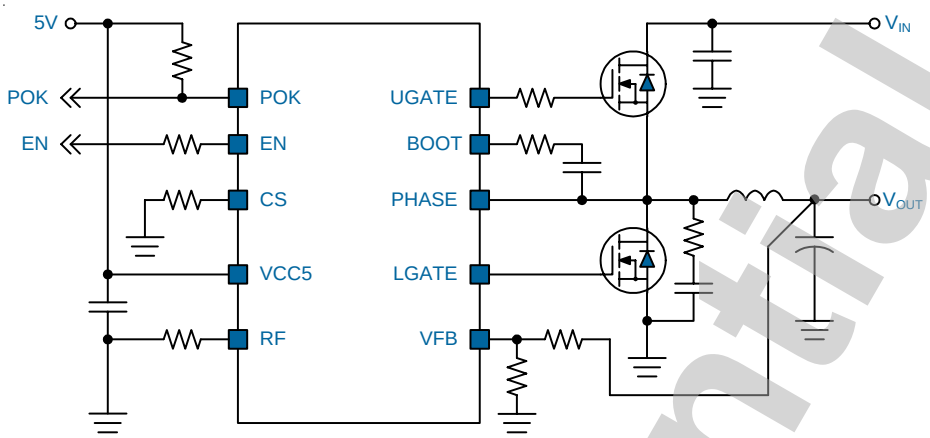


WQFN2x2-12L

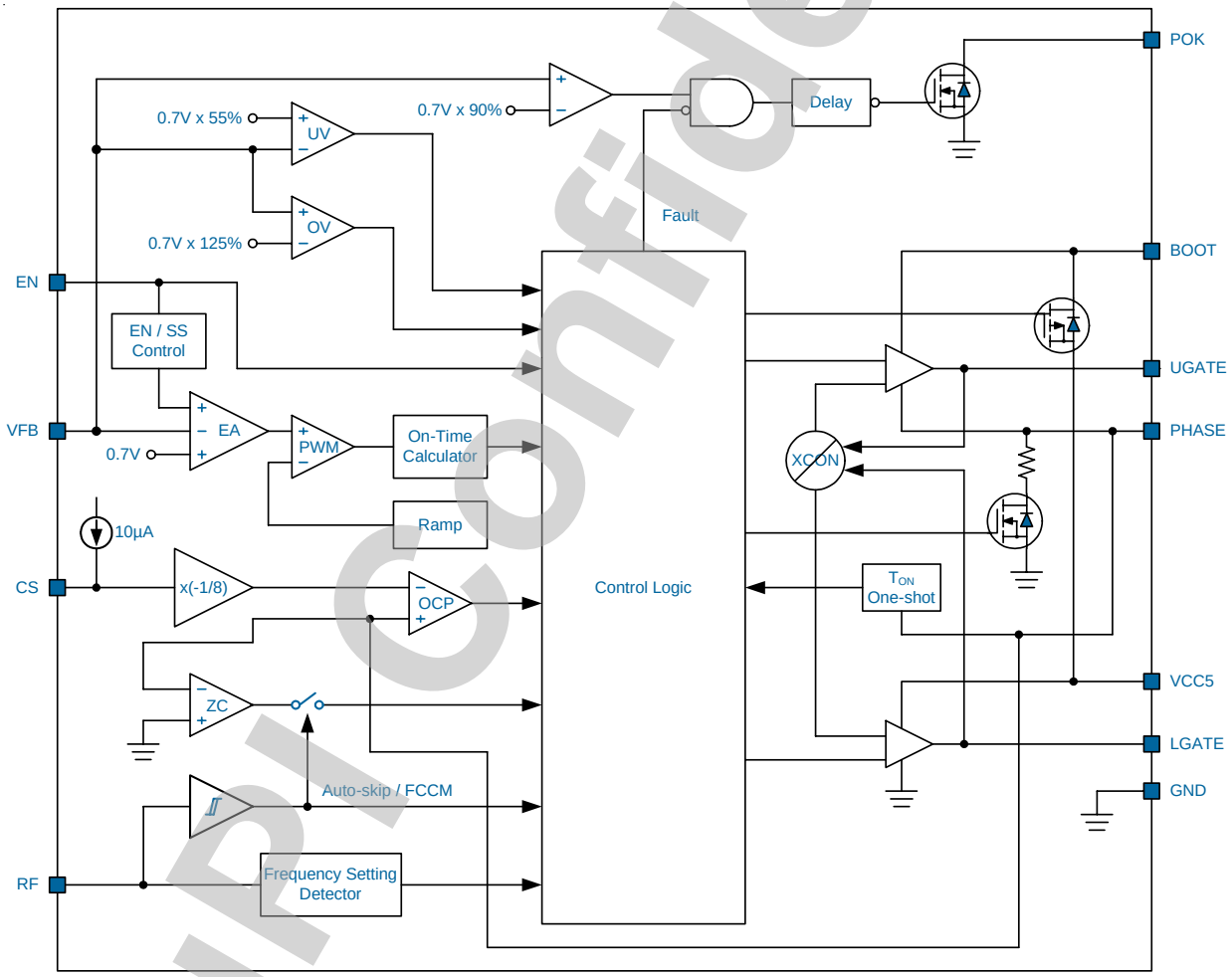
Functional Pin Description

Pin No.		Pin Name	Pin Function
uP1537P	uP1537R		
1	6	POK	**Power OK Indicator.** This pin is an open-drain output.
2	7	CS	**Over Current Protection Setting.** Connect a resistor from this pin to GND to set the over current protection level.
3	8	EN	**Chip Enable.** Short to GND to disable the device.
4	9	VFB	**Feedback Input.** This pin is the inverting input to the error amplifier. A resistor divider from output to GND is used to set regulator voltage.
5	10	RF	**Switching Frequency Programming.** This pin also controls Auto-skip mode or forced CCM selection. Connect a resistor from this pin to GND: Auto-Skip Mode. Connect a resistor from this pin to POK: Forced CCM after POK becomes high.
--	12	GND	**Ground.**
6	1	LGATE	**Lower MOSFET Gate Driver Output.** Connect this pin to the gate of lower MOSFET. This pin is monitored by the adaptive shoot-through protection circuitry to determine when the lower MOSFET has turned off.
7	2	VCC5	**Supply Voltage for the IC.** This pin provides bias voltage for the IC. Connect this pin to 5V voltage source and bypass it with a R/C filter.
8	3	PHASE	**Switch Node.** Connect this pin to the source of the upper MOSFET and the drain of the lower MOSFET. This pin is used as the sink for the UGATE driver. This pin is also monitored by the adaptive shoot-through protection circuitry to determine when the upper MOSFET has turned off. A Schottky diode between this pin and ground is recommended to reduce negative transient voltage which is common in a power supply system.
9	4	UGATE	**Upper MOSFET Gate Driver Output.** Connect this pin to the gate of upper MOSFET. This pin is monitored by the adaptive shoot-through protection circuitry to determine when the upper MOSFET has turned off.
10	5	BOOT	**Bootstrap Supply for the Floating Upper MOSFET Gate Driver.** Connect the bootstrap capacitor C_{BOOT} between BOOT pin and the PHASE pin to form a bootstrap circuit. The bootstrap capacitor provides the charge to turn on the upper MOSFET. Ensure that C_{BOOT} is placed near the IC.
--	11	NC	**Not Internally Connected.**
Exposed Pad			**Ground.** The exposed pad dominates heat conduction path and should be well soldered to PCB for optimal thermal performance.

Typical Application Circuit



Functional Block Diagram



Functional Description

The uP1537 implements an unique RCOT™ control topology for the synchronous Buck. The uP1537 does not require the external compensator. The RCOT™ supports extremely low ESR output capacitors and makes the design easier and robust.

Enable and Soft Start

When the EN pin voltage rises above the enable threshold, the controller enters its start up sequence. The first 250µs calibrates the switching frequency setting resistance attached at RF to GND and stores the switching frequency code in internal registers. A voltage of 0.1V is applied to RF for measurement. Switching is inhibited during this period. In the second period, internal soft-start reference voltage starts ramping up from 0V to 0.7V. This ramping time is 750µs. Smooth and constant ramp up of the output voltage is maintained during start up regardless of load current. Connect a 1kΩ resistor in series with the EN pin to provide protection.

On-Time Control and Frequency Setting

The uP1537 does not have a dedicated oscillator that determines switching frequency. However, the device runs with pseudo-constant frequency by feed-forwarding the input and output voltages into its on-time one-shot timer. The RCOT™ control adjusts the on-time to be inversely proportional to the input voltage and proportional to the output voltage. This makes the switching frequency fairly constant in steady state conditions over wide input voltage range. The switching frequency is selectable from four preset values by a resistor connected to RF as shown in Table 1. Leaving the RF pin open sets the switching frequency to the lowest value, 290kHz, with Auto-skip mode. However, it is recommended to apply one of the resistances on the table in any application designs.

Table 1. Resistor and Switching Frequency

Resistance (R_{RF}) (kΩ)	Switching Frequency (f_{SW}) (kHz)
470	290
200	340
100	380
39	430

The off-time is modulated by a PWM comparator. The VFB node voltage (the mid point of resistor divider) is compared to the internal 0.7V reference voltage added with a ramp signal. When both signals match, the PWM comparator asserts the set signal to terminate the off-time (turn off the low side MOSFET and turn on high side MOSFET). The set signal becomes valid if the inductor current level is below OCP threshold, otherwise the off-time is extended until the current level becomes below the threshold.

Light Load Condition in Auto-Skip Operation

When RF pin is pulled down to low via R_{RF}, the uP1537 automatically reduces switching frequency at light load to maintain high efficiency. This reduction of the frequency is achieved smoothly and without increasing VOUT ripples or load regulation. As the output current decreases from heavy load condition, the inductor current will also be reduced, and eventually comes to the point that its valley touches zero current, which is the boundary between continuous conduction and discontinuous conduction modes. By emulating the behavior of diodes, the low side MOSFET allows only partial of negative current when the inductor freewheeling current reaches negative. As the load current is further decreased, it takes longer time to discharge the output capacitor to the level than requires the next ON cycle.

The transition point from discontinuous to continuous conduction mode can be calculated as:

$$I_{OUT} = \frac{1}{2 \times f_{OSC} \times L_{OUT}} \times V_{OUT} \times (1 - \frac{V_{OUT}}{V_{IN}})$$

Forced Continuous Conduction Mode

When the RF pin is tied high, the controller keeps continuous conduction mode (CCM) in light load condition. In this mode, switching frequency is kept almost constant over the entire load range which is suitable for applications need tight control of the switching frequency at a cost of lower efficiency. To set the switching frequency to be the same as Auto-skip mode, it is recommended to connect R_{RF} to POK. In this way, RF is tied low prior to soft-start operation to set frequency and tied high after POK indicates high.

Output Voltage Setting

Connect a resistor voltage-divider at the FB between VOUT and GND to adjust the respective output voltage between 0.7V and 2.6V. Choose R_{FB2} and solve for R_{FB1} using the equation as follows:

$$V_{OUT} = V_{REF} \times (1 + \frac{R_{FB1}}{R_{FB2}})$$

where V_{REF} is 0.7V (typ.).

Functional Description

POK

The uP1537 has POK output that indicates high when switcher output is within the target. The POK function is activated after soft-start has finished. If the output voltage becomes within 90% of the target value, internal comparators detect POK state and the POK signal becomes high after a 1ms internal delay. If the output voltage goes outside of 55% of the target value, the POK signal becomes low. The POK output is an open-drain output and should be pulled up externally if used.

Output Discharge Control

When EN is low, the uP1537 discharges the output capacitor using internal MOSFET connected between PHASE and GND while high side and low side MOSFETs are kept off. The current capability of this MOSFET is limited to discharge slowly.

Over Current Limit

The uP1537 monitors the inductor valley current by low side MOSFET $R_{DS(ON)}$ when it turns on. The over current limit is triggered once the sensing current level is higher than V_{OCSET}. When triggered, the over current limit will keep high side MOSFET off even the voltage loop commands it to turn on.

The output voltage will decrease if the load continuously demands more current than current limit level. The current limit level is set at I_{LIM}/2 if the output voltage is lower than 90% of its target level, letting V_{OUT} decrease faster until UVP occurs and shuts down the uP1537.

The current limit threshold is set by connecting a resistor from CS to GND. The CS pin will sink a 10μA current source and create a voltage drop across R_{CS} as the V_{OCSET}. V_{OCSET} = 10μA x R_{CS}. When the voltage drop across the low side MOSFET equals the voltage across the setting resistor, the current limit will be activated.

The voltage across PHASE and GND pins is compared with V_{OCSET} for current limit. The current limit level is calculated as:

$$I_{LIM} = \frac{V_{OCSET}}{8 \times R_{DS(ON)}} + \frac{I_{RIPPLE}}{2}$$

where I_{RIPPLE} is the peak-to-peak inductor ripple current at steady state.

Over Voltage/Under Voltage Protection

The uP1537 monitors feedback voltage to detect overvoltage and undervoltage. When the feedback voltage becomes higher than 125% of the target voltage, the OVP is triggered, high side MOSFET is off and low side MOSFET is on. When the feedback voltage is lower than 55% of the target voltage, the UVP is triggered, then high side MOSFET and low side MOSFET are latched. This function is enabled after 1ms following EN has becomes high.

VCC5 UVLO

The uP1537 has VCC5 under voltage lockout protection (UVLO) that inhibits switching and resets the protection faults.

When the VCC5 voltage is lower than UVLO threshold voltage, all functions are turned off. This is the non-latch protection.

Over Temperature Protection

The uP1537 monitors the temperature of itself. If the temperature exceeds typical 150°C, the uP1537 will be turned off. This is the non-latch protection. It will be recovered once temperature is lower than 130°C.

Absolute Maximum Rating

(Note 1)

VCC5 to GND ---------- -0.3V to +6V

BOOT to GND

DC ---------- -0.3V to +36V

< 200ns ---------- -5V to +42V

BOOT to PHASE

DC ---------- -0.3V to +6V

< 200ns ---------- -5V to +7.5V

PHASE to GND

DC ---------- -0.3V to +30V

< 200ns ---------- -5V to +38V

UGATE to GND

DC ---------- -0.3V to +36V

<200ns ---------- -10V to +42V

UGATE to PHASE

DC ---------- -0.3V to +6V

<200ns ---------- -5V to +7V

LGATE to GND

DC ---------- -0.3V to + 6V

<200ns ---------- -2V to +7V

Other Pins to GND ---------- -0.3V to +6V

Storage Temperature Range ---------- -65°C to +150°C

Lead Temperature (Soldering, 10 sec) ---------- 260°C

ESD Rating (Note 2)

HBM (Human Body Mode) ---------- 2kV

MM (Machine Mode) ---------- 200V

Thermal Information

Package Thermal Resistance (Note 3)

WDFN3x3-10L θ_{JA} ---------- 68°C/W

WDFN3x3-10L θ_{JC} ---------- 6°C/W

WDFN2x2-12L θ_{JC} ---------- 155°C/W

WDFN2x2-12L θ_{JC} ---------- 20°C/W

Power Dissipation, P_D @ T_A = 25°C

WDFN3x3-10L ---------- 1.47W

WDFN2x2-12L ---------- 0.65W

Recommended Operation Conditions

(Note 4)

Input Voltage, V_{IN} ---------- 3V to 26V

Operating Junction Temperature Range ---------- -40°C to +125°C

Operating Ambient Temperature Range ---------- -40°C to +85°C

Note 1. Stresses listed as the above *Absolute Maximum Ratings* may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

Note 2. Devices are ESD sensitive. Handling precaution recommended.

Note 3. θ_{JA} is measured in the natural convection at T_A = 25°C on a low effective thermal conductivity test board of JEDEC 51-3 thermal measurement standard.

Note 4. The device is not guaranteed to function outside its operating conditions.

Electrical Characteristics

(V_{IN} = 12V, V_{VCC5} = 5.0V, V_{OUT} = 1.05V, T_A = 25°C, unless otherwise specified)

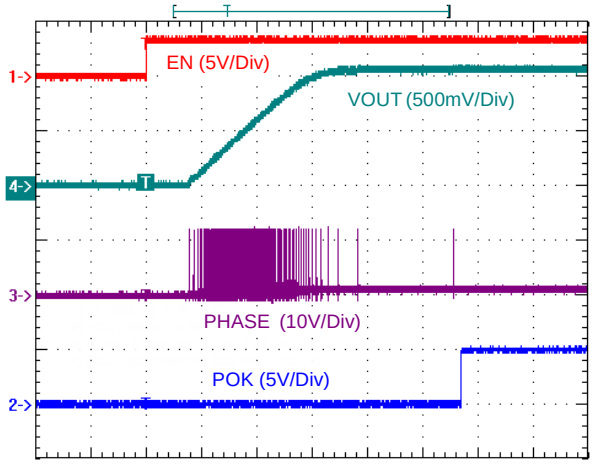
Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Supply Current						
VCC5 Supply Current	I_{VCC5}	V_{EN} = 5V, No Load	--	320	500	µA
VCC5 Shutdown Current	I_{VCC5_SD}	V_{EN} = 0V, No Load	--	--	1	µA
Internal Reference Voltage						
VFB Regulation Voltage	V_{FB}	CCM condition	--	0.704	--	V
		Tolerance	-1.0	--	+1.0	%
VFB Input Current	I_{FB}	V_{FB} = 0.735V, skip mode	--	0.01	0.2	µA
Output Discharge						
Output Discharge Current from PHASE Pin	I_{DIS}	V_{EN} = 0V, V_{PHASE} = 0.5V	5	13	--	mA
Output Drivers						
UGATE Resistance	R_{UGATE}	Source, I_{UGATE} = - 150mA	--	2	--	Ω
		Sink, I_{UGATE} = 150mA	--	1	--	
LGATE Resistance	R_{LGATE}	Source, I_{LGATE} = -150mA	--	1	--	Ω
		Sink, I_{LGATE} = 150mA	--	0.7	--	
Dead Time	T_D	UGATE-off to LGATE-on	--	17	--	ns
		LGATE-off to UGATE-on	--	22	--	
Internal Bootstrap Switch						
Internal Resistance	R_{BST_F}	I_F = 10mA	--	80	--	Ω
Reverse Leakage Current	I_{BST_LK}	V_{BOOT} = 26V	--	0.01	1.5	µA
Duty and Frequency Control						
Minimum Off-Time	T_{OFF_MIN}		--	400	--	ns
Minimum On-Time	T_{ON_MIN}	V_{IN} = 26V, V_{OUT} = 0.7V, R_{RF} = 39kΩ	--	80	--	
Soft Start						
Internal SS Time	T_{SS}	From V_{EN} = high to V_{OUT} = 90%	--	1	--	ms
POK Comparator						
POK Threshold	V_{TPOK}	POK in from lower, V_{FB} with respect to reference, No load.	87	90	93	%
POK Sink Current	I_{POK_MAX}	V_{POK} = 0.5V	--	50	--	mA
POK Delay Time	T_{POK_DEL}	Delay from 90% of V_{FB} to POK go high	0.8	1	1.2	ms

Electrical Characteristics

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Logic Threshold and Setting Conditions						
EN Voltage Threshold	V_{EN}	Enable	1.8	--	--	V
		Disable	--	--	0.5	
EN Input Current	I_{EN}	V_{EN} = 5V	--	--	1	µA
On-Time	T_{ON}	R_{RF} = 470kΩ for F_{SW} = 290kHz	--	302	--	ns
		R_{RF} = 200kΩ for F_{SW} = 340kHz	--	257	--	
		R_{RF} = 100kΩ for F_{SW} = 380kHz	--	230	--	
		R_{RF} = 39kΩ for F_{SW} = 430kHz	--	203	--	
CCM Setting Voltage	V_{RF}	CCM	1.8	--	--	V
		Auto-Skip	--	--	0.5	
Protection: Current Sense						
CS Source Current	I_{CS}		9	10	11	µA
OCP Comparator Offset	V_{OC_OFS}		- 10	0	10	mV
Zero Crossing Comparator Offset	V_{ZC_OF}		- 4	- 2	0	mV
Protection: UVP and OVP						
Over Voltage Trip Threshold Voltage	V_{OVP}	Percentage of V_{REF}	120	125	130	%
OVP Propagation Delay Time	T_{OVPDEL}		--	5	--	µs
Under Voltage Trip Threshold Voltage	V_{UVP}	Percentage of V_{REF}	50	55	60	%
Output UVP Enable Delay Time	T_{UVPEN}	From Enable to UVP workable	1	--	--	ms
UVLO						
VCC5 POR Threshold	$V_{UVLOVCC5}$	Rising	3.8	4	4.2	V
		Hysteresis	--	0.3	--	V
Thermal Shutdown						
Thermal Shutdown Threshold	T_{SDN}	Shutdown temperature	--	150	--	°C
		Hysteresis	--	20	--	°C

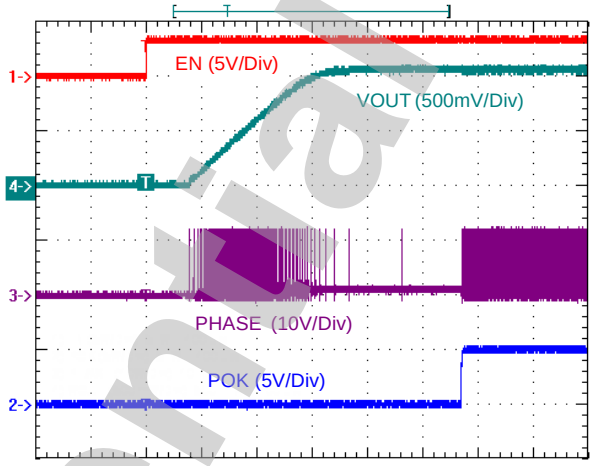
Typical Operation Characteristics

PSM, Power On from EN



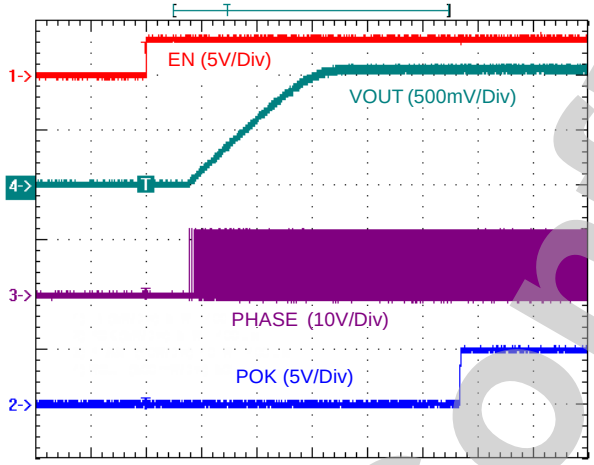
400us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, no load

CCM, Power On from EN



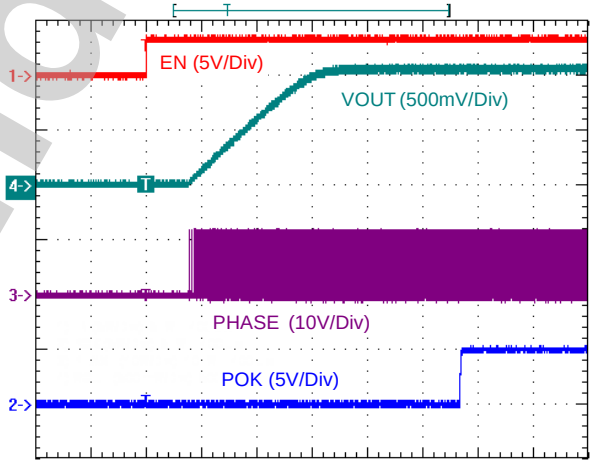
400us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, no load

PSM, Power On from EN



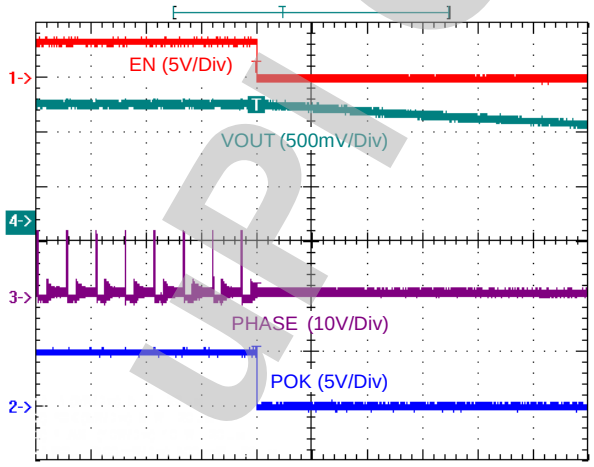
400us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, Load = 0.05Ω

CCM, Power On from EN



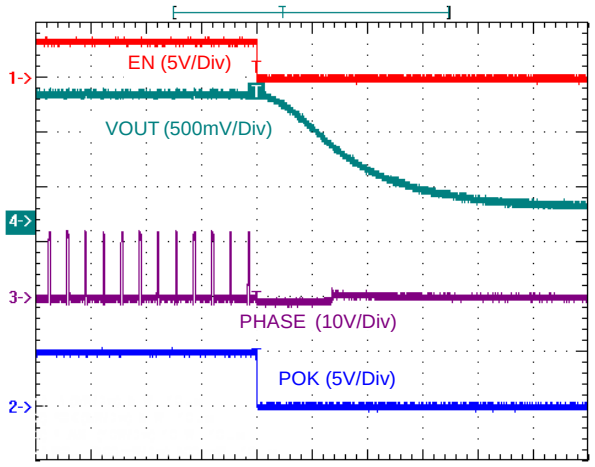
400us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, Load = 0.05Ω

PSM, Power Off from EN



20us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, Load = 2Ω

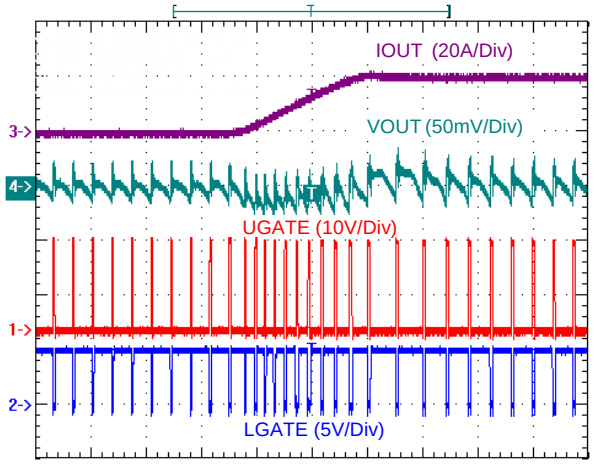
CCM, Power Off from EN



10us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, Load = 0.05Ω

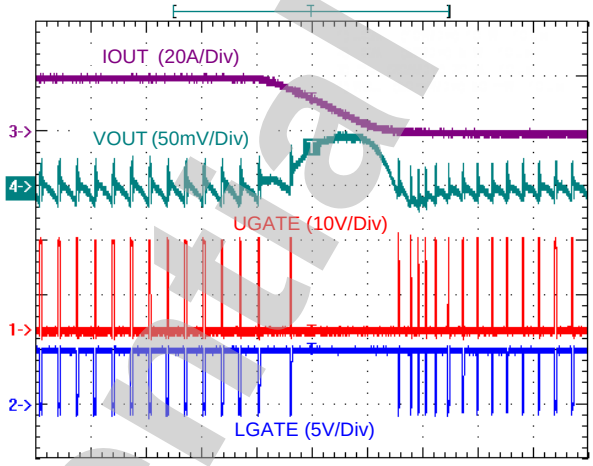
Typical Operation Characteristics

CCM Undershoot: 0A to 20A



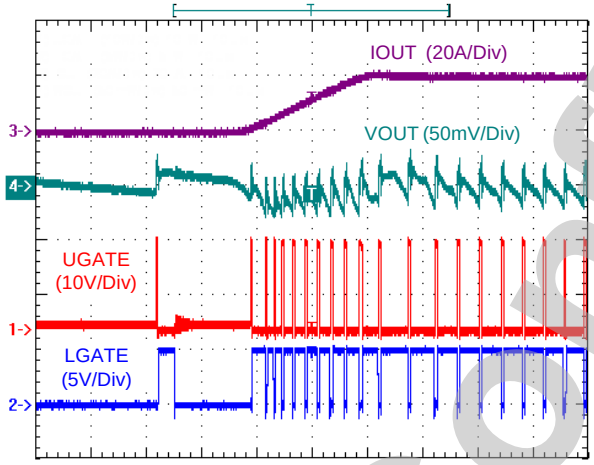
10us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, L = 1uH, C_{OUT} = 330uF

CCM Overshoot: 20A to 0A



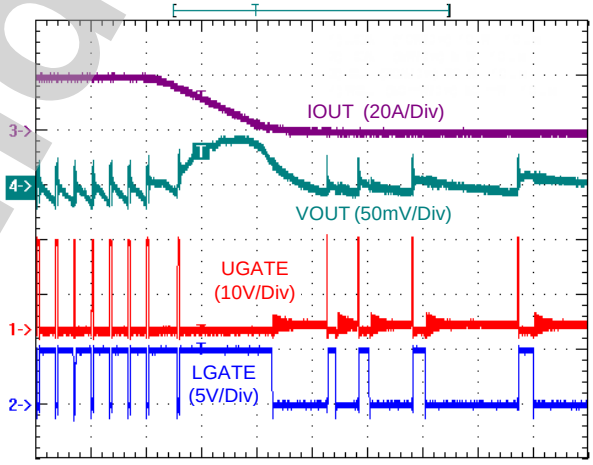
10us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, L = 1uH, C_{OUT} = 330uF

PSM Undershoot: 0.1A to 20A



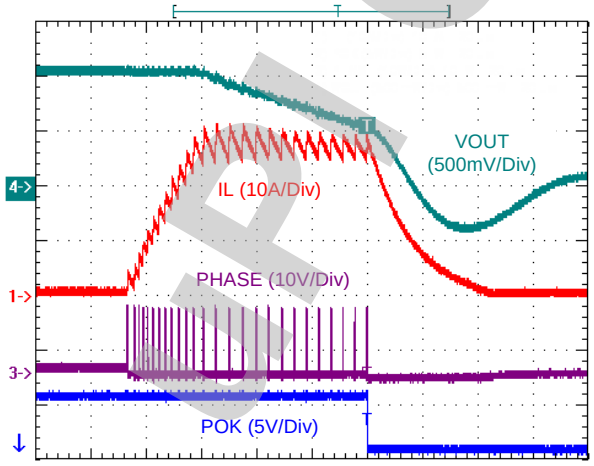
10us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, L = 1uH, C_{OUT} = 330uF

PSM Overshoot: 20A to 0.1A



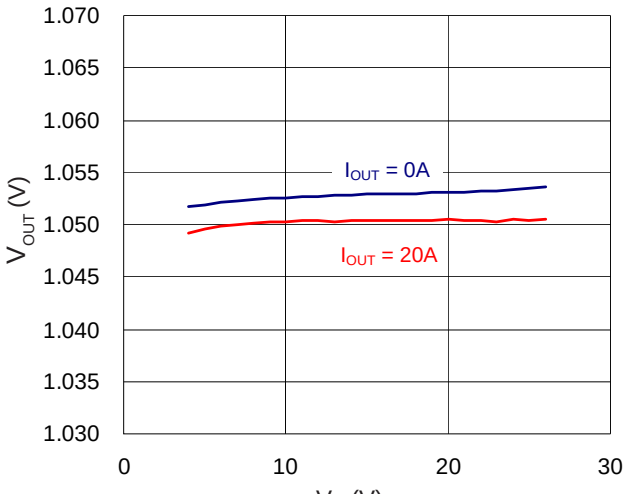
10us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, L = 1uH, C_{OUT} = 330uF

Current Limit



20us/Div
V_{IN} = 12V, V_{OUT} = 1.05V, R_{CS} = 62kΩ,
Lower MOSFET = QM3006M5*2

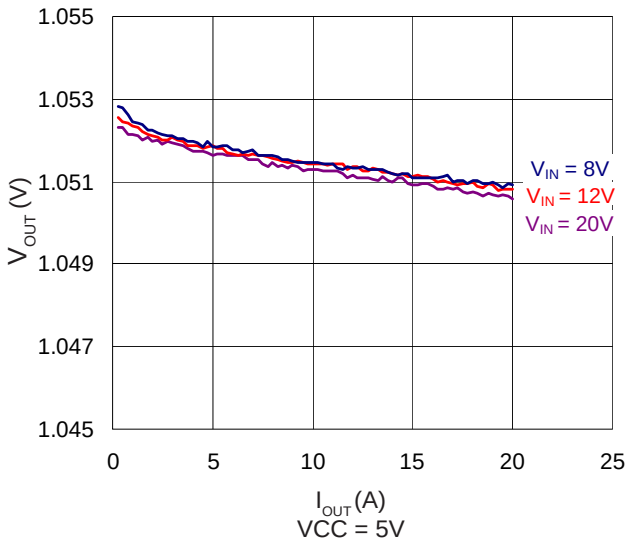
Line Regulation



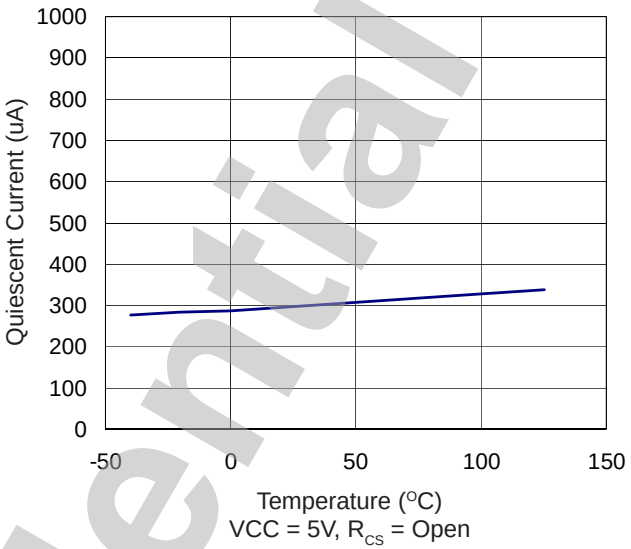
VCC = 5V

Typical Operation Characteristics

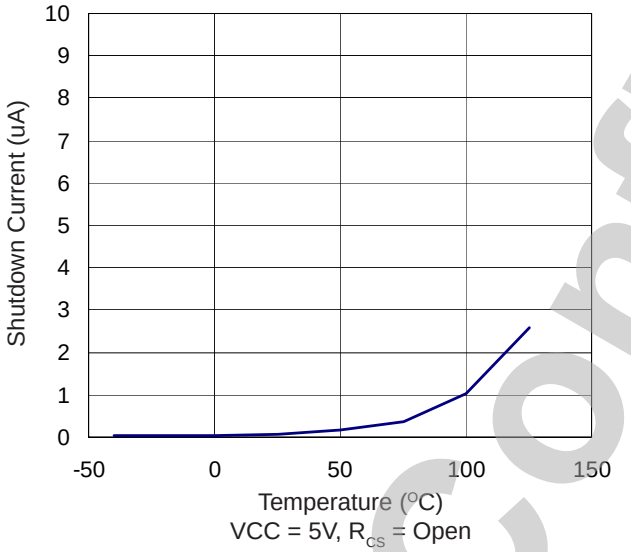
Load Regulation



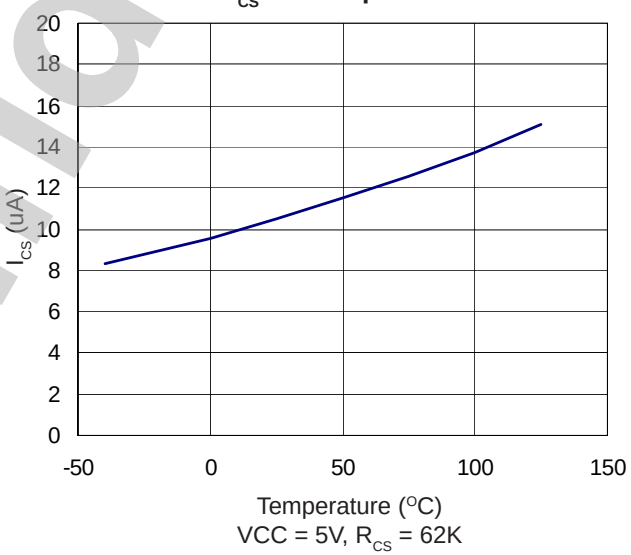
Quiescent Current vs. Temperature



Shutdown Current vs. Temperature



I_{cs} vs. Temperature



Output Inductor Selection

The inductor plays an important role in step-down converters because it stores the energy from the input power rail and then releases the energy to the load. From the viewpoint of efficiency, the dc resistance (DCR) of the inductor should be as small as possible to minimize the conduction loss. In addition, the inductor covers a significant proportion of the board space, so its size is also important. Low profile inductors can save board space especially when the height has a limitation. However, low DCR and low profile inductors usually cost ineffective.

Additionally, larger inductance results in lower ripple current which translates into the lower power loss. However, the inductor current rising time increases with inductance value. This means the transient response will be slower. Therefore, the inductor design is a trade-off between performance, size and cost.

In general, the switching frequency (on-time) and operating point (% ripple or LIR) determine the inductor value as shown in the following equation:

$$L = \frac{t_{ON} \times (V_{IN} - V_{OUT})}{LIR \times I_{LOAD(MAX)}}$$

where LIR is the ratio of the peak to peak ripple current to the average inductor current.

Find a low loss inductor having the lowest possible DC resistance that fits in the allotted dimensions. Ferrite cores are often the best choices because powdered iron is inexpensive and can work well at 200kHz. The core must be large enough not to saturate at the peak inductor current (I_{PEAK}):

$$I_{PEAK} = I_{LOAD(MAX)} + \frac{LIR}{2} \times I_{LOAD(MAX)}$$

The calculation above shall serve as a general reference. To further improve the transient response, the output inductance can be reduced even further. This needs to be considered along with the selection of the output capacitor.

Output Capacitor Selection

The capacitor value and ESR determine the amount of output voltage ripple and load transient response. Thus, the capacitor value must be greater than the largest value calculated from below equations:

$$V_{SOAR} = \frac{\Delta I_{LOAD}{}^2 \times L}{2 \times C_{OUT} \times V_{OUT}}$$

$$V_{P-P} = LIR \times I_{LOAD(MAX)} \times \left(ESR + \frac{1}{8 \times C_{OUT} \times f_{SW}}\right)$$

where V_{SOAR} are the allowable amount of undershoot voltage and overshoot voltage in the load transient, V_{P-P} is the output ripple voltage.

MOSFET Selection

The majority of power loss in the step-down power converter is the loss in the power MOSFETs. For low voltage high current applications, the duty cycle of the upper MOSFET is small. Therefore, the switching loss of the upper MOSFET is of concern. Power MOSFETs with lower total gate charge are preferred in such kind of application. However, the small duty cycle means the lower MOSFET is on for most of the switching cycle. Therefore, the conduction loss tends to dominate the total power loss of the converter.

To improve the overall efficiency, MOSFETs with low $R_{DS(ON)}$ are preferred in the circuit design. In some cases, more than one MOSFET are connected in parallel to further decrease the on-state resistance. However, this depends on the MOSFET driver capability and the budget.

Layout Considerations

Layout is very important in high frequency switching converter designs, the PCB could radiate excessive noise and contribute to the converter instability with improper layout. Certain points must be considered before starting a layout.

1 Place the filter capacitor close to the IC.

2 Keep current limit setting network as close as possible to the IC. Routing of the network should avoid coupling to high voltage switching node.

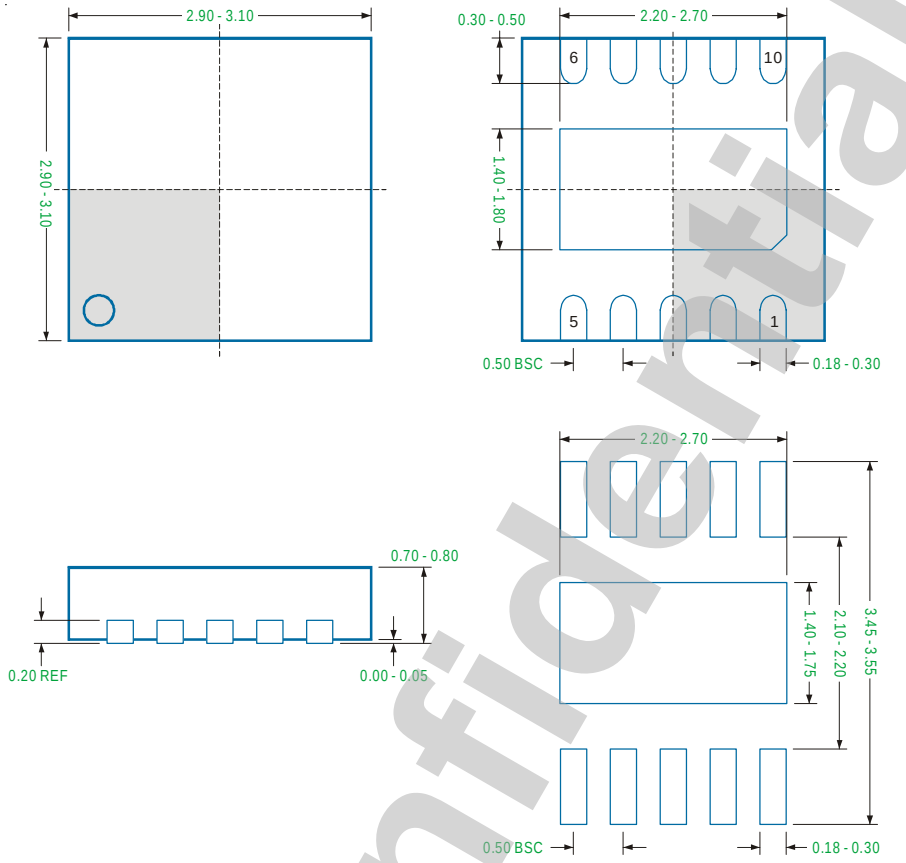
3 Connections from the drivers to the respective gate of the both MOSFETs should be as short as possible to reduce stray inductance.

4 All sensitive analog traces and components such as VFB, GND, EN, POK, and RF should be placed away from high voltage switching nodes such as PHASE, LGATE, UGATE, or BOOT nodes to avoid coupling. Use internal layer(s) as ground plane(s) and shield the feedback trace from power traces and components.

5 Place the ground terminals of VIN capacitor(s), VOUT capacitor(s), and source of lower MOSFETs as close as possible. The PCB trace defined as PHASE node, which connects to source of upper MOSFET, drain of lower MOSFET and high voltage side of the inductor, should be as short and wide as possible.

Package Information

WDFN3X3 - 10L



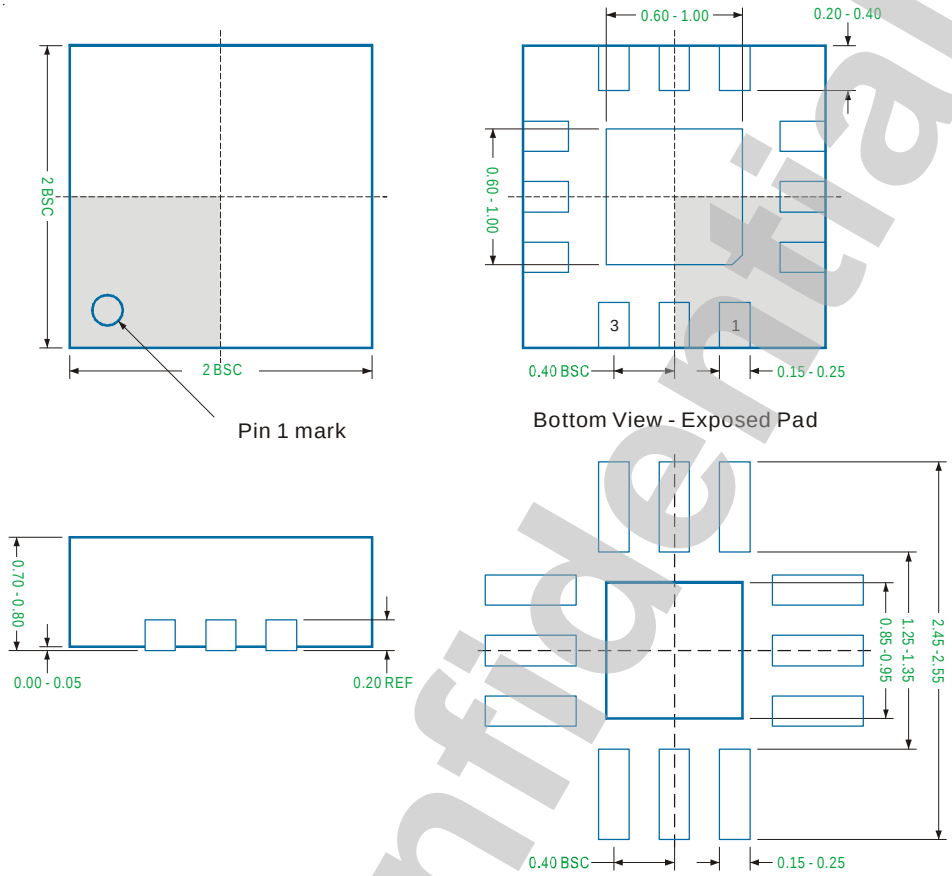
Recommended Solder Pitch and Dimensions

Note

1. Package Outline Unit Description:
   BSC: Basic. Represents theoretical exact dimension or dimension target
   MIN: Minimum dimension specified.
   MAX: Maximum dimension specified.
   REF: Reference. Represents dimension for reference use only. This value is not a device specification.
   TYP. Typical. Provided as a general value. This value is not a device specification.
2. Dimensions in Millimeters.
3. Drawing not to scale.
4. These dimensions do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.15mm.

Package Information

WQFN2x2 - 12L



Note

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   MIN: Minimum dimension specified.
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2. Dimensions in Millimeters.
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