ELM613xxC 4A, 30V, 500kHz, synchronous step-down DC/DC converter

■General description

ELM613xxC is a fully integrated high efficiency synchronous step-down converter which requires minimum number of external components. It offers very compact solution with up to 4A continuous output current over a wide input range. ELM613xxC employs proprietary Constant On-Time (COT) control scheme providing superior transient response and maintaining constant switching frequency under the continuous conduction mode operation. The internal ramp compensation network allows stable operation with ultra-low equivalent series resistance (ESR) output ceramic capacitors without using external compensation network. An error amplifier in the control loop provides excellent line and load regulation. ELM613xxC integrates extensive protection functions include: UVLO, OCP and thermal shutdown. Input under- voltage lockout is internally set as 3.8V.

The unique ultrasonic pulse-skipping mode (ELM613UDC) maintains the switching frequency above 25kHz, which eliminates noise in audio applications. Other features include pulse skipping mode (ELM613NxC), which maximizes efficiency in light-load applications, and forced PWM mode(ELM613ADC) which operates in constant frequency PWM mode regardless of load current.

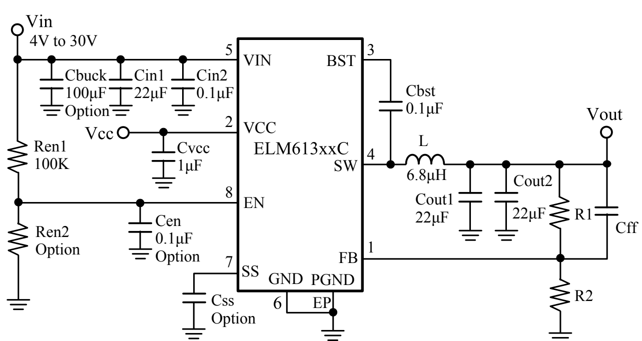
■Features

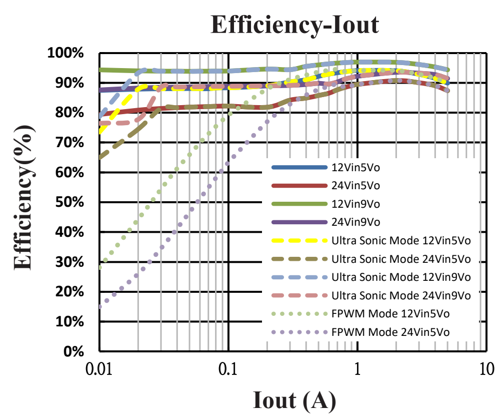
- Stable operation with output low ESR ceramic capacitors
- Externally adjustable built-in soft start (Typ.2ms)
- Fast PWM Constant On Time (COT) control scheme with superior transient performance
- Accurate EN threshold for the external programmable Vin UVLO
- Low quiescent current
- Thermal shutdown with auto recovery
- Hiccup mode 8 times then latch-off over current protection
- Input voltage range : 4.0V to 30.0V
- Feedback voltage accuracy : 0.8V±2%
- Continuous output current : Max.4A(5A Peak)
- Duty cycle (low dropout operation) : Max.100%
- Switching frequency : Typ.500kHz
- 2 Types of light load mode and a forced PWM mode control schemes
  - ELM613UDC : Ultrasonic pulse skip mode (25kHz min)
  - ELM613NxC : Pulse skip mode
  - ELM613ADC : Forced PWM mode
- Integrated high side and low side switches : Typ.40mΩ/40mΩ
- Package : SOP-8(with Exposed Pad), DFN14-4x3(with Exposed Pad)

■Application

- Laptop computer
- Tablet PC
- Networking systems
- Personal video recorders
- Flat panel television and monitors
- Distributed power systems

■Standard circuit





■Selection guide

ELM613xxC-N

Symbol		
a	Light load operation	U: Ultra-sonic mode N: PFM mode A: Forced PWM mode
b	Package	D: SOP-8 (with Exposed Pad) G: DFN14-4x3 (with Exposed Pad)
c	Product version	C
d	Taping direction	N: Please refer to page 14 (SOP-8) N: Please refer to page 16 (DFN14-4x3)

∗ Taping direction is one way.

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ELM613 x x C - N
       ↑ ↑ ↑   ↑
       a b c   d
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■Maximum absolute ratings (1)

Parameter	Symbol	Limit	Unit
VIN supply voltage	Vin	+36	V
EN to GND	Ven	+36	V
SW to GND	Vsw	-0.3 to Vin+0.3	V
PGND to GND	Vpgnd	-0.3 to +0.3	V
BST to SW	Vbst	-0.3 to +6.0	V
All other pins to GND	Vall	-0.3 to +6.0	V
Junction temperature	Tj	+150	°C
Thermal resistance (3), (4)	θja	51 (SOP-8)	°C/W
		48 (DFN14-4x3)	
Power dissipation (3), (4)	Pd	2.45 (SOP-8)	W
		2.60 (DFN14-4x3)	
Storage temperature range	Tstg	-65 to +150	°C

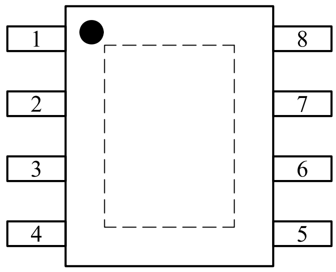
■Recommend operating conditions (2)

Parameter	Symbol	Limit	Unit
Supply voltage	Vin	+4.0 to +30.0	V
Output voltage	Vout	0.8 to Vin	V
Operating temperature	Top	-40 to +125	°C

Note:
(1) Stress exceeding those listed “Maximum absolute ratings” may damage the device.
(2) The device is not guaranteed to function outside of the recommended operating conditions.
(3) Measured on JESD51-7, 4-Layer PCB.
(4) The maximum allowable power dissipation is a function of the maximum junction temperature Tj_max, the junction to ambient thermal resistance θJA, and the ambient temperature Ta. The maximum allowable continuous power dissipation at any ambient temperature is calculated by Pd_max= (Tj_max-Ta)/θja. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.

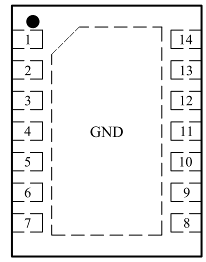
■Pin configuration

SOP-8(TOP VIEW)



Exposed pad on backside

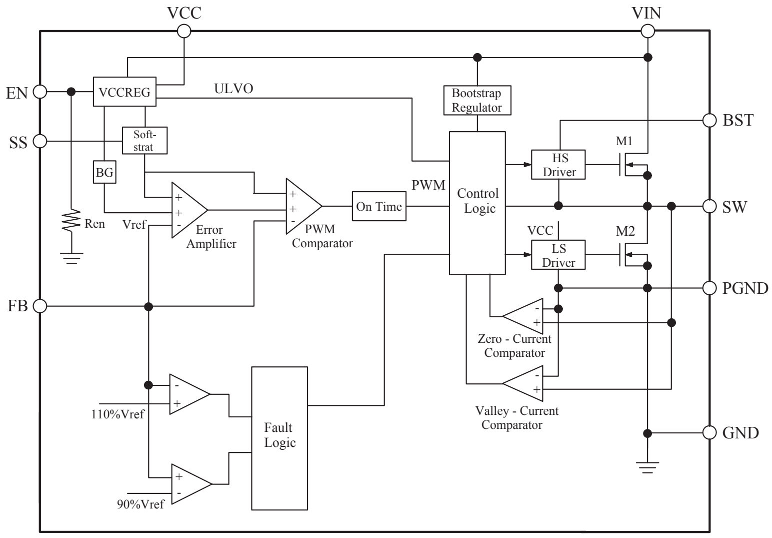
DFN14-4×3(TOP VIEW)



Exposed pad on backside

Pin No. SOP-8	Pin No. DFN14-4x3	Pin name	Pin description
1	1	FB	Feedback Input. Connect FB to the center of the external resistor divider from the output to the AGND to set the output voltage.
2	2	VCC	Internal 5V LDO output. The driver and control circuits are powered from this voltage. Decouple with a minimum 1µF ceramic capacitor to PGND as close to the pin as possible.
3	3	BST	High-Side Driver Bootstrap Supply. Connect a 0.1µF capacitor between SW and BST for proper operation.
4	4, 5, 6, 7	SW	Output pin of internal power switches. Connect this pin to the inductor and bootstrap capacitor.
5	8, 9, 10, 11	VIN	Supply voltage. VIN pin supplies power for internal MOSFET and regulator. ELM613xxC operates from a +4V to +30V input rail. Bypass VIN to PGND with a 22µF or greater low ESR ceramic capacitor. If the voltage spike on VIN pin exceeds 36V, additional 100µF electrolytic capacitor is recommended.
6	12	GND	System analog ground.
7	13	SS	Output Soft-Start Pin. This pin allows user control of output voltage ramp rate during start-up. An internal 10µA pull-up current from VCC on this pin allows a capacitor to program output voltage slew rate. This pin is pulled to ground with an internal 200Ω MOSFET during shutdown and fault conditions.
8	14	EN	The device is shut down when this pin is low and active when this pin is high. The hysteretic threshold voltage is 1.3V going up and 1.2V going down. An external resistor divider from VIN can be used to program a VIN threshold below which the device will shut down. Connect EN to VIN through a 100k resistor for automatic startup.
EP	EP	PGND	Exposed pad is connected to the low side MOSFET Power Ground. Connect EP to a large-area contiguous copper ground plane for effective power dissipation.

■Block diagram



■Electrical characteristics

Top=+25°C, Vin=+12V, Vout=5V and Ven=2V, unless otherwise noted.

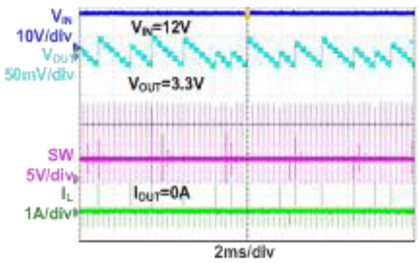
Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Input voltage range	Vin		4		30	V
Shutdown current	Is	Ven=0V, Vin=12V		1	8	μA
Input under voltage lockout threshold	Vuvlo	Vin increasing		3.80	4.05	V
Input under voltage lockout hysteresis	Vth_hys			430		mV
Supply current	Icc	Vfb=0.84V		130		μA
Feedback regulation voltage	Vfbref		784	800	816	mV
Feedback current	Ifb	Vfb=0.8V	-100		+100	nA
Internal soft-start time	Tss			2		msec
Switching frequency	Fsw	Iout=1A		500		kHz
		Ultrasonic mode ELM613UDC Iout=0A	25	30		
Minimum off time	Toff			120		ns
Maximum duty cycle (5)	Dmax	Vfb=0.76V		100		%
HS main switch on resistance	Ron_hs			40		mΩ
HS switch leakage current	Ileak_H	Vin=12V, Ven=Vsw=0V			1	μA
Low side(LS) switch valley current limit	Ivalley		4.5	6.5	8.5	A
LS switch zero-cross current limit	Izx			80		mA
LS switch on resistance	Ron_ls			40		mΩ
LS switch leakage current	Ileak_ls	Vin=Vsw=12V, Ven=0V			1	μA
EN on threshold	Ven_on	Ven ramp up	1.2	1.3	1.4	V
EN off threshold	Ven_off	Ven ramp down	1.1	1.2	1.3	V
EN internal pull down resistor	Ren		700	1000	1300	kΩ
Vcc linear regulator	Vreg	0<Ivcc<10mA	4.7	5.0	5.3	V
Thermal shutdown	Tsd1			160		°C
Thermal shutdown hysteresis	Tsd2			30		°C

Note(5):
When the input voltage approaches the output voltage, ELM613xxC will extend the on-time and force the main high side switch remaining on for multiple cycles (>10 μsec). High side switch is only turned off momentarily, and low side switch is forced on shortly (typical 120ns) to refresh the BST capacitor. High side switch will resume on after the BST refresh.

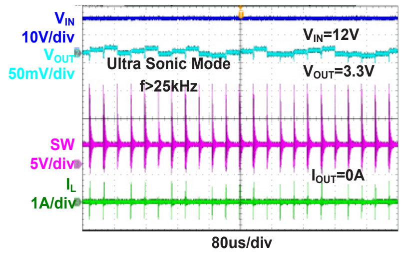
■Typical characteristics

- Vin=12V, Vout=3.3V/5V, L=4.7µH/6.8µH, Cbuck=100µF, Cin1=22µF, Cin2=0.1µF, Cout=22µF×2, Ta=+25°C, unless otherwise noted.

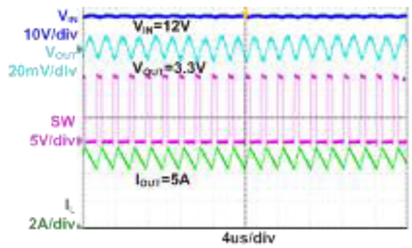
Steady State Test



Steady State Test (Ultra-sonic mode)



Steady State Test



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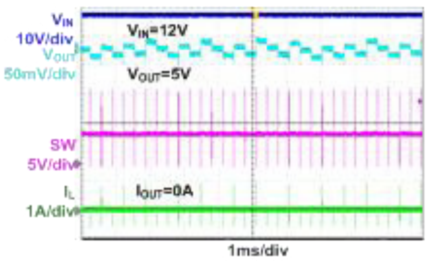
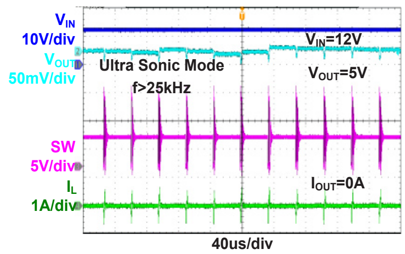
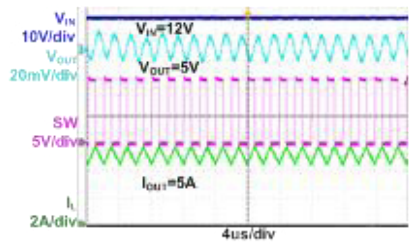


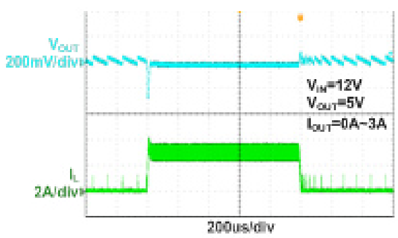
Steady State Test (Ultra-sonic mode)



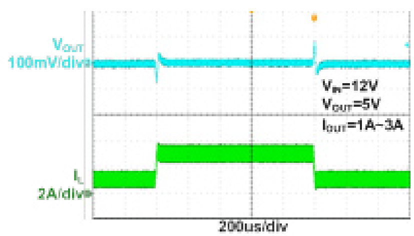
Steady State Test



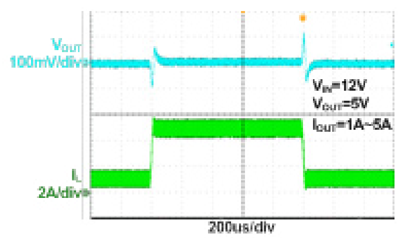
Load Transient Response



Load Transient Response

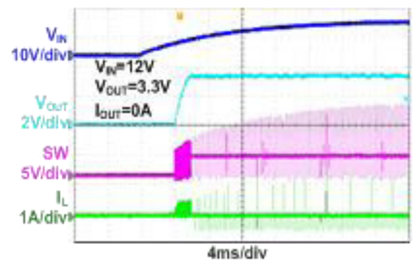


Load Transient Response



- Vin=12V, Vout=3.3V/5V, L=4.7µH/6.8µH, Cbuck=100µF, Cin1=22µF, Cin2=0.1µF, Cout=22µF×2, Ta=+25°C, unless otherwise noted.

VIN power on



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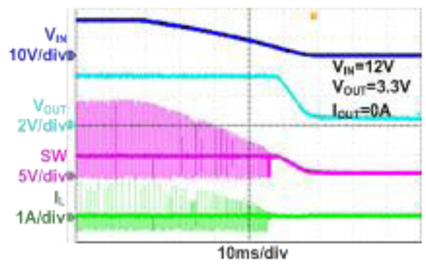

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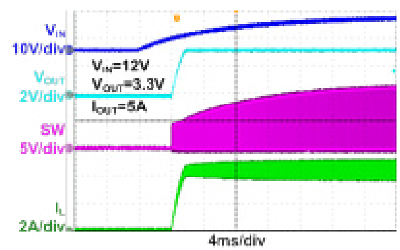

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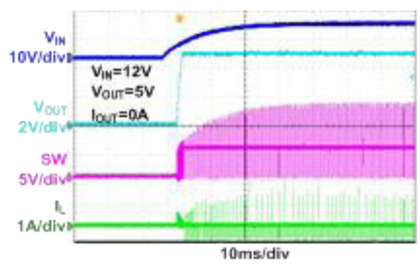

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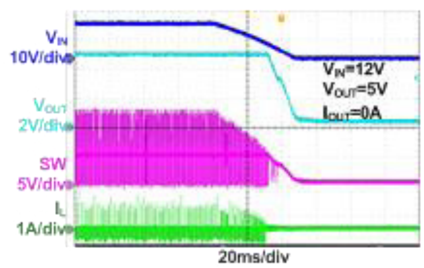

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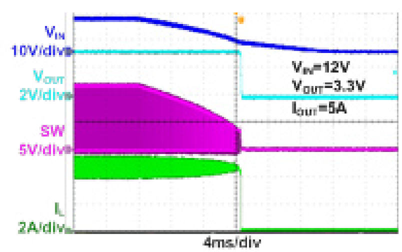
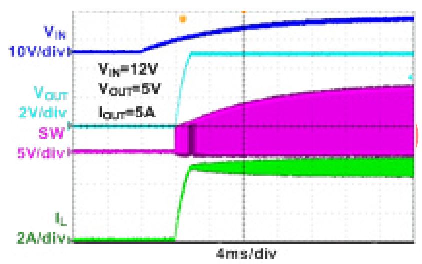
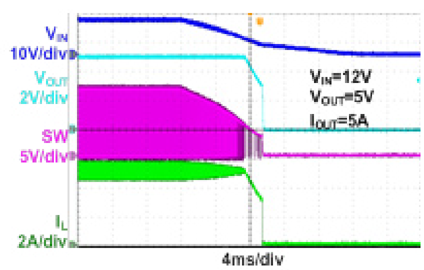


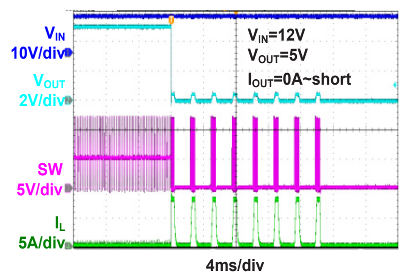
VIN power on



VIN power off



Short Protection



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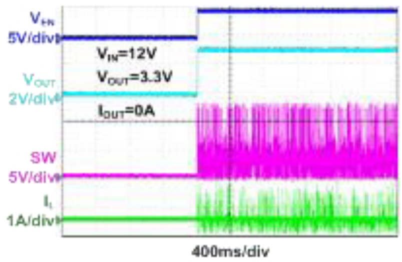
EN power on



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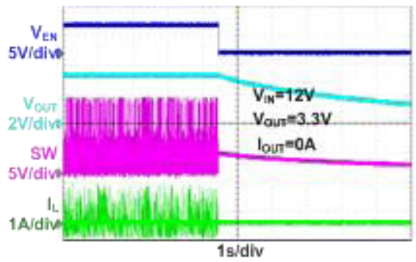

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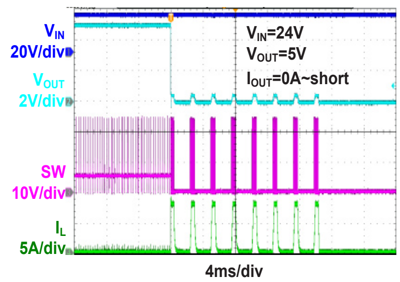

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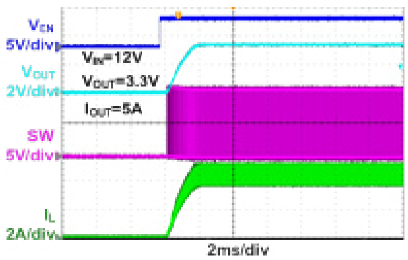

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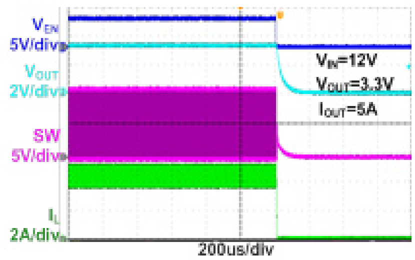

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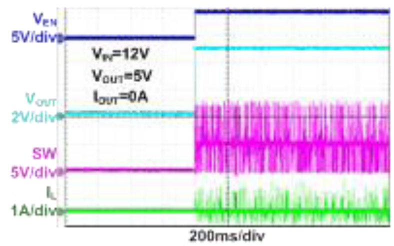

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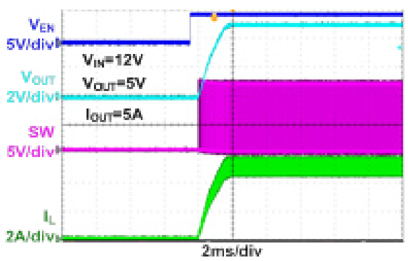

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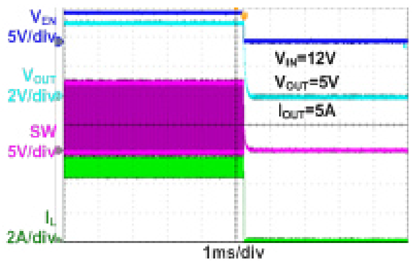
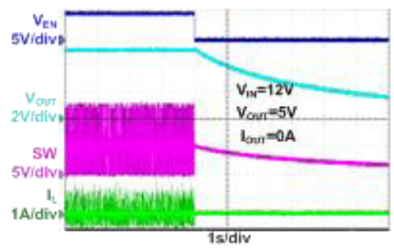


EN power off



■Operation

ELM613xxC is a fully integrated synchronous step-down converter employing constant on-time (COT) control scheme to achieve superior transient performance. Its proprietary internal ramp compensation offers stable operation with lower ESR ceramic output capacitors without using external complex compensation networks.

1. Constant on-time control

The constant on-time control (COT) operates by comparing the feedback voltage Vfb with the reference voltage. When FB droops below the reference, the control circuit turns on HS switch immediately for a pre-determined period of time (on-time) to ramp up the inductor current. When this on-time times out, the LS switch is then turned on to ramp down the inductor current. The LS switch is turned off when inductor current reaches zero Izx (or triggers negative current limit) or HS switch is turned on again for the next cycle. This operation repeats itself if FB droops below reference again.

ELM613xxC uses a proprietary algorithm to calculate the on-time based on input voltage, output voltage and load current to achieve nearly constant switching frequency over entire continuous conduction load current range. The on-time can be estimated as:

$$\text{Ton} = \frac{\text{Vout}}{\text{Vin}} \times 2\mu\text{s}$$

Due to its immediate response on FB voltage droop and simplified loop compensation, The ELM613xxC offers superior transient response compare to traditional fixed frequency PWM control converters.

2. Light load operation

In medium and heavy load condition, ELM613xxC operates in PWM mode with typical switching frequency of 500kHz. When load current reduces, ELM613NxC naturally transitions from PWM mode to PFM mode where the pulse width remains the calculated on-time but the switching frequency reduces to accommodate the low output current. The lower the output current, the lower the switching frequency. Once the switching frequency drops to low enough, the devices enter sleep mode to cut down its quiescent current to maintain high efficiency in light load.

The critical load current at the boundary of PWM mode and PFM mode is related to the inductor ripple current, which depends on the inductor value, input voltage and output voltage. Typically this critical load current level is estimated as:

$$\text{Icrit} = \frac{1}{2}\,\frac{(\text{Vin - Vout}) \times \text{Vout}}{\text{L} \times \text{Fsw} \times \text{Vin}}$$

When switching frequency drops below 20kHz in very light load condition, the switching noise can be heard by the human ears. ELM613UDC offers a unique pulse-skipping mode with a minimum switching frequency of 25kHz. This ultrasonic pulse-skipping mode reduces audio-frequency modulation of the power supply that may occur at very light loads. The transition to fixed-frequency PWM operation is automatic and occurs at the same point as in pulse-skipping Mode. Ultrasonic pulse skipping occurs if no switching has taken place within the last 30µs. Low side switch turns on for a short period to induce a negative current in the inductor to discharge the output. High side turns on if the output drops below the regulation point. The ELM613ADC in forced PWM mode performs PWM mode control with a fixed oscillation frequency of 500kHz regardless of the load. Therefore, the ELM613ADC emphasizes easy noise suppression, low output ripple voltage and high output voltage accuracy, and high speed response to load fluctuations, rather than high efficiency under light load.

3. 100% Duty cycle low dropout operation

When input voltage approaches the output voltage, ELM613xxC will extend the on-time toward the maximum on-time to satisfy the duty cycle requirement to regulate the output voltage. If the input further drops to equal or lower than the output level, ELM613xxC forces the main high side (HS) switch to remain on for more than one cycle, eventually reaching 100% duty cycle. The 100% duty cycle operation allows the converter to effectively pass through the input voltage directly to output with minimum voltage drops on the HS switch and the inductor. In the low dropout operation mode, ELM613xxC turns on HS switch for multiple switching cycles until it turns off HS switch momentarily and turns on low side (LS) switch (typical 120ns) to refresh the BST supply voltage. The LS switch is turned off after the BST refresh pulse, then the HS switch resumes on for multiple switching cycles which gives the effective 100% duty cycle. The refresh BST pulse is needed to charge the BST capacitor and ensure the HS switch driver circuit proper operation.

4. Enable

ELM613xxC offers an accurate enable threshold of EN pin, which is typically 1.3V rise and 1.2V fall. ELM613xxC is enabled by pulling up the EN pin above 1.3V and ELM613xxC is disabled by pulling down the EN pin below 1.2V.

When using the EN pin threshold voltage to program the input startup voltage level, the following equation shall be used:

$$\text{Vin-shutdown} = 1.2\text{V} \times \frac{\text{Ren1} + \text{Ren2} \mathbin{//} \text{1M}}{\text{Ren2} \mathbin{//} \text{1M}}$$

Where the 1MegΩ is the internal pull down resistor on EN pin.

When EN is pulled high, ELMx613xxC will start up if VIN is higher than UVLO threshold. When EN is pulled low, ELM613xxC will go into shutdown. Tie EN pin to VIN if the shutdown feature is not used.

5. Soft start

ELM613xxC has built-in soft start of 2 msec. During the soft start period, output voltage is ramped up linearly to the regulation level, independent of the load current and output capacitor value. SS pin allows user control of output voltage ramp rate during start-up. An internal 10μA pull-up current from VCC on this pin allows a capacitor to program output voltage slew rate. The soft start time with different capacitor is below:

$$\text{Tss} = \frac{0.8\text{V} \times \text{Css}}{10\mu\text{A}} \times 1000, \quad \text{here Css} > 0.025\mu\text{F}$$

6. Current limit and hiccup mode

ELM613xxC has built-in cycle-by-cycle current limit protection to prevent inductor current from running away in any fault conditions. ELM613xxC continuously monitors the inductor valley current during its operation. Once the valley current exceeds the limit level, ELM613xxC will turn on LS and wait for the inductor current to drop down to a pre-determined level before the HS can be turned on again. If this current limit condition is repeated for a sustained long period of time, ELM613xxC will enter hiccup mode, where it stop switching for a pre-determined period of time before automatically re-try to start up again. It always starts up with soft-start to limit inrush current and avoid output overshoot.

When ELM613xxC enters valley current limit mode, the peak current is also limit due to the fixed on-time of the HS, and this peak current can be estimated as:

$$\text{Ipeak} = \text{Ivalley} + \text{Ton} \times \frac{\text{Vin - Vout}}{\text{L}}$$

■Application information

1. Setting the output voltage

External feedback resistors are used to set the output voltage. 1% resistors are recommended to maintain output voltage accuracy. Refer to typical application circuit on page1, the top feedback resistor R1 has some impact on the loop stability, R1 recommended range is between 10kΩ~150kΩ. For any chosen R1, the bottom feedback resistor R2 can be calculated as:

$$R2 = \frac{R1}{\frac{Vout}{0.8} - 1}$$

2. Inductor

The inductor is necessary to supply constant current to the output load while being driven by the switched input voltage. A larger-value inductor will result in less ripple current that will result in lower output ripple voltage. However, a larger-value inductor will have a larger physical footprint, higher series resistance, and/or lower saturation current. A good rule for determining the inductance value is to design the peak-to-peak ripple current in the inductor to be in the range of 30% to 40% of the maximum output current, and that the peak inductor current is below the maximum switch current limit. The inductance value can be calculated by:

$$L = \frac{Vout}{Fsw \times \Delta I_L} \times \left(1 - \frac{Vout}{Vin}\right)$$

Where ΔI_L is the peak-to-peak inductor ripple current.

To avoid overheating and poor efficiency, an inductor must be chosen with an RMS current rating that is greater than the maximum expected output load of the application. In addition, the saturation current (typically labeled ISAT) rating of the inductor must be higher than the maximum load current plus 1/2 of in inductor ripple current.

The peak inductor current can be calculated by:

$$I_{LP} = Iout + \frac{Vout}{2Fsw \times L} \times \left(1 - \frac{Vout}{Vin}\right)$$

3. Input capacitor

The input current to the step-down converter is discontinuous and therefore requires a capacitor to supply the AC current to the step-down converter while maintaining the DC input voltage. Ceramic capacitors are recommended for best performance and should be placed as close to the VIN pin as possible. Capacitors with X5R and X7R ceramic dielectrics are recommended because they are fairly stable with temperature fluctuations. The capacitors must also have a ripple current rating greater than the maximum input ripple current of the converter. The input ripple current can be estimated as follows:

$$Icin = Iout \times \sqrt{\frac{Vout}{Vin} \times \left(1 - \frac{Vout}{Vin}\right)}$$

The worst-case condition occurs at Vin = 2*Vout, where:

$$Icin = \frac{Iout}{2}$$

For simplification, choose the input capacitor with an RMS current rating greater than half of the maximum load current. The input capacitance value determines the input voltage ripple of the converter. If there is an input voltage ripple requirement in the system, choose the input capacitor that meets the specification. The input voltage ripple can be estimated as follows:

$$\Delta Vin = \frac{Iout}{Fsw \times Cin} \times \frac{Vout}{Vin} \times \left(1 - \frac{Vout}{Vin}\right)$$

Under worst-case conditions where Vin = 2*Vout:

$$\Delta Vin = \frac{1}{4} \times \frac{Iout}{Fsw \times Cin}$$

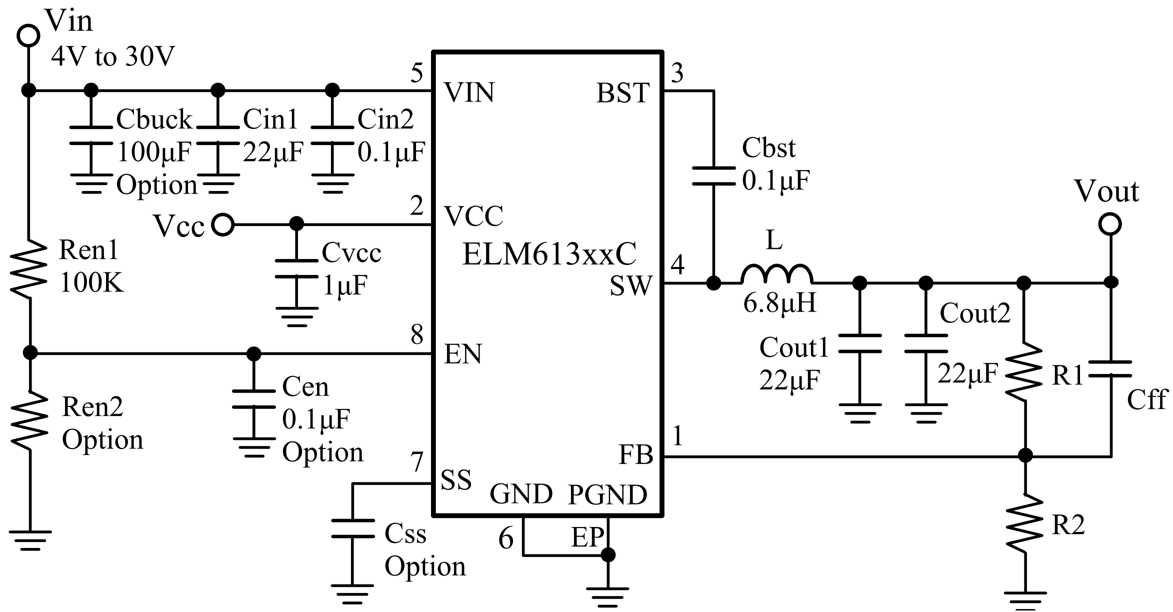
4. Output capacitor

The output capacitor has two essential functions. Along with the inductor, it filters the square wave generated by the ELM613xxC to produce the DC output. In this role it determines the output ripple, thus low impedance at the switching frequency is important. The second function is to store energy in order to satisfy transient loads and stabilize the ELM613xxC's control loop. X5R or X7R type ceramic capacitors have very low equivalent series resistance (ESR) and provide low output ripple and good transient response. Transient performance can be improved with a higher value output capacitor and the addition of a feed-forward capacitor placed between Vout and FB. Increasing the output capacitance will also decrease the output voltage ripple. A lower value of output capacitor can be used to save space and cost but transient performance will suffer and may cause loop instability. When choosing a capacitor, special attention should be given to the data sheet to calculate the effective capacitance under the relevant operating conditions of voltage bias and temperature. A physically larger capacitor or one with a higher voltage rating may be required.

5. PCB Layout instruction

(1) The high current paths (PGND, VIN, and SW) should be placed very close to the device with short, direct and wide traces.
(2) Put the input capacitors as close to the VIN and PGND pins as possible.
(3) Put the decoupling capacitor as close to the VCC and PGND pins as possible. If necessary to use VIA, place 3 or more VIAs to reduce the parasitic inductance of the VIA.
(4) Keep the switching node SW short and away from the feedback network.
(5) The external feedback resistors should be placed next to the FB pin, which is a high-impedance node.
(6) Keep the BST voltage path (BST, Cbst and SW) as short as possible.
(7) Keep the VIN and PGND pads connected with large copper and use at least two layers for VIN and PGND trace to achieve better thermal performance. Also, add several Vias with 10mil_drill/18mil_copper_width close to the VIN and PGND pads to help on thermal dissipation.
(8) Four-layer layout is strongly recommended to achieve better thermal performance.

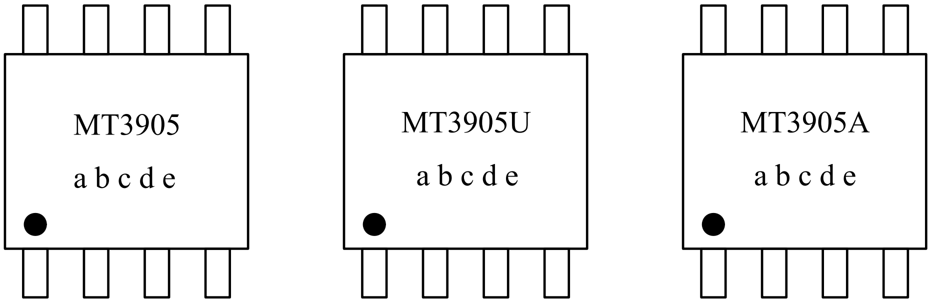
■Application schematic



Application schematic BOM list

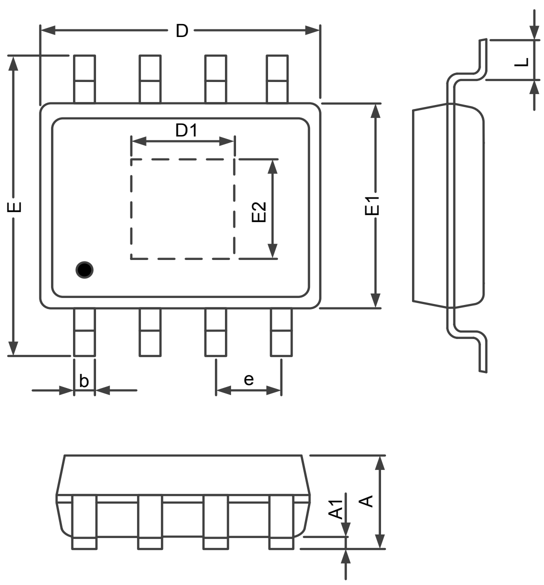
Qty	Ref	Value		Description	Package (size inch)
1	Cin1	22μF		Ceramic capacitor, 50V, X5R	1206
1	Cin2	0.1μF		Ceramic capacitor, 50V, X5R	0603
1	Cbuck	100μF (Option, see Pin configuration item-5)		Electrolytic capacitor, 50V	8×12(mm)
2	Cout	22μF		Ceramic capacitor, 16V, X5R	1206
1	Cbst	0.1μF		Ceramic capacitor, 10V, X5R	0603
1	Cvcc	1μF		Ceramic capacitor, 10V, X5R	0603
1	Css	(Option, see Operation item-5)		Ceramic capacitor, 10V, X5R	0603
1	Cen	0.1μF(Option, for delayed EN)		Ceramic capacitor, 50V, X5R	0603
1	L	Vout=5.0V	6.8μH	Inductor, Isat>6A	SMD
		Vout=3.3V	4.7μH		
1	R1	Vout=5.0V	120KΩ	Resistor, ±1%	0603
		Vout=3.3V	120KΩ		
1	R2	Vout=5.0V	22.6KΩ	Resistor, ±1%	0603
		Vout=3.3V	38.3KΩ		
1	Cff	Vout=5.0V	10~47pf	Ceramic capacitor, 10V	0603
		Vout=3.3V	10~47pf		
1	Ren1	100KΩ		Resistor, ±5%	0603
1	Ren2	(Option, see Operation item-4)		Resistor, ±5%	0603
1	Power IC	ELM613xxC		Step-down DC/DC converter	SOP-8 DFN14-4x3

■SOP-8 Marking



Mark	Content
MT3905	Product ID: ELM613NDC
MT3905U	Product ID: ELM613UDC
MT3905A	Product ID: ELM613ADC
a to e	Assembly lot No.

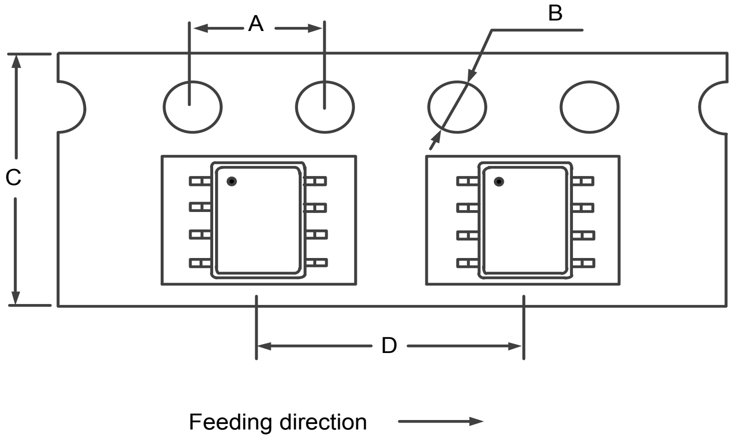
■SOP-8 Outline dimensions



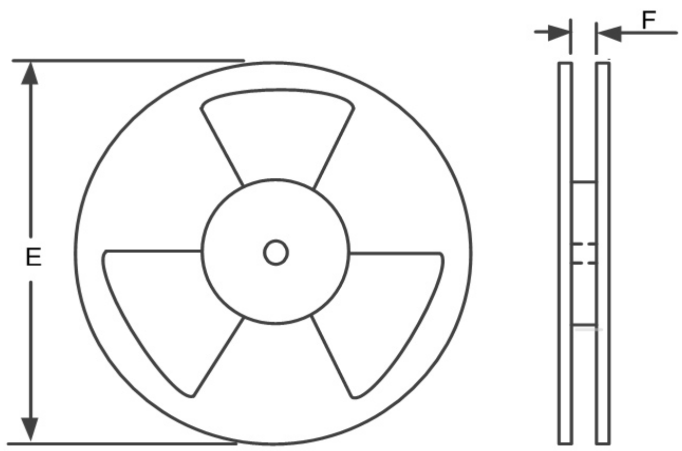
Symbol	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	1.35	1.75	0.053	0.069
A1	0.00	0.15	0.000	0.006
D	4.70	5.10	0.185	0.200
E1	3.70	4.10	0.145	0.161
D1	2.90	3.50	0.114	0.138
E2	2.00	2.50	0.080	0.098
E	5.80	6.20	0.228	0.244
L	0.40	1.27	0.016	0.050
b	0.31	0.51	0.012	0.020
e	1.16	1.37	0.046	0.054

■SOP-8 Reel & carrier tape dimension

• Orientation / Carrier tape information



• Reel information



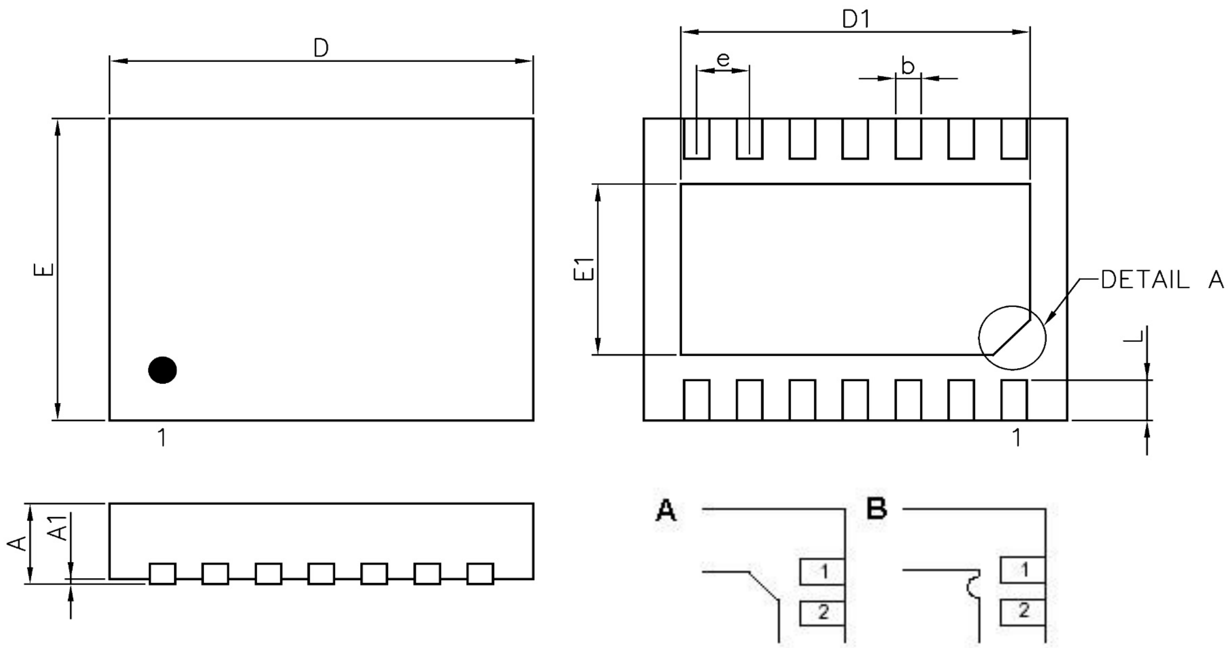
• Dimension details

PKG Type	A	B	C	D	E	F	Q'ty/Reel
SOP-8	4.0 mm	1.5 mm	12.0 mm	8.0 mm	13 inches	13.0 mm	2,500

■DFN14-4x3 Marking

Mark	Content
MT3905	Product ID: ELM613NGC
a to e	Assembly lot No.

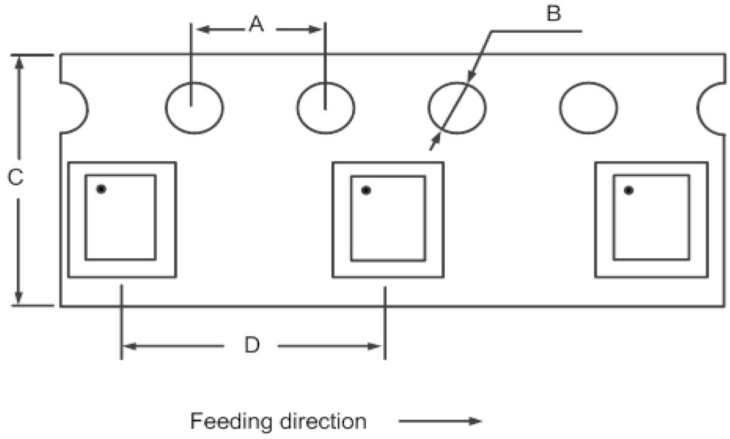
■DFN14-4x3 Outline dimensions



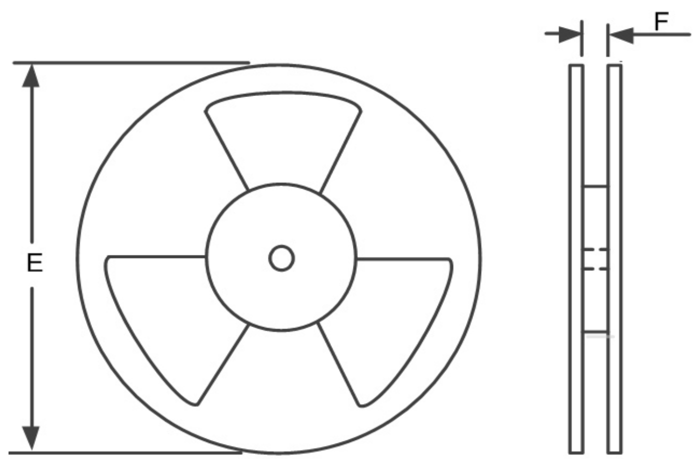
Symbol	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A	0.70	0.80	0.028	0.031
A1	0.00	0.05	0.000	0.002
b	0.18	0.30	0.007	0.012
D	3.90	4.10	0.154	0.161
D1	3.20	3.40	0.126	0.134
E	2.90	3.10	0.114	0.122
E1	1.60	1.80	0.063	0.071
e	0.50		0.020	
L	0.30	0.50	0.012	0.020

■Reel & carrier tape dimension

• Orientation / Carrier tape information



• Reel information



• Dimension details

PKG Type	A	B	C	D	E	F	Q'ty/Reel
DFN14-4x3	4.0 mm	1.5 mm	12.0 mm	8.0 mm	13 inches	13.0 mm	5,000