AS1302

Data Sheet

5V/30mA Adaptive Inductorless Boost Converter

1 General Description

The AS1302 is a 30mA inductorless boost converter using a double H-bridge charge-pump topology with two external flying capacitors. The AS1302 charge pump features 1:2 and 2:3 operation modes as well as a 1:1 operation mode where the input is directly connected to the output.

The AS1302 runs on a 1.2MHz fixed frequency and is utilized with a low noise regulation scheme to allow usage together with sensitive RF circuitry from the same battery supply. Additionally to increase efficiency the AS1302 switches to 49kHz at light loads.

Designed to reside in portable and space limited equipment the 1.2MHz charge pump converts a 2.9V to 5.15V input to regulated 5V output with 3% accuracy.

The shutdown function reduces the supply current to <1µA and disconnects the load from the output. The integrated soft-start circuitry prevents high inrush currents being drawn from the battery during start-up.

The AS1302 includes built-in under-voltage lockout, short circuit-, and thermal protection circuitry.

The AS1302 is available in TDFN (3x3x0.8mm) 10-pin and an extremely small 1.2x1.2mm WL-CSP 8-bumps package with 0.4mm pitch.

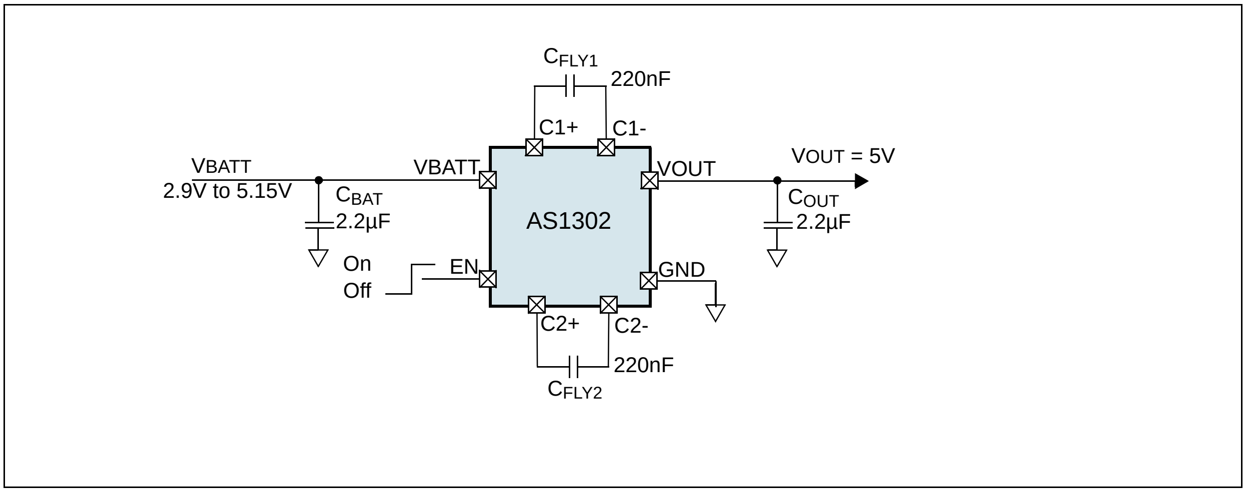
2 Key Features

- Up to 90% Efficiency
- 2.9V to 5.15V Input Voltage
- Regulated 5V Output
- Automatic Mode Switching
- <1µA Shutdown Current
- Startup with Full Load (within 1ms)
- Up to 30mA Load Current
- Short Circuit Protection
- Output Disconnected During Shutdown
- Soft-Start
- No Inductor Required
- Small External Components Required (C_{OUT} =2.2µF, C_{FLY} =220nF)
- Low Noise Fixed Frequency (1.2MHz, 49kHz) Charge Pump:
  - 1:1 Battery Feed Through Mode
  - 2:3 Single Phase Mode
  - 1:2 Single Phase Mode
- Package Options:
  - TDFN (3x3x0.8mm) 10-pin
  - WL-CSP 8-bumps with 0.4mm Pitch

3 Applications

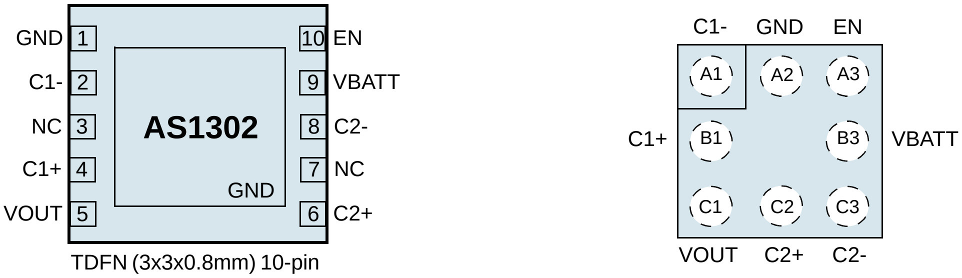
The device is ideal for two or three AA cells or a single Li-Ion battery cell to 5V conversion, mobile phones, portable instruments, microprocessor based systems and remote data-acquisition systems.

Figure 1. Typical Application Diagram



4 Pin Assignments

Figure 2. Pin Assignments (Through View)



Pin Descriptions

Table 1. Pin Descriptions

Pin Name	Pin Number	Description
C1-	A1	**Connector 1-.** Negative terminal of flying cap 1.
GND	A2	**Ground.**
EN	A3	**Enable.** (operating if EN = 1). Set this digital input to logic high for normal operation. For shutdown, set to logic low.
C1+	B1	**Connector 1+.** Positive terminal of flying cap 1.
VBATT	B3	**+2.9V to 5.15V Input Voltage.** Bypass this pin to GND with a ≥2.2µF low ESR ceramic capacitor.
VOUT	C1	**+5V Output Voltage.** This pin must be bypassed with a ≥2.2µF low ESR ceramic capacitor.
C2+	C2	**Connector 2+.** Positive terminal of flying cap 2.
C2-	C3	**Connector 2-.** Negative terminal of flying cap 2.

5 Absolute Maximum Ratings

Stresses beyond those listed in Table 2 may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in Section 6 Electrical Characteristics on page 4 is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 2. Absolute Maximum Ratings

Parameter	Min	Max	Units	Notes
All pins to GND	-0.3	+7.0	V	
Operating Temperature Range	-40	+85	ºC	
Storage Temperature Range	-65	+125	ºC	
ESD	2		kV	*HBM MIL-Std. 883E 3015.7* methods
	500		V	*CDM JESD22-C101C* methods
Package Body Temperature	+260		ºC	The reflow peak soldering temperature (body temperature) specified is in accordance with *IPC/JEDEC J-STD-020C “Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices”.* The lead finish for Pb-free leaded packages is matte tin (100% Sn).

6 Electrical Characteristics

V_{BATT} = 2.9V to 5.15V, V_{OUT} = 5V, C_{OUT} = C_{BAT} = 2.2µF, C_{FLY1} = C_{FLY2} =220nF, T_{AMB} = -40 to +85ºC. Typical values are at T_{AMB} = +25ºC and V_{IN} = 3.3V, unless otherwise specified.

Table 3. Electrical Characteristics

Symbol	Parameter	Conditions	Min	Typ	Max	Units
$V_{BATT(on)}$	Undervoltage Lockout	Rising V_{BATT}		2.8	2.9	V
$V_{BATT(off)}$	Undervoltage Lockout	Falling V_{BATT}	2.4	2.5	2.8	V
V_{BATT}	Battery Supply Voltage		2.9		5.15	V
V_{OUT}	Output Voltage Accurracy	I_{OUT} = 0mA, 15mA	4.85	5.0	5.15	V
$\Delta V_O/\Delta I_{O11}$	Load Regulation in 1:1 Mode	V_{BATT} = 5.4V, I_{OUT} = 10~30mA		2		mV/mA
$\Delta V_O/\Delta I_{O23}$	Load Regulation in 2:3 Mode	V_{BATT} = 4.3V, I_{OUT} = 10~30mA		3		
$\Delta V_O/\Delta I_{O12}$	Load Regulation in 1:2 Mode	V_{BATT} = 3.3V, I_{OUT} = 10~30mA		3		
$V_{tgr11/23}$	Mode Switching Voltage	1:1 / 2:3 mode, falling V_{BATT}		5.1		V
$V_{tgr23/12}$		2:3 / 1:2 mode, falling V_{BATT}		3.6		
		Mode switching voltage hysteresis		150		mV
I_{OUT}	Load Current[1]				30	mA
V_{ripple}	Output Voltage Ripple	V_{BATT} = 3.6V, I_{OUT} = 30mA		22		mV_{PP}
		V_{BATT} = 3.6V, I_{OUT} = 2mA		40		mV_{PP}
I_{inr}	Inrush Current[2]				150	mA
I_{short}	Short-Circuit Current				150	mA
η_{12}	Efficiency in Switching Mode	1:2 mode, V_{BATT} = 2.9V, I_{OUT} = 30mA		85		%
η_{23}		2:3 mode, V_{BATT} = 3.8V, I_{OUT} = 30mA		85		%
I_{OP12}	Operating Quiescent Current	V_{BATT} = 3.4V (1:2 mode without load)		240	300	µA
I_{OP23}		V_{BATT} = 4.5V (2:3 mode without load)		170	230	
I_{OP11}		V_{BATT} = 5.3V (1:1 mode without load)		100	150	
I_{OFF}	Shutdown Current	EN = 0V		0.01	1	µA
Input Levels						
V_{IH}	Input High Level	pin EN	1.1		5.5	V
V_{IL}	Input Low Level		0.0		0.4	V
Timing						
f_{OSC}	Oscillator Frequency	V_{BATT} = 3.6V, I_{OUT} = 30mA	0.9	1.2	1.5	MHz
		V_{BATT} = 3.6V, I_{OUT} = 2mA	40	49	65	kHz
t_{START}	Startup Time			0.5	1	ms
Thermal Regulation						
T_{OFF}	Temperature Shutdown	Temperature rising		145		ºC
		Hysteresis		10		

1. The device is tested in a proprietary test mode.
2. The inrush current is limited by the internal soft-start circuitry.

7 Typical Operating Characteristics

V_{BATT} = 3.3V, V_{OUT} = 5V, C_{OUT} = C_{BAT} = 2.2µF, C_{FLY1} = C_{FLY2} =220nF, T_{AMB} = +25ºC, unless otherwise specified.

Figure 3. Efficiency vs. Input Voltage; I_{LOAD} = 1mA

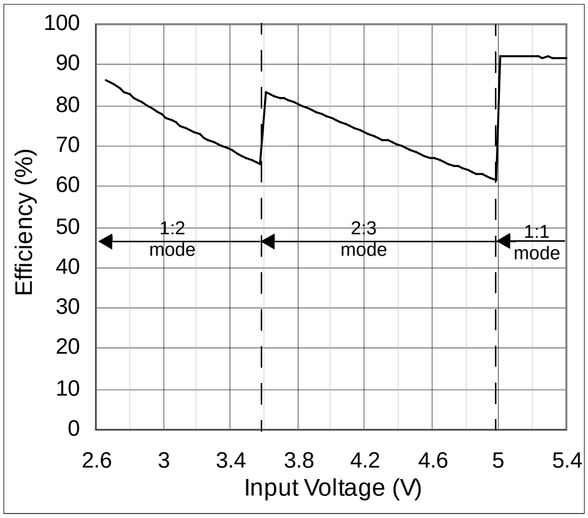


Figure 4. Efficiency vs. Input Voltage; I_{LOAD} = 10mA

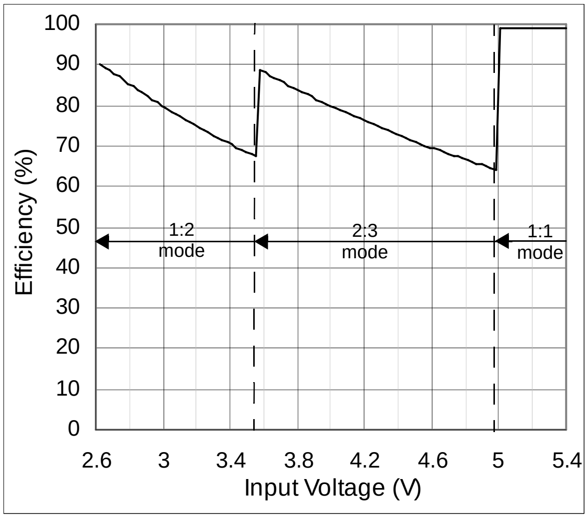


Figure 5. Efficiency vs. Input Voltage; I_{LOAD} = 20mA

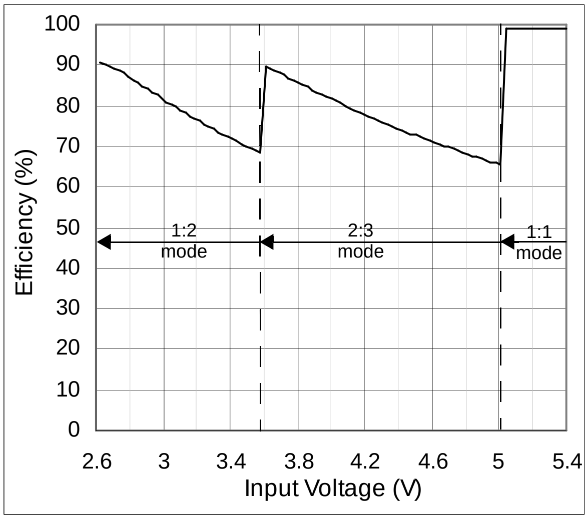


Figure 6. Efficiency vs. Input Voltage; I_{LOAD} = 30mA

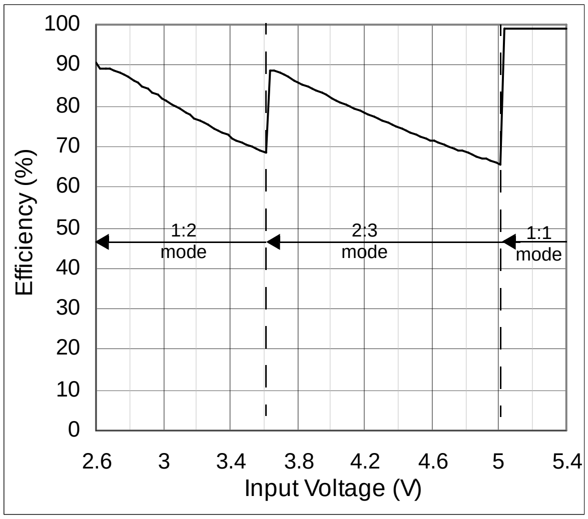


Figure 7. Quiescent Current vs. Input Voltage

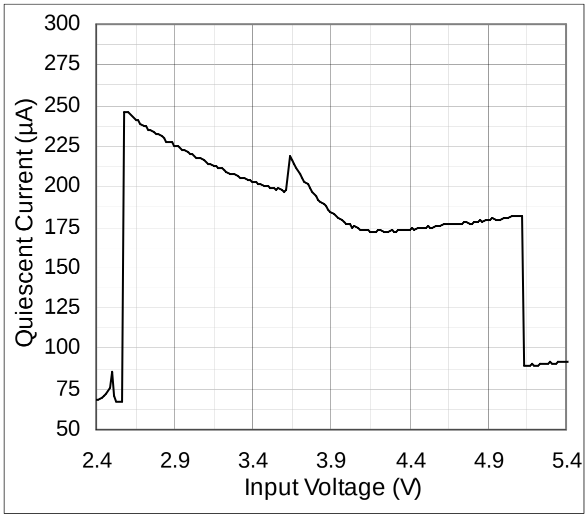


Figure 8. Quiescent Current vs. Temperature

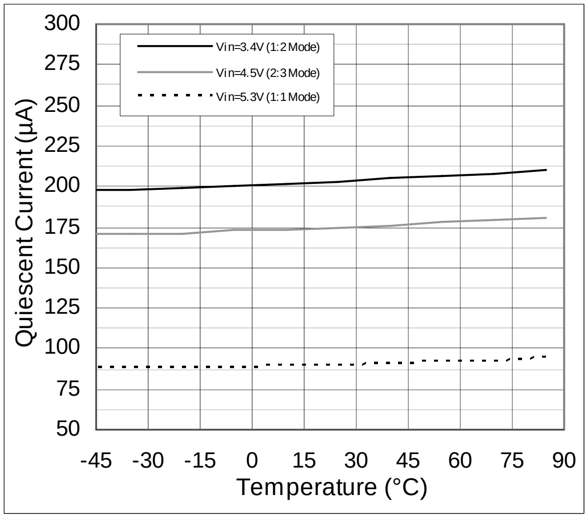


Figure 9. Efficiency vs. Output Current; VBATT = 2.9V

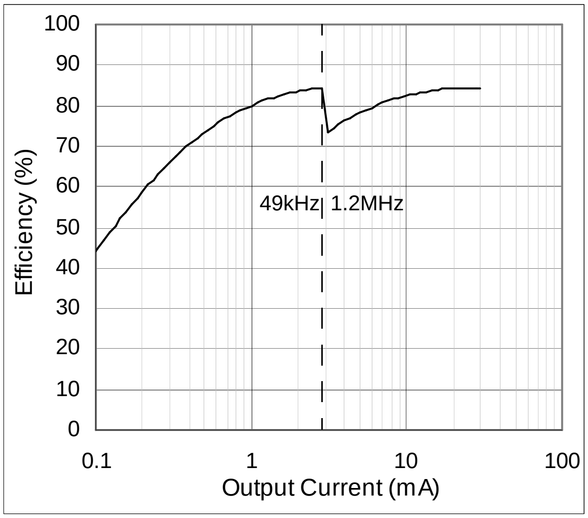


Figure 10. Efficiency vs. Output Current; VBATT = 3.3V

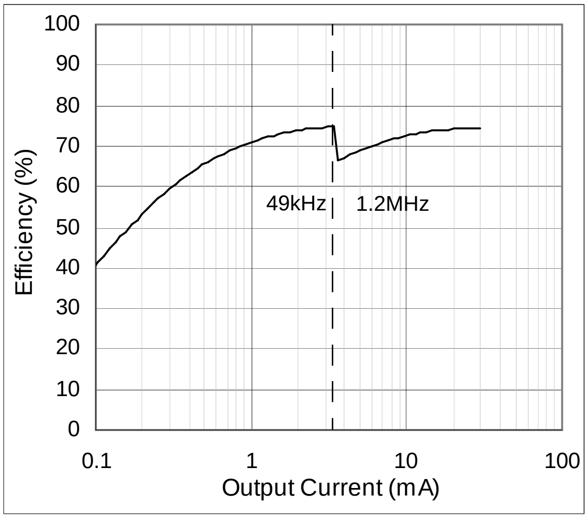


Figure 11. Efficiency vs. Output Current; VBATT = 3.6V

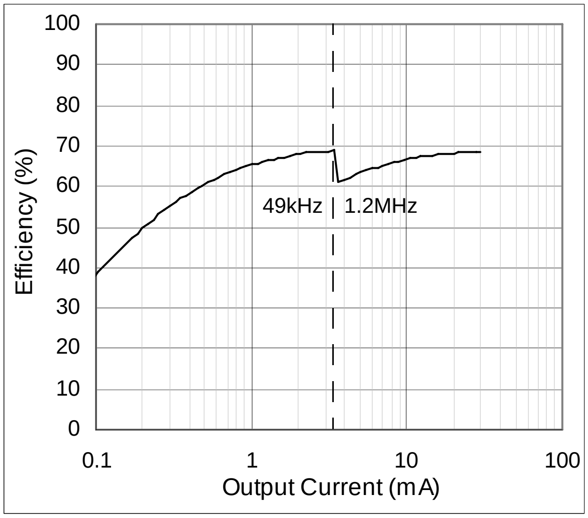


Figure 12. Efficiency vs. Output Current; VBATT = 4V

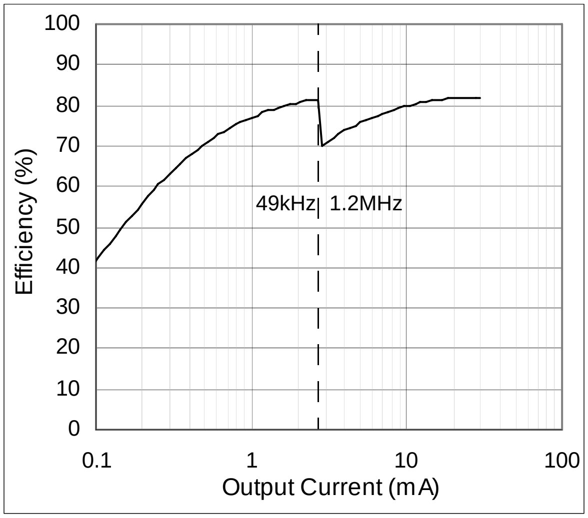


Figure 13. Efficiency vs. Output Current; VBATT = 4.3V

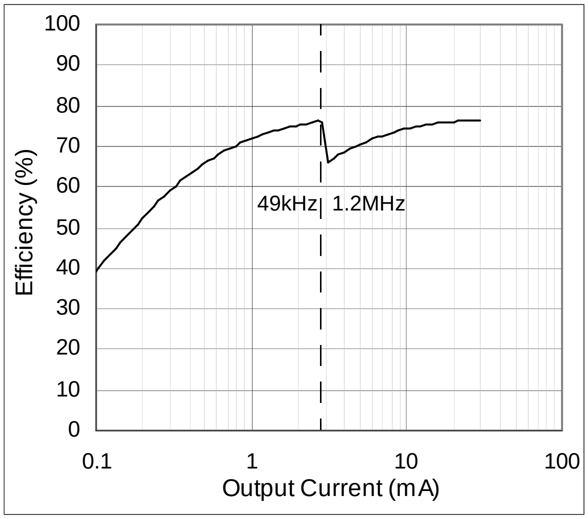


Figure 14. Efficiency vs. Output Current; VBATT = 5.4V

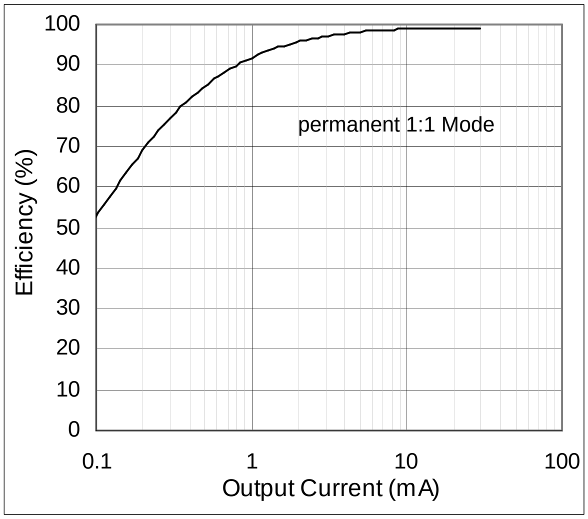


Figure 15. Output Voltage vs. Output Current

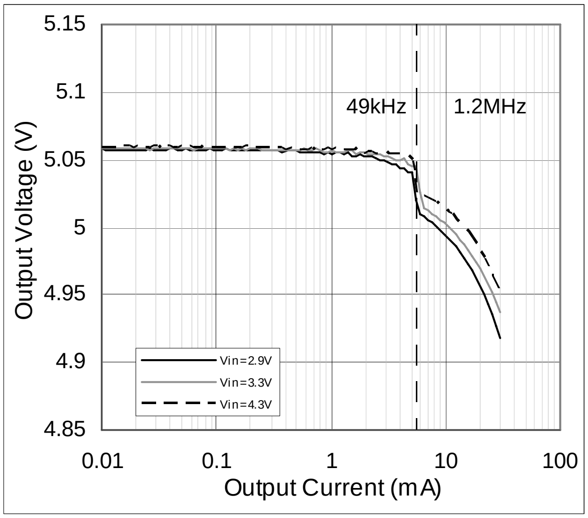


Figure 16. Output Voltage vs. Output Current

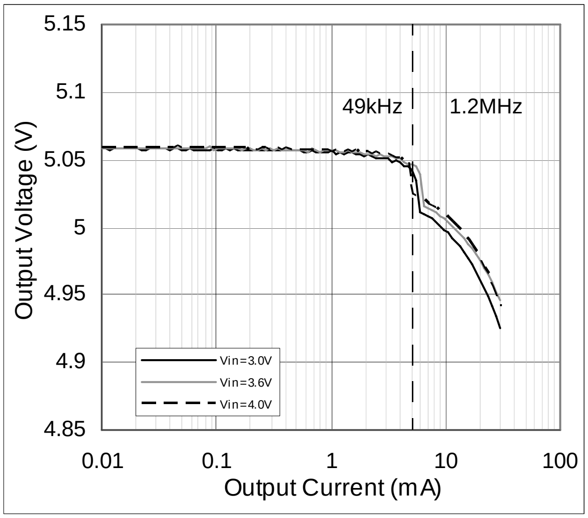


Figure 17. Output Voltage vs. Input Voltage

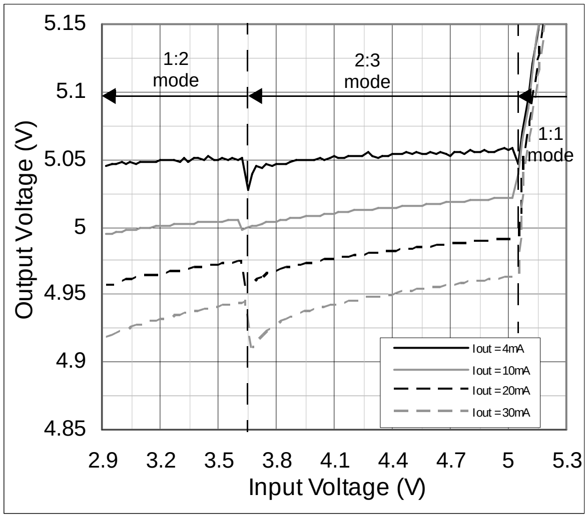


Figure 18. Output Voltage vs. Temperature

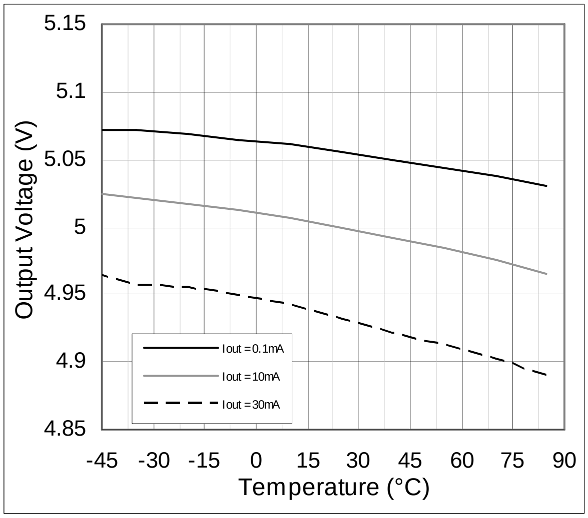


Figure 19. Startup Time vs. Input Voltage; load=166Ω

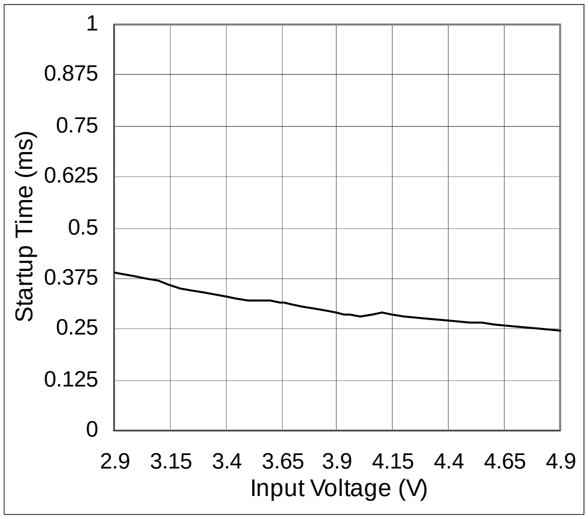


Figure 20. Turn-ON / Turn-OFF Time @ load = 166Ω

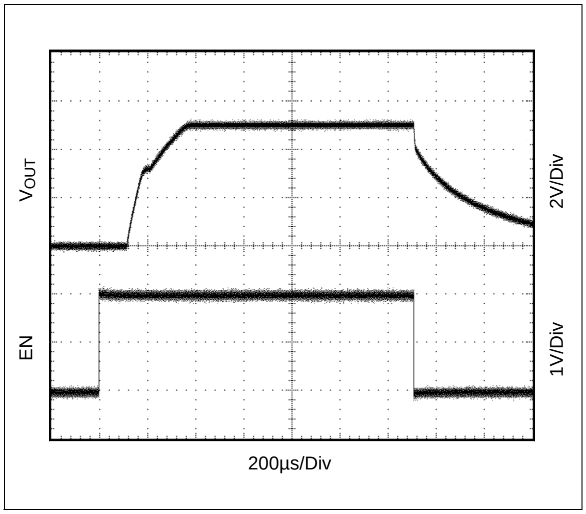


Figure 21. Inrush Current; no load

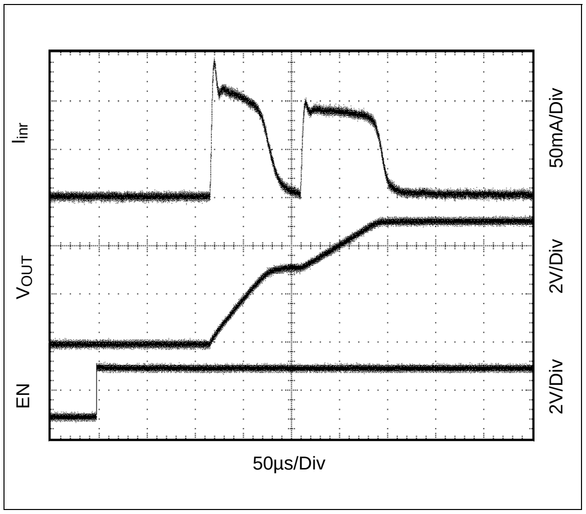


Figure 22. Switching Frequency vs. Input Voltage; I_{OUT} = 2mA

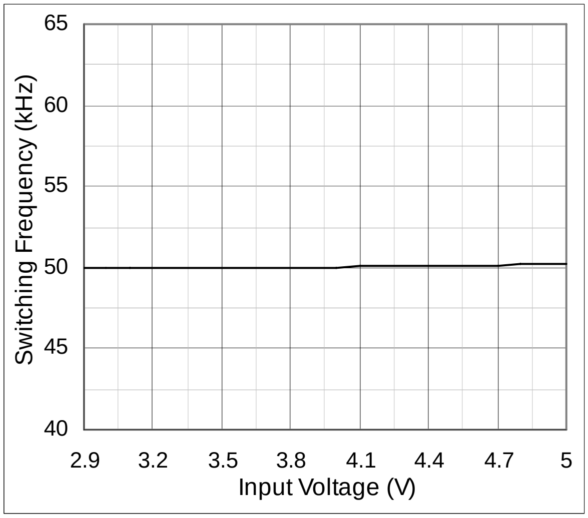


Figure 23. Switching Frequency vs. Input Voltage; I_{OUT} = 20mA

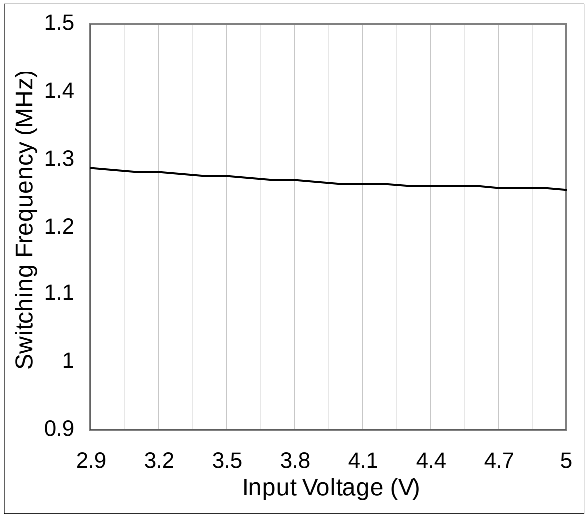


Figure 24. Switching Frequency vs. Temperature; I_{OUT} = 2mA

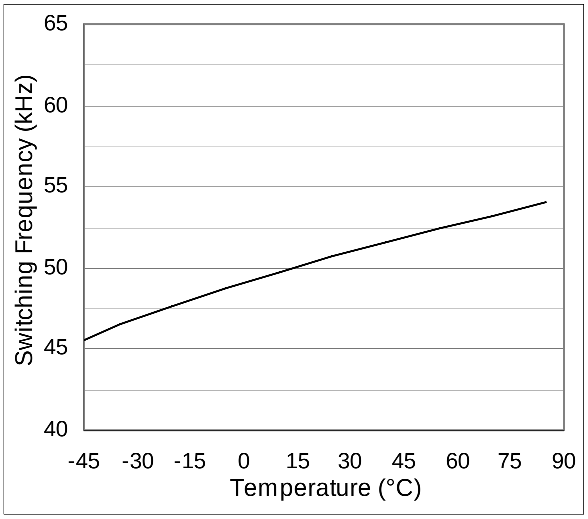


Figure 25. Switching Frequency vs. Temperature; I_{OUT} = 20mA

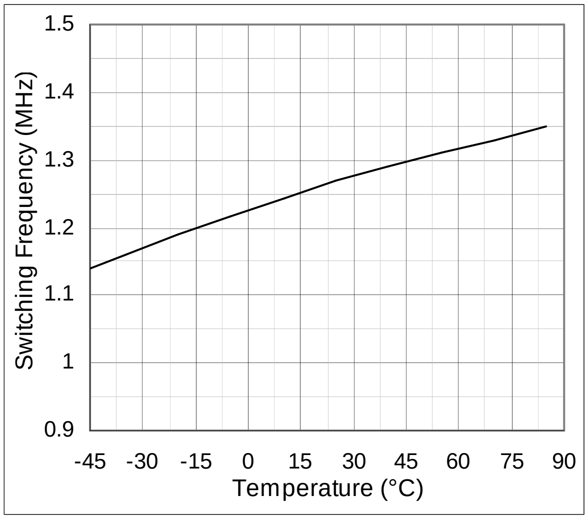


Figure 26. Load Transient; Mode = 1:1, I_{OUT} = 30 to 10 to 30 mA

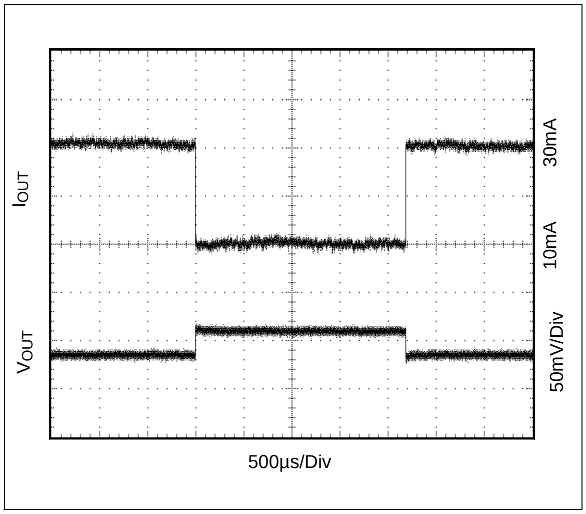


Figure 27. Load Transient; Mode = 2:3, I_{OUT} = 30 to 10 to 30 mA

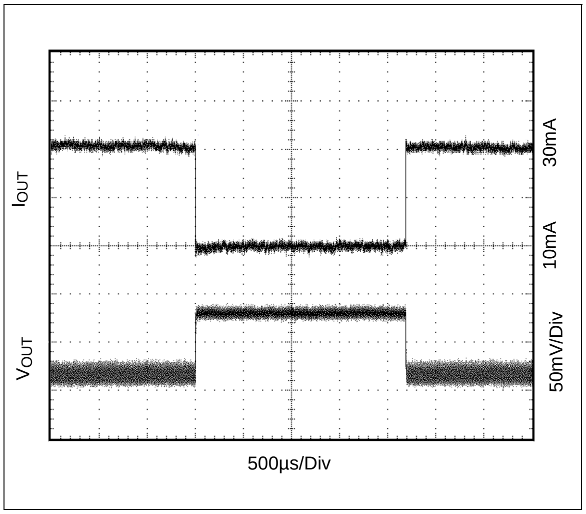


Figure 28. Load Transient; Mode = 1:2, I_{OUT} = 30 to 10 to 30 mA

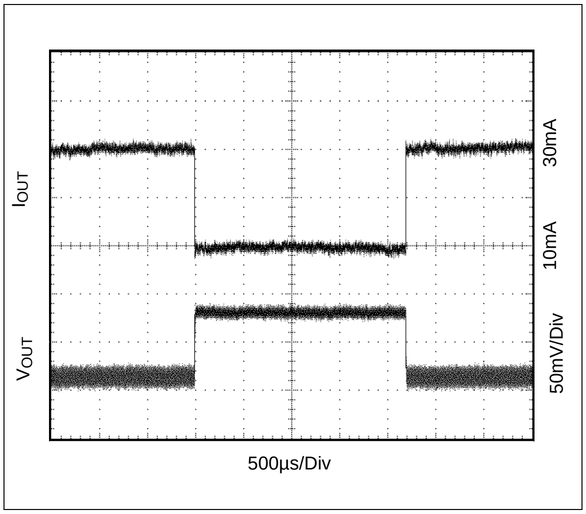


Figure 29. Load Transient; Mode = 1:2, I_{OUT} = 20 to 4 to 20 mA

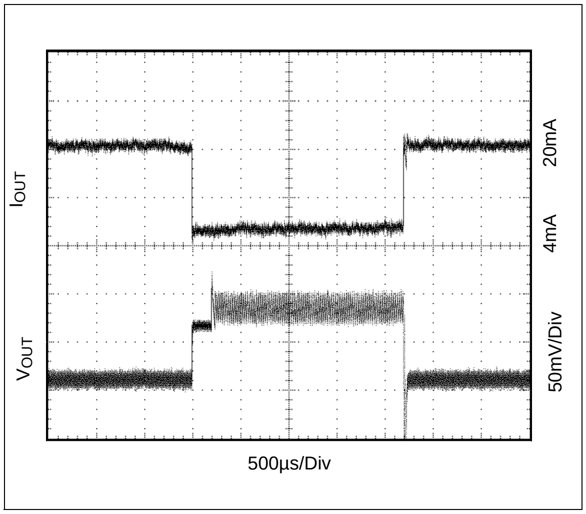


Figure 30. Line Transient

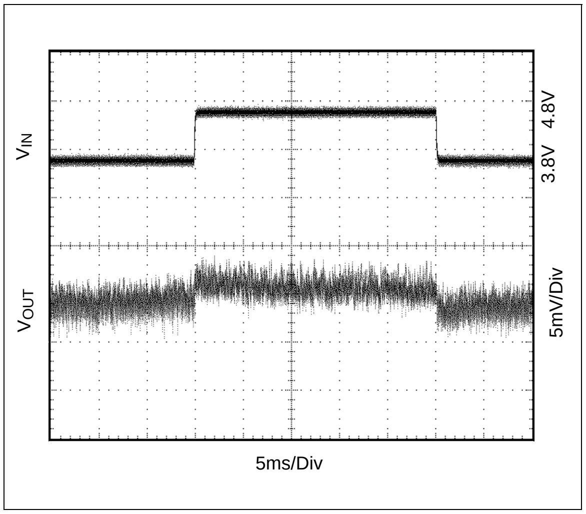
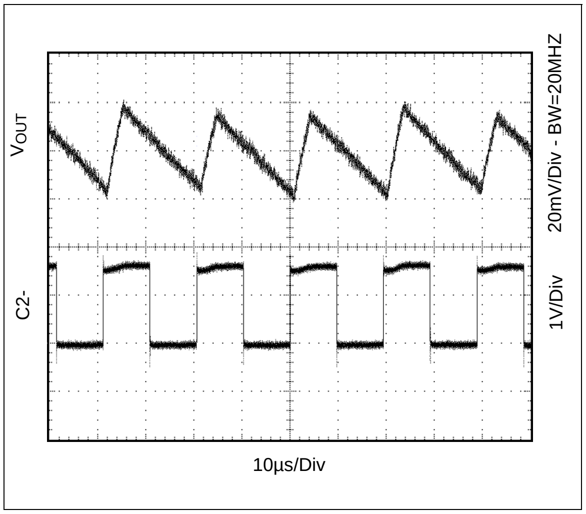


Figure 31. Output Ripple



8 Detailed Description

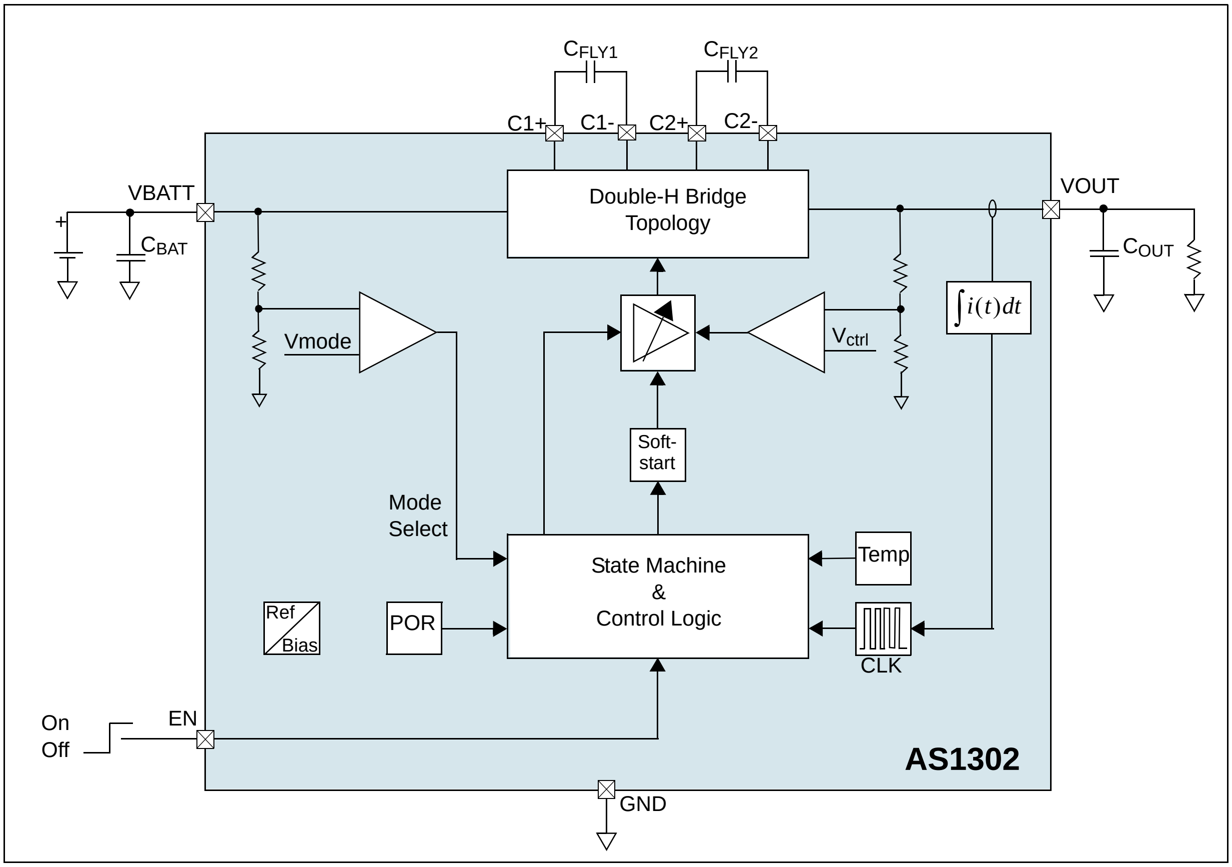
Functional Description

The AS1302 is a high efficiency and low noise switched capacitor DC-DC converter that is capable of boost operation. It is equipped with two built-in coupled H-bridge type switch configurations. Based on the value of the output voltage the system automatically initiates mode-switching to achieve the highest possible efficiency. The regulation of the output voltage is achieved by a regulation loop, which modulates the current drive capability of the power transistors so that the amount of charge transferred from the input to the output at each clock cycle is controlled and is equal to the charge needed by the load.

Regulation Loop

The AS1302 operates at a constant frequency. For the regulation loop power transistors, a resistor divider and an error amplifier are used to keep the output voltage within the allowed limits. The error amplifier takes the feedback and reference signals as inputs and generates the error voltage signal. The error voltage controls a driver that triggers the gate voltage of the power transistor which modulates the current drive capability of the power amplifier. The modulated transistor controls the charge transferred from the input to the output and therefore the regulation of the output is realized. This regulation concept which is based on adjusting the amount of charge transferred, delivers the smallest voltage ripple possible.

Figure 32. Functional Block Diagram



Light/Heavy Load Monitor

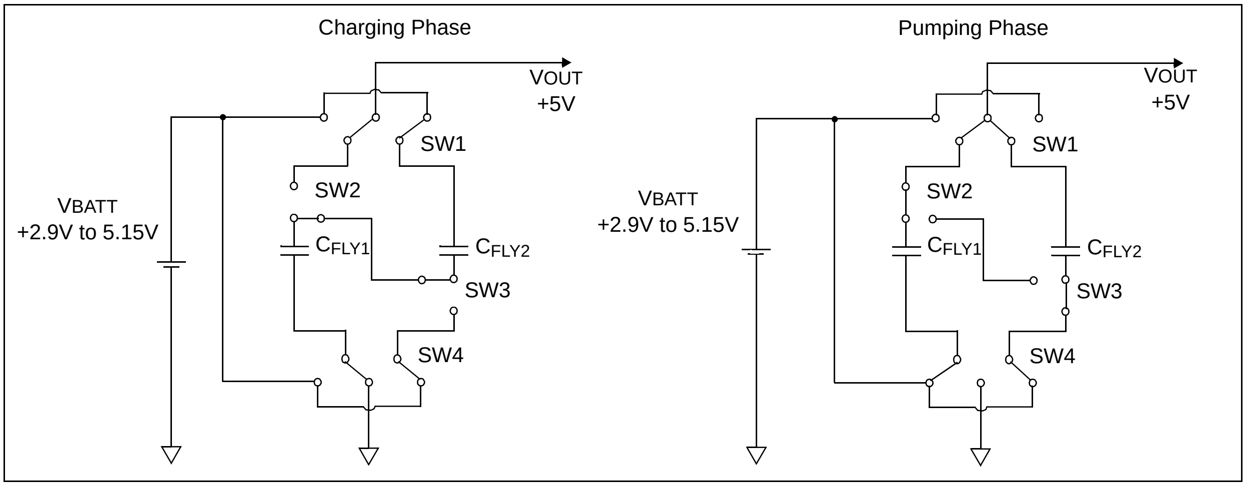
To detetect the output current in the 2:3 and in the 1:2 mode, a current sense is used. The device switches to a lower switching frequency (49kHz typ), due to a detected light-load condition. With this frequency an excellent light-load efficiency is achieved and no audible noise is generated. If the load is increasing (typically more than 3mA), the device operates at 1.2MHz.

Switch Configuration

The AS1302 has nine built-in power switches in the shape of two coupled H-bridge topologies. The system features 1:2 and 2:3 operation modes as well as a 1:1 operation where the input is directly connected to the output.

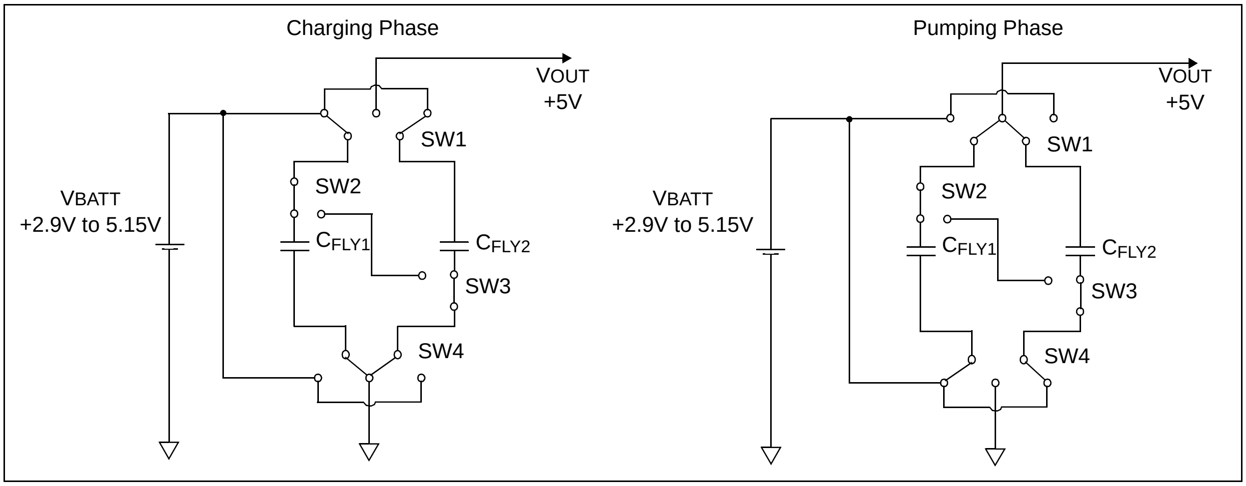
In 2:3 operation mode two flying capacitors are placed in series and each capacitor is charged to the half of the input voltage. In pumping phase the flying capacitors are placed in parallel. The bottom-plates of the parallel flying capacitors C_{FLY1} and C_{FLY2} are connected to the input voltage so that the voltage at the top-plates of the flying capacitors is boosted to a voltage equal to V_{BATT} + V_{BATT}/2. By connecting the top-plates of the capacitors to the output, the output voltage in the 2:3 mode can be up to one and a half of V_{BATT}. If the top-plate voltage is higher than 5V, the regulation loop adapts the power transistor’s on-resistance to drop some voltage.

Figure 33. 2:3 Operating Mode



In 1:2 operation both flying capacitors are placed in parallel to the input voltage, and therefore charged to the input voltage. During pumping phase the input voltage is connected to the bottom of the charged flying capacitors. The voltage at the top-plates of the parallel capacitors is now boosted to $2V_{BATT}$. By connecting the top-plates of the capacitors to the output, the output can be charged to twice the voltage of V_{BATT}. If the top-plate voltage is higher than 5V the regulation loop limits the charge transfer to the output.

Figure 34. 1:2 Operating Mode



Soft-start

The soft-start circuit prevents the supply from high inrush currents caused by the converter's power-up sequence. During the soft-start (0.5ms typ) the device limits the inrush current. The device is capable to power-up at the minimum specified battery voltage and with the maximum load (ohmic equivalent) applied to the output.

Undervoltage Lockout, UVLO

The AS1302 is equipped with an undervoltage lockout functionality. If the battery voltage drops below 2.5V (typ) the device enters the undervoltage lockout condition. The device remains in this condition until the battery voltage is high enough to enter the soft start sequence. An internal hysteresis of 300mV prevents ringing during startup. If the input voltage increases to 2.8V (typ) again after such a condition the device turns-on automatically.

Shutdown Mode

The AS1302 enters low-power shutdown mode when EN is set to logic low. In shutdown the charge-pump action is halted, the output is completely disconnected from the input and VOUT will drop to 0V.

Short-Circuit Protection

Short-circuit protection prevents damage to the device if the output is shorted to ground. Whenever the output voltage is pulled significantly below VBATT, short-circuit protection is triggered and limits the current. As soon as VOUT recovers the protection is released and the device enters soft-start mode.

Thermal Shutdown

The AS1302 offers thermal shutdown, which prevents damage due to an over-temperature condition. Thermal shutdown will be initiated if the junction temperature exceeds 145°C. If the temperature drops below this value, the thermal shutdown will be released automatically and the device resumes operation. A hysteresis prevents the thermal shutdown from oscillating.

Efficiency Consideration

In the 2:3 operation mode the input current of the charge pump is approximately 1.5x the load current. In an ideal charge pump the efficiency can be calculated by:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{BATT} \times 1,5 I_{OUT}} = \frac{V_{OUT}}{1,5 V_{BATT}} \qquad \text{(EQ 1)}$$

The same works for the 1:2 operation mode. The input current of the charge pump is approximately 2x the load current. The efficiency of a charge pump in 1:2 operation mode can be calculated by:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{BATT} \times 2 I_{OUT}} = \frac{V_{OUT}}{2 V_{BATT}} \qquad \text{(EQ 2)}$$

For typical and high output power conditions the quiescent current and the switching losses are negligible and (EQ 1) and (EQ 2) are valid. Hence, with the same input Voltage the 2:3 operation mode will result into a higher efficiency than the 1:2 operation mode.

9 Application Information

External Component Selection

The high internal oscillator frequency of 1.2MHz permits the use of small capacitors for both, the flying capacitors and the output capacitors. For any given load the value of the flying- and output capacitors as well as their ESR are affecting the output voltage performance.

In general, the capacitor's ESR is inversely proportional to its physical size. Larger capacitances and higher voltage ratings tend to reduce ESR. The ESR is a function of the frequency too, so it must be rated at the devices operating frequency. Another factor affecting capacitor ESR is temperature.

Note: Many capacitors have a huge capacity variation over temperature. This can be compensated by choosing a capacitor with a better thermal coefficient or by choosing a larger nominal value to ensure proper operation over temperature.

It is not critical which type of input bypass capacitor CBAT and output filter capacitor COUT is used, but it will affect the performance of the charge pump. Low ESR capacitors should be used to minimize VOUT ripple. Multi-layer ceramic capacitors are recommended since they have extremely low ESR and are available in small footprints.

Input Capacitor

A 2.2µF input bypass low ESR capacitor such as tantalum or ceramic is recommended to reduce noise and supply transients. During startup and mode change it supplies a part of the peak input current drawn by the device.

Output Capacitor

The output capacitor is charged to VOUT during the pumping phase. The ESR of the output capacitor introduces spikes in the output voltage waveform whenever the charge pump charges COUT. These spikes contribute to the ripple voltage of VOUT. Therefore, ceramic or tantalum low ESR capacitors are recommended for COUT to minimize the output voltage ripple.

Table 4. Recommended Input and Output Capacitors

Part Number	C	TC Code	Rated Voltage	Dimensions	Manufacturer
GRM188R61C225KE15	2.2µF	X5R	16V	0603	Murata www.murata.com
GRM21BR71E225KA73	2.2µF	X7R	25V	0805	
GRM188R60J475KE19	4.7µF	X5R	6.3V	0603	
GRM188R60J106ME47	10µF	X5R	6.3V	0603	

Figure 35. Load Regulation Comparision with different Capacitors

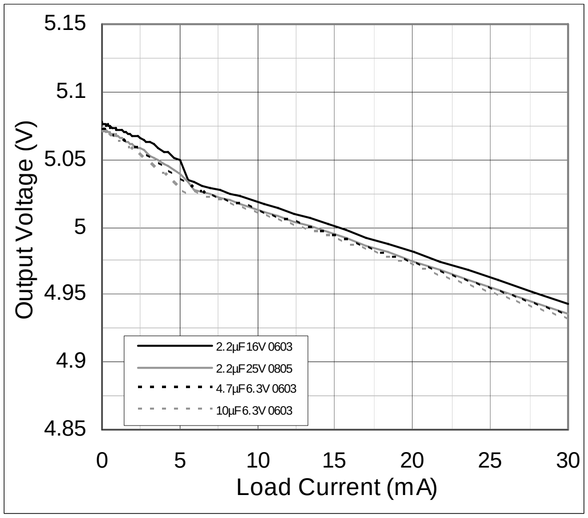
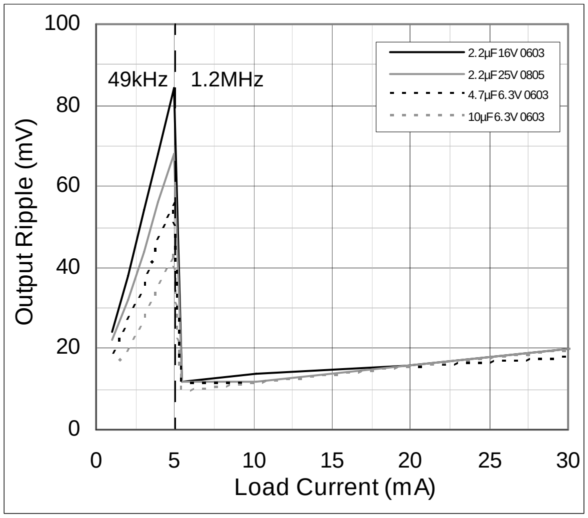


Figure 36. Output Ripple vs. Output Current Comparision with different Capacitors



Flying Capacitor Selection

To ensure the required output current and avoid high peak currents the values of the flying capacitors C_{FLY1} and C_{FLY2} are very critical. A 220nF capacitor is sufficient for most applications. Dependent on the operation mode the AS1302 alternately charges and discharges the $C_{FLY1/2}$. While the ESR of the output capacitor produces a part of the output voltage ripple, the ESR of the flying capacitors directly adds to the charge pump's output source resistance. Therefore low ESR capacitors, e.g. tantalum or ceramic, are recommended for the flying capacitors as well.

Due to different materials for ceramic capacitors the on the material depending temperature and voltage coefficients have to be considered. The capacitance of a X7R ceramic capacitor is more stable than a Z5U or Y5V ceramic capacitor over the whole temperature range from -40°C to +85°C. As an additional effect a Z5U or Y5V ceramic capacitor will loose about the half of his nominal capacitance when the rated voltage is applied.

It is important to choose the ceramic capacitor according to the minimum available capacitance over the operating voltage and the bias voltage. This information is stated in the datasheets of the capacitor manufacturer.

Table 5. Recommended Flying Capacitors

Part Number	C	TC Code	Rated Voltage	Dimensions	Manufacturer
GRM188R71E224KA88	220nF	X7R	25V	0603	Murata www.murata.com
GRM155R61A224KE19	220nF	X5R	10V	0402	

Layout Consideration

To achieve the best performance of the AS1302 a careful board layout is necessary to reduce the impact of the high switching frequency and the high transient currents which are produced by the device. For a proper regulation under all conditions a true ground plane and short connections to all external capacitors are needed.

10 Package Drawings and Markings

The device is available in a TDFN (3x3x0.8mm) 10-pin and *WL-CSP 8-bumps* package.

Figure 37. TDFN (3x3x0.8mm) 10-pin package Diagram

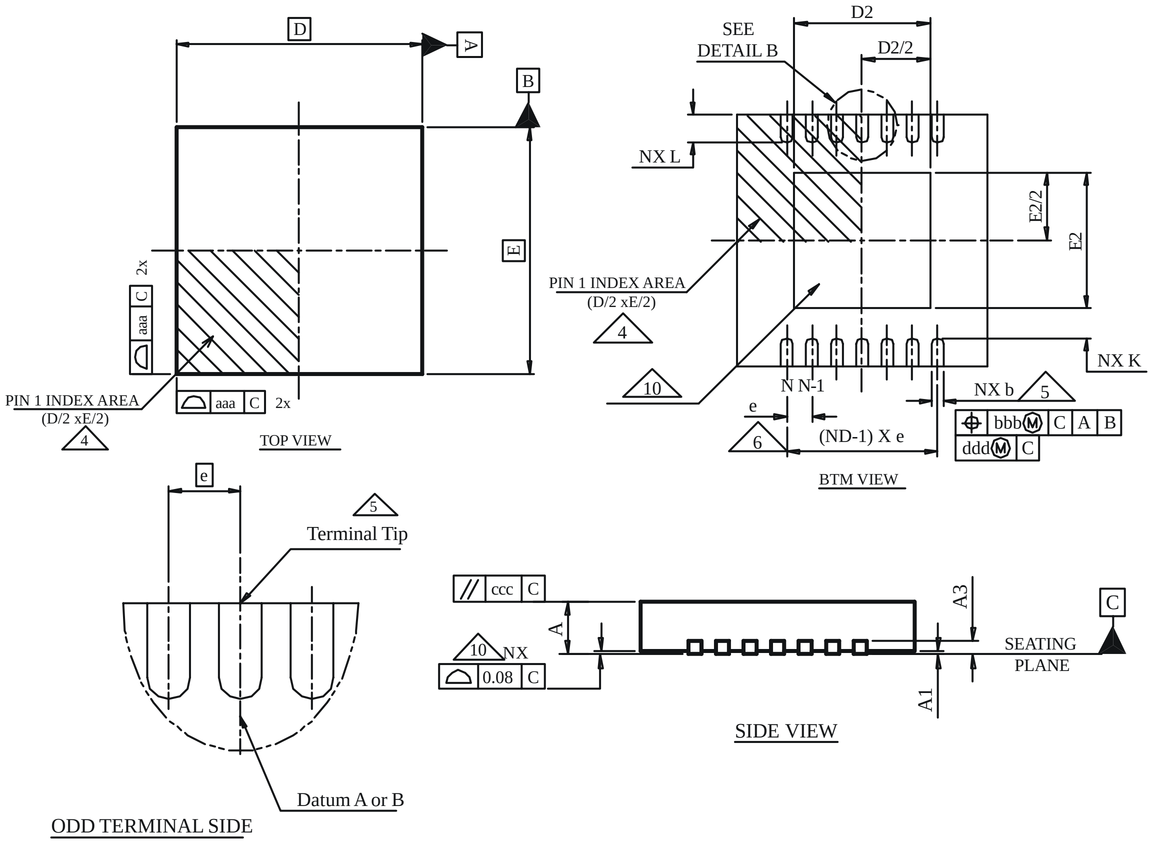


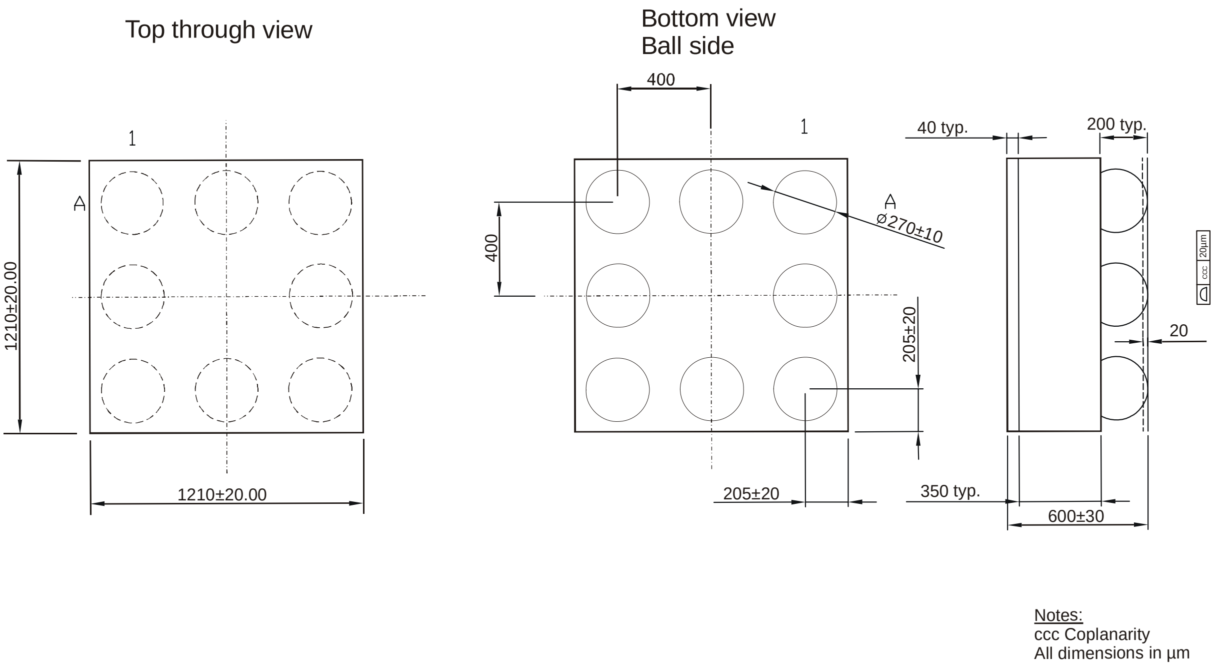
Table 6. TDFN (3x3x0.8mm) 10-pin package Dimensions

Symbol	Min	Typ	Max	Symbol	Min	Typ	Max
A	0.70	0.75	0.80	D BSC		3.00	
A1	0.00	0.02	0.05	E BSC		3.00	
A3		0.20 REF		D2	2.20		2.70
L1	0.03		0.15	E2	1.40		1.75
L2			0.13	L	0.30	0.40	0.50
aaa		0.15		θ	0º		
bbb		0.10		k	0.20		
ccc		0.10		b	0.18	0.25	0.30
ddd		0.05		e		0.50	
eee		0.08		N		10	
ggg		0.10		ND		5	

Note:

1. Dimensioning and tolerancing conform to *ASME Y14.5M-1994*.
2. All dimensions are in millimeters, angle is in degrees.
3. N is the total number of terminals.

Figure 38. WL-CSP 8-bumps Package Diagram



11 Ordering Information

Table 7. Ordering Information

Part	Marking	Description	Delivery Form	Package
AS1302-BWLT	ASQ7	5V/30mA Adaptive Inductorless Boost Converter	T&R	WL-CSP 8-bumps
AS1302-BTDT	ASQ7	5V/30mA Adaptive Inductorless Boost Converter	T&R	TDFN (3x3x0.8mm) 10-pin

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