

# Ultra Efficient Energy Harvester with Battery Management, Buck Converter and 5 V Linear Charger

## General Description

The CE95A04XXX is specifically designed to extract DC energy harvesting, high-impedance sources like photovoltaic(solar) or thermal electric generators (TEGs) without collapsing those sources. 5 V input Linear Charger can also be used to charge the battery (e.g. if the battery gets depleted). This fully integrated and compact power management system allows for extending battery lifetime and eliminating the primary energy storage in a large range of applications.

The CE95A04XXX has a built-in cold-start circuit, it can start operating with an input voltage as low as 275 mV (min. 5  $\mu$ W power), it makes CE95A04XXX to better harvest the energy from those energy harvesting.

There is a boost from the energy harvesting to the battery. The boost can implements voltage regulation of the energy harvesting, allowing for harvesting the maximum efficiency energy harvesting from the source to the battery.

There is a buck regulator with selectable output voltage from the battery which allows an application circuit to be supplied with high efficiency.

CE95A04XXX has abundant analog and digital configurable resources to meet the requirements of various customized functions.

CE95A04XXX can work in shipping mode which can avoid charging and discharging of the storage element during shipping or storage.

## Features

- Cold Start from 275 mV / 5  $\mu$ W Input
  - Startup at Ultra-low Power from Harvesting Source Input
- Selectable Input Regulation Voltage of Boost for Energy Harvesting
  - Up to 110 mA Current Extracted from the Harvester
- Selectable Overdischarge and Overcharge Protection
  - Supports Various Types of Rechargeable Batteries (LiC, Li-ion, LiPo...)
- Selectable Output of Buck for Application Circuit
  - Buck with Efficiency above 90%
  - Output Current up to 135 mA
- System Configuration by GPIO
- Shipping Mode with less than 10 nA Leakage Current of Battery
- 5 V Linear Charger
  - Provide a way for Fast Charging with Pre-Charge/CC/CV Charge Mode when no Source is Available for Long Time

- Part No. and Package Information

Part No.	Package	Packing Option	MSL
CE95A04XXX	DFN10 (3.0 mm×3.0 mm)	Tape and Reel, 3 K/Reel	3

## Applications

- Remote Control
- Portable Device
- Wearable Device
- Wireless Keyboards

## Device Information

CE95A04 X X X

<u>X</u> PV_CELL constant regulation MPPT voltage choice	<u>X</u> Storage element configuration voltage choice	<u>X</u> SYS output voltage choice
See <a href="#">Table 1</a>	See <a href="#">Table 2</a>	See <a href="#">Table 3</a>

Table 1. PV\_CELL constant regulation MPPT voltage choice

<u>X</u> PV_CELL constant regulation MPPT voltage choice			
<u>X</u> Value	V <sub>PV_CELL,REG</sub>	<u>X</u> Value	V <sub>PV_CELL,REG</sub>
0	0.25	G	1.10
1	0.30	H	1.20
2	0.35	I	1.30
3	0.40	J	1.40
4	0.45	K	1.50
5	0.50	L	1.60
6	0.55	M	1.70
7	0.60	N	1.80
8	0.65	O	1.90
9	0.70	P	2.00
A	0.75	Q	2.20
B	0.80	R	2.40
C	0.85	S	2.60
D	0.90	T	2.80
E	0.95	U	3.00
F	1.00	V	3.20

Table 2. Storage element configuration voltage choice

<b>X</b> Storage element configuration voltage choice				
<b>X</b> Value	Overdischarge voltage $V_{BAT\_UVP\_F}$ (V)	Charge ready voltage $V_{BAT\_UVP\_R}$ (V)	Overcharge voltage $V_{BAT\_REG}^{(1)}$ (V)	Pre-Charge/CC Ratio
0	2.46	2.56	3.80	30%
1	3.00	3.20	4.12	10%
2	3.00	3.20	4.35	10%
3	3.50	3.55	3.90	10%

**Note1:** Above  $V_{BAT\_REG}$  is for PV\_CELL harvester charge;

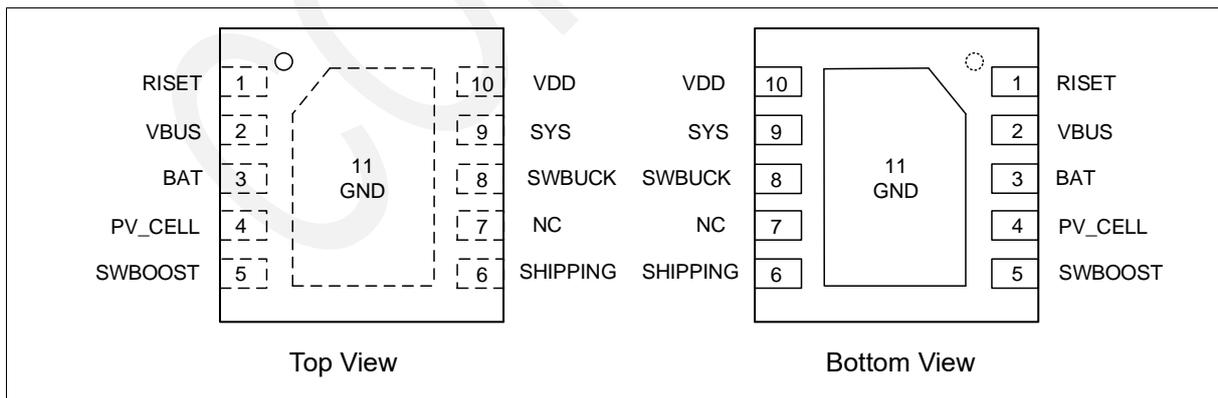
If use Linear Charger, it will be  $V_{BAT\_REG} - 60$  mV to protect storage element.

Table 3. SYS output voltage choice

<b>X</b> SYS output voltage choice	
<b>X</b> Value	SYS voltage $V_{SYS}^{(2)}$ (V)
0	OFF
1	2.2
2	2.5
3	2.8

**Note2:** The buck output voltage cannot be selected higher than  $V_{BAT\_UVP\_F}$ . As in such situation, CE95A04XXX will not start the buck converter. Only when  $V_{SYS}$  set 2.8 V,  $V_{BAT\_UVP\_F}$  can not choose 2.46 V.

## Pin Configuration



## Pin Function

Pin No.	Pin Name	Description
1	RISSET	Connection to an external resistor to set the charging current from VBUS supply to BAT. Leave floating if the VBUS power supply is not used.
2	VBUS	DC Power Supply Input(optional). Leave floating if not used.
3	BAT	Connection to the energy storage element (rechargeable battery).
4	PV_CELL	Connection to the PV cell energy source harvested.
5	SWBOOST	Switch node connection of the boost converter.
6	SHIPPING	Logic input. When HIGH: <ul style="list-style-type: none"> <li>• Minimum consumption from the storage element.</li> <li>• Boost converter is disabled</li> <li>• Buck is disabled.</li> <li>• VDD is charged only when energy is available on PV_CELL.</li> </ul> Read as LOW if left floating.
7	NC	None connect.
8	SWBUCK	Switch node connection of the buck converter.
9	SYS	Output voltage of the buck converter to supply system circuit.
10	VDD	Connection for C <sub>VDD</sub> buffering capacitor. Internal power supply (do not connect any external circuit on VDD).
11	GND	Ground

## Block Diagram

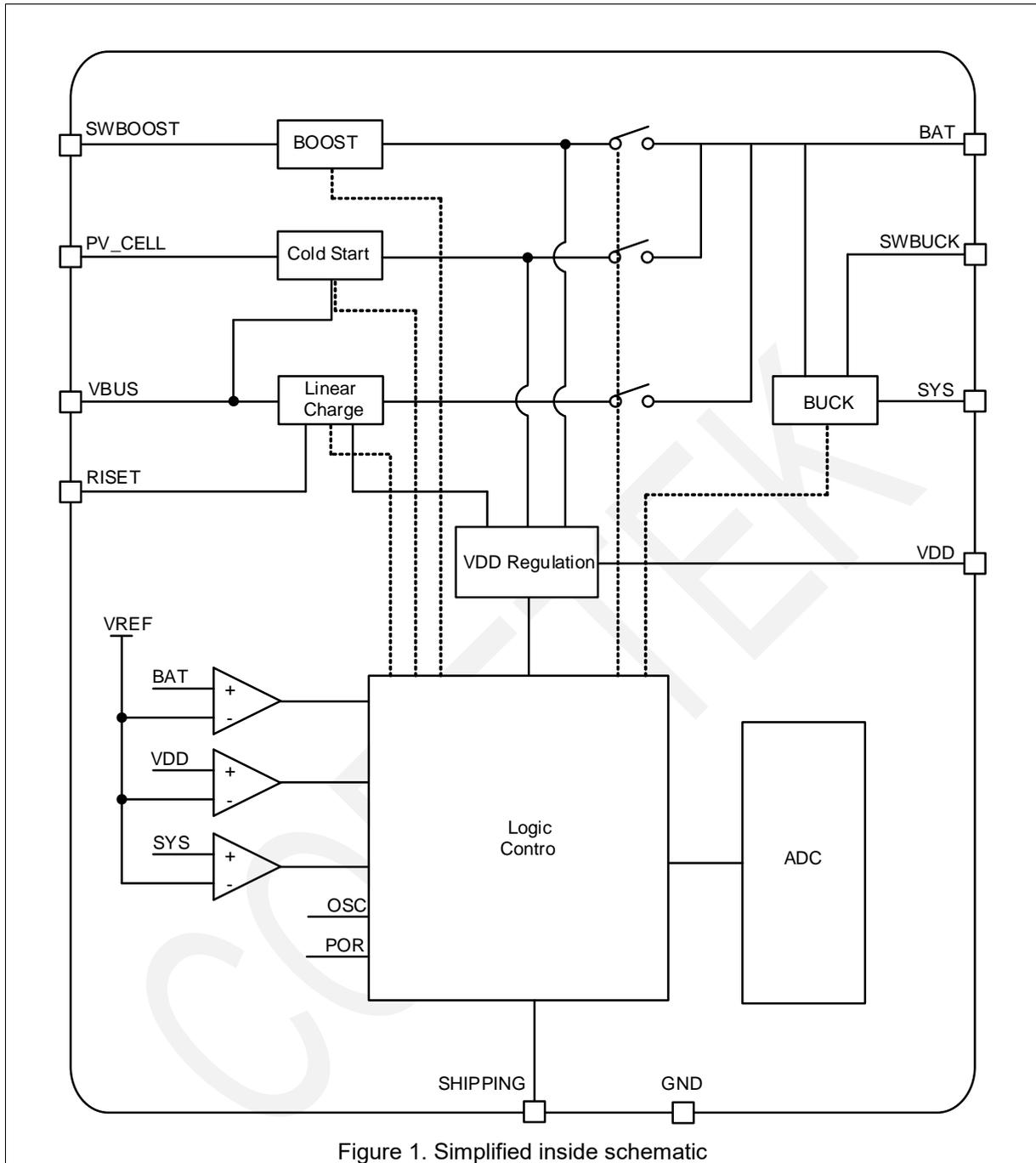


Figure 1. Simplified inside schematic

## Absolute Maximum Ratings

Symbol	Rating	Min	Max	Unit
V <sub>VDD</sub>	VDD pin DC Voltage	-0.3	3.3	V
V <sub>S</sub>	Other pins DC Voltage	-0.3	5.5	V
T <sub>J</sub>	Operating junction temperature	-40	150	°C
T <sub>STG</sub>	Storage Temperature	-65	150	°C
V <sub>ESD</sub> <sup>(3)</sup>	Electrostatic Discharge Capability(HBM)		2000	V
	Electrostatic Discharge Capability(CDM)		500	V

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

**Note3:** This device series incorporates ESD protection and is tested by the following methods:

ESD Human Body Model tested per ESDA/JEDEC JS-001-2017.

CDM tested per ESDA/JEDEC JS-002-2018.

## Recommended Operating Conditions

Symbol	Parameter	Min	Typ	Max	Unit
<b>Recommended Operating Temperature Range</b>					
T <sub>A</sub>	Operating Temperature Range	-40		85	°C
<b>External components</b>					
C <sub>PV_CELL</sub>	Capacitor decoupling of PV_CELL terminal	10	22		μF
C <sub>SYS</sub>	Capacitor decoupling of buck converter	10	22		μF
C <sub>VDD</sub>	Capacitor decoupling of VDD terminal	4.7	10		μF
C <sub>BAT</sub>	Capacitor decoupling of BAT terminal	10	47		μF
C <sub>VBUS</sub>	Capacitor decoupling of VBUS terminal	1	3.3		μF
L <sub>BOOST</sub>	Inductor of boost converter	10	33		μH
L <sub>BUCK</sub>	Inductor of buck converter	3.3	10		μH
R <sub>RISET</sub>	Resistor for configuring the 5 V charger current when in constant current mode (CC). (Optional)	0.37		3.7	kΩ
<b>Logic input pins</b>					
SHIP_MODE	Shipping mode enable	Logic LOW (0)	Connect to GND		
		Logic HIGH (1)	Connect to BAT		

## Electrical Characteristics

T<sub>A</sub> = 25 °C, unless otherwise noted.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
<b>Input voltage and input power</b>						
P <sub>PV_CELL,CS</sub>	Minimum source power required for cold start			5		μW
V <sub>PV_CELL,CS</sub>	Minimum source voltage required for cold start			0.275		V
V <sub>PV_CELL,REG</sub>	Target MPPT regulation voltage of the source, See <a href="#">Table 1</a>		0.25		3.20 <sup>(4)</sup>	V
V <sub>VBUS</sub>	Voltage on the VBUS pin to allow for Linear Charging		3.5 <sup>(5)</sup>		5.5	V
I <sub>SET</sub>	Maximum charging current of Linear Charger when in constant current mode. This is programmed by the resistor on the RISET pin.		13.5		135	mA
<b>Time parameter</b>						
t <sub>DEB</sub>	Debounce Time from V <sub>BAT</sub> < V <sub>BAT_UVP_F</sub> to buck SYS turn off			2.50		s
<b>BAT Storage element</b>						
V <sub>BAT_UVP_F</sub>	Minimum voltage accepted on BAT before stopping to supply SYS	ET9504X0X		2.46		V
		ET9504X1X/ET9504X2X		3.00		V
		ET9504X3X		3.50		V
V <sub>BAT_UVP_R</sub>	Voltage required on BAT to start supplying to SYS	ET9504X0X		2.56		V
		ET9504X1X/ET9504X2X		3.20		V
		ET9504X3X		3.55		V
V <sub>BAT_REG</sub>	Maximum voltage accepted on BAT before disabling its charging	ET9504X0X		3.80		V
		ET9504X1X		4.12		V
		ET9504X2X		4.35		V
		ET9504X3X		3.90		V
<b>SYS output voltage</b>						
V <sub>SYS</sub>	SYS output voltage	ET9504XX1		2.2		V
		ET9504XX2		2.5		V
		ET9504XX3		2.8		V
<b>Internal supply &amp; quiescent current</b>						
V <sub>VDD</sub>	Internal voltage supply			1.8		V
V <sub>VDD,RESET</sub>	Minimum voltage on VDD of internal circuit operation normal			1.6		V
V <sub>VDD,START</sub>	Minimum voltage on VDD of internal circuit startup when first power-on			1.85		V
I <sub>BAT1</sub>	Quiescent current on BAT in discharge Mode	SYS disabled		400		nA
		SYS enabled		650		nA

## Electrical Characteristics(Continued)

T<sub>A</sub> = 25 °C, unless otherwise noted.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
I <sub>BAT2</sub>	Quiescent current on BAT when charge done	SYS disabled		350		nA
		SYS enabled		550		nA
I <sub>SHIP</sub>	Quiescent current on BAT when in shipping mode			10		nA

**Note4:** To harvest energy from the source, the open-circuit voltage of the PV\_CELL energy source V<sub>oc</sub> need higher than V<sub>PV\_CELL,REG</sub>.

**Note5:** In order for 5 V Linear Charger operate, V<sub>BUS</sub> voltage must be above 3.5 V and V<sub>BUS</sub> ≥ V<sub>BAT</sub> + 200 mV.

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## Functional Description

### Overview

CE95A04XXX has two regulated switching converters, the boost converter and the buck converter with high-power conversion efficiency. At first start-up, as soon as a required cold start voltage of 275 mV and a scant amount of power of just 5  $\mu$ W available from the harvested energy source, then CE95A04XXX cold starts.

After the cold start, the Boost starts, it will extract energy from the energy harvesting to Battery. The boost can implements voltage regulation of the energy harvesting, allowing for harvesting the maximum efficiency energy harvesting from the source to the Battery. The constant regulation MPPT voltage of PV\_CELL can choose from 0.25 V to 3.2 V as [Table 1](#).

When the battery voltage ( $V_{BAT}$ ) higher than  $V_{BAT\_UVP\_R}$ , the buck converter starts up, it will supply power to the application system, and the output voltage of buck can choose 2.2/2.5/2.8 V as [Table 3](#).

A build-in 5 V Linear Charger provides a way for fast charging with Pre-Charge/CC/CV Charge Mode when no source is available for a long time, and the charge parameters can choose as [Table 2](#), the charge current is set by an external resistor of Riset pin.

### Cold-Start

The CE95A04XXX can cold start from PV\_CELL or VBUS. The cold start circuits supply to CE95A04XXX internal circuit (connected to VDD) when  $V_{BAT}$  below  $V_{BAT\_UVP\_F}$ . VDD is supplied by BAT when  $V_{BAT}$  high than  $V_{BAT\_UVP\_F}$ .

### Boost Converter

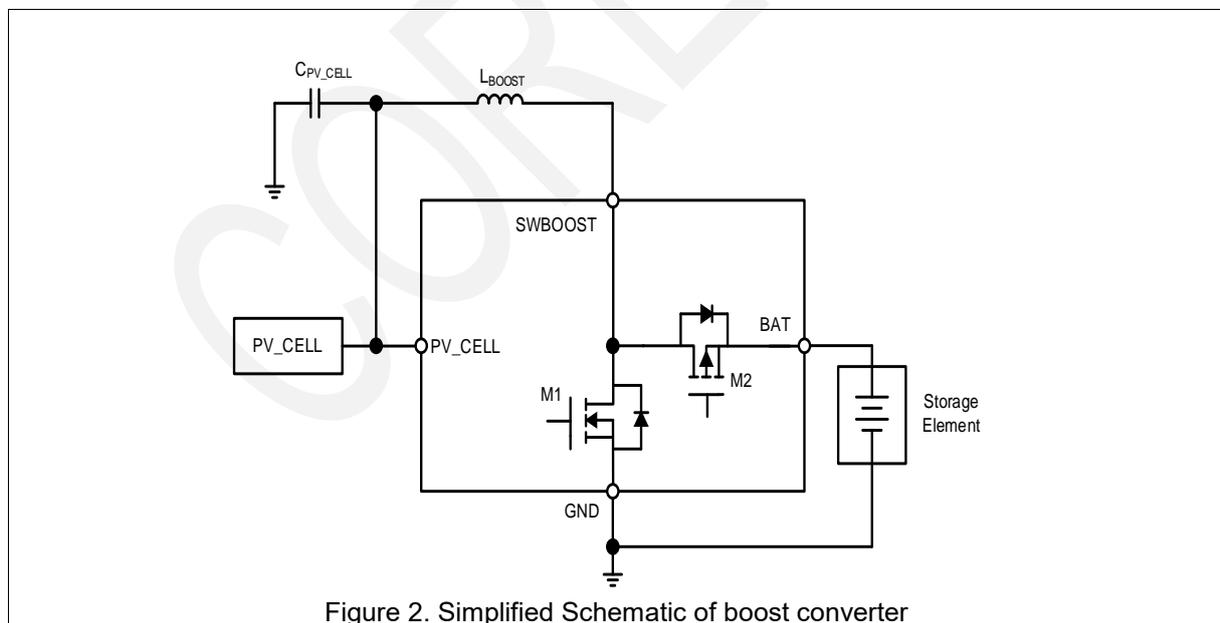


Figure 2. Simplified Schematic of boost converter

The boost converter can extract the energy from energy harvester to charge the battery.

The boost can regulate the voltage of the energy harvester to prevent the power collapse, and the voltage can choose as [Table 1](#). An external inductor  $L_{BOOST}$  and a capacitor  $C_{PV\_CELL}$  are needed. The recommended value of the  $L_{BOOST}$  is 33  $\mu$ H. The recommended value of the capacitor  $C_{PV\_CELL}$  is 22  $\mu$ F which prevent the regulation voltage from the current pulses induced by the boost converter.

The inductor peak current depends on the value of  $L_{BOOST}$ .

The Boost does not work under the following conditions:

- If the open-circuit voltage of the energy harvester is lower than  $V_{PV\_CELL\_REG}$ , the boost does not work.
- If battery voltage higher than  $V_{BAT\_REG}$ , the boost does not work.

### Linear Charger

The CE95A04XXX has a 5 V Linear Charger for fast charging of the battery with Pre-Charge/CC/CV Charge Mode. When the  $V_{BUS}$  voltage higher than 3.5 V and the BAT voltage less than  $V_{BAT\_REG}$ , higher than  $V_{BAT\_UVP\_R}$ , the Linear Charger starts charging the battery with CC mode; If the the BAT voltage less than  $V_{BAT\_UVP\_R}$ , the Linear Charger starts charging the battery with Pre\_Charge mode. When the BAT voltage is close to  $V_{BAT\_REG}$ , the Linear Charger starts charging the battery with CV mode, at that time the charging current gradually decrease to zero as the  $V_{BAT}$  reaches  $V_{BAT\_REG}$ .

The 5 V Charger implements CC/CV operation. When in CC, the maximum charging current  $I_{SET}$  can be set by connecting a resistor  $R_{RISET}$  between RISET pin and GND:

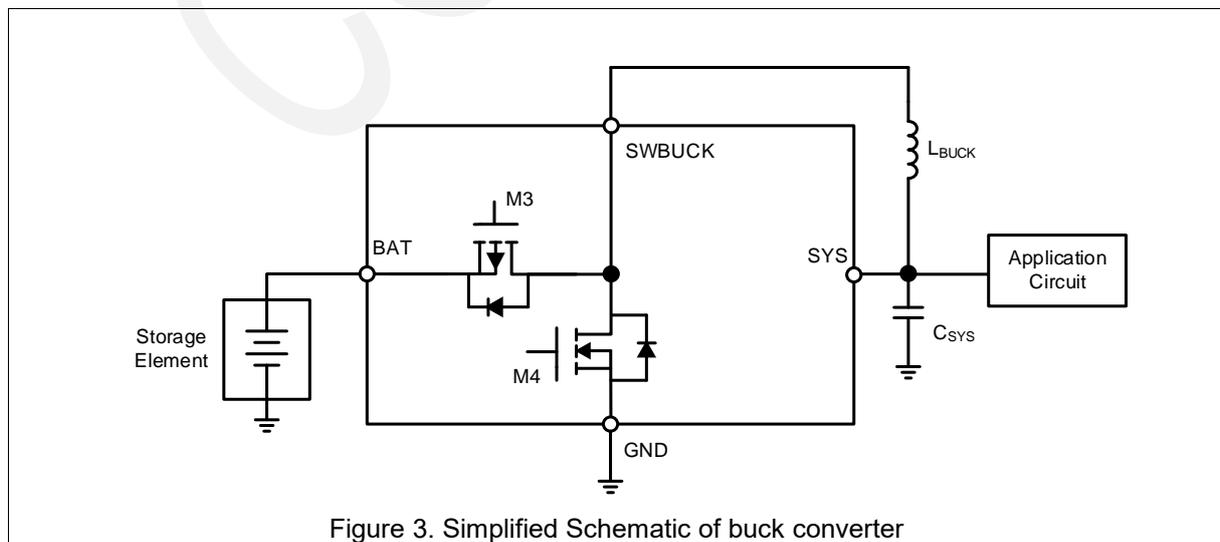
$$I_{SET} = 50/R_{RISET}$$

Please note that  $R_{RISET}$  must be chosen so that  $I_{SET}$  complies to the range. Example values can be found in [Table 4](#):

Table 4. Typical resistor values for setting 5 V charger max.current

Resistor( $\Omega$ )	Maximum Charging Current(mA)
$R_{RISET}$	$I_{SET}$
370	135
680	73.5
1500	33.3
3700	13.5

### Buck Converter



CE95A04XXX provides a buck converter to extract energy from the battery to the regulated SYS output. The SYS regulation voltage  $V_{SYS}$  can choose as [Table 3](#).

An external inductor  $L_{BUCK}$  and a capacitor  $C_{SYS}$  are needed. The recommended value of the  $L_{BUCK}$  is 10 $\mu$ H. The recommended value of the capacitor  $C_{SYS}$  is 22  $\mu$ F which prevent the regulation voltage from the current pulses induced by the buck converter.

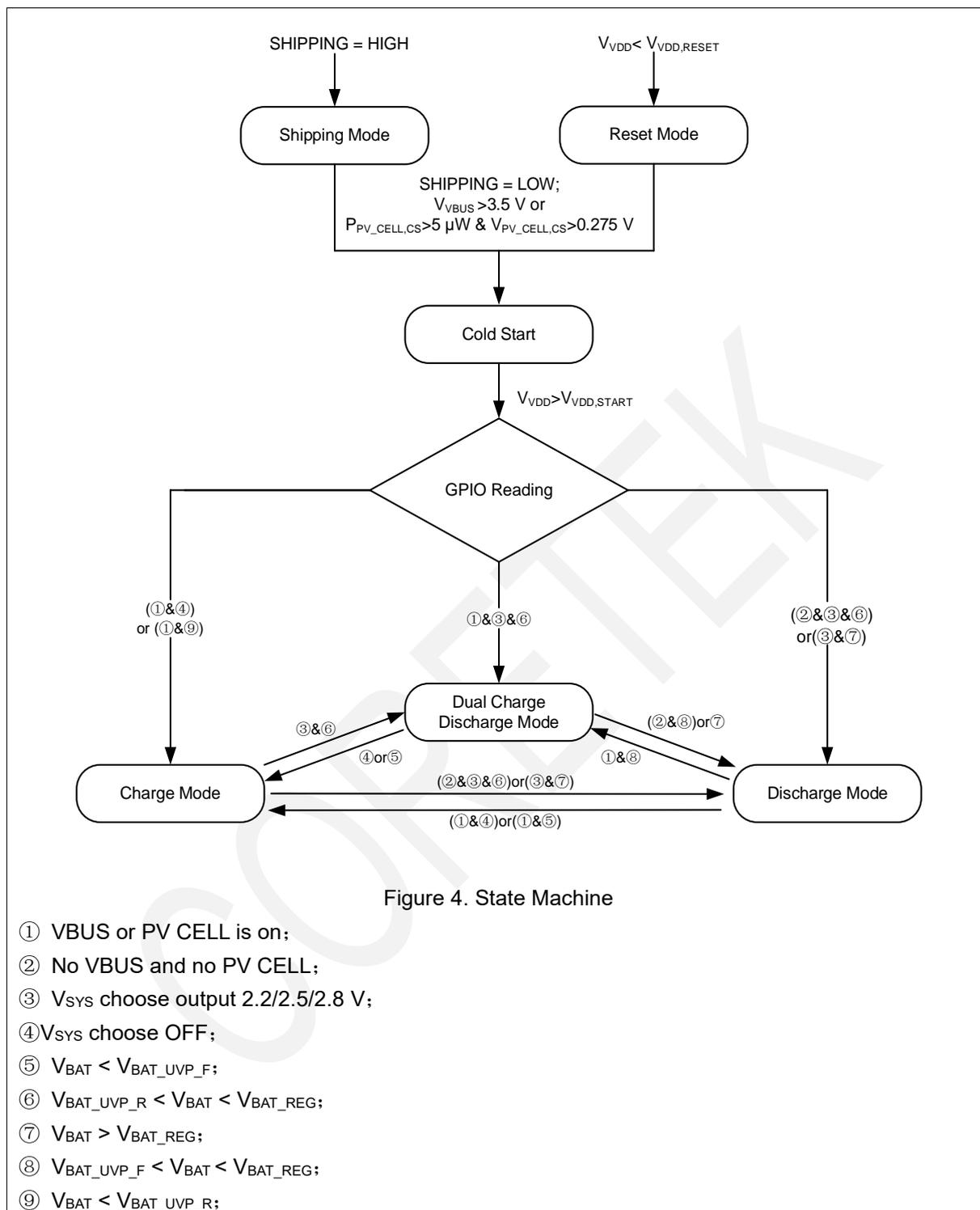
After cold start, if the battery voltage is higher than  $V_{BAT\_UVP\_R}$ , the buck starts to work and supply the SYS output until the battery voltage drops below  $V_{BAT\_UVP\_F}$  longer than  $t_{DEB}$ .

The buck will switch to “Hysteresis Control” mode under the following conditions:

- $V_{BAT} - V_{SYS} < 0.25$  V.
- When  $V_{SYS}$  is too low because of load current, the “Hysteresis Control” mode enabled, making  $V_{SYS}$  rise.

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**State Machine Description**



### Reset Mode

The CE95A04XXX enters Reset Mode under the following conditions:

- $V_{DD} < 1.6\text{ V}(V_{VDD, RESET})$ .
- Shipping mode is enabled (SHIPPING pin is HIGH).

In RESET STATE, the CE95A04XXX works as follows:

- The cold start circuit of CE95A04XXX starts to make VDD rise to 1.85 V when  $V_{PV\_CELL} > 0.275\text{ V}$  and  $P_{PV\_CELL, CS} > 5\ \mu\text{W}$  or  $VBUS > 3.5\text{ V}$
- The internal circuit supplied by VDD will be started.

The CE95A04XXX stays in RESET STATE until the  $V_{DD}$  reach 1.85 V. If  $V_{DD} < 1.6\text{ V}$ , CE95A04XXX will switch to RESET STATE again.

If shipping mode is enabled, both boost converter and buck converter are disabled, CE95A04XXX stays in RESET STATE until shipping mode is disabled by setting SHIPPING LOW.

### GPIO Reading

During GPIO Reading, CE95A04XXX will read the GPIO setting every time interval, and there is a build-in ADC to detect the voltage of the battery and the energy harvester, and compare with the internal reference voltage.

For CE95A04XXX GPIO pin is not package out.

### Charge Mode

During Charge Mode, the battery is charged by VBUS or energy harvester, and the SYS output is disabled.

The CE95A04XXX will enter into Charge Mode under the following conditions:

- VBUS or PV CELL is on.
- $V_{BAT} < V_{BAT\_UVP\_R}$  or  $V_{SYS}$  choose OFF.

### Discharge Mode

During Discharge Mode, the charge current from VBUS or energy harvester is off, and the SYS output is enabled.

The CE95A04XXX will enter into Discharge Mode under the following conditions:

- $V_{BAT} > V_{BAT\_REG}$  or (no VBUS and no PV CELL).
- $V_{BAT} > V_{BAT\_UVP\_R}$  and  $V_{SYS}$  choose output 2.2/2.5/2.8 V.

### Dual Charge-Discharge Mode

During Dual Charge-Discharge Mode, the battery is charged by VBUS or energy harvester, and the SYS output is enabled.

The CE95A04XXX will enter into Dual Charge-Discharge mode under the following conditions:

- $V_{BAT\_UVP\_R} < V_{BAT} < V_{BAT\_REG}$  and (VBUS or PV CELL is on).
- $V_{SYS}$  choose output 2.2/2.5/2.8 V.

## Typical Application Circuits

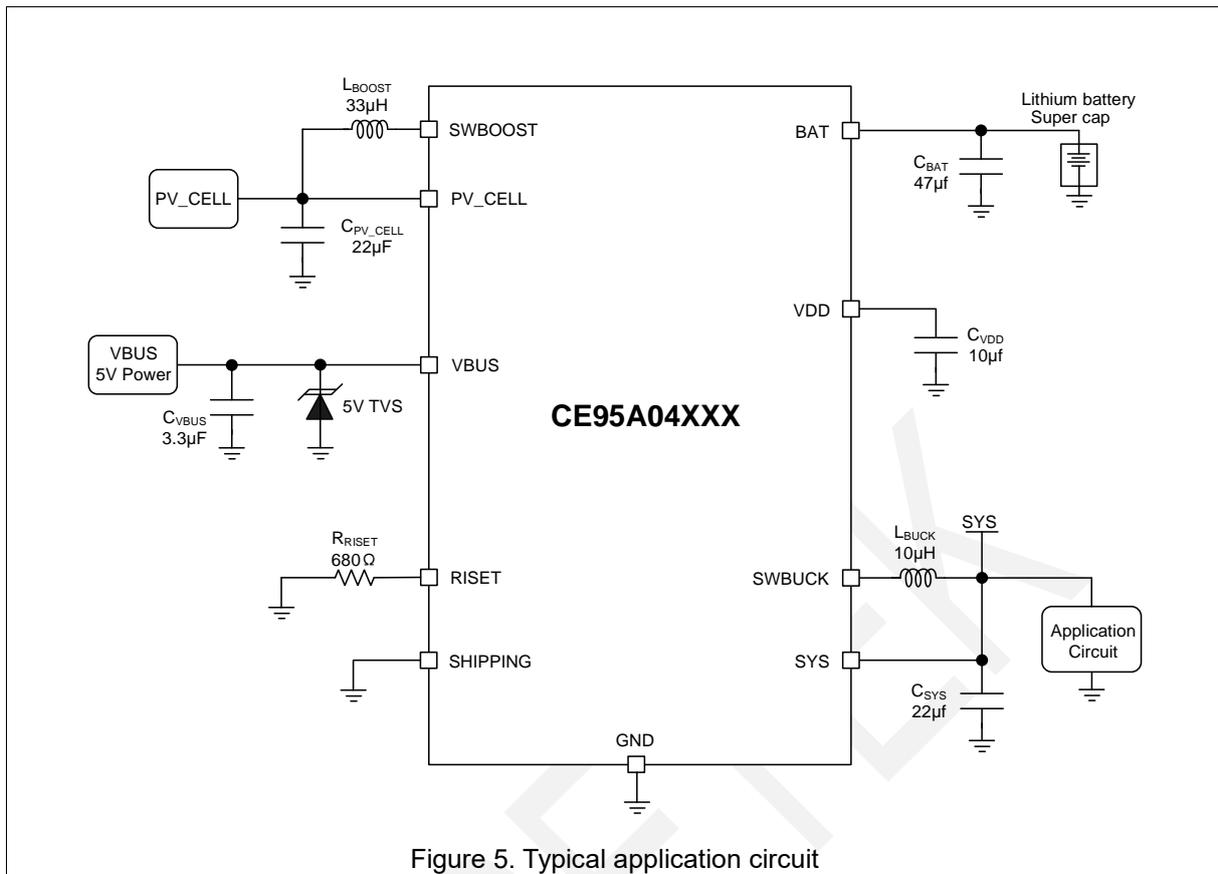


Figure 5. Typical application circuit

### For Example——CE95A04P02 part:

- PV\_CELL constant regulation MPPT voltage is 0.5 V.
- Storage element threshold voltages are set as follows:
  - $V_{BAT\_UVP\_F} = 2.46\text{ V}$
  - $V_{BAT\_UVP\_R} = 2.56\text{ V}$
  - $V_{BAT\_REG} = 3.8\text{ V}$
- SYS output voltage is 2.5 V.
- VBUS 5 V Linear Charger current is set 73.5 mA.
- SHIPPING is connected to GND, so shipping mode is not used.

## Typical Operating Characteristics

BOOST conversion efficiency ( $L_{BOOT} = 33 \mu\text{H}$  and  $BOOST\_SET = 1$ ):

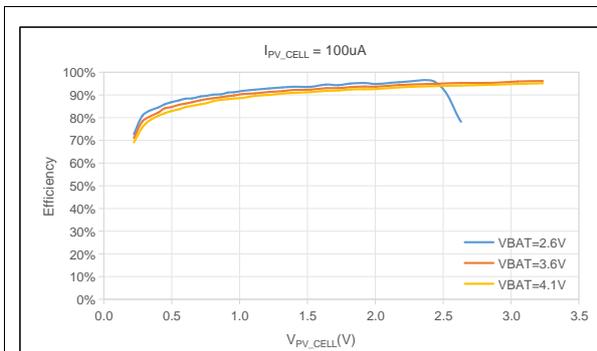


Figure 6. BOOST conversion efficiency  
( $I_{PV\_CELL} = 100 \mu\text{A}$ )

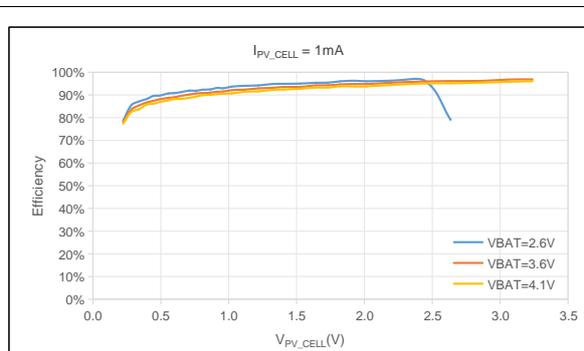


Figure 7. BOOST conversion efficiency  
( $I_{PV\_CELL} = 1 \text{ mA}$ )

BUCK conversion efficiency ( $L_{BUCK} = 10 \mu\text{H}$ ):

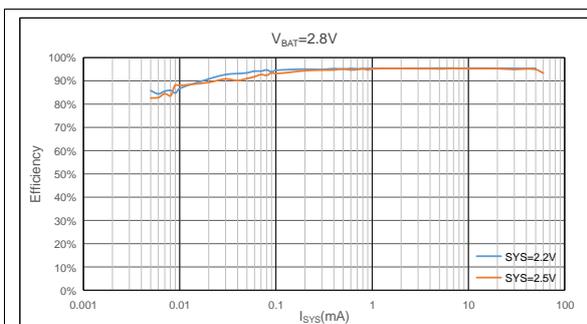


Figure 8. BUCK conversion efficiency  
( $V_{BAT} = 2.8 \text{ V}$ )

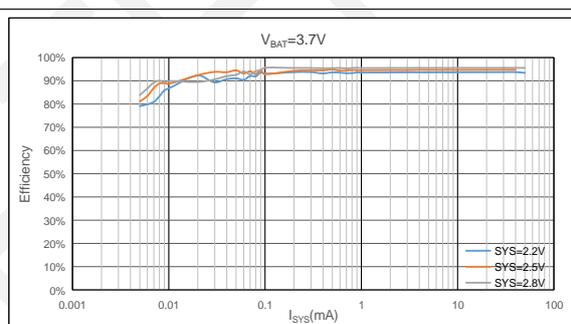
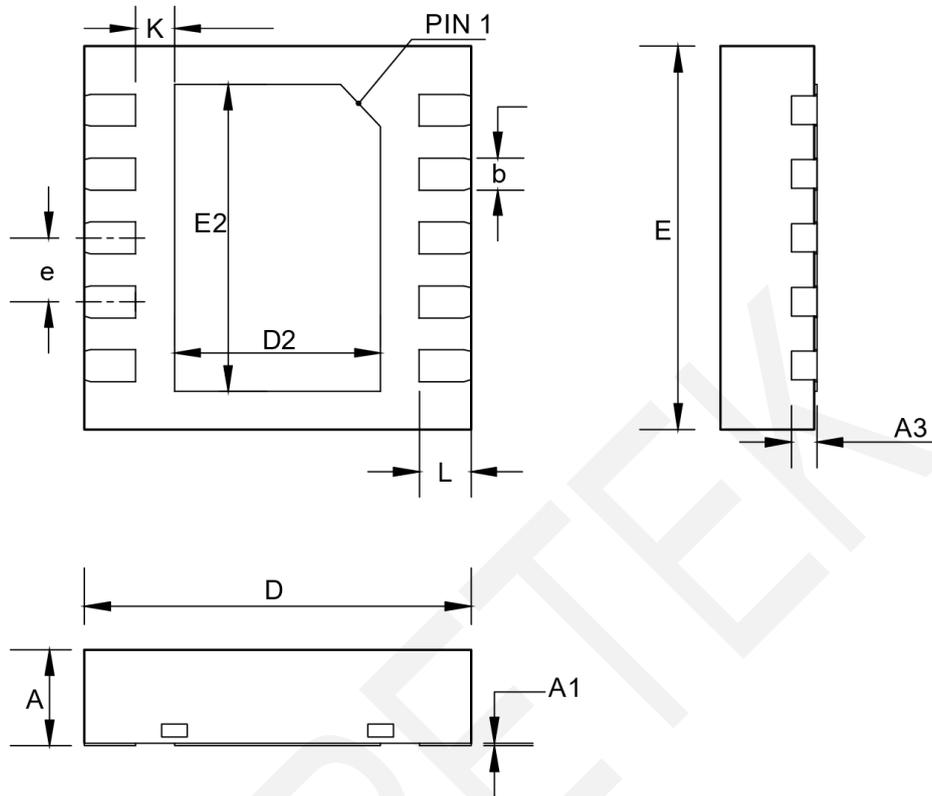


Figure 9. BUCK conversion efficiency  
( $V_{BAT} = 3.7 \text{ V}$ )

## Package Dimension

DFN10(3.0 mm × 3.0 mm)



COMMON DIMENSIONS  
(Unit: mm)

SYMBOL	MIN	NOM	MAX
A	0.70	0.75	0.80
A1	—	0.02	0.05
A3	0.203 REF		
b	0.19	0.24	0.29
D	2.90	3.00	3.10
E	2.90	3.00	3.10
D2	1.52	1.62	1.72
E2	2.38	2.48	2.58
e	0.50 BSC		
K	0.29 REF		
L	0.35	0.40	0.45

## Revision History and Checking Table

Version	Date	Revision Item	Modifier	Function & Spec Checking	Package & Tape Checking
1.0	2025-12-25	Officially version	Chen Zuxiong	Xia Yongjie	Liu Jiaying

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