

# Ultra Efficient Energy Manager with Constant Source Voltage Regulation, Regulated Buck Output and 5 V CC/CV Charger

## Features and Benefits

### Single source input

- Efficiency above 90 % on the source.
- Harvest from 250 mV after cold start.
- Up to 135 mA current extracted from the harvester.

### Maximum Power Point Tracking

- Constant voltage regulation method.
- Optimized for constant voltage PV cells.
- Selectable input regulation voltage.

### Cold start from 275 mV / 1.5 $\mu$ W input

- Startup at ultra-low power from harvesting source input.

### Selectable overdischarge and overcharge protection

- Supports various types of rechargeable batteries (LiC, Li-ion, LiPo...).

### Regulated output for application circuit

- Buck regulator with efficiency above 90 %.
- Selectable output voltage (2.2 V, 2.5 V or 2.8 V).
- Output current up to 100 mA.

### System configuration by GPIO

- All settings are dynamically configurable through GPIO.

### Shipping mode

- Disables charging and discharging the battery during shipment.

### External 5 V charging capability

- Extra charging input for 5 V power supplies.
- CC/CV charging with configurable current limit in CC mode (max. 135 mA).
- Provides a fast charging alternative when no source is available for a long time.

## Applications

Smart home	Industrial sensor
Smart building	Retail
Edge IoT	PC accessories

## Description

The AEM00920 is a fully integrated and compact power management circuit that extracts DC power from a harvesting source to store energy in a rechargeable battery and supply an application circuit. A 5 V input can also be used to charge the battery (e.g. if the battery gets depleted). This compact and ultra-efficient battery charger allows for extending battery lifetime and eliminating the primary energy storage element in a large range of applications.

The AEM00920 implements constant voltage regulation of the source, allowing for harvesting the maximum power available from the source to charge the storage element.

With its unique cold-start circuit, it can start operating with an input voltage as low as 275 mV (min. 1.5  $\mu$ W power).

The configurable protection levels determine the storage element voltage protection thresholds to avoid overcharging and overdischarging the storage element and thus damaging it.

A shipping mode is available to avoid charging and discharging the storage element during shipping or storage.

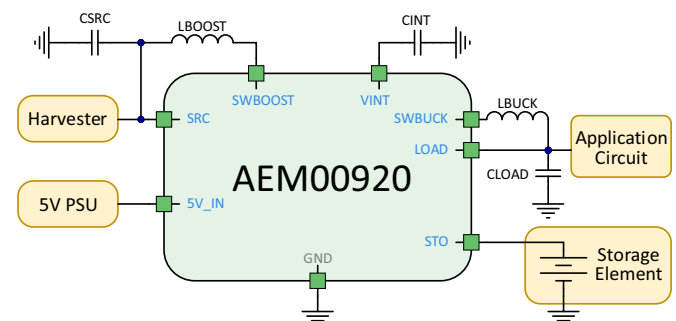
A buck regulator with selectable output voltage allows an application circuit to be supplied with high efficiency.

## Device Information

Part Number	Package	Body size
10AEM00920A0000	QFN 24-pin	4x4mm

## Evaluation Board

Part number
2AAEM00920A001



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## 1. Pin Configuration and Functions

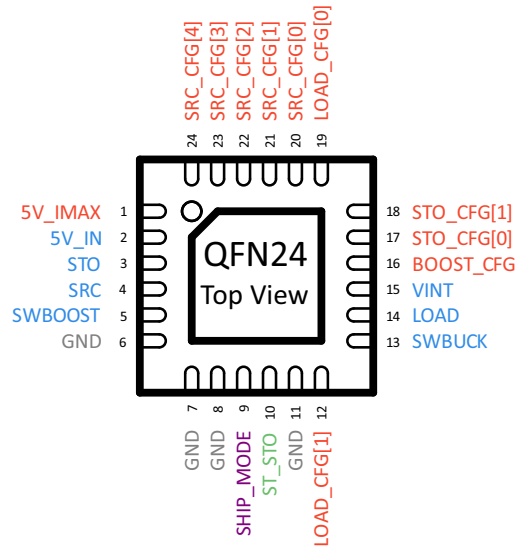


Figure 1: Pinout diagram

NAME	PIN NUMBER	FUNCTION
<b>Power Pins</b>		
SRC	4	Connection to the energy source harvested by the boost converter.
SWBOOST	5	Switching node of the boost converter.
STO	3	Connection to the energy storage element (rechargeable battery).
SWBUCK	13	Switching node of the buck converter.
LOAD	14	Output voltage of the buck converter to supply an application circuit.
5V_IN	2	Input of the 5 V DC power supply (optional). Leave floating if not used.
VINT	15	Connection for $C_{INT}$ buffering capacitor. AEM00920 internal power supply (do not connect any external circuit on VINT).

Table 1: Pins description (part 1)

NAME	PIN NUMBER	LOGIC LEVEL		FUNCTION
		LOW	HIGH	
<b>Control Pin</b>				
SHIP_MODE	9	GND	STO	Logic input. When HIGH: <ul style="list-style-type: none"> <li>- Minimum consumption from the storage element.</li> <li>- Storage element charge is disabled (boost converter is disabled).</li> <li>- Buck (LOAD) is disabled.</li> <li>- VINT is charged only if energy is available on SRC.</li> </ul> Read as LOW if left floating.
<b>Configuration Pins</b>				
SRC_CFG[4]	24	GND	VINT	Used for the configuration of SRC regulation voltage. SRC_CFG[4:0] are all read as HIGH when left floating.
SRC_CFG[3]	23	GND	VINT	
SRC_CFG[2]	22	GND	VINT	
SRC_CFG[1]	21	GND	VINT	
SRC_CFG[0]	20	GND	VINT	
STO_CFG[1]	18	GND	VINT	Used to configure the storage element voltage thresholds. Read as HIGH if left floating.
STO_CFG[0]	17	GND	VINT	
LOAD_CFG[1]	12	GND	VINT	Used to configure the LOAD output regulation voltage. Read as HIGH if left floating.
LOAD_CFG[0]	19	GND	VINT	
BOOST_CFG	16	GND	VINT	Used to configure the boost converter timings, as described in Section 5.4. Read as HIGH if left floating.
5V_IMAX	1	Analog Pin		Connection to an external resistor to set the charging current from the 5V_IN supply to STO. Leave floating if the 5V_IN power supply is not used.
<b>Status Pin</b>				
ST_STO	10	GND	STO	Logic output. <ul style="list-style-type: none"> <li>- HIGH when in SUPPLY STATE and SLEEP STATE.</li> <li>- LOW otherwise.</li> </ul>
<b>Other pins</b>				
GND	Thermal Pad, 6, 7, 8, 11			The thermal pad must be strongly tied to the PCB ground plane, as it is the main GND connection of the AEM00920.

Table 2: Pins description (part 2)

## 2. Specifications

### 2.1. Absolute Maximum Ratings

Parameter	Min	Max	Unit	
Operating junction temperature $T_j$	-40	85	°C	
Storage temperature $T_{stg}$	-65	150	°C	
Input voltage	5V_IN, STO, SRC, SWBOOST, SWBUCK, LOAD, 5V_IMAX, LOAD_CFG[1], SHIP_MODE, ST_STO	-0.3	5.50	V
	VINT, LOAD_CFG[0], BOOST_CFG, STO_CFG[1:0], SRC_CFG[4:0]	-0.3	2.75	V


Table 3: Absolute maximum ratings

### 2.2. ESD Ratings

Parameter		Value	Unit
Electrostatic discharge $V_{ESD}$	Human-Body Model (HBM) <sup>1</sup>	± 2000	V
	Charged-Device Model (CDM) <sup>2</sup>	± 500	V

Table 4: ESD ratings

1. ESD Human-Body Model (HBM) value tested according to JEDEC standard JS-001-2023.
2. ESD Charger-Device Model (CDM) value tested according to JEDEC standard JS-002-2022.

ESD CAUTION	
	<b>ESD (ELECTROSTATIC DISCHARGE) SENSITIVE DEVICE</b> These devices have limited built-in ESD protection and damage may thus occur on devices subjected to high-energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality

### 2.3. Thermal Resistance

Package	$\theta_{JA}$	$\theta_{JC}$	Unit
QFN-24	60	6	°C/W

Table 5: Thermal data



## 2.4. Electrical Characteristics at 25 °C

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
<b>Power conversion</b>						
$P_{SRC,CS}$	Minimum source power required for cold start.			1.5		$\mu\text{W}$
$V_{SRC,CS}$	Minimum source voltage required for cold start.			0.275		V
$V_{SRC,REG}$	Target regulation voltage of the source, depending on $SRC\_CFG[4:0]$ configuration.		0.25		$3.20^1$	V
$V_{OC}$	Open-circuit voltage of the source.		$0.00^2$		$V_{STO}$	V
$V_{5V\_IN}$	Voltage on the $5V\_IN$ pin to allow for charging the battery.		$3.50^3$		5.50	V
$P_{5V\_IN,MIN}$	Minimum power on $5V\_IN$ to start charging the battery.	$V_{5V\_IN} = 3.50\text{ V}$		51		$\mu\text{W}$
		$V_{5V\_IN} = 5.50\text{ V}$		80		
$I_{5V,CC}$	Maximum charging current of 5 V charger when in constant current (CC) mode. This is programmed by the resistor on the $5V\_IMAX$ pin.		13.50		135	mA
$T_{5V,RISE}$	Minimum rise time from 0 V to 5 V on the $5V\_IN$ pin.			50		$\mu\text{s}$
<b>Timing</b>						
$T_{CRIT}$	In <b>SUPPLY STATE</b> , the AEM00920 waits for $T_{CRIT}$ before switching to <b>OVDIS STATE</b> when $V_{STO}$ drops below $V_{OVDIS}$ .			2.50		s
$T_{GPIO,MON}$	GPIO reading rate.			1.85		s

Table 6: Electrical characteristics (part 1)

1. To harvest energy from the source,  $V_{SRC,REG}$  must remain below  $V_{OC}$ .
2. When the open-circuit voltage is below the source regulation voltage, the AEM00920 does not extract power from the source. Voltages down to **GND** do not damage the AEM00920.
3. For the 5 V charger to operate, the voltage on  $5V\_IN$  must be greater than or equal to 3.5 V and at least 200 mV higher than the voltage on  $STO$ .

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
<b>Storage element</b>						
V <sub>STO</sub>	Voltage on the storage element.		2.50 <sup>1</sup>		4.35 <sup>2</sup>	V
V <sub>OVDIS</sub>	Minimum voltage accepted on the storage element before stopping to supply <b>LOAD</b> .	Configured by <b>STO_CFG[1:0]</b> .	2.50		3.50	V
V <sub>CHRDY</sub>	Voltage required on the storage element to start supplying <b>LOAD</b> in <b>START STATE</b> .	Configured by <b>STO_CFG[1:0]</b> .	2.55		3.55	V
V <sub>OVCH</sub>	Maximum voltage accepted on the storage element before disabling its charging.	Configured by <b>STO_CFG[1:0]</b> .	3.80		4.35	V
<b>Internal supply &amp; quiescent current</b>						
V <sub>INT</sub>	Internal voltage supply.		2.20	2.25	2.30	V
V <sub>INT,RESET</sub>	Minimum voltage on <b>VINT</b> before switching to <b>RESET STATE</b> (from any other state).			2.0		V
V <sub>INT,CS</sub>	Minimum voltage on <b>VINT</b> to allow the AEM00920 to switch from <b>RESET STATE</b> to <b>SENSE STO STATE</b> .			2.3		V
I <sub>QSUPPLY</sub>	Quiescent current on <b>VINT</b> in <b>SUPPLY STATE</b> . <sup>3</sup>	<b>LOAD</b> disabled.		270		nA
		<b>LOAD</b> enabled. <sup>4</sup>		480		
I <sub>QSLEEP</sub>	Quiescent current on <b>VINT</b> in <b>SLEEP STATE</b> . <sup>3</sup>	<b>LOAD</b> disabled.		205		nA
		<b>LOAD</b> enabled. <sup>4</sup>		415		
I <sub>QSHIP</sub>	Quiescent current drawn on the storage element when the AEM00920 is in shipping mode ( <b>SHIP_MODE</b> is HIGH) and that no energy is available on <b>SRC</b> (the AEM00920 is off in that case).	No energy on <b>SRC</b> .		10		nA
I <sub>QSHIP,SRC</sub>	Quiescent current on <b>STO</b> when the shipping mode functionality is enabled ( <b>SHIP_MODE</b> set HIGH).	Energy on <b>SRC</b> .		10		nA

Table 7: Electrical characteristics (part 2)

1. As set by the battery overdischarge threshold configuration.
2. As set by the battery overcharge threshold configuration.
3. When neither the boost converter nor the buck converter are running.
4. V<sub>LOAD</sub> set to 2.2 V and **LOAD** pin left floating.

## 2.5. Recommended Operation Conditions

Symbol	Parameter	Condition	Min <sup>1</sup>	Typ	Max <sup>1</sup>	Unit
<b>External components</b>						
L <sub>BOOST</sub>	Inductor of the boost converter.	BOOST_CFG = L	3.3	10 <sup>2</sup>		μH
		BOOST_CFG = H	9.9	33 <sup>2</sup>		μH
C <sub>SRC</sub>	Capacitor decoupling the SRC terminal.			10		μF
L <sub>BUCK</sub>	Inductor of the buck converter.		3.3	10 <sup>2</sup>		μH
C <sub>LOAD</sub>	Capacitor of the buck converter.		10	22		μF
C <sub>INT</sub>	Capacitor decoupling the VINT terminal.		5	10		μF
C <sub>STO</sub>	Capacitor decoupling the STO terminal.		5	10		μF
R <sub>5V_IMAX</sub>	Resistor for configuring the 5V charger current when in constant current mode (CC). (Optional)		0.37		3.7	kΩ

Table 8: Recommended external components

1. All minimum and maximum values are real components values, taking into account tolerances, derating, temperatures, voltages and any operating conditions (special care must be taken with capacitor derating).

2. L<sub>BOOST</sub> and L<sub>BUCK</sub> typical values recommended for best tradeoff between boost efficiency and maximum current.

Symbol	Parameter		
<b>Logic input pins</b>			
SRC_CFG[4:0]	Boost source voltage regulation settings.	Logic LOW (L)	Connect to GND.
		Logic HIGH (H)	Connect to VINT.
STO_CFG[1:0]	Storage element voltage thresholds configuration.	Logic LOW (L)	Connect to GND.
		Logic HIGH (H)	Connect to VINT.
LOAD_CFG[1:0]	Configuration of the LOAD buck output voltage regulation.	Logic LOW (L)	Connect to GND.
		Logic HIGH (H)	Connect to VINT.
BOOST_CFG	Used to configure the boost converter timings, as described in Section 5.4.	Logic LOW (L)	Connect to GND.
		Logic HIGH (H)	Connect to VINT.
SHIP_MODE	Shipping mode enable.	Logic LOW (L)	Connect to GND.
		Logic HIGH (H)	Connect to STO.

Table 9: Logic input pin connections

## 2.6. Typical Characteristics

### 2.6.1. Boost Converter Conversion Efficiency

Figure 2 shows the AEM00920 boost efficiency with:

- $L_{BOOST} = 33 \mu\text{H}$  (Coilcraft LPS4018-333MRB).
- `BOOST_CFG = H (x3)`.

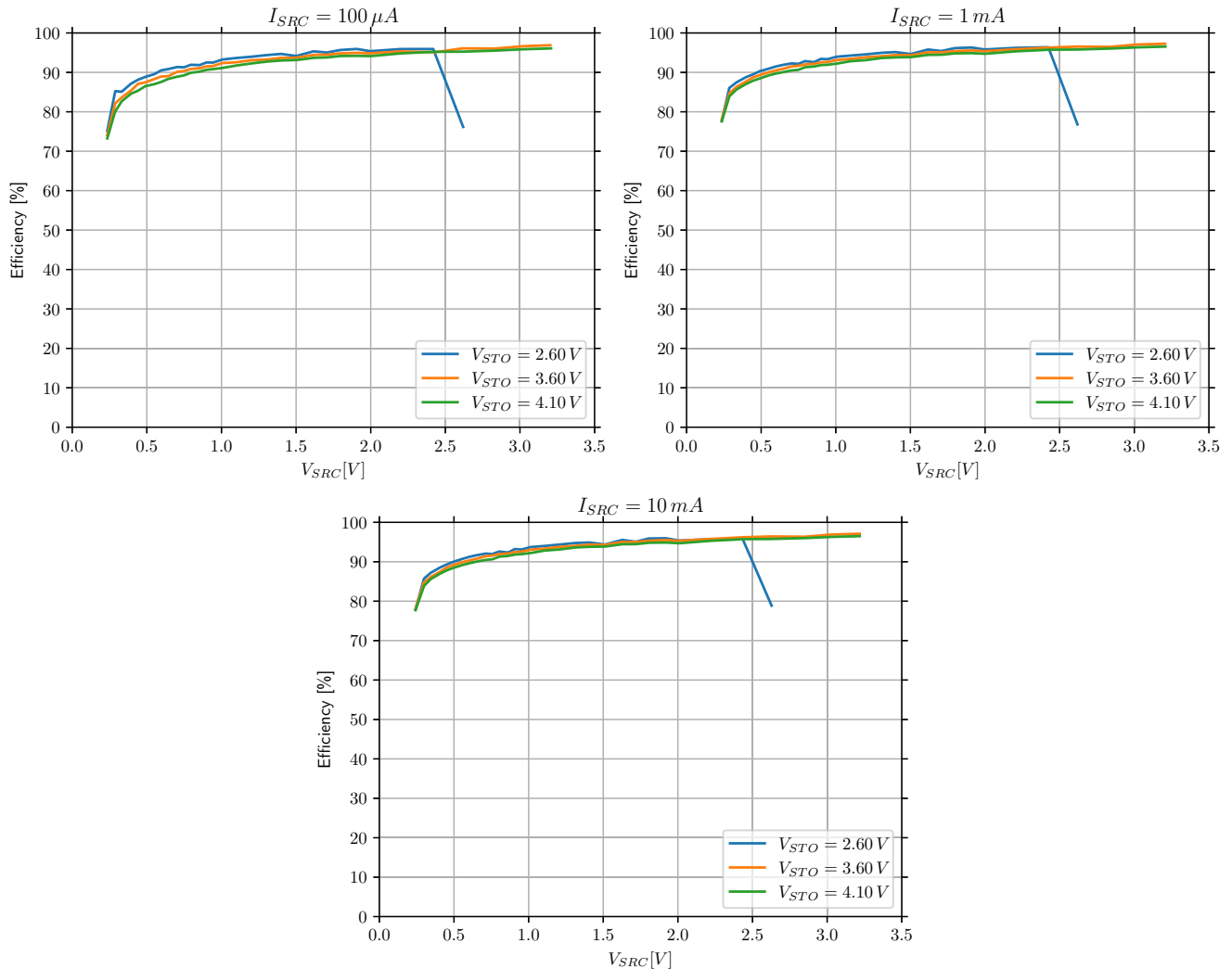


Figure 2: Boost converter efficiency

NOTE: The boost efficiency data presented in Figure 2 include the AEM00920 quiescent current.

### 2.6.2. Buck Converter Conversion Efficiency

Figure 3 shows the AEM00920 buck efficiency with  $L_{BUCK} = 10 \mu\text{H}$  (TDK VLS252012CX-100M-1).

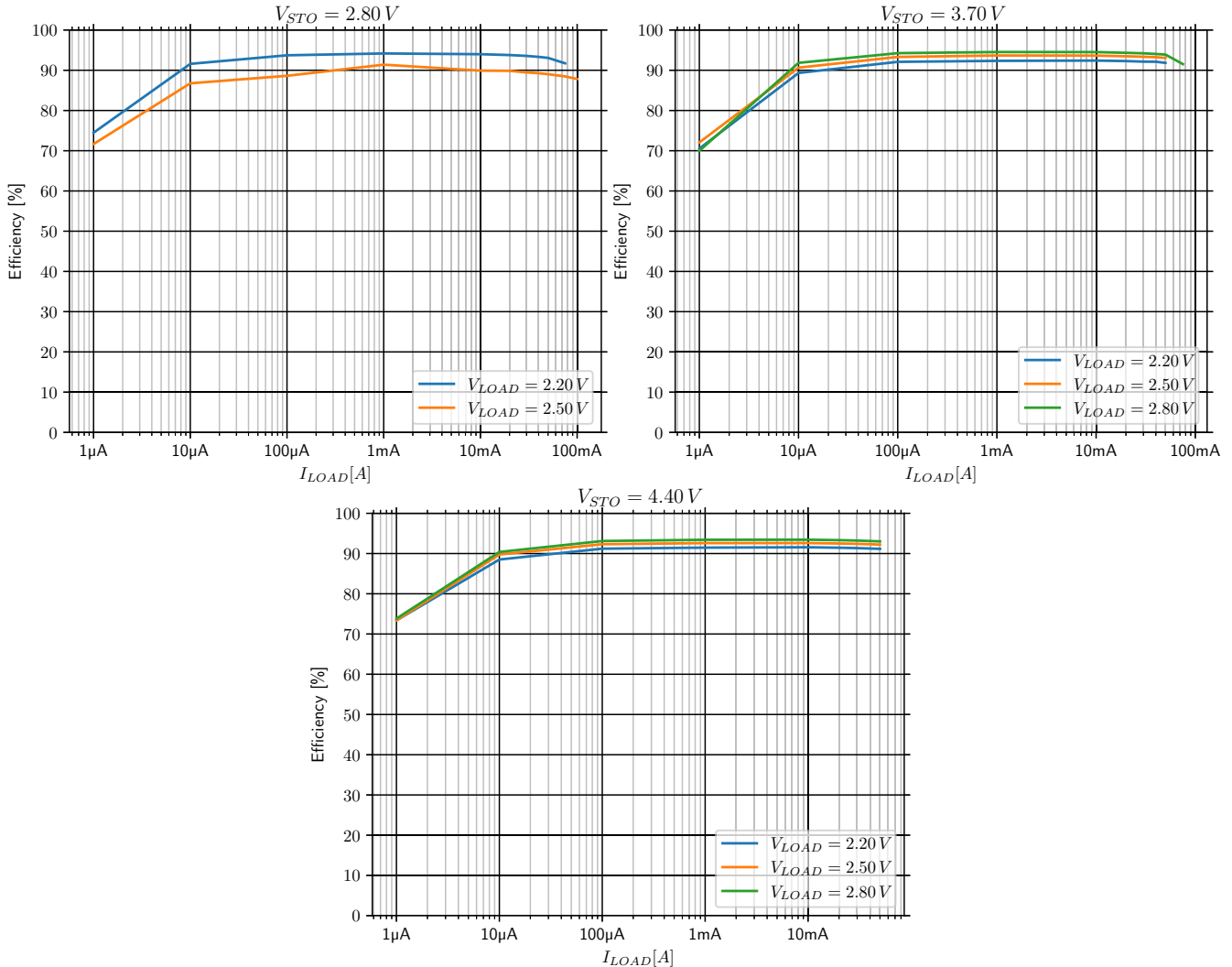


Figure 3: Buck (LOAD) converter efficiency

**NOTE:** The quiescent current of the AEM00920 is not included in the buck efficiency data presented in Figure 3, as it has already been included in the boost efficiency data shown in Section 2.6.1. This quiescent current has been measured with the boost converter in **SLEEP STATE** and the buck converter switched off.

### 3. Functional Block Diagram

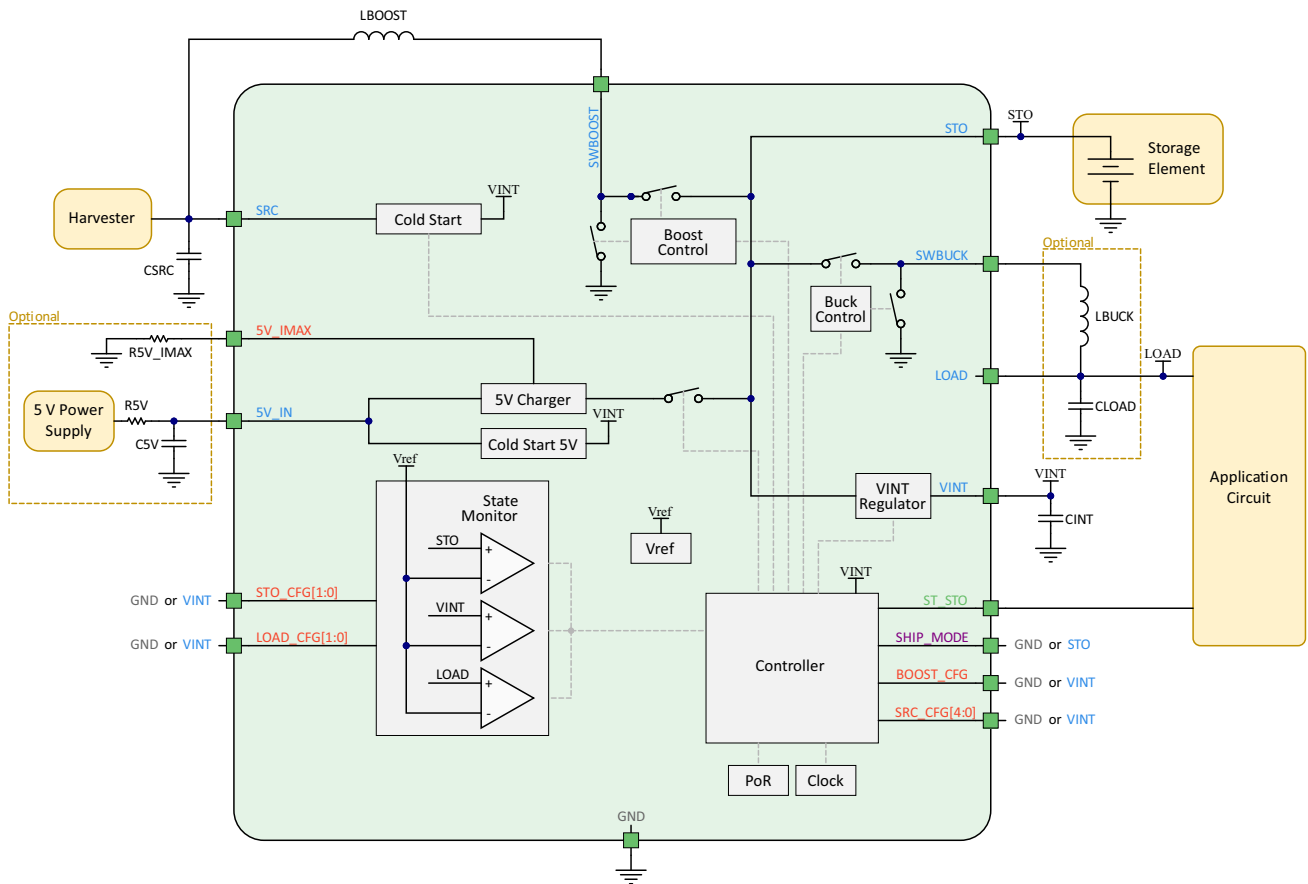


Figure 4: Functional block diagram

## 4. Theory of Operation

### 4.1. Cold-Start Circuits

The AEM00920 is able to coldstart from **SRC** or from **5V\_IN**. The cold-start circuits supply the AEM00920 internal circuit (connected to **VINT**) when the device is in **RESET STATE**, **SENSE STO STATE** or **OVDIS STATE**.

### 4.2. Boost Converter

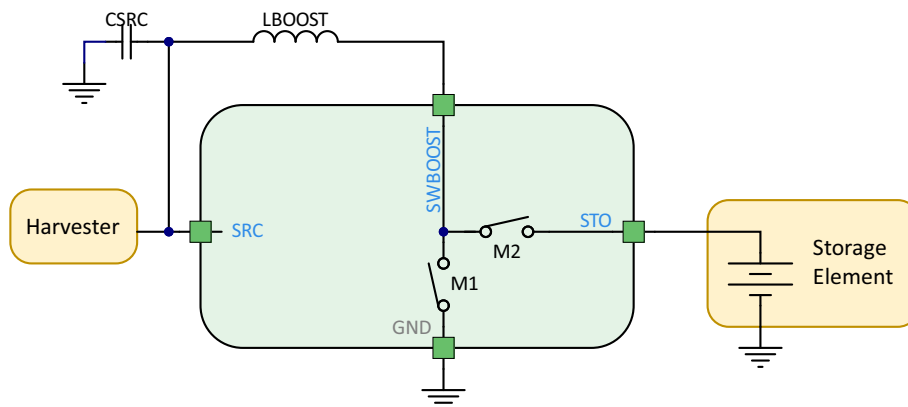


Figure 5: Simplified schematic view of the boost converter

#### 4.2.1. Operation Principle

The boost (step-up) converter raises the voltage available at **SRC** to a level suitable for charging the storage element, in the range of 2.50 V to 4.35 V, according to the system configuration. The switching transistors of the boost converter are M1 and M2. The reactive power component of this converter is the external inductor  $L_{BOOST}$ .

Target source regulation voltage is determined by the constant voltage regulation setting (**SRC\_CFG[4:0]**).

**SRC** is decoupled by the capacitor  $C_{SRC}$ , which smooths the voltage against the current pulses induced by the boost converter.

The storage element is connected to the **STO** pin, which voltage is  $V_{STO}$ . This node is linked to the output of the boost converter through transistor M2. When energy harvesting is occurring, the converter charges the battery.

The maximum current supplied to the **STO** pin depends on the value of  $L_{BOOST}$  and on the **BOOST\_CFG** settings (see Section 5.4).

#### 4.2.2. Source Voltage Regulation

During **START STATE**, **OVDIS STATE** and **SUPPLY STATE**, the voltage on **SRC** is regulated to a voltage configured by the user. The AEM00920 offers a wide choice of values for the source regulation voltage  $V_{SRC,REG}$ .

The AEM00920 behaves as follows:

- If the open-circuit voltage  $V_{OC}$  of the harvester is lower than  $V_{SRC,REG}$ , the AEM00920 does not extract power from the source.
- If **SRC** voltage is higher than  $V_{SRC,REG}$ , the AEM00920 regulates  $V_{SRC}$  to  $V_{SRC,REG}$  and thus extracts power from the source.

### 4.3. 5V Charger

The AEM00920 is equipped with a 5 V charger for fast charging of the battery connected on the **STO** pin.

The 5 V charger can be used when the following conditions are met:

- $V_{5V\_IN} \geq 3.5\text{ V}$
- $V_{5V\_IN} \geq V_{STO} + 200\text{ mV}$

With the 5 V charger, the battery is charged by implementing a constant current / constant voltage operation (CC/CV):

- Constant current (CC) operation:
  - When  $V_{STO}$  is not close to  $V_{OVCH}$ .
  - Battery charging current  $I_{5V,CC}$  is configured by the value of the  $R_{5V\_IMAX}$  resistor connected to the **5V\\_IMAX** pin (see Section 5.6 for further details about  $R_{5V\_IMAX}$  configuration).  $I_{5V,CC}$  range is from 13.5 mA to 135 mA.

- Constant voltage (CV) operation:
  - When  $V_{STO}$  is close to  $V_{OVCH}$ .
  - The charging current  $I_{5V,CV}$  gradually decreases to zero as  $V_{STO}$  reaches  $V_{OVCH}$ .

Using the 5 V charger is not mandatory. When not used, leave both **5V\\_IN** and **5V\\_IMAX** pins floating.

Please note that the rise time of the voltage applied on the **5V\\_IN** must not be too short. See Section 5.6 for more information and Section 6.1 for a design example.

### 4.4. Buck Converter

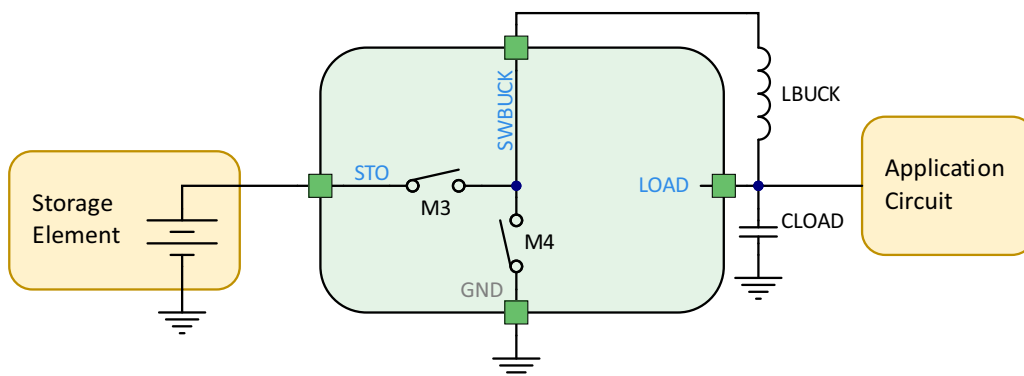


Figure 6: Simplified schematic view of the buck converter

The buck (step-down) converter transfers energy from the battery connected on **STO** to the regulated **LOAD** output. The switching transistors of the buck converter are M3 and M4. The reactive power component of this converter is the external inductor  $L_{BUCK}$ . **LOAD** is decoupled by the capacitor  $C_{LOAD}$ , which smooths the voltage against the current pulses induced by the buck converter and by the external circuit connected to **LOAD**.

Setting the **LOAD** regulation voltage  $V_{LOAD}$  is done through **LOAD\_CFG[1:0]** pins.

After cold start, the buck converter starts once  $V_{STO}$  is higher than  $V_{CHRDY}$ . It stays enabled, and thus regulates  $V_{LOAD}$ , until  $V_{STO}$  drops below  $V_{OVDIS}$  longer than  $T_{CRIT}$ .

When the difference between  $V_{STO}$  and  $V_{LOAD}$  is smaller than 0.25V, it switches to “bang-bang” controlled converter mode:

- When  $V_{LOAD}$  is too low, a switch connects **STO** directly to **LOAD**, making  $V_{LOAD}$  rise.
- When  $V_{LOAD}$  is too high, the controller disconnects **STO** and **LOAD** so that  $V_{LOAD}$  decreases.



## 4.5. State Machine Description

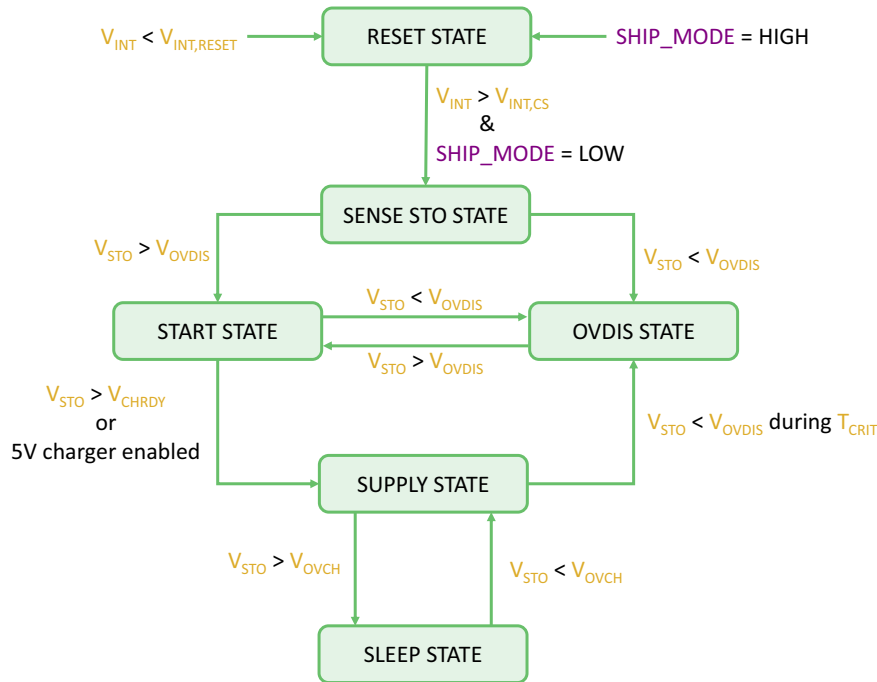


Figure 7: AEM00920 state machine

### 4.5.1. Reset State

The AEM00920 enters **RESET STATE** if one of the following is true:

- $V_{INT}$  is below  $V_{INT,RESET}$ .
- shipping mode is enabled (**SHIP\_MODE** is HIGH).

In **RESET STATE**, the AEM00920 behaves as follows:

- The AEM00920 is performing a cold start to make  $V_{INT}$  rise to 2.3 V. Cold start can be done from any of the following energy sources:
  - **SRC** ( $V_{SRC} > 0.275$  V and  $P_{SRC,CS} > 1.5$   $\mu$ W).
  - **5V\_IN** ( $V_{5V_IN} > 3.5$  V).
- The AEM00920 internal circuit, connected on **VINT**, is supplied by **SRC** or **5V\_IN**. No current is drawn from the battery.
- **ST\_STO** is LOW.

The AEM00920 stays in **RESET STATE** until the power available on **SRC** or on **5V\_IN** meets the cold-start requirements long enough to make  $V_{INT}$  reach 2.3 V (see Table 6). Then:

- If shipping mode is disabled (**SHIP\_MODE** is LOW), the AEM00920 reads the value on all configuration pins and switches to **SENSE STO STATE**.

- If shipping mode is enabled (**SHIP\_MODE** is HIGH), the AEM00920 stays in **RESET STATE** until shipping mode is disabled by setting **SHIP\_MODE** LOW. **SHIP\_MODE** is read every  $T_{GPIO,MON}$ .

Please note that, from any state, the AEM00920 will switch to **RESET STATE** if  $V_{INT}$  drops below  $V_{INT,RESET}$ .

### 4.5.2. Sense STO State

In **SENSE STO STATE**, a first measure of  $V_{STO}$  is performed by the AEM00920.

- If  $V_{STO} > V_{OVDIS}$ , the AEM00920 switches to **START STATE**.
- If  $V_{STO} < V_{OVDIS}$ , the AEM00920 switches to **OVDIS STATE**.
- **ST\_STO** is LOW.

In **SENSE STO STATE**, none of the DCDC converters are running.

### 4.5.3. Start State

When in **SENSE STO STATE**, the AEM00920 switches to **START STATE** if  $V_{STO}$  is above  $V_{OVDIS}$ .

In **START STATE**, the AEM00920 behaves as follows:

- The battery connected on **STO** is charged by the boost converter or by the 5 V charger, until  $V_{STO}$  reaches  $V_{CHRDRY}$ .
- The AEM00920 internal circuit connected on **VINT** is supplied by the battery regardless of the power available on **SRC** or **5V\_IN**.
- The buck converter (**LOAD**) is disabled.
- **ST\_STO** is LOW.

### 4.5.4. Supply State

When in **START STATE**, the AEM00920 switches to **SUPPLY STATE** if one of the following conditions is true:

- $V_{STO}$  is above  $V_{CHRDRY}$ .
- The 5V charger is enabled, meaning that the following conditions are both true:
  - $V_{5V\_IN} > V_{STO} + 200 \text{ mV}$
  - $V_{5V\_IN} > 3.5 \text{ V}$

In **SUPPLY STATE**, the AEM00920 behaves the same as when in **START STATE**, but with the following differences:

- The buck converter driving **LOAD** is enabled (if enabled by the user).
- **ST\_STO** is HIGH.

When in **SUPPLY STATE**, the AEM00920 switches to **SLEEP STATE** if  $V_{STO} > V_{OVCH}$ .

In **SUPPLY STATE**, the AEM00920 switches to **OVDIS STATE** if the following condition is met:

- $V_{STO} < V_{OVDIS}$  during  $T_{CRIT}$

### 4.5.5. OVDIS State

The AEM00920 switches to **OVDIS STATE** if:

- $V_{STO}$  is below  $V_{OVDIS}$  when in **SENSE STO STATE** or **START STATE**.
- $V_{STO}$  remains below  $V_{OVDIS}$  for more than  $T_{CRIT}$  when in **SUPPLY STATE**.

In **OVDIS STATE**, the AEM00920 behaves as follows:

- The battery connected on **STO** is charged by the boost converter or by the 5 V charger, until  $V_{STO}$  exceeds  $V_{OVDIS}$ .
- The AEM00920 internal circuit, connected on **VINT**, is supplied by **SRC** or **5V\_IN**. If not enough power is available on either of those pins, the AEM00920 switches to **RESET STATE**. No current is drawn from the battery.
- The buck converter (**LOAD**) is disabled.
- **ST\_STO** is LOW.

### 4.5.6. Sleep State

**SLEEP STATE** allows for reducing the AEM00920 internal circuit consumption, and thus, keeping battery discharge to the minimum.

The AEM00920 switches from **SUPPLY STATE** to **SLEEP STATE** if  $V_{STO} > V_{OVCH}$ .

In **SLEEP STATE**, the AEM00920 behaves as follows:

- The battery connected on **STO** is not charged by **SRC**, allowing for reducing the quiescent current on **VINT** and thus, on **STO**.
- The AEM00920 internal circuit connected on **VINT** is supplied by the battery regardless of the power available on **SRC** or **5V\_IN**.
- The buck converter (**LOAD**) is enabled.
- **ST\_STO** is HIGH.

When in **SLEEP STATE**, the AEM00920 switches back to **SUPPLY STATE** if  $V_{STO}$  falls below  $V_{OVCH}$ .

## 5. System Configuration

### 5.1. Configuration Pins Reading

After a cold start, the AEM00920 reads the configuration pins. Those are then read periodically every  $T_{GPIO,MON}$ . The configuration pins can be changed on-the-fly. The floating configuration pins are read as HIGH, except `SHIP_MODE` which is read as LOW.

### 5.2. Source Voltage Regulation

User can set the regulation voltage with `SRC_CFG[4:0]` (see Table 10).

Configuration pins					Voltage [V]
<code>SRC_CFG[4:0]</code>					$V_{SRC,REG}$
L	L	L	L	L	0.25
L	L	L	L	H	0.30
L	L	L	H	L	0.35
L	L	L	H	H	0.40
L	L	H	L	L	0.45
L	L	H	L	H	0.50
L	L	H	H	L	0.55
L	L	H	H	H	0.60
L	H	L	L	L	0.65
L	H	L	L	H	0.70
L	H	L	H	L	0.75
L	H	L	H	H	0.80
L	H	H	L	L	0.85
L	H	H	L	H	0.9
L	H	H	H	L	0.95
L	H	H	H	H	1.00
Configuration pins					Voltage [V]
<code>SRC_CFG[4:0]</code>					$V_{SRC,REG}$
H	L	L	L	L	1.10
H	L	L	L	H	1.20
H	L	L	H	L	1.30
H	L	L	H	H	1.40
H	L	H	L	L	1.50
H	L	H	L	H	1.60
H	L	H	H	L	1.70
H	L	H	H	H	1.80
H	H	L	L	L	1.90
H	H	L	L	H	2.00
H	H	L	H	L	2.20
H	H	L	H	H	2.40
H	H	H	L	L	2.60
H	H	H	L	H	2.80
H	H	H	H	L	3.00
H	H	H	H	H	3.20

Table 10: Configuration of the source constant regulation voltage with `SRC_CFG[4:0]` pins

## 5.3. Storage Element Thresholds

### 5.3.1. Configuration Pins

The storage element protection thresholds  $V_{OVCH}$ ,  $V_{CHRDY}$  and  $V_{OVDIS}$ , can be configured through the `STO_CFG[1:0]` pins as shown in Table 11.

Configuration pins		Overdischarge voltage [V]	Charge ready voltage [V]	Overcharge voltage [V]	Battery Type
<b>STO_CFG[1:0]</b>		$V_{OVDIS}$	$V_{CHRDY}$	$V_{OVCH}$	
L	L	2.50	2.55	3.80	Lithium-ion Super Capacitor (LiC)
L	H	3.00	3.20	4.12	Lithium-ion battery
H	L	3.00	3.20	4.35	LiPo battery
H	H	3.50	3.55	3.90	Li-ion battery (ultra long life)

Table 11: Storage element configuration with `STO_CFG[1:0]` pins

**DISCLAIMER:** storage element thresholds provided in the table above are indicative to support a wide range of storage element variants. They are provided as is to the best knowledge of e-peas's application laboratory. They should not replace the actual values provided in the storage element manufacturer's specifications and datasheet.

## 5.4. Boost Converter Timings

The **BOOST\_CFG** pin allows for modifying the peak current of the boost inductor by multiplying the on/off timings of the boost converter, as shown in Table 12. The higher the timing multiplier, the higher the boost inductor peak current, and thus the higher the average source current pulled from **SRC** to **STO**.

The peak current in the inductor also depends on the value of the inductor. Table 12 shows the minimum inductor value to be implemented for each timing value. Lower value may lead to damaging the AEM00920.

Configuration pin	Function		
	Timing multiplication factor	Minimum $L_{BOOST}$ [ $\mu$ H]	$L_{BOOST}$ [ $\mu$ H] for best efficiency
<b>BOOST_CFG</b>			
L	x1	3.3	15
H	x3	9.9	47

Table 12: Boost converter timings configuration

## 5.5. LOAD Output Voltage

Table 13 shows how to configure the regulated voltage on **LOAD** output with the **LOAD\_CFG[1:0]** pins.

Configuration pins		LOAD voltage [V]
<b>LOAD_CFG[1:0]</b>		$V_{LOAD}$
L	L	OFF
L	H	2.2
H	L	2.5
H	H	2.8

Table 13: Configuration of LOAD voltage with **LOAD\_CFG[1:0]** pins

The buck voltage cannot be selected higher than  $V_{OVDIS}$ . In such situation, the AEM00920 will not start the buck converter.

## 5.6. 5 V Charger

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

$$I_{5V,CC} = \frac{50}{R_{5V\_MAX}}$$

Please note that  $R_{5V\_IMAX}$  must be chosen so that  $I_{5V,CC}$  complies to the range defined in Table 6. Example values can be found in Table 14:

Resistor [ $\Omega$ ]	Maximum Charging Current [mA]
$R_{5V\_IMAX}$	$I_{5V,CC}$
370	135.0
680	73.5
1500	33.3
3700	13.5

Table 14: Typical resistor values for setting 5 V charger max. current

Please note that the rise time of the voltage applied on **5V\_IN** must not be too short. Thus, it is recommended to add a RC circuit in series with the **5V\_IN** pin which matches the following, with  $R_{5V}$  in series and  $C_{5V}$  between **5V\_IN** and **GND**:

$$R_{5V} \cdot C_{5V} > T_{5V,RISE}$$

- $T_{5V,RISE}$  is the rise time from 0 V to 5 V of the voltage on the **5V\_IN** pin (see Table 2.4). Comparing this to the RC constant adds a margin as the RC constant defines 63% of the final voltage.
- $R_{5V}$  must be determined so that, for the configured  $I_{5V,CC}$ , the voltage on the **5V\_IN** pin is:
  - above 3.5 V.
  - above  $V_{STO} + 200$  mV.
- $C_{5V}$  is determined from the value of  $R_{5V}$  using the equation above. A low charging current allows for high  $R_{5V}$  value and thus for a low  $C_{5V}$  value.

## 6. Typical Application Circuit

### 6.1. Example Circuit 1

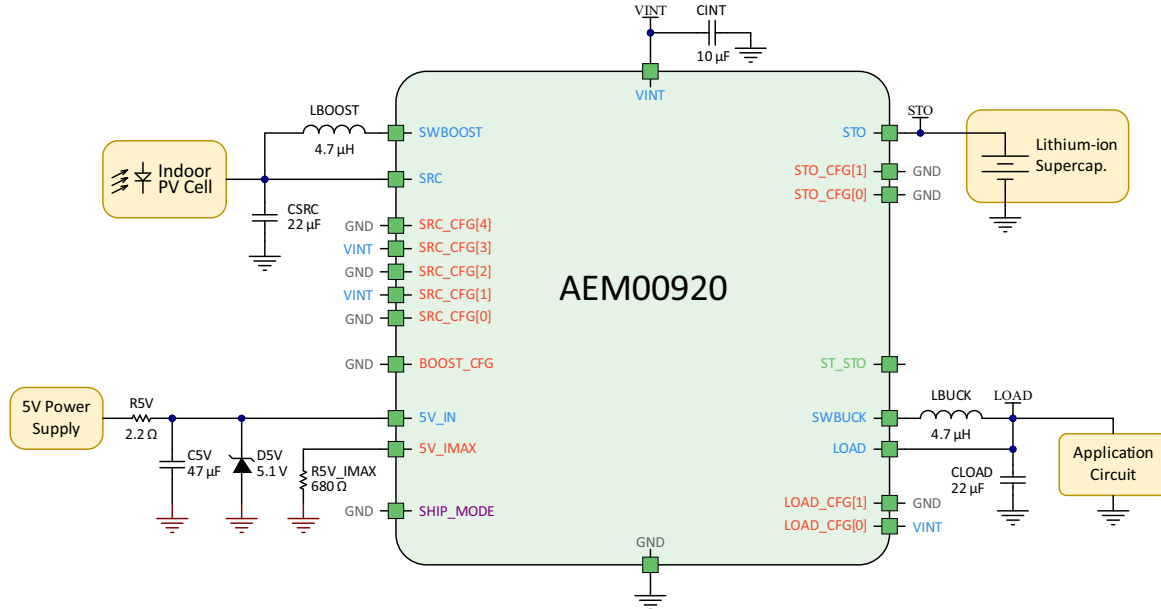


Figure 8: Typical application circuit 1

Figure 8 shows a typical application circuit of the AEM00920.

#### Configuration of SRC

The energy source is an indoor PV cell which provides the maximum power at 0.75 V. SRC is thus configured as follows:

- SRC\_CFG[4:0] = LHLHL (0.75 V regulation).
- BOOST\_CFG = L: x1 boost timing.
- L<sub>BOOST</sub> = 4.7 µH for high current capability with x1 boost timing (see Section 5.4) and low-cost inductor.

#### Configuration of STO

The storage element is a Lithium-ion supercapacitor, so storage element threshold voltages are set as follows:

- STO\_CFG[1:0] = LL.
- V<sub>OVDIS</sub> = 2.5 V.
- V<sub>CHRDY</sub> = 2.55 V.
- V<sub>OVCH</sub> = 3.8 V.

#### Configuration of LOAD

The application circuit is supplied with 2.2 V with current peaks up to 40 mA. The buck converter is configured as follows:

- LOAD\_CFG[1:0] = LH (2.2 V)
- L<sub>BUCK</sub> = 4.7 µH for high current capability and low cost inductor.

#### Shipping mode

Shipping mode is not used.

- SHIP\_MODE is connected to GND.

#### Configuration of 5V\_IN

The maximum allowed current to charge the storage element is 75 mA. Closest standard series resistor is 680 Ω, which leads to a 73.5 mA maximum current.

- R<sub>5V\_IMAX</sub> = 680 Ω.
- I<sub>5V,CC</sub> = 73.5 mA.

The RC filter, which role is to slow down the rise time of the 5 V source, can be determined with the following steps.

R<sub>5V</sub> is calculated so that its voltage drop across it ensures a voltage on 5V\_IN higher than V<sub>OVCH</sub> + 200 mV:

$$I_{5V,CC} \cdot R_{5V} < 5V - V_{OVCH} - 0.2V$$

$$R_{5V} < \frac{5V - V_{OVCH} - 0.2V}{I_{5V,CC}} \Leftrightarrow R_{5V} < \frac{5V - 3.8V - 0.2V}{73.5 \times 10^{-3}}$$

$$R_{5V} < 13.6\Omega$$

C<sub>5V</sub> is calculated so that the 5V\_IN voltage rise time remains below T<sub>5V,RISE</sub>:

$$R_{5V} \cdot C_{5V} > T_{5V,RISE}$$

$$R_{5V} \cdot C_{5V} > 50\mu s$$

To meet these two conditions, the following component values have been selected:

- $R_{5V} = 2.2 \Omega$
- $C_{5V} = 47 \mu\text{F}$

The 5 V source is expected to have ripple and/or over voltages up to 5.5 V, so a 5.1 V zener diode  $D_{5V}$  is added to prevent those to damage the AEM00920.

The minimum power rating of  $D_{5V}$  is computed as follows, from its maximum reverse current  $I_{D5V}$ , its voltage  $V_{D5V}$ , and the resistor  $R_{5V}$ :

$$P_{D5V} \geq I_{D5V} \cdot V_{D5V} \Leftrightarrow P_{D5V} \geq \frac{5.5V - 5.1V}{R_{5V}} \cdot 5.1V$$

$$P_{D5V} \geq \frac{5.5V - 5.1V}{2.2} \cdot 5.1V \Leftrightarrow P_{D5V} \geq 927\text{mW}$$

$R_{5V}$  dissipated power  $P_{R5V,idle}$  when the 5V charger does not pull any current to charge the storage element is determined as follows:

$$P_{R5V,idle} = \frac{(5.5V - 5.1V)^2}{R_{5V}} \Leftrightarrow P_{R_{5V},idle} = \frac{(5.5V - 5.1V)^2}{2.2}$$

$$P_{R_{5V},idle} = 73\text{mW}$$

Furthermore,  $R_{5V}$  dissipated power  $P_{R5V,CC}$  at  $I_{5V,CC}$  current (73.5 mA) is determined as follows:

$$P_{R_{5V},CC} = R_{5V} \cdot I_{5V,CC}^2 = 2.2\Omega \cdot (73.5\text{mA})^2 = 12\text{mW}$$

The minimum required power rating of  $R_{5V}$  is the maximum of  $P_{R5V,idle}$  and  $P_{R5V,CC}$ , thus, 73 mW.

## 6.2. Example Circuit 2

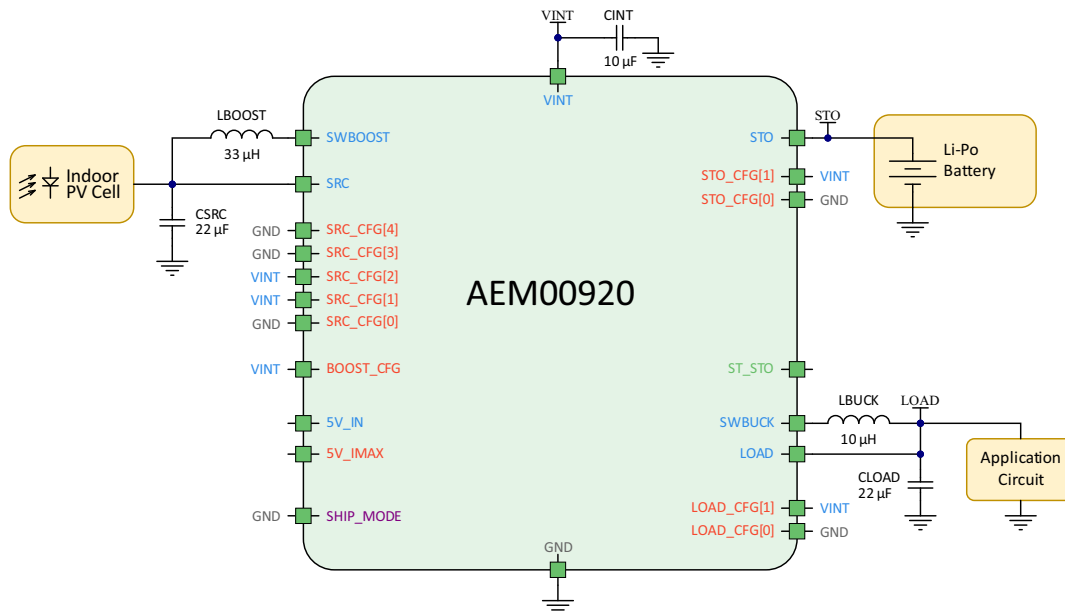


Figure 9: Typical application circuit 2

Figure 9 shows a typical application circuit of the AEM00920.

### Configuration of SRC

The energy source is an indoor PV cell which provides the maximum power at 0.55 V. SRC is thus configured as follows:

- SRC\_CFG[4:0] = LLHHL (0.55 V regulation).
- BOOST\_CFG = H: x3 boost timing.
- L<sub>BOOST</sub> = 33 µH for best tradeoff between efficiency and maximum current with x3 boost timing (see Table 8).

### Configuration of STO

The storage element is a Lithium-Polymer (Li-Po) battery used with the matching STO\_CFG[1:0] preset:

- STO\_CFG[1:0] = HL
- V<sub>OVDIS</sub> = 3.00 V
- V<sub>CHRDY</sub> = 3.20 V

- V<sub>OVCH</sub> = 4.35 V

### Configuration of LOAD

The application circuit is supplied with 2.5 V with current peaks up to 10 mA. The buck converter is configured as follows:

- LOAD\_CFG[1:0] = HL (2.5 V)
- L<sub>BUCK</sub> = 10 µH for best tradeoff between efficiency and maximum current (see Table 8).

### Configuration of 5V\_IN

5 V charger is not used so both 5V\_IN and 5V\_IMAX are left floating.

### Shipping mode

Shipping mode is not used.

- SHIP\_MODE is connected to GND.



## 7. Minimum BOM

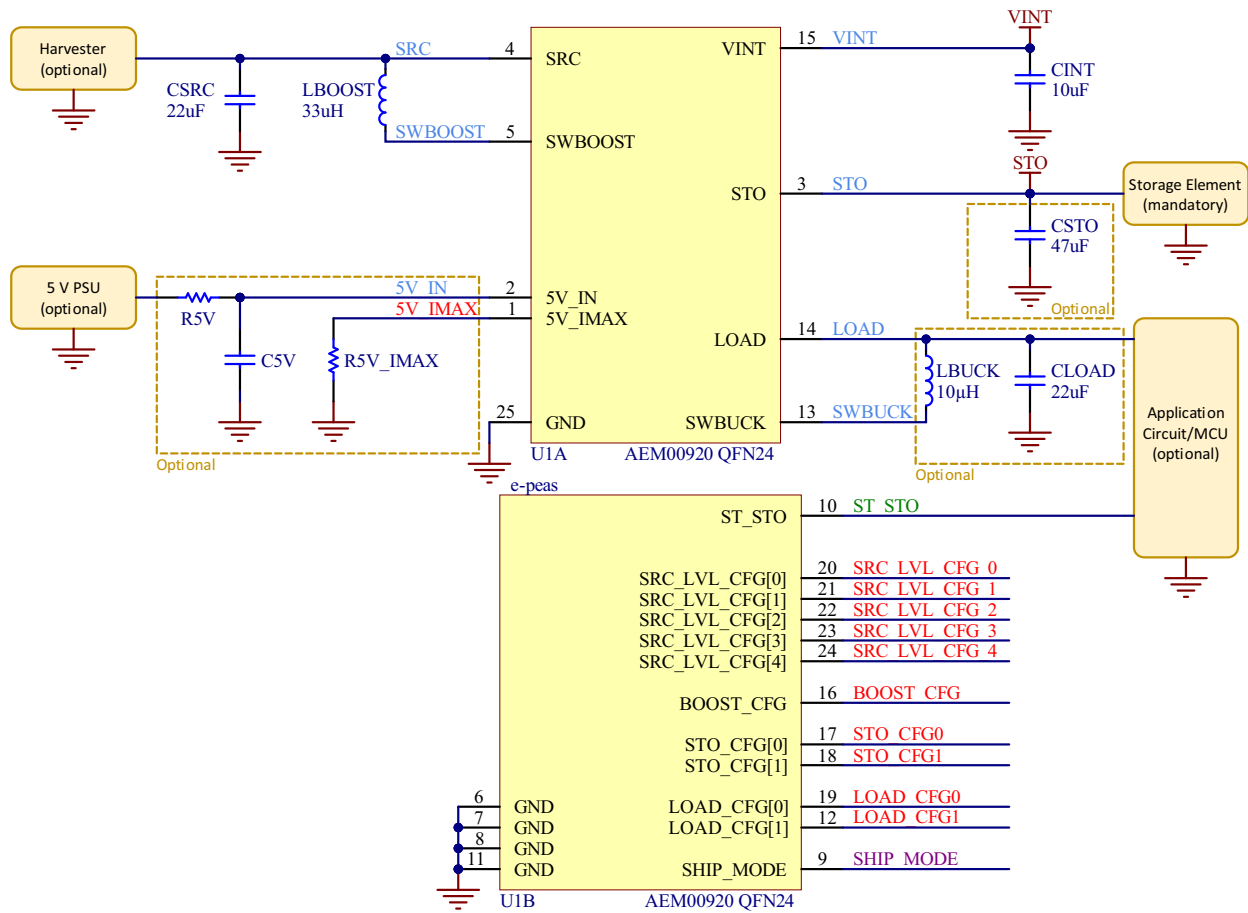


Figure 10: Schematic with minimum BOM

Designator	Description	Quantity	Manufacturer	Part Number
Mandatory	U1	1	e-peas	order at sales@e-peas.com
	CSRC <sup>1</sup>	1	Murata	GRM188R61A226ME15D
	LBOOST <sup>1</sup>	1	Coilcraft	LPS4018-333MRB
Optional	CINT	1	Murata	GRM155R60J106ME44D
	CSTO <sup>2</sup>	1	Murata	GRM188R60J476ME15D
	R5V_IMAX <sup>1</sup>	1	To be defined	
	C5V <sup>1</sup>	1	To be defined	
	R5V <sup>1</sup>	1	To be defined	
	D5V <sup>1</sup>	1	To be defined	
	LBUCK	1	TDK	VLS252012CX-100M-1
CLOAD	1	Murata	GRM188R61A226ME15D	

Table 15: Minimum BOM

1. The AEM00920 must have at least one energy source to work: boost (SRC), 5 V input (5V\_IN) or both.
2. CSTO is not mandatory but ensures high boost converter efficiency with high ESR storage elements.

## 8. Layout

### 8.1. Guidelines

Figure 11 shows an example of PCB layout with AEM00920.

The following guidelines must be applied for best performances:

- Make sure that ground and power signals are routed with large tracks. If an internal ground plane is used, place via as close as possible to the components, especially for decoupling capacitors.
- Reactive components related to the boost/buck converter must be placed as close as possible to the corresponding pins (**SWBOOST**, **SRC**, **STO**, **SWBUCK** and **LOAD**), and be routed with large tracks/polygons.

- PCB track capacitance must be reduced as much as possible on the boost converter switching node **SWBOOST**, as well as on the buck converter switching node **SWBUCK**. This is done as follows:
  - Keep the connection between the **SWBOOST**/**SWBUCK** pins and the corresponding inductor short.
  - Remove the ground and power planes under the **SWBOOST**/**SWBUCK** nodes. The polygon on the opposite external layer may also be removed.
  - Increase the distance between **SWBOOST**/**SWBUCK** and the ground polygon on the external PCB layer where the AEM00920 is mounted.

### 8.2. Example

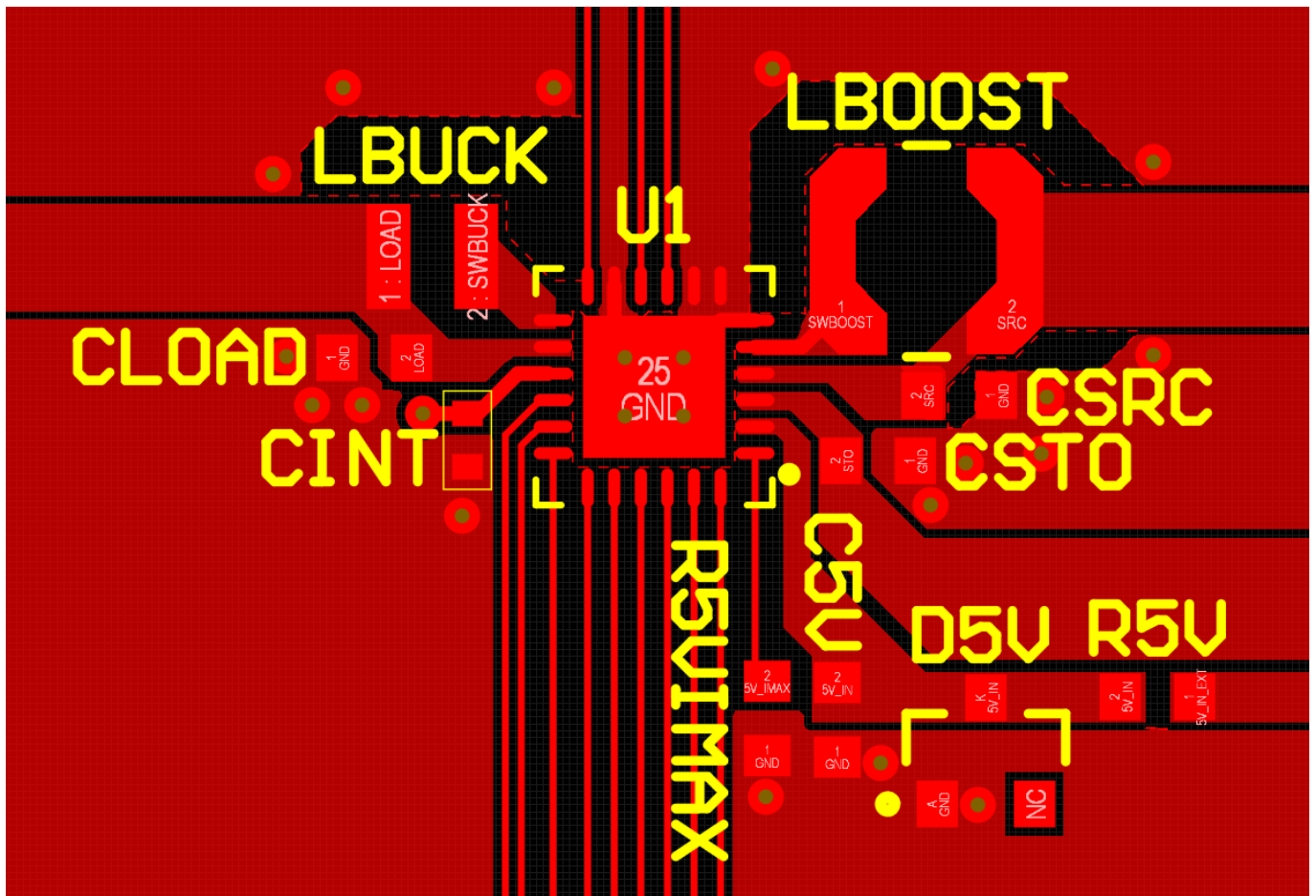


Figure 11: Layout example for the AEM00920 with associated passive components

## 9. Package Information

### 9.1. Moisture Sensitivity Level

Package	Moisture Sensitivity Level (MSL) <sup>1</sup>
QFN-24	Level 1

Table 16: Moisture sensitivity level

1. According to JEDEC 22-A113 standard.

### 9.2. RoHS Compliance

e-peas product complies with RoHS requirement.

e-peas defines “RoHS” to mean that semiconductor end-products are compliant with RoHS regulation for all 10 RoHS substances.

This applies to silicon, die attached adhesive, gold wire bonding, lead frames, mold compound, and lead finish (pure tin).

### 9.3. REACH Compliance

The component and elements used by e-peas subcontractors to manufacture e-peas PMICs and devices are REACH compliant. For more detailed information, please contact e-peas sales team.

**9.4. Package Dimensions**

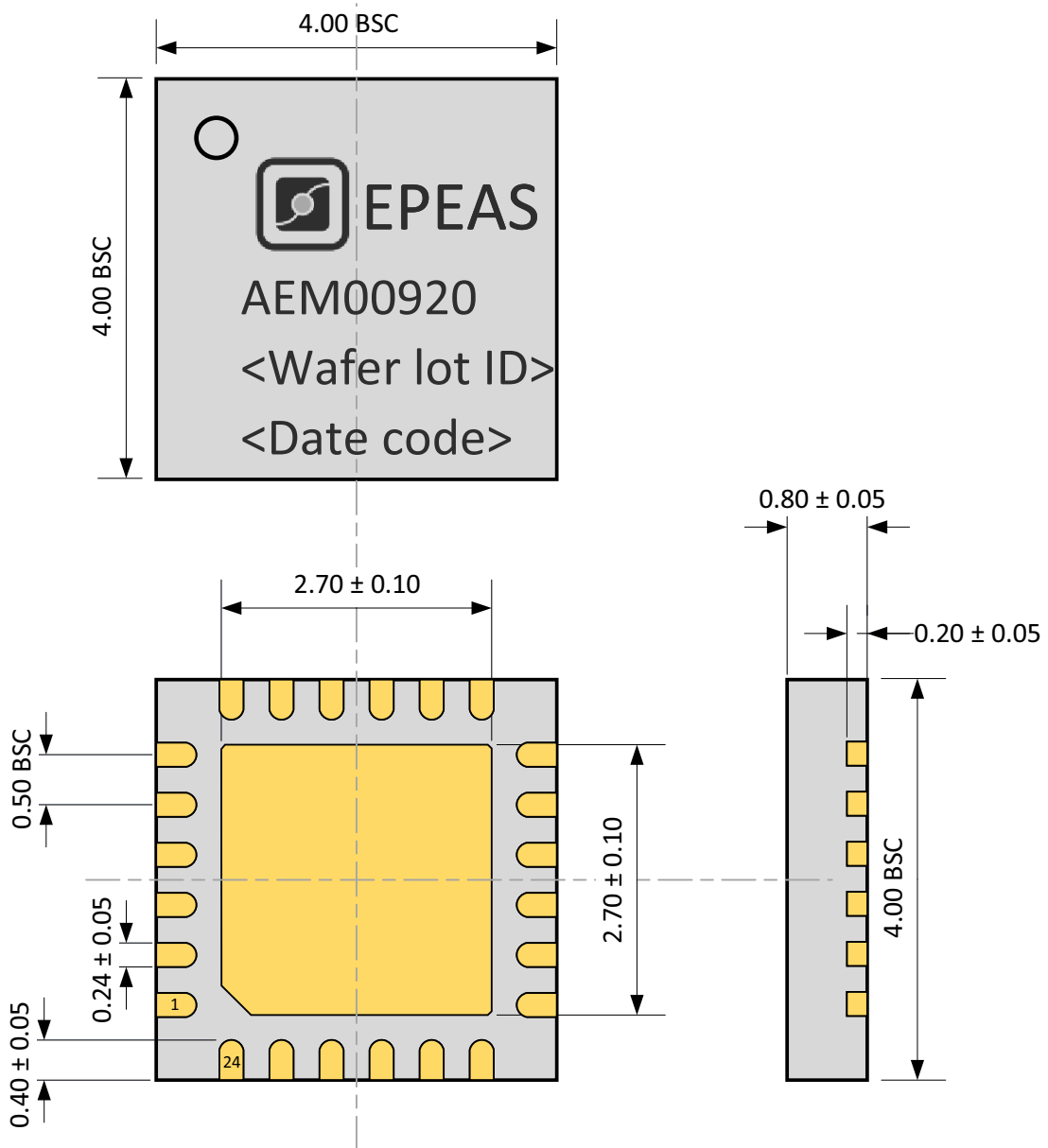


Figure 12: QFN 24-pin 4x4mm drawing (all dimensions in mm)

### 9.5. Board Layout

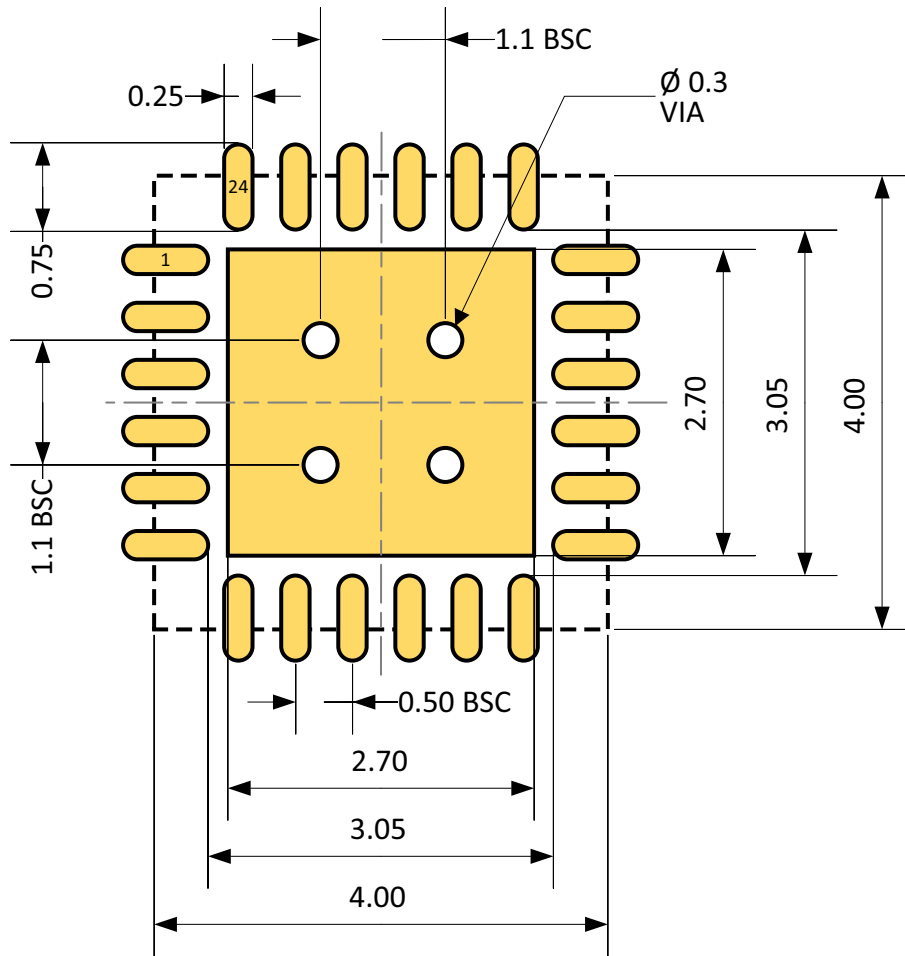


Figure 13: Recommended board layout for QFN24 package (all dimensions in mm)

## 10. Glossary

### 10.1. VINT Acronyms

**C<sub>INT</sub>**

Decoupling capacitor on **VINT** pin.

**V<sub>INT</sub>**

Voltage on the **VINT** pin.

**V<sub>INT,CS</sub>**

Minimum voltage on **VINT** to allow the AEM00920 to switch from **RESET STATE** to **SENSE STO STATE**.

**V<sub>INT,RESET</sub>**

Minimum voltage on **VINT** before switching to **RESET STATE** (from any other state).

**I<sub>QSLEEP</sub>**

Quiescent current drawn on **STO** when the AEM00920 is in **SLEEP STATE**.

**I<sub>QSUPPLY</sub>**

Quiescent current drawn on **STO** when the AEM00920 is in **SUPPLY STATE**.

**I<sub>QSHIP</sub>**

Quiescent current drawn on the storage element when the AEM00920 is in shipping mode (**SHIP\_MODE** is HIGH) and that no energy is available on **SRC** (the AEM00920 is off in that case).

**I<sub>QSHIP,SRC</sub>**

Current drawn on the storage element when the AEM00920 is in shipping mode and energy is available on **SRC**.

### 10.2. SRC Acronyms

**V<sub>SRC</sub>**

Voltage on the **SRC** pin.

**V<sub>OC</sub>**

Open circuit voltage of the harvester connected on **SRC**.

**V<sub>SRC,REG</sub>**

Target regulation voltage of the source, depending on **SRC\_CFG[4:0]** configuration.

**V<sub>SRC,CS</sub>**

Minimum voltage required on **SRC** for the AEM00920 to coldstart.

**P<sub>SRC,CS</sub>**

Minimum power required on **SRC** for the AEM00920 to coldstart.

**L<sub>BOOST</sub>**

Boost converter inductor.

**C<sub>SRC</sub>**

Boost converter input capacitor.

### 10.3. STO Acronyms

**V<sub>STO</sub>**

Voltage on the **STO** pin.

**V<sub>OVDIS</sub>**

Minimum voltage accepted on the storage element before stopping to supply **LOAD** (see Section 5.3).

**V<sub>CHRDY</sub>**

Minimum voltage accepted on the storage element before starting to supply **LOAD** in **START STATE** (see Section 5.3).

**V<sub>OVCH</sub>**

Maximum voltage accepted on the storage element before disabling its charging (see Section 5.3).

### 10.4. LOAD Acronyms

**V<sub>LOAD</sub>**

Voltage on the **LOAD** pin.

**C<sub>LOAD</sub>**

Decoupling capacitor on **LOAD** pin.

**L<sub>BUCK</sub>**

Buck converter inductor.

## 10.5. 5V\_IN Acronyms

### $V_{5V\_IN}$

Voltage on **5V\_IN** pin.

### $V_{5V\_IN,MIN}$

Minimum voltage on **5V\_IN** pin.

### $I_{5V,CC}$

Current provided to the storage element by the **5V\_IN** when in constant current mode.

### $I_{5V,CV}$

Current provided to the storage element by the **5V\_IN** when in constant voltage mode.

### $R_{5V\_IMAX}$

Resistor connected between **5V\_IMAX** and GND that defines the maximum current provided to the storage element by the 5 V charger (**5V\_IN** pin).

### $R_{5V} / C_{5V}$

Respectively, resistor and capacitor creating a RC filter to slow down the rising time of the voltage on the **5V\_IN** pin.

### $D_{5V}$

Zener diode that ensures that the voltage on **5V\_IN** stays below 5.5 V at any time.

### $P_{R_{5V},idle}$

Power dissipated by  $R_{5V}$  when no current is pulled by the 5 V charger (current only flowing in the zener protection diode).

### $P_{R_{5V},CC}$

Power dissipated by  $R_{5V}$  when the 5 V charger is in constant current (CC) mode.

## 10.6. Various Acronyms

### $T_{GPIO,MON}$

GPIO reading rate.

### $T_{CRIT}$

In **SUPPLY STATE**, the AEM00920 waits for  $T_{CRIT}$  before switching to **OVDIS STATE** when  $V_{STO}$  drops below  $V_{OVDIS}$ .

## 11. Revision History

Revision	Date	Description
1.0	December, 2023	Creation of the document.
1.1	January, 2024	Added typical application circuits.
1.2	January, 2024	<ul style="list-style-type: none"> <li>- Added Glossary.</li> <li>- "LOAD Output Voltage" section: "buck voltage cannot be selected <del>smaller</del> higher than <math>V_{OVDIS}</math>"</li> </ul>
1.3	June, 2024	<ul style="list-style-type: none"> <li>- <math>L_{BUCK}</math> in BOM in <math>\mu H</math> instead of <math>\mu F</math>.</li> <li>- Specified BOOST_CFG state when left floating in "Pin Configuration and Functions" section.</li> <li>- Added BOOST_CFG pin info to "Logic input pin connections" table.</li> <li>- Added cautionary statement about the AEM00920 storage element thresholds presets.</li> <li>- Added <math>I_{QSUPPLY}</math> and <math>I_{QSLEEP}</math> values in "Electrical characteristics" table.</li> <li>- "State Machine Description" section: Added missing transition from START STATE to SUPPLY STATE when 5V charger is enabled.</li> </ul>
1.4	June, 2024	<ul style="list-style-type: none"> <li>- Added REACH and RoHS compliances.</li> <li>- Added info about 5 V charger voltage rise time limit and how to handle it.</li> <li>- Added cautionary statement along with storage element threshold voltages.</li> <li>- Corrected state machine transitions:               <ul style="list-style-type: none"> <li>- From START_STATE to SUPPLY_STATE.</li> <li>- From SUPPLY_STATE to SLEEP_STATE.</li> </ul> </li> <li>- Pin description table: fixed pin 4 name.</li> <li>- Fixed cold start minimum power value.</li> </ul>

Table 17: Revision history (part 1)



Revision	Date	Description
1.5	November, 2024	<ul style="list-style-type: none"> <li>- Reworked of the first page.</li> <li>- Corrected the maximum input and output currents on the first page.</li> <li>- Added Absolute Maximum Ratings values.</li> <li>- Added ESD ratings table.</li> <li>- Added Moisture Sensitivity Level section.</li> <li>- Moved the RoHS and REACH compliances sections into the “Package Information” section.</li> <li>- Renamed “Typical Electrical Characteristics at 25°C” section to “Electrical Characteristics at 25°C”.</li> <li>- Modified the typ. minimum source power required for cold start to 1.5 <math>\mu</math>W.</li> <li>- Modified the evaluation board part number on first page.</li> <li>- Corrected pin 4 name to SRC in “Pins description” table.</li> <li>- In “Recommended external components” table:               <ul style="list-style-type: none"> <li>- Added BOOST_CFG configuration condition for <math>L_{BOOST}</math> values and the corresponding min. and typ. values.</li> <li>- Modified <math>L_{BUCK}</math> typical value to 10 <math>\mu</math>H.</li> <li>- Modified <math>L_{BOOST}</math> minimum values.</li> <li>- Added minimum and typical values for <math>C_{LOAD}</math>.</li> </ul> </li> <li>- In “Boost converter timings configuration” table:               <ul style="list-style-type: none"> <li>- Modified <math>L_{BOOST}</math> minimum values for each boost converter timing.</li> <li>- Added recommended <math>L_{BOOST}</math> values for best efficiency.</li> </ul> </li> <li>- Added <math>V_{5V\_IN} \geq V_{STO} + 200</math> mV condition for the 5 V charger to operate in the different 5 V charger sections.</li> <li>- Updated the state machine figure SLEEP STATE input and output conditions and the “Sleep State” section.</li> <li>- Modified “Example Circuit 1” section for <math>R5V = 2.2 \Omega</math> and <math>C5V = 47 \mu</math>F.</li> <li>- Corrected STO_CFG[1] connection to VINT instead of GND on “Typical application circuit 2” figure.</li> <li>- Renamed “Performances” section to “Typical Characteristics” and moved it in “Specifications” section.</li> <li>- Updated “Minimum BOM” section to specify CSTO, LBUCK and CLOAD as optional.</li> <li>- Updated layout example figure by adding R5V, C5V, D5V and R5V_IMAX.</li> <li>- Updated package dimensions and added markings in “QFN 24-pin 4x4mm drawing” figure.</li> <li>- Added “Board Layout” section and figure.</li> </ul>

Table 17: Revision history (part 2)