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 µW 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 µW 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.

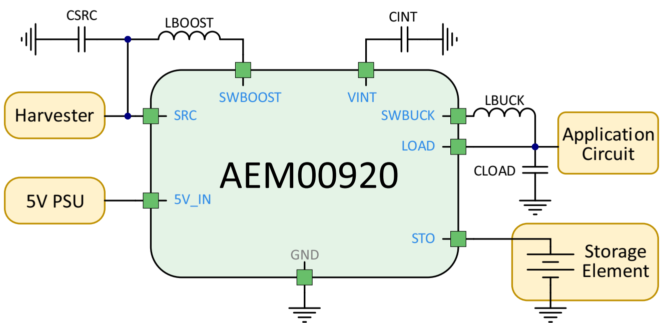
A buck regulator with selectable output voltage allows an application circuit to be supplied with high efficiency.

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

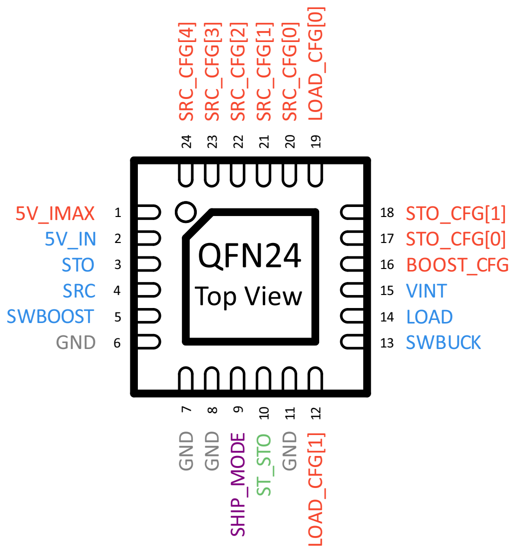

Figure 1: Pinout diagram

NAME	PIN NUMBER	FUNCTION
Power Pins		
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 LOW	LOGIC LEVEL HIGH	FUNCTION
Control Pin				
SHIP_MODE	9	GND	STO	Logic input. When HIGH: - Minimum consumption from the storage element. - Storage element charge is disabled (boost converter is disabled). - Buck (LOAD) is disabled. - VINT is charged only if energy is available on SRC. Read as LOW if left floating.
Configuration Pins				
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.
Status Pin				
ST_STO	10	GND	STO	Logic output. - HIGH when in SUPPLY STATE and SLEEP STATE. - LOW otherwise.
Other pins				
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)[1]	± 2000	V
	Charged-Device Model (CDM)[2]	± 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

ESD (ELECTROSTATIC DISCHARGE) SENSITIVE DEVICE
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	θJA	θJC	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
Power conversion						
$P_{SRC,CS}$	Minimum source power required for cold start.			1.5		µW
$V_{SRC,CS}$	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 V		51		µW
		V_{5V_IN} = 5.50 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		µs
Timing						
T_{CRIT}	In SUPPLY STATE, the AEM00920 waits for T_{CRIT} before switching to OVDIS STATE 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
Storage element						
V_{STO}	Voltage on the storage element.		2.50[1]		4.35[2]	V
V_{OVDIS}	Minimum voltage accepted on the storage element before stopping to supply LOAD.	Configured by STO_CFG[1:0].	2.50		3.50	V
V_{CHRDY}	Voltage required on the storage element to start supplying LOAD in START STATE.	Configured by STO_CFG[1:0].	2.55		3.55	V
V_{OVCH}	Maximum voltage accepted on the storage element before disabling its charging.	Configured by STO_CFG[1:0].	3.80		4.35	V
Internal supply & quiescent current						
V_{INT}	Internal voltage supply.		2.20	2.25	2.30	V
$V_{INT,RESET}$	Minimum voltage on VINT before switching to RESET STATE (from any other state).			2.0		V
$V_{INT,CS}$	Minimum voltage on VINT to allow the AEM00920 to switch from RESET STATE to SENSE STO STATE.			2.3		V
$I_{QSUPPLY}$	Quiescent current on VINT in SUPPLY STATE.[3]	LOAD disabled.		270		nA
		LOAD enabled.[4]		480		
I_{QSLEEP}	Quiescent current on VINT in SLEEP STATE.[3]	LOAD disabled.		205		nA
		LOAD enabled.[4]		415		
I_{QSHIP}	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).	No energy on SRC.		10		nA
$I_{QSHIP,SRC}$	Quiescent current on STO when the shipping mode functionality is enabled (SHIP_MODE set HIGH).	Energy on SRC.		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_{LOAD} set to 2.2 V and LOAD pin left floating.

2.5. Recommended Operation Conditions

Symbol	Parameter	Condition	Min[1]	Typ	Max[1]	Unit
External components						
L_{BOOST}	Inductor of the boost converter.	BOOST_CFG = L	3.3	10[2]		µH
		BOOST_CFG = H	9.9	33[2]		µH
C_{SRC}	Capacitor decoupling the SRC terminal.			10		µF
L_{BUCK}	Inductor of the buck converter.		3.3	10[2]		µH
C_{LOAD}	Capacitor of the buck converter.		10	22		µF
C_{INT}	Capacitor decoupling the VINT terminal.		5	10		µF
C_{STO}	Capacitor decoupling the STO terminal.		5	10		µF
R_{5V_IMAX}	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_{BOOST} and L_{BUCK} typical values recommended for best tradeoff between boost efficiency and maximum current.

Symbol	Parameter		
Logic input pins			
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 µH (Coilcraft LPS4018-333MRB).
- BOOST_CFG = H (x3).

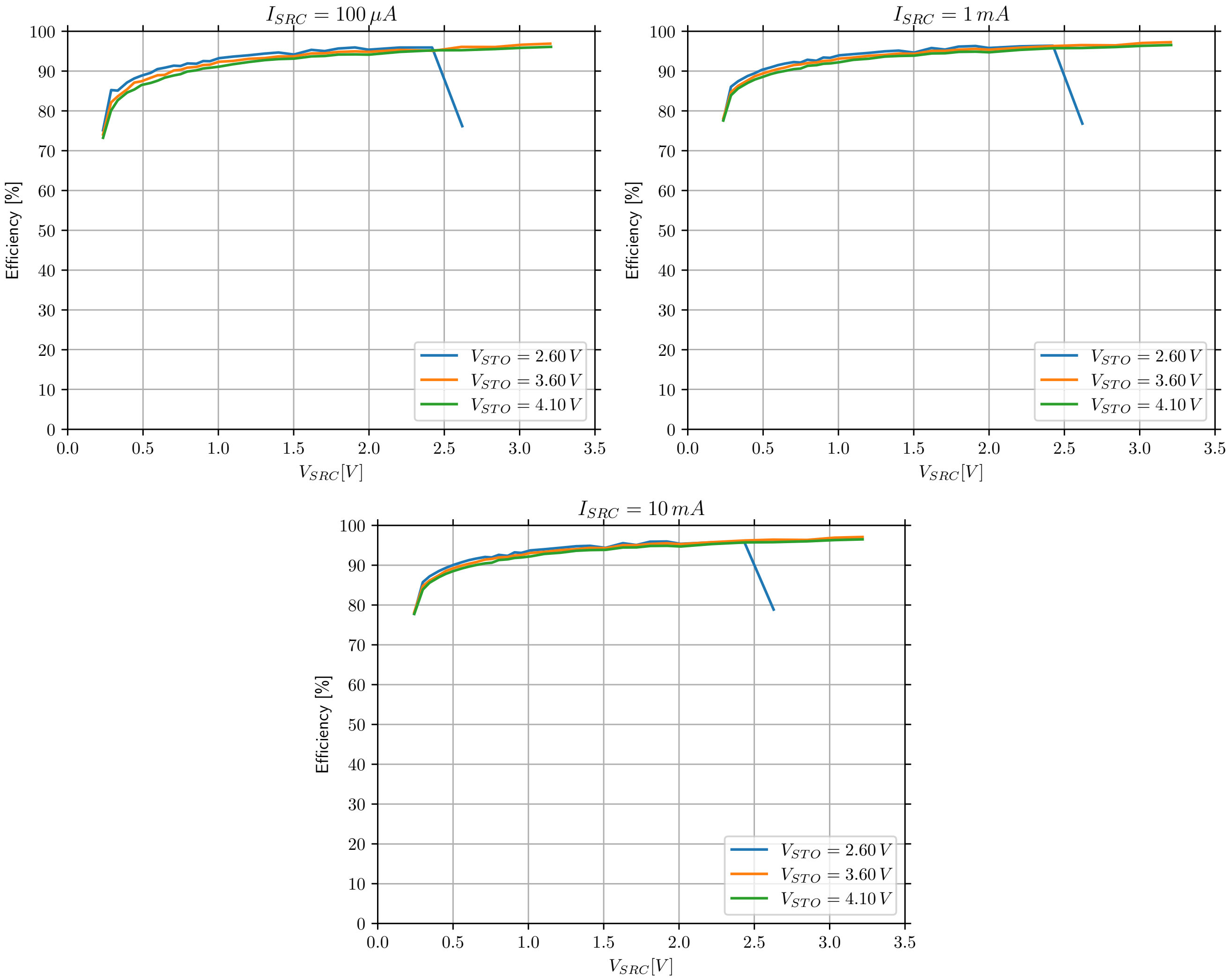

Figure 2: Boost converter efficiency

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 µH (TDK VLS252012CX-100M-1).

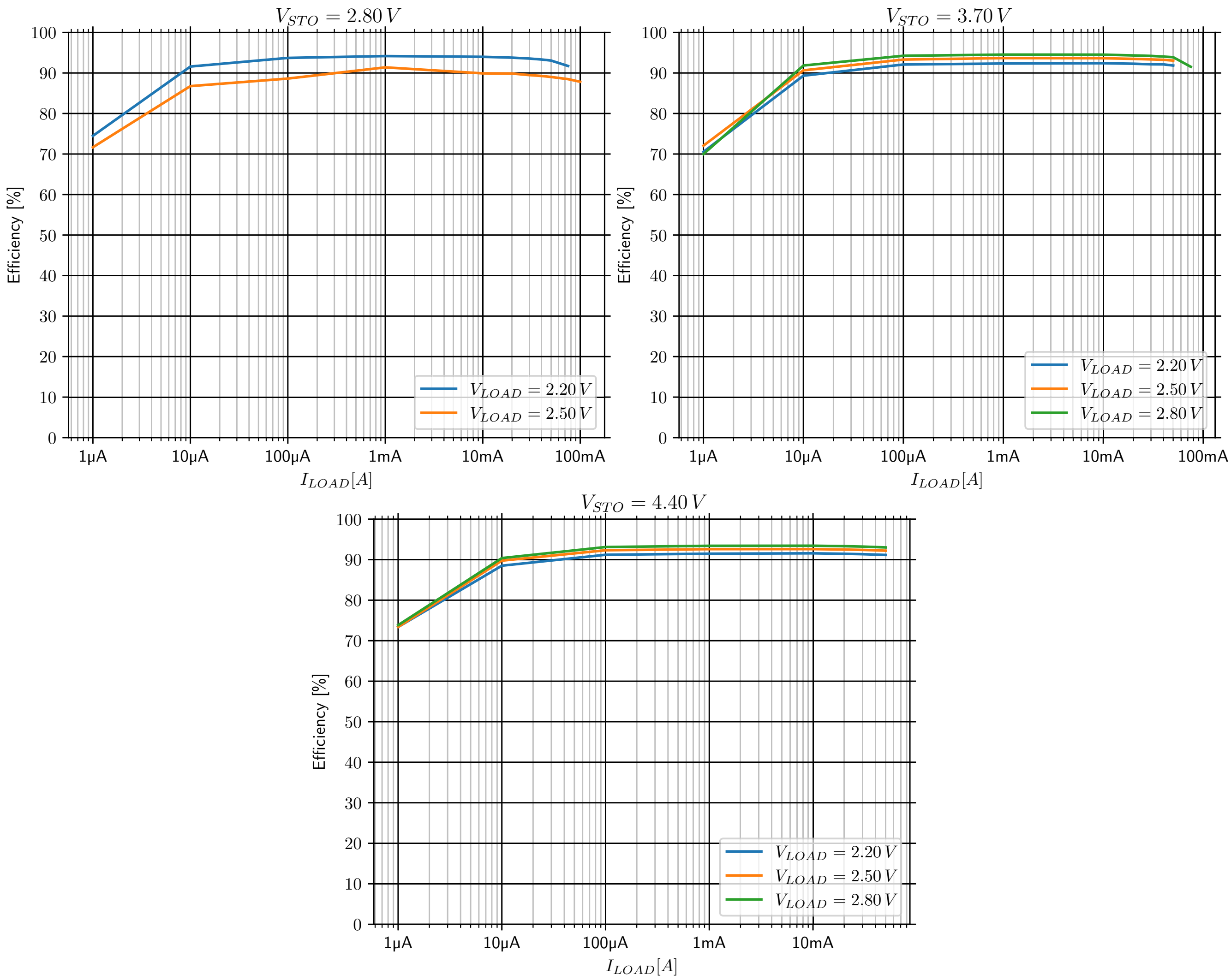

Figure 3: Buck (LOAD) converter efficiency

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

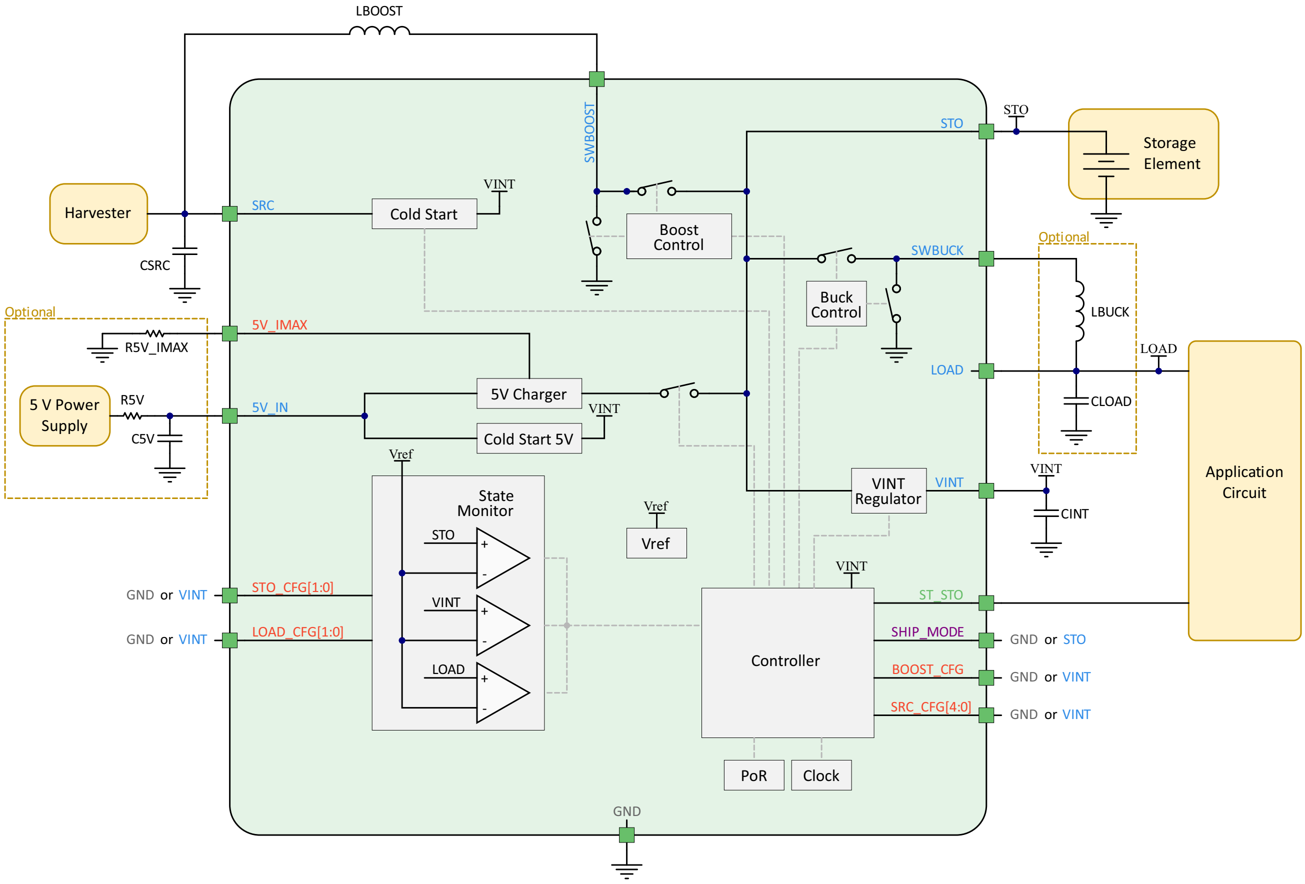

Figure 4: Functional block diagram

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

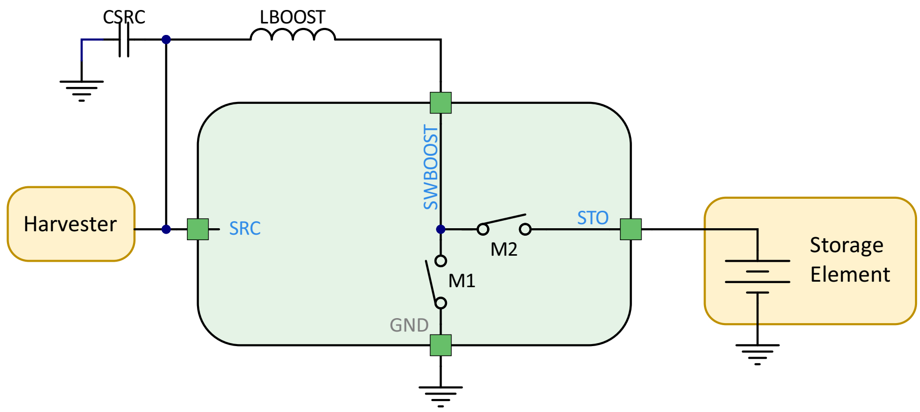

Figure 5: Simplified schematic view of the boost converter

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:

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

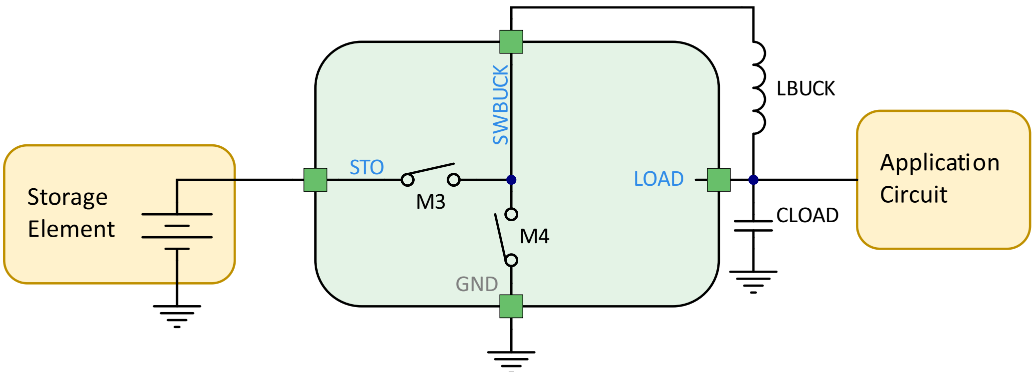

Figure 6: Simplified schematic view of the buck converter

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

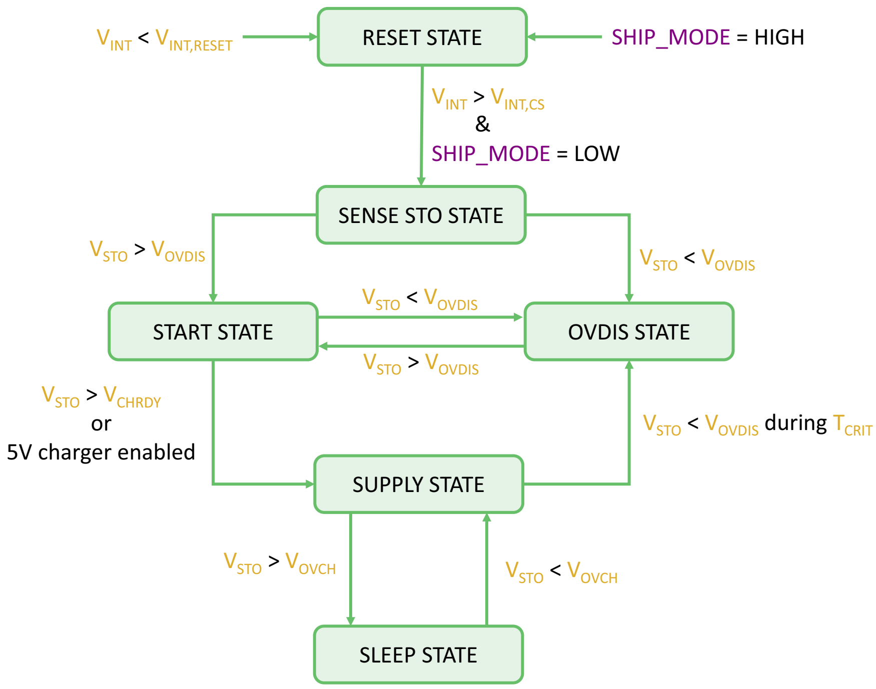

Figure 7: AEM00920 state machine

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 µW).
  - 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_{CHRDY}.
- 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_{CHRDY}.
- The 5V charger is enabled, meaning that the following conditions are both true:
  - $V_{5V\_IN} > V_{STO}$ + 200 mV
  - $V_{5V\_IN} >$ 3.5 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]	Configuration pins					Voltage [V]
SRC_CFG[4:0]					$V_{SRC,REG}$	SRC_CFG[4:0]					$V_{SRC,REG}$
L	L	L	L	L	0.25	H	L	L	L	L	1.10
L	L	L	L	H	0.30	H	L	L	L	H	1.20
L	L	L	H	L	0.35	H	L	L	H	L	1.30
L	L	L	H	H	0.40	H	L	L	H	H	1.40
L	L	H	L	L	0.45	H	L	H	L	L	1.50
L	L	H	L	H	0.50	H	L	H	L	H	1.60
L	L	H	H	L	0.55	H	L	H	H	L	1.70
L	L	H	H	H	0.60	H	L	H	H	H	1.80
L	H	L	L	L	0.65	H	H	L	L	L	1.90
L	H	L	L	H	0.70	H	H	L	L	H	2.00
L	H	L	H	L	0.75	H	H	L	H	L	2.20
L	H	L	H	H	0.80	H	H	L	H	H	2.40
L	H	H	L	L	0.85	H	H	H	L	L	2.60
L	H	H	L	H	0.9	H	H	H	L	H	2.80
L	H	H	H	L	0.95	H	H	H	H	L	3.00
L	H	H	H	H	1.00	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_{OVCH}, 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
STO_CFG[1:0]		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		
BOOST_CFG	Timing multiplication factor	Minimum L_{BOOST} [µH]	L_{BOOST} [µH] for best efficiency
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]
LOAD_CFG[1:0]		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 [Ω]	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

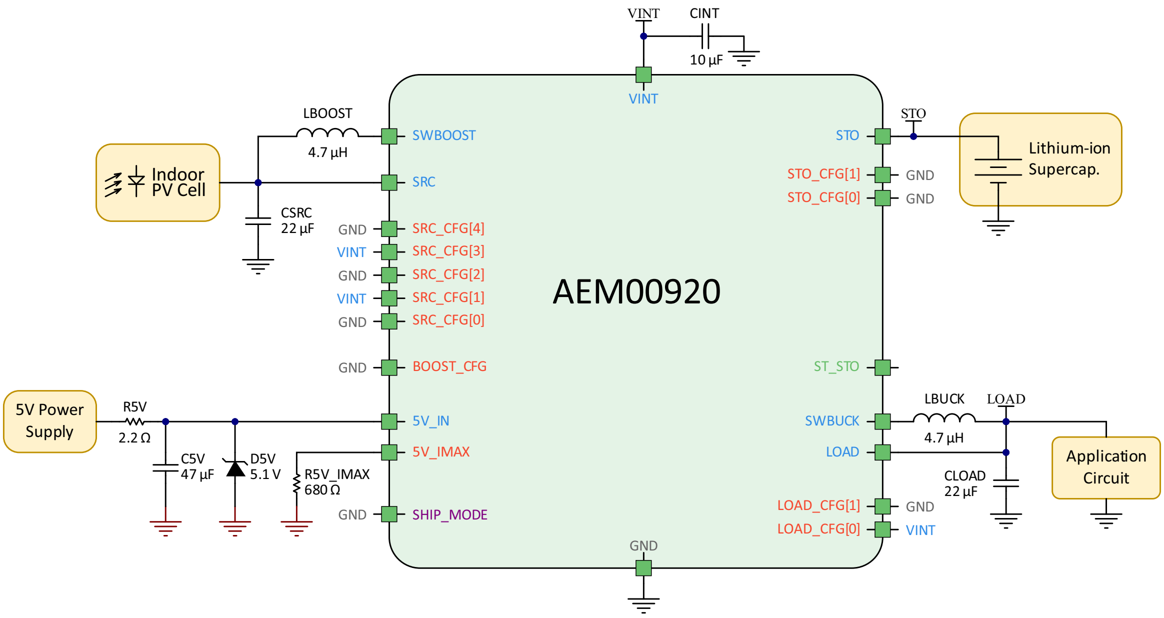

Figure 8: Typical application circuit 1

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_{BOOST} = 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_{OVDIS} = 2.5 V.
  - V_{CHRDY} = 2.55 V.
  - V_{OVCH} = 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_{BUCK} = 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_{5V_IMAX} = 680 Ω.
- $I_{5V,CC}$ = 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_{5V} is calculated so that its voltage drop across it ensures a voltage on 5V_IN higher than V_{OVCH} + 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_{5V} is calculated so that the 5V_IN voltage rise time remains below $T_{5V,RISE}$:

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

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

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

- R_{5V} = 2.2 Ω
- C_{5V} = 47 µF

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}:

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

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

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:

$$P_{R5V,idle} = \frac{(5.5V - 5.1V)^2}{R_{5V}} \Leftrightarrow P_{R\_5V,idle} = \frac{(5.5V - 5.1V)^2}{2.2}$$

$$P_{R\_5V,idle} = 73mW$$

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

$$P_{R\_5V,CC} = R_{5V} \cdot I_{5V,CC}{}^2 = 2.2\Omega \cdot (73.5mA)^2 = 12mW$$

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

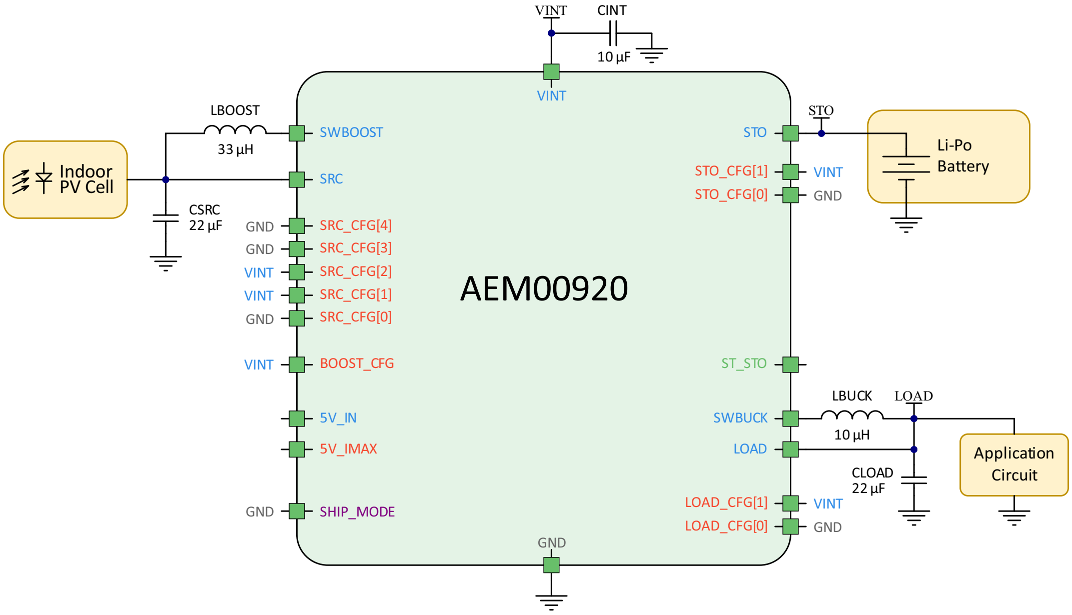

Figure 9: Typical application circuit 2

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_{BOOST} = 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_{OVDIS} = 3.00 V
- V_{CHRDY} = 3.20 V
- V_{OVCH} = 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_{BUCK} = 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

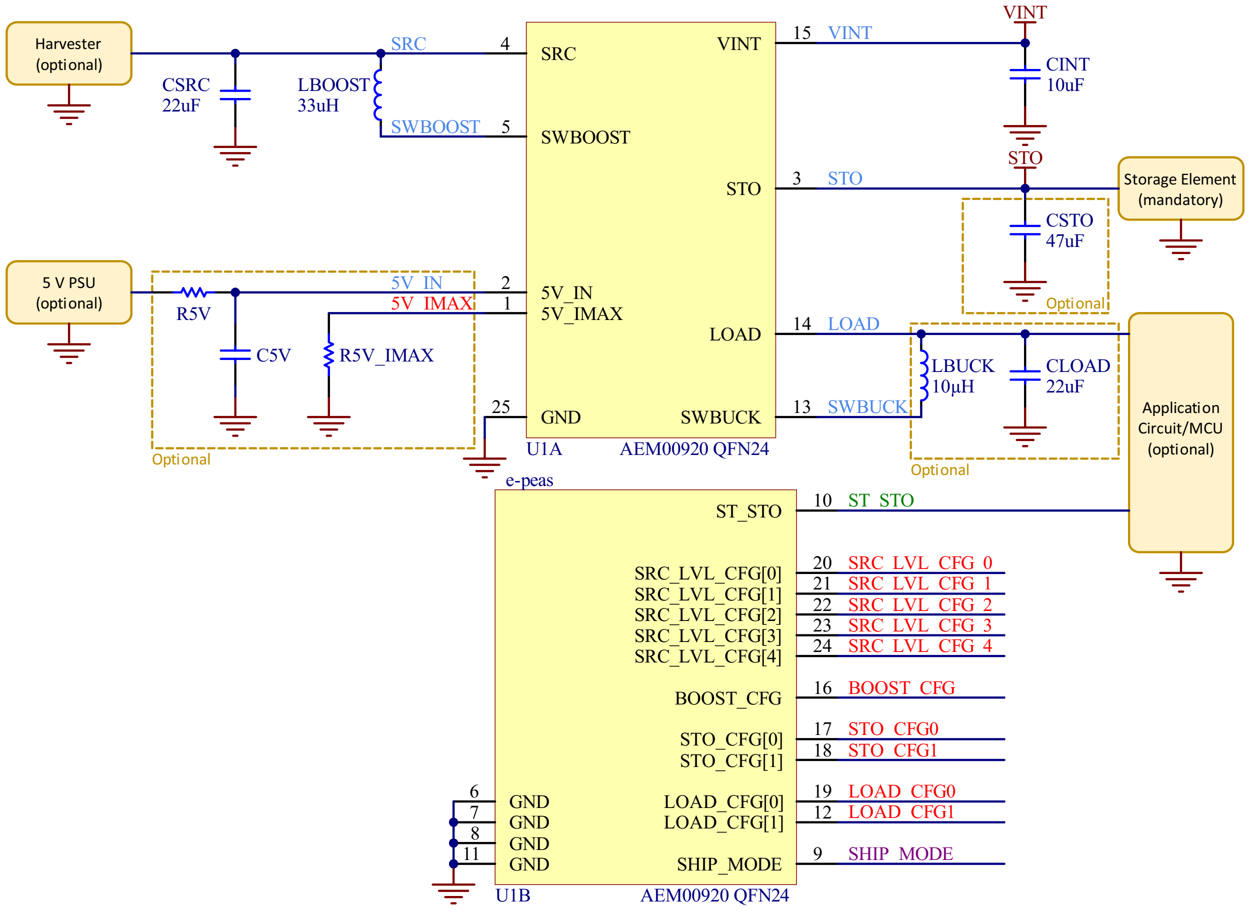

Figure 10: Schematic with minimum BOM

	Designator	Description	Quantity	Manufacturer	Part Number
Mandatory	U1	AEM00920	1	e-peas	order at sales@e-peas.com
	CSRC[1]	Ceramic Capacitor 22 µF, 10 V, 20%, X5R 0603	1	Murata	GRM188R61A226ME15D
	LBOOST[1]	Power Inductor 33 µH, 0.68 A, LPS4018	1	Coilcraft	LPS4018-333MRB
	CINT	Ceramic Capacitor 10 µF, 6.3 V, 20%, X5R, 0402	1	Murata	GRM155R60J106ME44D
Optional	CSTO[2]	Ceramic Capacitor 47 µF 6.3 V, 20%, X5R, 0603	1	Murata	GRM188R60J476ME15D
	R5V_IMAX[1]	Resistor (to be defined)	1	To be defined	
	C5V[1]	Capacitor (to be defined)	1	To be defined	
	R5V[1]	Resistor (to be defined)	1	To be defined	
	D5V[1]	Zener diode (to be defined)	1	To be defined	
	LBUCK	Power Inductor 10 µH TDK VLS-CX-1	1	TDK	VLS252012CX-100M-1
	CLOAD	Ceramic Capacitor 22 µF, 10 V, 20%, X5R, 0603	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

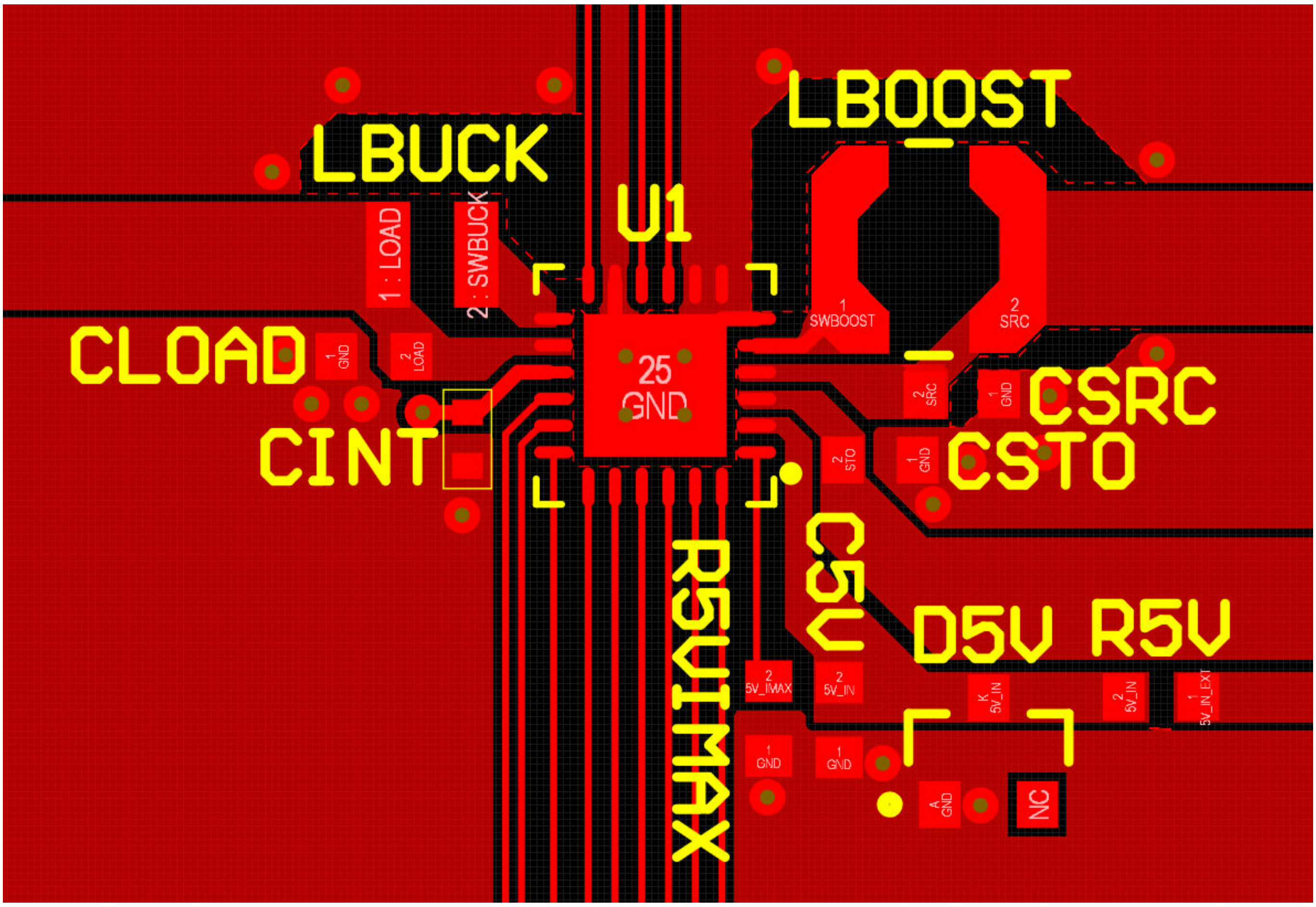

Figure 11: Layout example for the AEM00920 with associated passive components

9. Package Information

9.1. Moisture Sensitivity Level

Package	Moisture Sensitivity Level (MSL)[1]
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

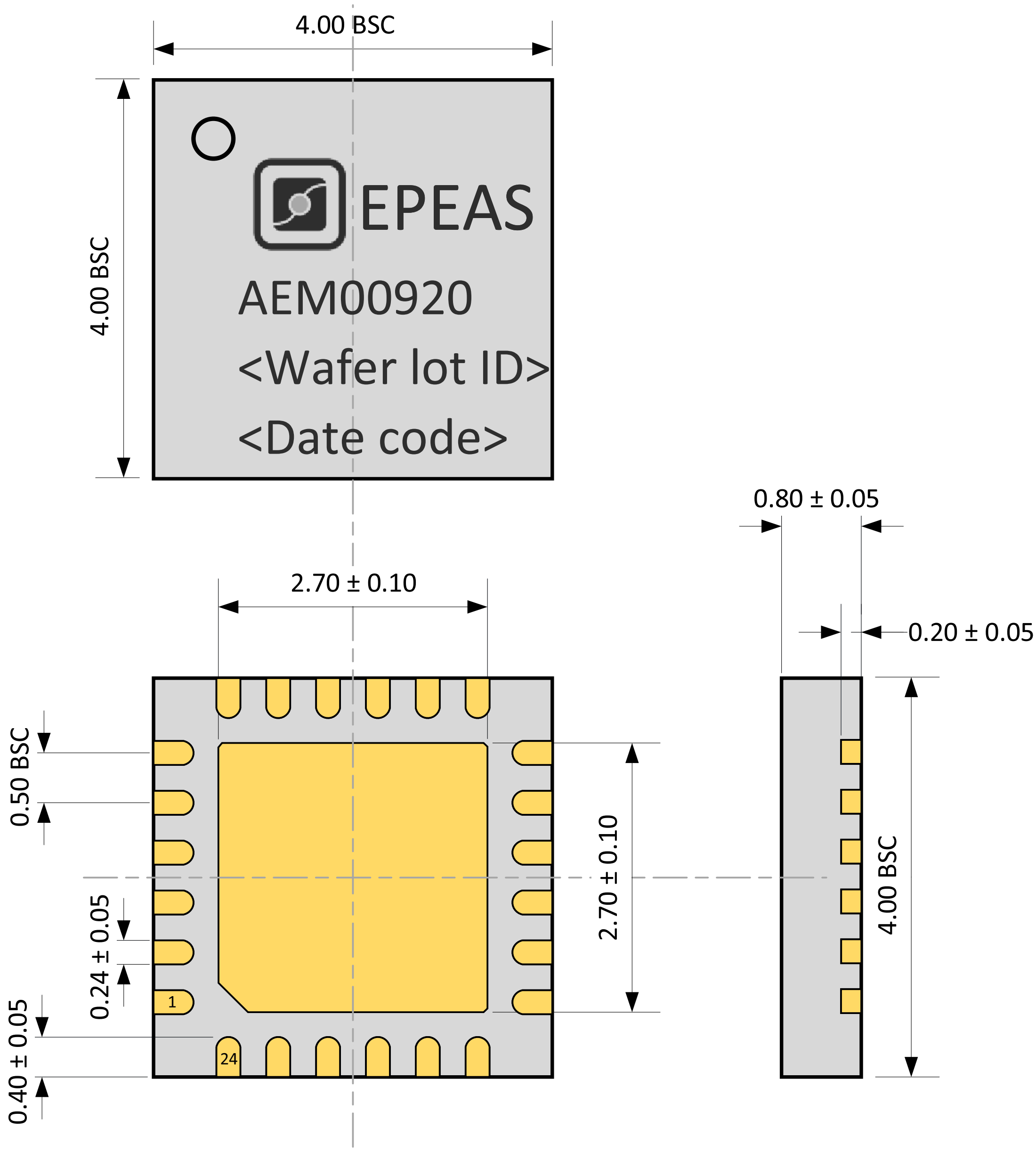

Figure 12: QFN 24-pin 4x4mm drawing (all dimensions in mm)

9.5. Board Layout

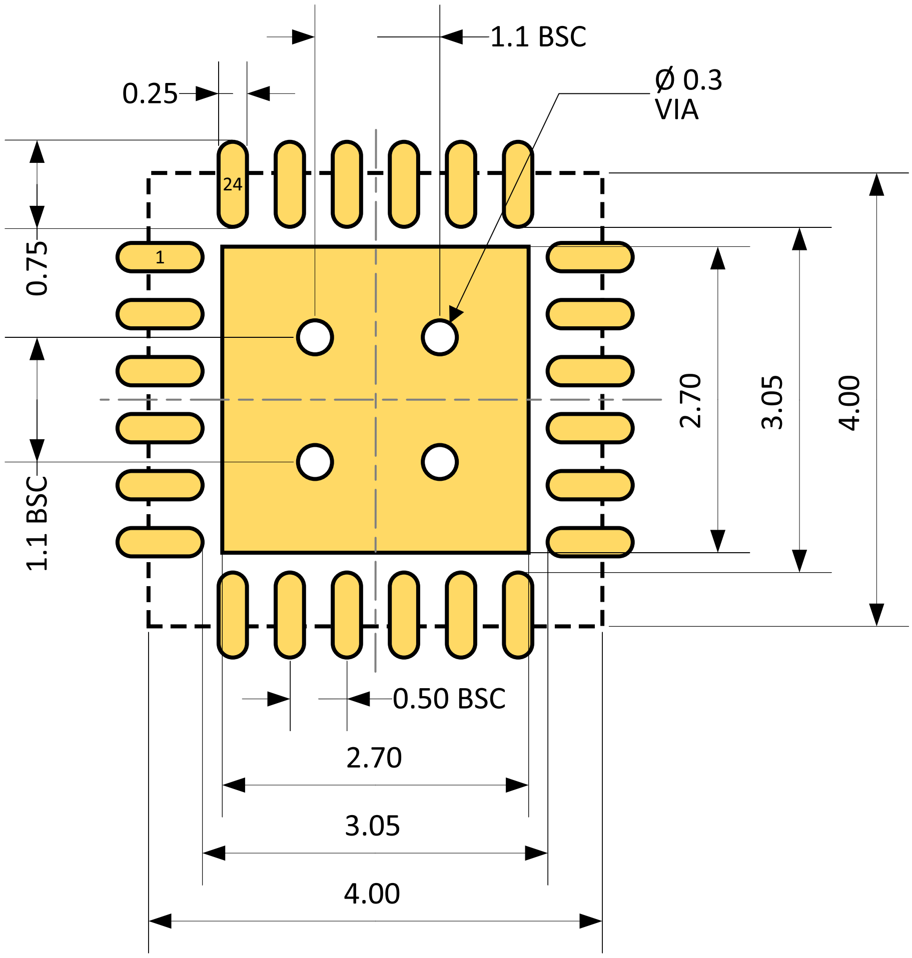

Figure 13: Recommended board layout for QFN24 package (all dimensions in mm)

10. Glossary

10.1. VINT Acronyms

C_{INT}

Decoupling capacitor on VINT pin.

V_{INT}

Voltage on the VINT pin.

$V_{INT,CS}$

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

$V_{INT,RESET}$

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

I_{QSLEEP}

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

$I_{QSUPPLY}$

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

I_{QSHIP}

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).

$I_{QSHIP,SRC}$

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

10.2. SRC Acronyms

V_{SRC}

Voltage on the SRC pin.

V_{OC}

Open circuit voltage of the harvester connected on SRC.

$V_{SRC,REG}$

Target regulation voltage of the source, depending on SRC_CFG[4:0] configuration.

$V_{SRC,CS}$

Minimum voltage required on SRC for the AEM00920 to coldstart.

$P_{SRC,CS}$

Minimum power required on SRC for the AEM00920 to coldstart.

L_{BOOST}

Boost converter inductor.

C_{SRC}

Boost converter input capacitor.

10.3. STO Acronyms

V_{STO}

Voltage on the STO pin.

V_{OVDIS}

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

V_{CHRDY}

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

V_{OVCH}

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

10.4. LOAD Acronyms

V_{LOAD}

Voltage on the LOAD pin.

C_{LOAD}

Decoupling capacitor on LOAD pin.

L_{BUCK}

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.

$P_{R5V,idle}$

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

$P_{R5V,CC}$

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	- Added Glossary. - "LOAD Output Voltage" section: "buck voltage cannot be selected ~~smaller~~*higher* than V_{OVDIS}"
1.3	June, 2024	- L_{BUCK} in BOM in µH instead of µF. - Specified BOOST_CFG state when left floating in "Pin Configuration and Functions" section. - Added BOOST_CFG pin info to "Logic input pin connections" table. - Added cautionary statement about the AEM00920 storage element thresholds presets. - Added $I_{QSUPPLY}$ and I_{QSLEEP} values in "Electrical characteristics" table. - "State Machine Description" section: Added missing transition from START STATE to SUPPLY STATE when 5V charger is enabled.

1.4	June, 2024	- Added REACH and RoHS compliances.
		- Added info about 5 V charger voltage rise time limit and how to handle it.
		- Added cautionary statement along with storage element threshold voltages.
		- Corrected state machine transitions:
		    - From START_STATE to SUPPLY_STATE.
		    - From SUPPLY_STATE to SLEEP_STATE.
		- Pin description table: fixed pin 4 name.
		- Fixed cold start minimum power value.

Table 17: Revision history (part 1)

Revision	Date	Description

1.5	November, 2024	- Reworked of the first page.
		- Corrected the maximum input and output currents on the first page.
		- Added Absolute Maximum Ratings values.
		- Added ESD ratings table.
		- Added Moisture Sensitivity Level section.
		- Moved the RoHS and REACH compliances sections into the “Package Information” section.
		- Renamed “Typical Electrical Characteristics at 25°C” section to “Electrical Characteristics at 25°C”.
		- Modified the typ. minimum source power required for cold start to 1.5 µW.
		- Modified the evaluation board part number on first page.
		- Corrected pin 4 name to SRC in “Pins description” table.
		- In “Recommended external components” table:
		  - Added BOOST_CFG configuration condition for L_{BOOST} values and the corresponding min. and typ. values.
		  - Modified L_{BUCK} typical value to 10 µH.
		  - Modified L_{BOOST} minimum values.
		  - Added minimum and typical values for C_{LOAD}.
		- In “Boost converter timings configuration” table:
		  - Modified L_{BOOST} minimum values for each boost converter timing.
		  - Added recommended L_{BOOST} values for best efficiency.
		- Added $V_{5V\_IN} \geq V_{STO}$ + 200 mV condition for the 5 V charger to operate in the different 5 V charger sections.
		- Updated the state machine figure SLEEP STATE input and output conditions and the “Sleep State” section.
		- Modified “Example Circuit 1” section for R5V = 2.2 Ω and C5V = 47 µF.
		- Corrected STO_CFG[1] connection to VINT instead of GND on “Typical application circuit 2” figure.
		- Renamed “Performances” section to “Typical Characteristics” and moved it in “Specifications” section.
		- Updated “Minimum BOM” section to specify CSTO, LBUCK and CLOAD as optional.
		- Updated layout example figure by adding R5V, C5V, D5V and R5V_IMAX.
		- Updated package dimensions and added markings in “QFN 24-pin 4x4mm drawing” figure.
		- Added “Board Layout” section and figure.

Table 17: Revision history (part 2)