3-Wire Programmable Camkshaft Position Sensor

1. Features

- AEC-Q100 qualified
- ISO 26262 ASIL-B
- TPO functionality with optinal Auto-TPO adaption in EEPROM
- Customer-side programming enable
- Operation Temperature：-40°C～150°C
- Operation Voltage：4V～16V
- High Accuracy and High Sensitivity
- 3-pin PCB-less TS-3 package

2. Applications

- Camshaft position detection
- High accuracy gear position detection

3. Description

The SC9388 is produced by Bi-CMOS technology, it’s a chopper-stabilized & active differential Hall sensor ideally suited for camshaft phase detection applications. It have the auto-adjust function to keep the performance with high accuracy and low jitter capabilities.

Superior high-temperature performance is made possible through dynamic offset cancellation & internal temperature compensation algorithm, which reduces the residual offset voltage normally caused by device over molding, temperature dependencies, and thermal stress. Each device includes on a single silicon chip a voltage regulator, Hall-voltage generator, small-signal amplifier, chopper stabilization circuits, digital process circuits, EEPROM, diagnostic circuits.

An onboard regulator permits with supply voltages of 4 to 16V which makes the device suitable for a wide range of industrial and automotive applications

The device is available in a 3-pin package (TS-3) Which integrated with capacitor.

It is lead (Pb) free, with 100% matte tin-plated lead frame.

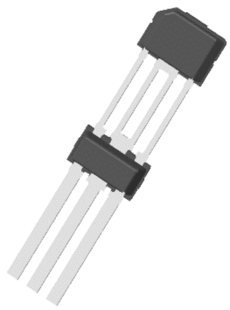

Fig.1 TS-3 Package Outline

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4. Terminal Configuration

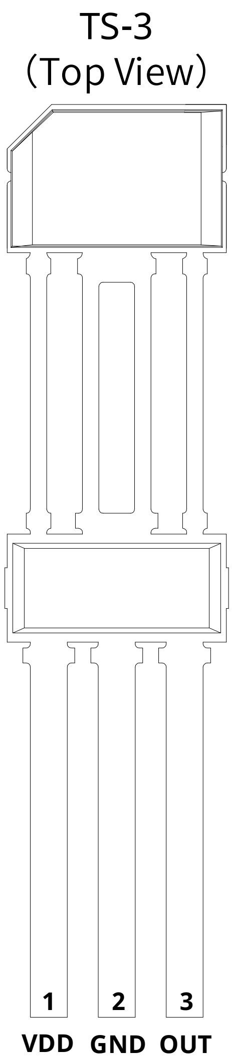


Fig.2 Pin Description

Terminal		Type	Description
Name	Number		
VDD	1	PWR	4V~16V power supply
GND	2	Ground	Ground terminal
OUT	3	Output	Open-drain output. The open drain requires a pull-up resistor

5. Ordering Information

Ordering Information	Marking	Ambient, T_A(℃)	Package	Packing	Quantity
SC9388T3-TR-Q	9388	-40 ~ 150	TS-3	Tape & reel	1500 /reel

6. Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)

Symbol	Parameter	Test conditions	Min.	Max.	Units
V_{DD}	Power supply voltage (1)	continuous, $T_J \leqslant 170$℃	-16	18	V
		max. 60s, $T_J \leqslant 170$℃	-18	27	V
$V_{OUT\text{-}Off}$	Output Off voltage (1)	continuous, $T_J \leqslant 170$℃	-0.3	26.5	V
		max. 1h, $T_{Amh} \leqslant 40$℃	-1.0	26.5	V
$V_{OUT\text{-}On}$	Output On voltage (1)	continuous, $T_{Amh} \leqslant 40$℃	-1.0	16	V
		max. 1h, $T_{Amh} \leqslant 40$℃	-0.3	18	V
		max. 60s, $T_{Amh} \leqslant 40$℃	-0.3	26.5	V
T_A	Operating ambient temperature		-40	150	℃
T_J	Maximum junction temperature	Exposure time: max. 10×1h, V_{DD}=16V	-4	175	℃
R_L	Magnetic field induction (2)	Magnetic pulse during magnet magnetization. Valid with $T_{ambient} \leq 80$°C	-4	4	T

Note :
(1) tresses above those listed here may cause permanent damage to the device. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.
(2) Guaranteed by design.

7. ESD Protection

Symbol	Parameter	Test conditions	Min.	Max.	Units
V_{ESD}	ESD-Protection	Refer to AEC-Q100-002E HBM standard,R=1.5kΩ, C=100pF	-8	8	kV

8. Thermal Characteristics

Symbol	Parameter	Test conditions	Min.	Max.	Units
$R_{\theta JA}$	Package thermal resistance	Without PCB, welding process with lead-frame	-	190	℃/W

9. Operating Characteristics

over operating free-air temperature range (V_{DD}=5.0V, unless otherwise noted)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Units
Electrical parameters						
V_{DD}	Supply Voltage		4	–	16	V
V_{Q_OFF}	Continuous Output Off voltage		1	–	16	V
dV_{DD}/dt	Supply voltage power- up/down voltage ramp		3	–	10000	V/ms
V_{Qsat}	Output saturation voltage	$I_Q \le 15mA$	-	-	500	mV
V_{DD_clamp}	Clamping voltage V_{DD}-Pin	Leakage current through ESD diode<0.5mA	42	-	-	V
V_{Qclamp}	Clamping voltage V_Q-Pin	leakage current through ESD-diode<0.5mA	42	-	-	V
V_{DD_reset}	Reset voltage		-	-	3.6	V
I_{DD}	Supply current		8	–	13.4	mA
I_{Q_ON}	Continuous output On current	$V_{Q\_LOW}<0.5V$	0.01	–	15	mA
I_{Qleak}	Output leakage current	V_Q=18V	-	0.1	10	μA
I_{Qshort}	Output current limit during short-circuit condition		30	-	80	mA
Time & Frequency Related						
t_{power_on}	Power on time	During this time the output is locked to high.	0.8	0.9	1	ms
t_{delay}	Delay time between magnetic signal switching point and corresponding output signal falling edge switching event	Falling edge	10	14	19	μs
t_{delay2}	Further options on delay time accessible using EEPROM	Option 2	13	17	22	μs
t_{delay3}		Option 3	16	20	25	μs
t_{delay4}		Option 4	19	23	28	μs
t_{fall}	Output fall time	V_{Pullup}=5V, R_{Pullup}=1.2kΩ (±10%), C_Q=1.8nF (±15%), valid between 80%-20%	2.0	2.5	3.0	μs
		V_{Pullup}=5V, R_{Pullup}=1.2kΩ (±10%), C_Q=1.8nF (±15%), valid between 90%-10%	3.2	4.5	5.8	μs
t_{rise}	Output rise time	R_{Pullup}=1.2kΩ (±10%), C_Q=1.8nF (±15%), valid between 10%-90%	4	-	11.4	μs
N_{PROG}	Maximum No. of EEPROM programming cycles	T_J<150℃	–	–	80	n
f	Magnetic signal frequency range	Full accuracy	0	–	8000	Hz
C_{VDD}	Capacitance between IC supply & ground pins		90	100	110	nF

Operating Characteristics（continued）

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Units
C_Q	Output capacitance between IC output and ground pins		2.09	2.2	2.31	nF
Magnetic Signal						
$DR_{mag\_field\_dir}$	Dynamic range of the magnetic field of the direction channel		-60	-	60	mT
$SR_{mag\_field\_s\_bb}$	Static range of the magnetic field of the outer Hall probes in back-bias configuration	No wheel in front of module / Offset-DAC- Compensation-range	0	-	550	mT
Hysteresis Of Switching Threshold						
Switch_Offset,Error	Switching level offset	For magnetic speed signal =10mT$_{pkpk}$: resulting in phase error/duty cycle error	-350	–	350	μT
K_factor	Programming switching level offset (k-factor)	EEPROM “K_FACTOR”:Option 0000	–	39.1	–	%
		EEPROM “K_FACTOR”:Option 0001	–	40.6	–	%
		EEPROM “K_FACTOR”:Option 0010	–	42.2	–	%
		EEPROM “K_FACTOR”:Option 0011	–	43.8	–	%
		EEPROM “K_FACTOR”:Option 0100	–	45.3	–	%
		EEPROM “K_FACTOR”:Option 0101	–	46.9	–	%
		EEPROM “K_FACTOR”:Option 0110	–	48.4	–	%
		EEPROM “K_FACTOR”:Option 0111	46.3	50.0	53.7	%
		EEPROM “K_FACTOR”:Option 1000	–	51.6	–	%
		EEPROM “K_FACTOR”:Option 1001	–	53.1	–	%
		EEPROM “K_FACTOR”:Option 1010	–	54.7	–	%
		EEPROM “K_FACTOR”:Option 1011	–	56.3	–	%
		EEPROM “K_FACTOR”:Option 1100	–	57.8	–	%
		EEPROM “K_FACTOR”:Option 1101	–	59.4	–	%
		EEPROM “K_FACTOR”: Option 1110	–	60.9	–	%
		EEPROM “K_FACTOR”:Option 1111	–	62.5	–	%

Operating Characteristics（continued）

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Units
Accuracy Related						
Jitter	Repeatability (Jitter)	3 sigma, ΔB_{pkpk}=20mT_{pkpk}, FILTER_SELECT=0	-	-	0.015	°Crank
		3 sigma, ΔB_{pkpk}=9mT_{pkpk} , measured on coil using sinus signal, T_A=150°C, f=8kHz, FILTER_SELECT=0	-	-	0.025	°Crank
Phirunning	Maximum phase error	ΔB_{Speed}>9mT_{pkpk} ,signature excluded, accuracy on mentioned wheel in Figure 4	-0.2	-	0.2	°Crank
Phistop, start	Maximum phase error after stop-start	Reduced phase accuracy only for first pulse after stop-start-state / signature excluded	-1.7	-	3.2	°Crank
Temperature Related						
T_J	Normal operating junction temperature	Exposure time: max. 2500h at T_J=175°C, V_{DD}=16V	-40	-	175	°C
		Exposure time: max. 10×1h at T_J=185°C, V_{DD}=16V, additive to other lifetime	-40	-	185	°C
T_{no}	Not operational lifetime	Without sensor function. Exposure time max 500h @ 150°C; increased time for lower temperatures according to Arrhenius-Model, additive to other lifetime	-40	-	150	°C
T_{RDPROG}	Ambient temperature range for customer programming		15	25	130	°C
T_C	Temperature compensation range of magnetic material	Internal compensation of magnetic signal amplitude of speed signal	1900	-	0	ppm

10. Block Diagram

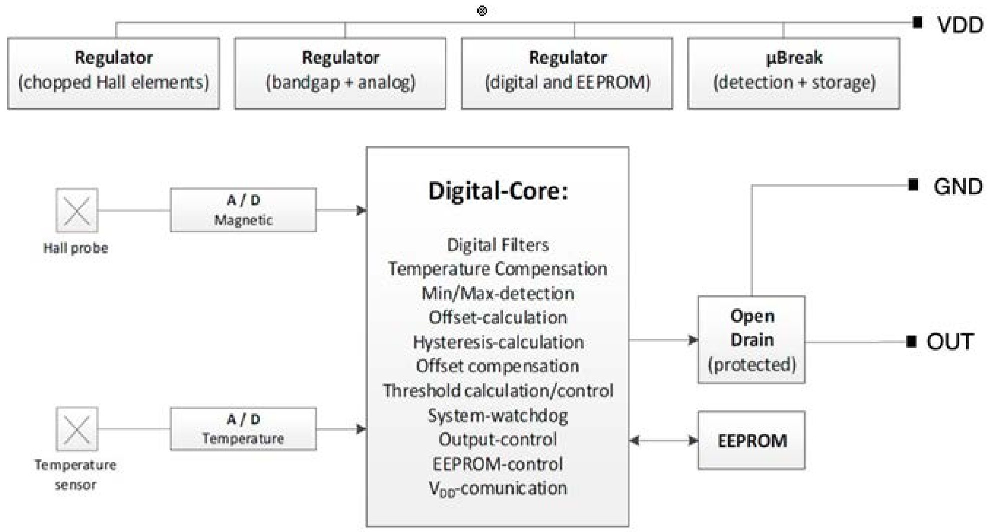


Fig.3 Block Diagram

Contains several circuits:

Chopped Hall Amplifier	Under/Over Voltage Detection
Offset Calibration ADC	POR
PGA + LPF	OSC
Channel ADC(Tracking ADC)	EEPROM programmable
Analog & Digital VDD Regulator	EMC Protection
Current Bias	ASIL / Diagnostic

11 Function Description

- **Working Principle**

Speed detection configuration of SC9388 is illustrated in below Figure. It contains a toothed wheel or magnetic encoder on a rotating shaft, the speed-sensor itself where connecting cables are attached and the back-bias magnet or magnetic encoder which generates a static field on the position of the sensing elements (Hall probes). The movement of the target wheel modulates the flux-lines of the magnetic field. This modulation is measured as camshaft phase signal which is output on the open drain mode.

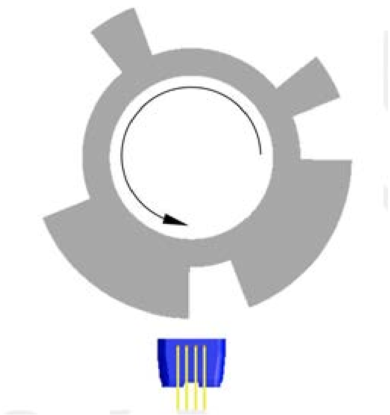


Fig.4 Detection Principle

- **Operation Temperature**

Ambient temperature：-40°C ~ 150°C

Peak temperature: 150°C during 3h

Frequency (peak temperature): 160 times during lifetime

Nominal temperature: T= 80°C ~ 110°C

Temperature Profile:

Temperature(℃)	-40	-20	25	80	100	110	125	150
Vehicle lifetime（%）	0.03	0.67	1.5	27	43.89	23	3.5	0.41

- **Operation Steps**

The basic operation of this sensor is to transpose the magnetic field produced by a spinning target wheel into phase information at the output pin. The output voltage indicates forward a teeth or valley and can be adjusted in EEPROM-options.

The correspondence between field polarity and output polarity can be set according to the application needs.

By definition a magnetic field is considered as positive if the magnetic North Pole is placed at the rear side of the sensor.

The operation need to be split to five different phases :

- Power-on phase
  - starts after supply release;
  - Lasts tpower-on (power-on time);
  - IC loads configuration and settings from EEPROM and initializes state machines and signal path;
- Initial phase
  - starts after Power-on phase;
  - lasts one clock cycle;
  - IC enables output switching, extrema detection and threshold adaption;
- Calibration phase
  - starts after Initial phase
- Running phase
  - starts after “Calibration Phase”;
  - after a programmable number of switching events (2 to 128) the accuracy is considered to be quite high. At this time the chip is switched into a calibrated phase(running phase) where only minor threshold corrections are allowed.
- **Averaging Algorithm**

To calculate the threshold within the running phase, valid maxima and minima are averaged to reduce possible offset-updates. Each offset-update gives an increased jitter, which has to be avoided.

The algorithm can be able to choose different number of teeth for averaging.

And the algorithm can be set to : Once the feature signal is captured, the offset calibration value can be updated to previous round result.

- **Hysteresis Concept**

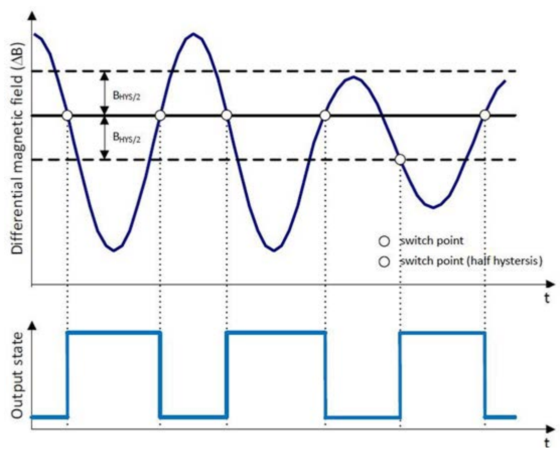


Fig.5 Hysteresis definition

The prefered switching behavior for camshaft application in terms of hysteresis is called hidden adaptive hysteresis. For reason of long notches or long teeth there is the EEPROM possibility to go for visible hysteresis as well. Another EEPROM possibility is fixed hysteresis, which allows robustness against metalic flakes attached by the back-bias-magnet.

Hidden adaptive hysteresis means, the output always switches at the same level, centered between upper and lower hysteresis. These hysteresis thresholds needs to be exceeded and are used to enable the output for the next following switching event. For example, if the differential magnetic field crosses the lower hysteresis level, then the output is able to switch at the zero crossing. Next following upper hysteresis needs to be exceeded again in order to enable for the next switching. Furthermore, the function of half hysteresis maintains switching whenever the upper hysteresis level is not exceeded, but the lower hysteresis level is crossed again, then the output is allowed to switch, so that no edge is lost. However, this causes additional phase error, see Figure 9.

Doing an adaptive hysteresis gives advantage at small airgap (large signal) to have big hysteresis. Compared with fixed hysteresis a small vibration cannot cause additional switching. According 10 adaptive hysteresis is calculated as 25% of the differential Speed-signal peak to peak. The minimum hysteresis is derived from EEPROM setting.

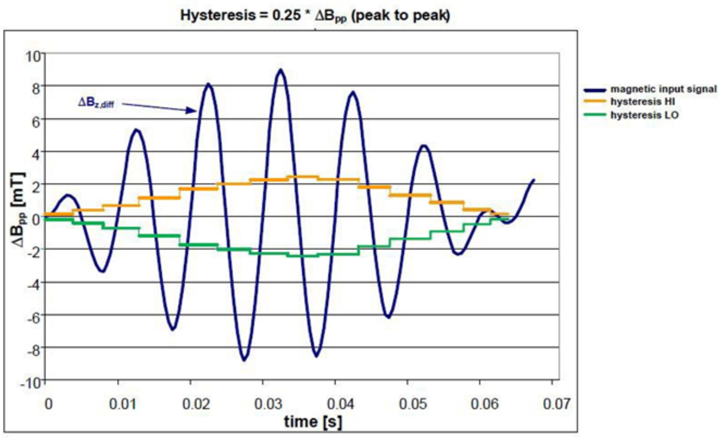


Fig.6 Adaptive Hysteresis

- **Adjust the proper k-factor**

Due to position tolerances of the sensor and of the magnet (X – displacement) the middle of the sensor is not always the middle of the module. And even if the sensor and the module would have the mechanical middle and the magnet is displaced there would be a deviation of the magnetic middle to the module middle.

These tolerances cause a wrong camshaft position sensed and calculated in the engine control unit. Translated to magnetic parameters the teeth are modulating the back bias magnet field lines. The sensor detects the modulation of these field lines.

As all components have their own magnetic and mechanical tolerances, an overall tolerance of something like +/-0.3°crank is the accuracy of the sensed camshaft position. With the introduction of adjustable switching threshold (k-factor) the accuracy of each module can be increased to +/-0.1°crank.

To offer better accuracy, several settings between 39% and 63% should be possible to program. The factor is known as k-factor.

The calculation of the adaptive programmable switching threshold is done as following: Switching Threshold = Bmin + (Bmax - Bmin) * k.

- **Temperature compensation**

This sensor should have a constant temperature-measurement of the sensor itself andcompensates the difference in the amplitude already in the analog signal path.So themain-comparator as well as the digital core can always see the same amplitude of the signal, independent from temperature of the magnet circuit.

12. Typical Application

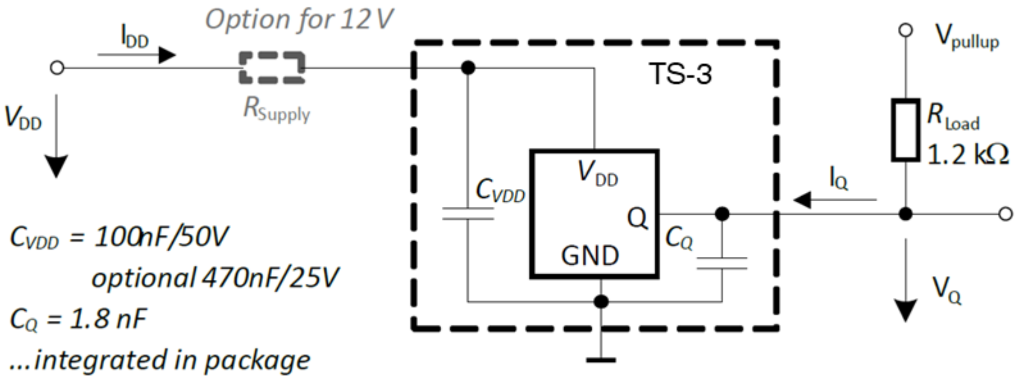
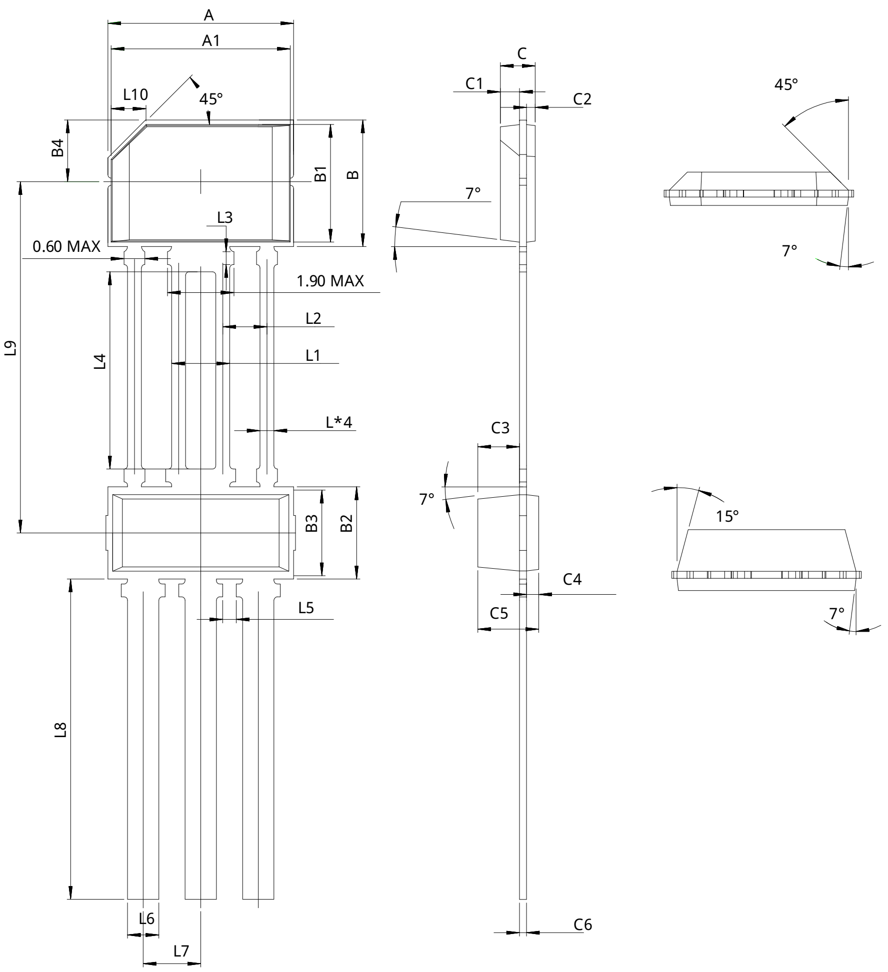


Fig.7 Typical Application Circuit

13. Package Information "TS-3"



Dimensions in Millimters			
Symbol	MIN	TYP	MAX
A	5.24	5.34	5.44
A1	5.05	5.15	5.25
B	3.52	3.64	3.76
B1	3.28	3.38	3.48
B2	2.40	2.65	2.90
B3	2.10	2.20	2.30
B4	1.68	1.78	1.88
C	0.92	0.96	1.00
C1	0.47	0.52	0.57
C2	0.19	0.24	0.49
C3	1.15	1.20	1.25
C4	0.30	0.35	0.40
C5	1.65	1.75	1.85
C6	—	0.20	—
L	0.35	0.40	0.45
L1	1.62	1.67	1.72
L2	—	1.27	—
L3	0.319	0.369	0.419
L4	5.62	5.67	5.72
L5	0.35	0.39	0.44
L6	0.85	0.90	0.95
L7	1.62	1.665	1.72
L8	9.16	9.21	9.26
L9	9.905	10.105	10.305
L10	—	1.00	—

Fig.8 Package Dimension

14. Packing Information

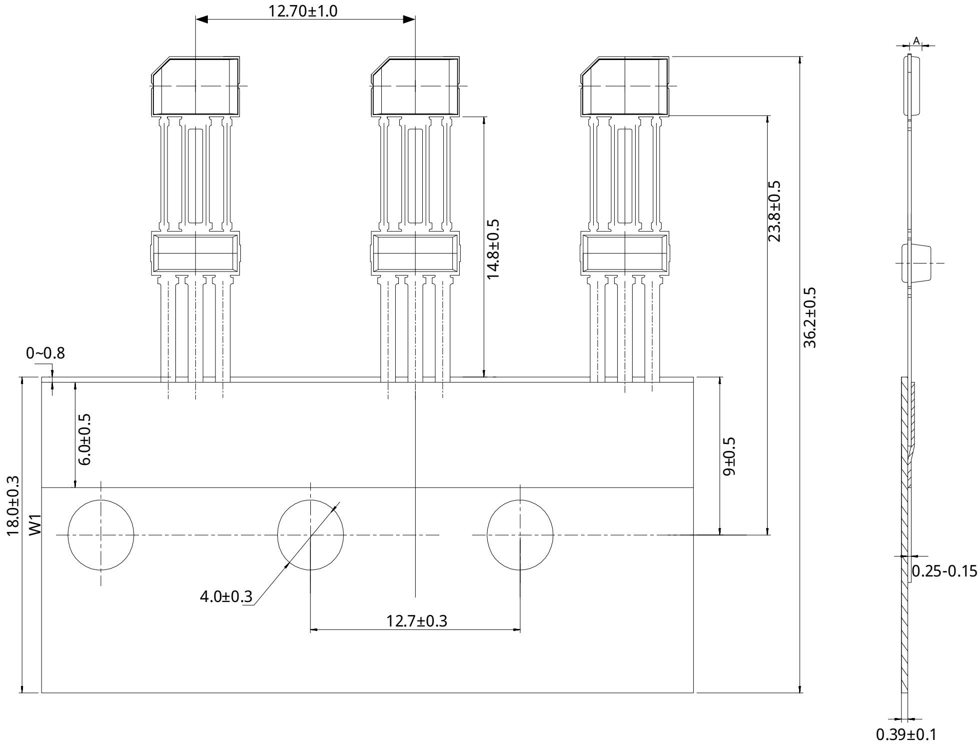


Fig.9 Packing Dimension

14. Revision History

Revision	Date	Description
Rev0.1	2024-03-20	Draft Version
Rev0.2	2025-06-11	Format Updates，Preliminary Version