Self-Calibrating Automatic-TPOS Camshaft Speed Sensor IC

FEATURES AND BENEFITS

- SL package provides a fully integrated solution with a non-rare-earth back-biasing magnet and EMC protection circuit
- True target state recognition at device power-on (TPOS) with automatic TPOS self-programming capability
- EEPROM programming for performance optimization, temperature compensation, and production traceability
- Fully synchronous digital logic with Scan Path and IDDQ testing for high quality and reliability
- Chopper stabilization reduces offset drift
- Absolute zero-speed performance

PACKAGE:

3-pin SIP (suffix SL)

Not to scale

DESCRIPTION

The ATS16301 is a True Power-On State camshaft sensor incorporating a non-rare-earth back-biasing magnet, advanced fully synchronous digital IC, and EMC protection circuit all in a single sensing solution.

The ATS16301 incorporates a single element Hall IC with an optimized custom magnetic circuit that switches in response to magnetic signals induced by a ferromagnetic target. The IC contains a sophisticated digital circuit designed to match the temperature behavior of the IC with the integrated magnet. Signal processing is used to provide zero-speed performance independent of air gap and is designed for the typical operating conditions found in automotive camshaft sensing applications. The resulting output of the device is a digital representation of the ferromagnetic target profile.

A number of factory-programmable options allow for performance optimization to meet specific application requirements.

The ATS16301 is provided in a 3-pin SIP package (SL) that is lead (Pb) free, with 100% NiPdAu leadframe plating.

Some commercial restrictions apply to this product—contact Allegro Sales for details.
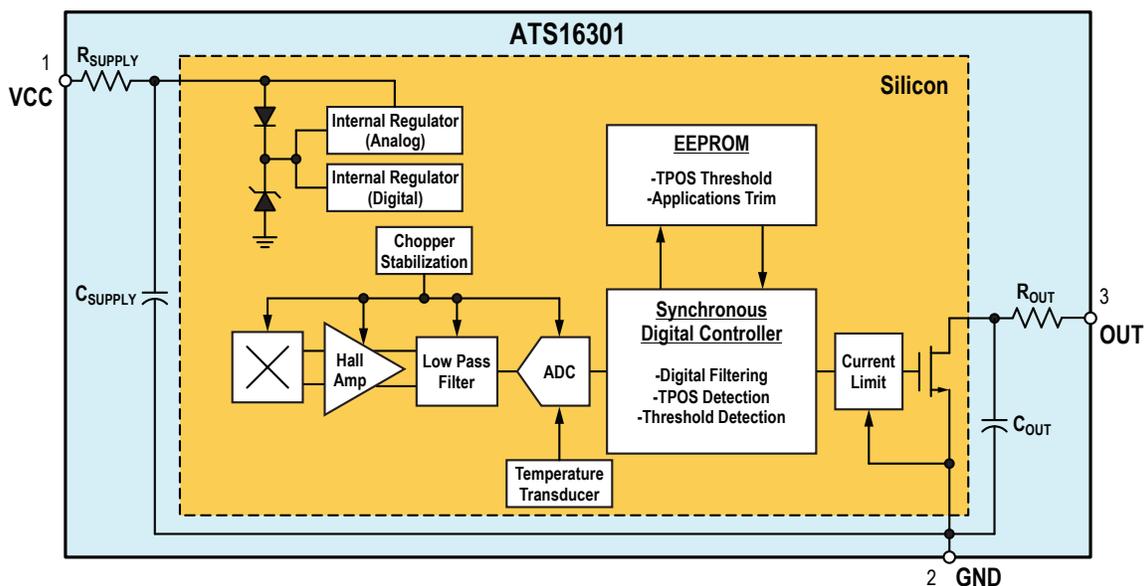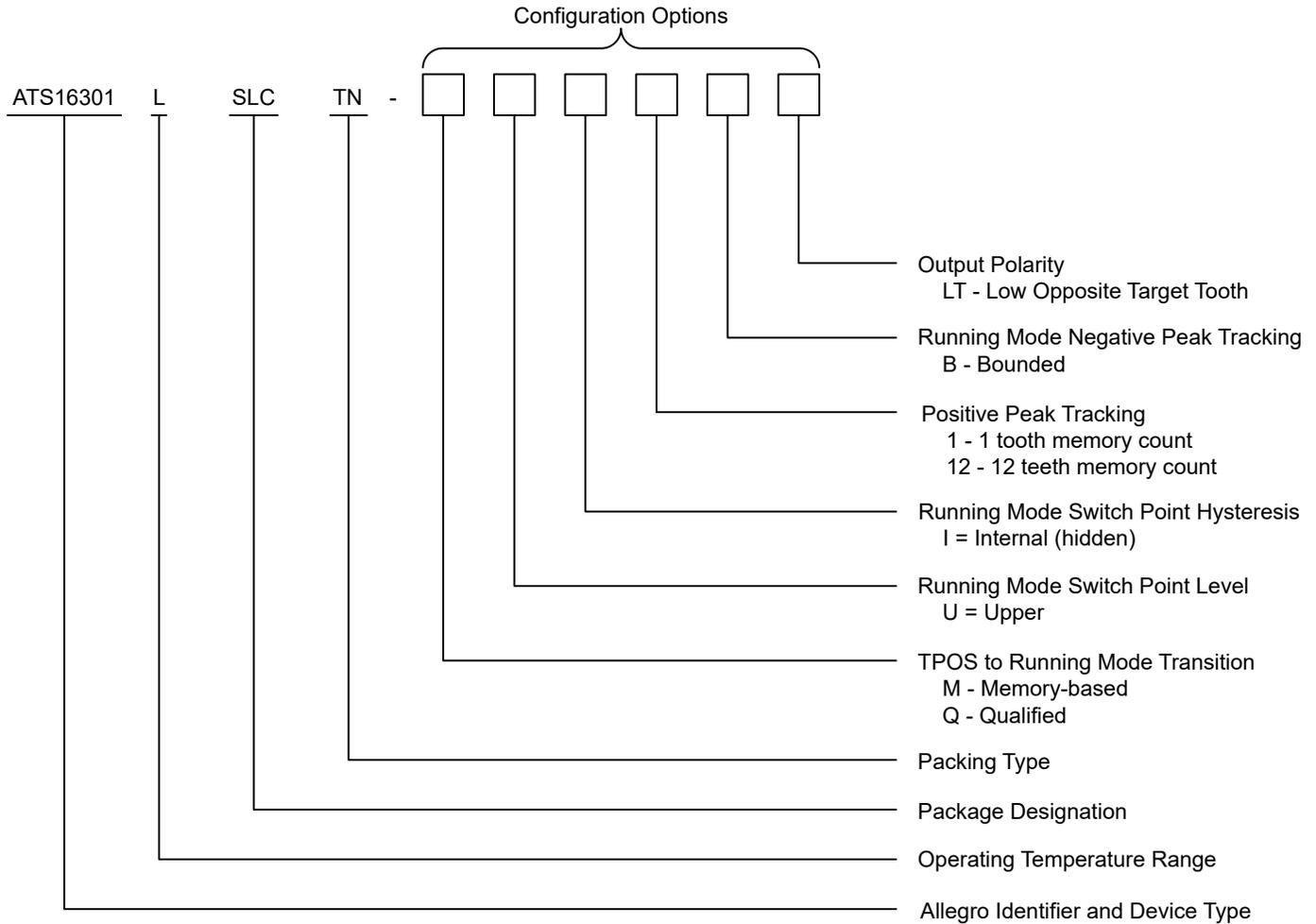

Functional Block Diagram

SELECTION GUIDE*

Part Number	Packing
ATS16301LSLCTN-QUI1B-LT	Tape and reel, 13-in. reel, 500 pieces per reel
ATS16301LSLCTN-MUI12B-LT	

* Not all combinations are available. Contact Allegro sales for availability and pricing of custom programming options.

Configuration Options

ATS16301 L SLC TN - ☐ ☐ ☐ ☐ ☐ ☐

Output Polarity
LT - Low Opposite Target Tooth

Running Mode Negative Peak Tracking
B - Bounded

Positive Peak Tracking
1 - 1 tooth memory count
12 - 12 teeth memory count

Running Mode Switch Point Hysteresis
I = Internal (hidden)

Running Mode Switch Point Level
U = Upper

TPOS to Running Mode Transition
M - Memory-based
Q - Qualified

Packing Type

Package Designation

Operating Temperature Range

Allegro Identifier and Device Type

ABSOLUTE MAXIMUM RATINGS

Characteristic	Symbol	Notes	Rating	Units
Supply Voltage	V_{CC}		27	V
Reverse Supply Voltage	V_{RCC}		−18	V
Output Voltage	V_{OUT}		27	V
Reverse Output Voltage	V_{ROUT}	$R_{PU} \geq 1000\ \Omega$	−0.5	V
Output Current	I_{OUT}	Internal current limiting is intended to protect the device from output short circuits, but is not intended for continuous operation.	25	mA
Reverse Output Current	I_{ROUT}	$V_{OUT} > −0.5$ V, $T_A = 25°C$	−50	mA
Operating Ambient Temperature	T_A	Range L	−40 to 150	°C
Maximum Junction Temperature	$T_{J(max)}$	Contact Allegro for extended junction temperature data	165	°C
Storage Temperature	T_{stg}		−65 to 170	°C
Allowable External Magnetic Field	B_{EXT}	Exceeding this level could result in permanent damage to SL magnet	−500 to 500	G

INTERNAL DISCRETE COMPONENT RATINGS

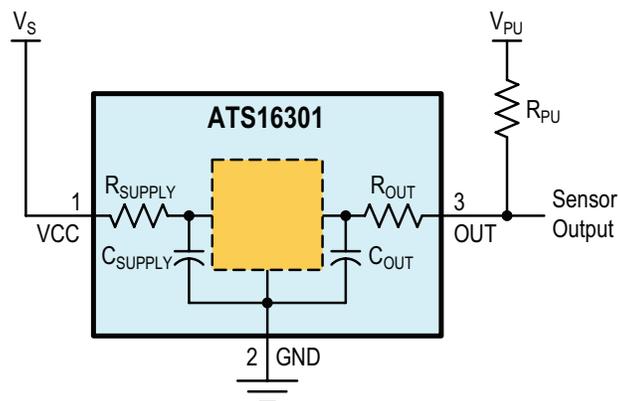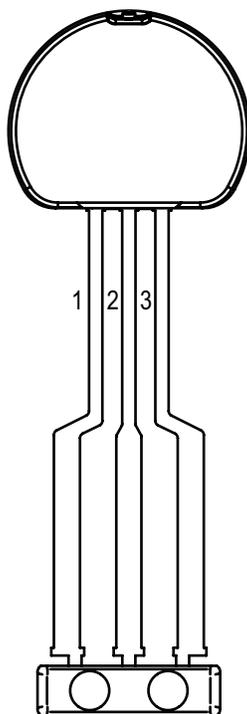| Symbol	Characteristic	Rating	Units
C_{SUPPLY}	Rated Nominal Capacitance	220	nF
C_{OUT}	Rated Nominal Capacitance	1.8	nF
R_{SUPPLY}	Rated Nominal Resistance	100	Ω
R_{OUT}	Rated Nominal Resistance	50	Ω

Figure 1: Typical Application Circuit

PINOUT DIAGRAM AND TERMINAL LIST TABLE

Package SL, 3-Pin SIP Pinout Diagram


1 2 3

Terminal List Table

Number	Name	Function
1	VCC	Supply voltage
2	GND	Ground
3	OUT	Open drain output

**THERMAL CHARACTERISTICS: May require derating at maximum conditions; see Power Derating section**

Characteristic	Symbol	Test Conditions*	Value	Unit
Package Thermal Resistance	$R_{\theta JA}$	Single-layer PCB, with copper limited to solder pads	134	°C/W

*Additional thermal information is available on the Allegro website.

Power Derating Curve
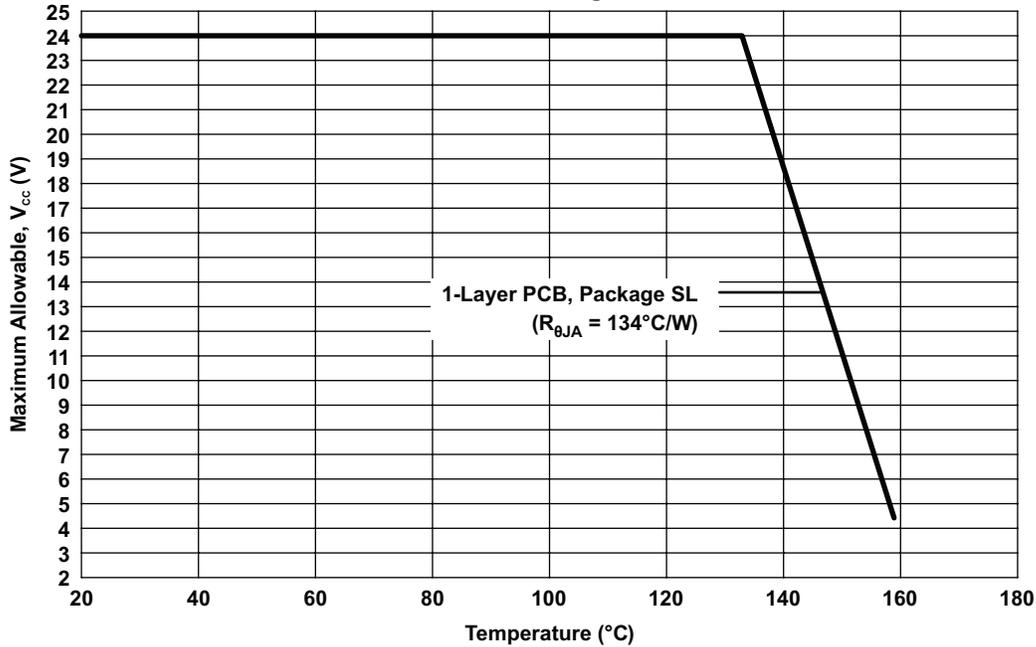
Power Dissipation versus Ambient Temperature
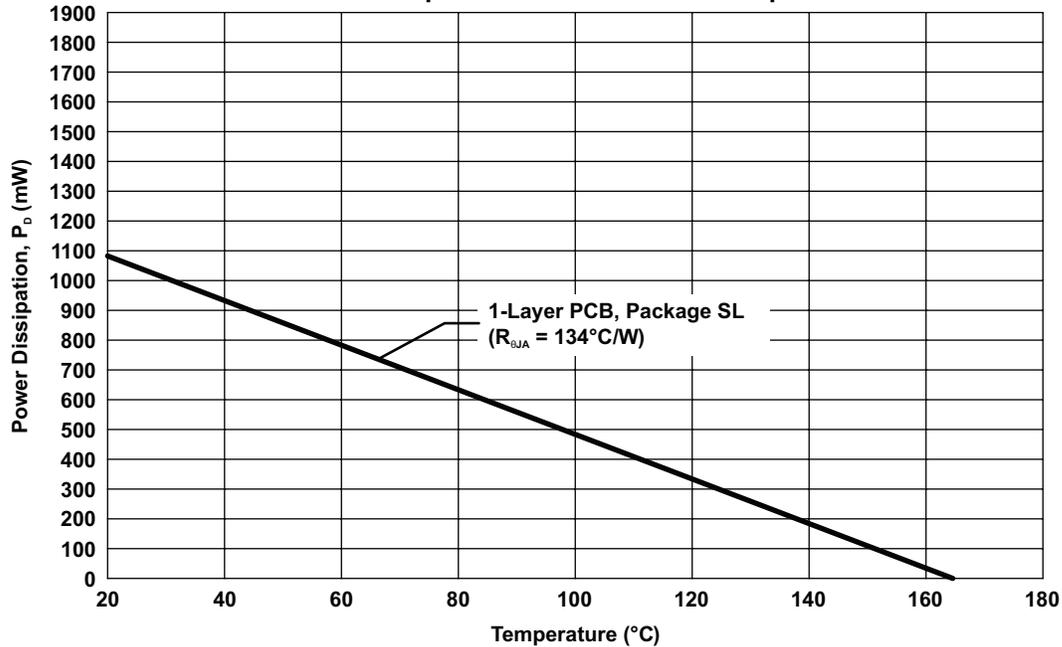
OPERATING CHARACTERISTICS: T_A and V_{CC} within specifications, using Reference Target 8X, unless otherwise noted

Characteristics	Symbol	Test Conditions		Min.	Typ.[1]	Max.	Unit
ELECTRICAL CHARACTERISTICS							
Supply Voltage	V_{CC}	Continuous operation, $T_J < T_{J(MAX)}$	$R_{SUPPLY} = 100\ \Omega$	4.4	–	24	V
Supply Zener Clamp Voltage	$V_{Zsupply}$	$I_{CC} = I_{CC(MAX)} + 3$ mA		27	–	–	V
Reverse Supply Zener Clamp Voltage	$V_{RZsupply}$	$I_{CC} = -3$ mA, $T_A = 25°C$		–	–	–18	V
Supply Current	I_{CC}			5	8	10	mA
OUTPUT STAGE CHARACTERISTICS							
Output On Voltage	$V_{OUT(SAT)}$	$I_{OUT} = 5$ mA, Output = on state (V_{OUT} = Low)	$R_{OUT} = 50\ \Omega$	–	–	500	mV
		$I_{OUT} = 15$ mA, Output = on state (V_{OUT} = Low)	$R_{OUT} = 50\ \Omega$	–	–	1300	mV
Output Zener Clamp Voltage	$V_{Zoutput}$	$I_{OUT} = 3$ mA, $T_A = 25°C$		27	–	–	V
Output Current Limit	$I_{OUT(LIM)}$	Output = on state (V_{OUT} = Low)		30	–	80	mA
Output Leakage Current	$I_{OUT(OFF)}$	$V_{OUT} = 24$ V, Output = off state (V_{OUT} = High)		–	–	10	µA
Output Rise Time	t_r	Measured 10% to 90% of V_{OUT}; $R_{PU} = 1$ kΩ; $V_{PU} = 5$ V	$R_{OUT} = 50\ \Omega$, $C_{OUT} = 1.8$ nF	–	4	–	µs
Output Fall Time	t_f	Measured 90% to 10% of V_{OUT}; $R_{PU} = 1$ kΩ; $V_{PU} = 5$ V		0.5	1.2	2.5	µs
		Measured 90% to 10% of V_{OUT}; $R_{PU} = 1$ kΩ; $V_{PU} = 12$ V		–	2	–	µs

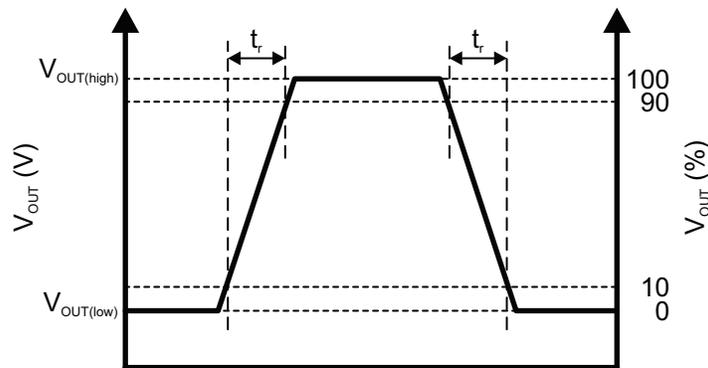**Figure 2: Output Rise Time and Output Fall Time**

[1] Typical values are at $T_A = 25°C$ and $V_{CC} = 12$ V. Performance may vary for individual units, within the specified maximum and minimum limits.

OPERATING CHARACTERISTICS (continued): T_A and V_{CC} within specifications, using Reference Target 8X, unless otherwise noted

Characteristics	Symbol	Note		Min.	Typ.	Max.	Unit
PERFORMANCE CHARACTERISTICS							
Operational Air Gap Range	AG	TPOS guaranteed; Allegro 8X reference target		0.5	–	3	mm
Extended Operational Air Gap Range		Running mode switching; TPOS not guaranteed; Allegro 8X reference target		–	–	3.5	mm
Signal Bandwidth	BW	Equivalent to –3 dB cutoff frequency		–	8	–	kHz
Phase Delay [2]	ΔErr_{SRELF}	Electrical falling edges; $R_{PU} = 1$ kΩ, $V_{PU} = 5$ V		0.88×10^{-4}	1.18×10^{-4}	1.50×10^{-4}	°/rpm
POWER-ON CHARACTERISTICS							
Power-On Time [3]	t_{PO}	$V_{CC} > V_{CC(MIN)}$		–	–	1	ms
TPOS Mode		Number of mechanical edges after power-on with output switching on TPOS threshold	*M* Option	–	–	2+2n [4]	edge
			Q Option	2	–	3	edge
Learning Mode		Number of target teeth after TPOS Mode with reduced accuracy threshold-based output switching	*M* Option	–	–	0	tooth
			Q Option	–	–	1	tooth

[2] Phase Delay is the change in edge position at detection, through the full operational tooth speed range for a single device at a single temperature and installation air gap.
[3] Power-On Time consists of the time from when V_{CC} rises above $V_{CC(MIN)}$ until a valid output state is realized.
[4] *n* = selected memory count for running mode positive peak tracking.

OPERATING CHARACTERISTICS (continued): T_A and V_{CC} within specifications, using Reference Target 8X, unless otherwise noted

| Characteristics	Symbol	Note		Min.	Typ.	Max.	Unit
OPERATING MODE CHARACTERISTICS							
Output Polarity	V_{OUT}	Opposite target tooth, connected as in Figure 1	*LT* option		Low		V
		Opposite target valley, connected as in Figure 1	*LT* option		High		V
Threshold Update Memory		Number of target teeth (peaks) stored in memory for threshold update algorithm		1	–	12	tooth
Operate Point [5]	B_{OP}	% of peak-to-peak, referenced to tooth signal	*U* option	–	30	–	%
Release Point [5]	B_{RP}	% of peak-to-peak, referenced to tooth signal	*U* option	–	30	–	%
Running Mode Hysteresis	$B_{HYS(int)}$	% of peak-to-peak signal		5	10	15	%
Maximum Allowable Signal Reduction	B_{reduce}	Reduction in magnetic signal amplitude between two consecutive peaks; all specifications within range		–	–	$B_{OP} - 15\%$	%
		Reduction in magnetic signal amplitude between two consecutive peaks; output switches, accuracy performance not guaranteed		–	–	$B_{OP} - 5\%$	%
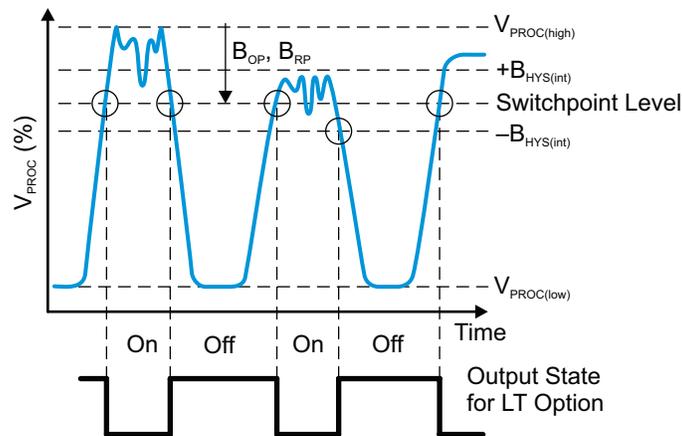
Figure 3: Switch points with Internal Hysteresis

[5] Custom programmable switch point options are also available, allowing independently programmable B_{OP} and B_{RP} between 50% and 70% with 1.56% resolution.

FUNCTIONAL DESCRIPTION

Sensing Technology

The ATS16301 contains a single-chip Hall-effect sensor IC, a 3-pin leadframe with integrated EMC protection components, and a specially designed permanent magnet. The IC includes a self-calibrating, chopper-stabilized Hall element that senses differences in magnetic field strength induced by ferromagnetic target teeth and valleys. The sensor generates a digital output signal that is representative of the target features, independent of the direction of target rotation or rotational orientation. The Hall transducer and the electronics are integrated on the same silicon substrate by a proprietary BiCMOS process. Changes in temperature do not negatively affect this device due to the stable amplifier design and advanced digital temperature compensation. The IC also contains a voltage regulator that provides undervoltage lockout and supply noise rejection over the operating voltage range.

Output Polarity

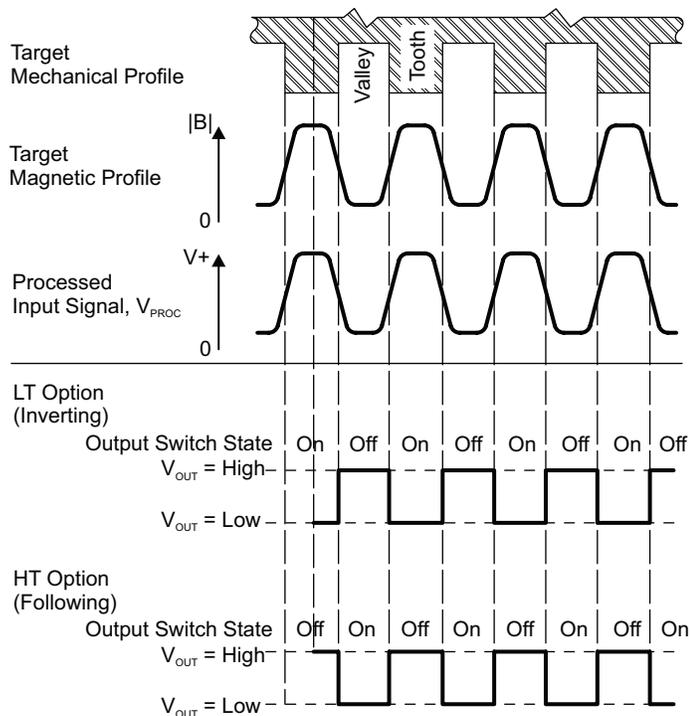The polarity of the output is low opposite target teeth (*LT* option). See Figure 4.

Figure 4: Output Polarity

(when connected as shown in Figure 1)

Threshold Update

The ATS16301 has two sets of programmable options that determine the threshold update used to establish running mode switching levels. The positive peak threshold update is set to *n* teeth, which is programmable between one and twelve. The negative peak threshold update is set to bounded update (*B* option).

With single tooth update ($n = 1$), the switching threshold for a tooth is established based on the measured peak value of the previous tooth. This option can be used with targets having any number of teeth and is comparable to the continuous update mode used in many Allegro sensors.

When $n = 12$, the device uses memory-based update. Peak information from the last 12 teeth is stored in on-chip memory. Switching thresholds for the upcoming tooth are established based on the stored information from 12 earlier teeth. When the number of teeth on the target is 12, this allows for optimized switch points based on the same tooth from the previous revolution of the target. The programmable threshold update results in improved output switching accuracy on targets with runout and tooth-to-tooth variation (including narrow valleys).

With bounded update (*B* option), large tooth-to-tooth changes in the negative peak tracking are filtered out and not applied to switching threshold generation. This option provides improved output accuracy on camshaft targets with narrow valley widths.

Switch Points and Hysteresis

The running mode switch points in the ATS16301 are established dynamically as a percentage of the tracked peaks and valleys, as described in the Threshold Update section.

Switch points are chosen as upper (*U* option) at 30% below the tracked positive peak. The *U* option gives tighter absolute output accuracy, but provides lower immunity to target variation. See Figure 5 for a description of switch point options.

Operating Modes

TPOS MODE / CALIBRATION MODE

After power-on, the output state is determined by the level of the detected magnetic field relative to the fixed-gauss TPOS threshold. Fixed-gauss TPOS threshold is determined by the ATS16301 Automatic TPOS Threshold update. The device remains in TPOS Mode for a number of edges that is dependent on the TPOS to
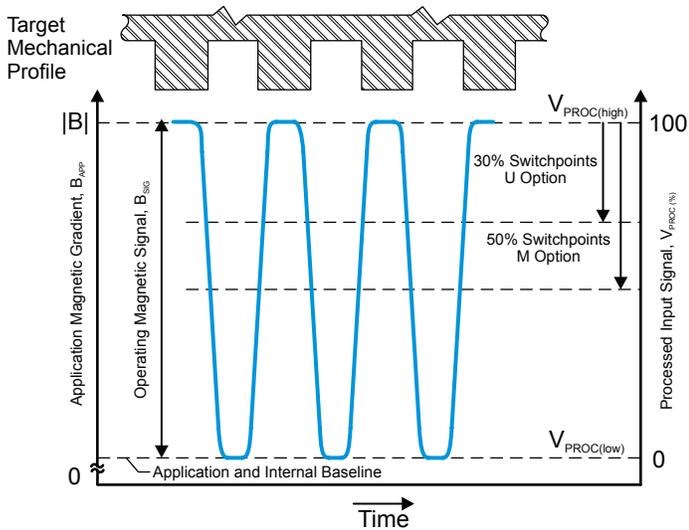
Figure 5: Switch Point Options

Running mode transition option selected: qualified (*Q* option), or memory-based (*M* option).

With the qualified option, the device remains in TPOS mode for at least two edges before transitioning to running mode. The *Q* option provides the lowest worst-case output accuracy difference between the first edge and subsequent running mode edges.

With the memory-based option, the device remains in TPOS mode for 13 teeth to guarantee it has correctly captured enough peaks to fill the running mode threshold memory. The *M* option provides transition to running mode thresholds for 13 teeth, but provides best runout capability.

After TPOS mode / Calibration mode is complete, the device transitions to running mode.

RUNNING MODE

In running mode, the ATS16301 uses threshold-based switching with internal hysteresis as described in the previous Threshold Update and Switch Points and Hysteresis sections. The threshold update is intended to optimize output switching accuracy when used with common camshaft targets, including cases with runout and narrow target valleys.

WATCHDOG

The ATS16301 has a peak detector continuously tracking the magnetic signal. If a sudden large signal change causes the sensor output to stop switching but the peak detector continues to detect valid signal movement, the watchdog will be triggered. When it is triggered, the sensor performs a self-reset and returns to initial startup hysteresis mode to regain output switching.

AUTOMATIC TPOS THRESHOLD

The ATS16301 has automatic threshold update to optimize accuracy during TPOS Mode.

The threshold update is active during first 25 mechanical edges after power on.

POWER DERATING

The device must be operated below the maximum junction temperature of the device ($T_{J(max)}$). Under certain combinations of peak conditions, reliable operation may require derating supplied power or improving the heat dissipation properties of the application. This section presents a procedure for correlating factors affecting operating T_J. (Thermal data is also available on the Allegro MicroSystems website.)

The Package Thermal Resistance ($R_{\theta JA}$) is a figure of merit summarizing the ability of the application and the device to dissipate heat from the junction (die), through all paths to the ambient air. Its primary component is the Effective Thermal Conductivity (K) of the printed circuit board, including adjacent devices and traces. Radiation from the die through the device case ($R_{\theta JC}$) is relatively small component of $R_{\theta JA}$. Ambient air temperature (T_A) and air motion are significant external factors, damped by overmolding.

The effect of varying power levels (Power Dissipation, P_D), can be estimated. The following formulas represent the fundamental relationships used to estimate T_J at P_D.

$$P_D = V_{IN} \times I_{IN} \qquad (1)$$

$$\Delta T = P_D \times R_{\theta JA} \qquad (2)$$

$$T_J = T_A + \Delta T \qquad (3)$$

For example, given common conditions such as:

$$T_A = 25°C$$

$$V_{CC} = 12 \ V$$

$$R_{\theta JA} = 134°C/W$$

$$I_{CC} = 7 \ mA$$

Then:

$$P_D = V_{CC} \times I_{CC} = 12 \ V \times 7 \ mA = 84 \ mW$$

$$\Delta T = P_D \times R_{\theta JA} = 84 \ mW \times 134°C/W = 11.3°C$$

$$T_J = T_A + \Delta T = 25°C + 11.3°C = 36.3°C$$

A worst-case estimate, $P_{D(max)}$, represents the maximum allowable power level, $V_{CC(max)}$, $I_{CC(max)}$, without exceeding $T_J(max)$, at a selected $R_{\theta JA}$ and T_A.

Example: Reliability for V_{CC} at $T_A = 150°C$.

Observe the worst-case ratings for the device, specifically:

$$R_{\theta JA} = 134°C/W$$

$$T_{J(max)} = 165°C$$

$$V_{CC(max)} = 24 \ V$$

$$I_{CC} = 10 \ mA.$$

Calculate the maximum allowable power level, $P_{D(max)}$. First, invert equation 3:

$$\Delta T_{(max)} = T_{J(max)} - T_A = 165°C - 150°C = 15°C$$

This provides the allowable increase to T_J resulting from internal power dissipation. Then, invert equation 2:

$$P_{D(max)} = \Delta T_{(max)} \div R_{\theta JA} = 15°C \div 134°C/W = 112 \ mW$$

Finally, invert equation 1 with respect to voltage:

$$V_{CC(est)} = P_{D(max)} \div I_{CC(max)} = 112 \ mW \div 10 \ mA = 11.2 \ V$$

The result indicates that, at T_A, the application and device can dissipate adequate amounts of heat at voltages $\leq V_{CC(est)}$.

Compare $V_{CC(est)}$ to $V_{CC(max)}$. If $V_{CC(est)} \leq V_{CC(max)}$, then reliable operation between $V_{CC(est)}$ and $V_{CC(max)}$ requires enhanced $R_{\theta JA}$. If $V_{CC(est)} \geq V_{CC(max)}$, then operation between $V_{CC(est)}$ and $V_{CC(max)}$ is reliable under these conditions.

PACKAGE OUTLINE DRAWING

For Reference Only – Not for Tooling Use

(Reference DWG-0000414, Rev. 4)
Dimensions in millimeters. NOT TO SCALE.
Dimensions exclusive of mold flash, gate burrs, and dambar protrusions
Exact case and lead configuration at supplier discretion within limits shown
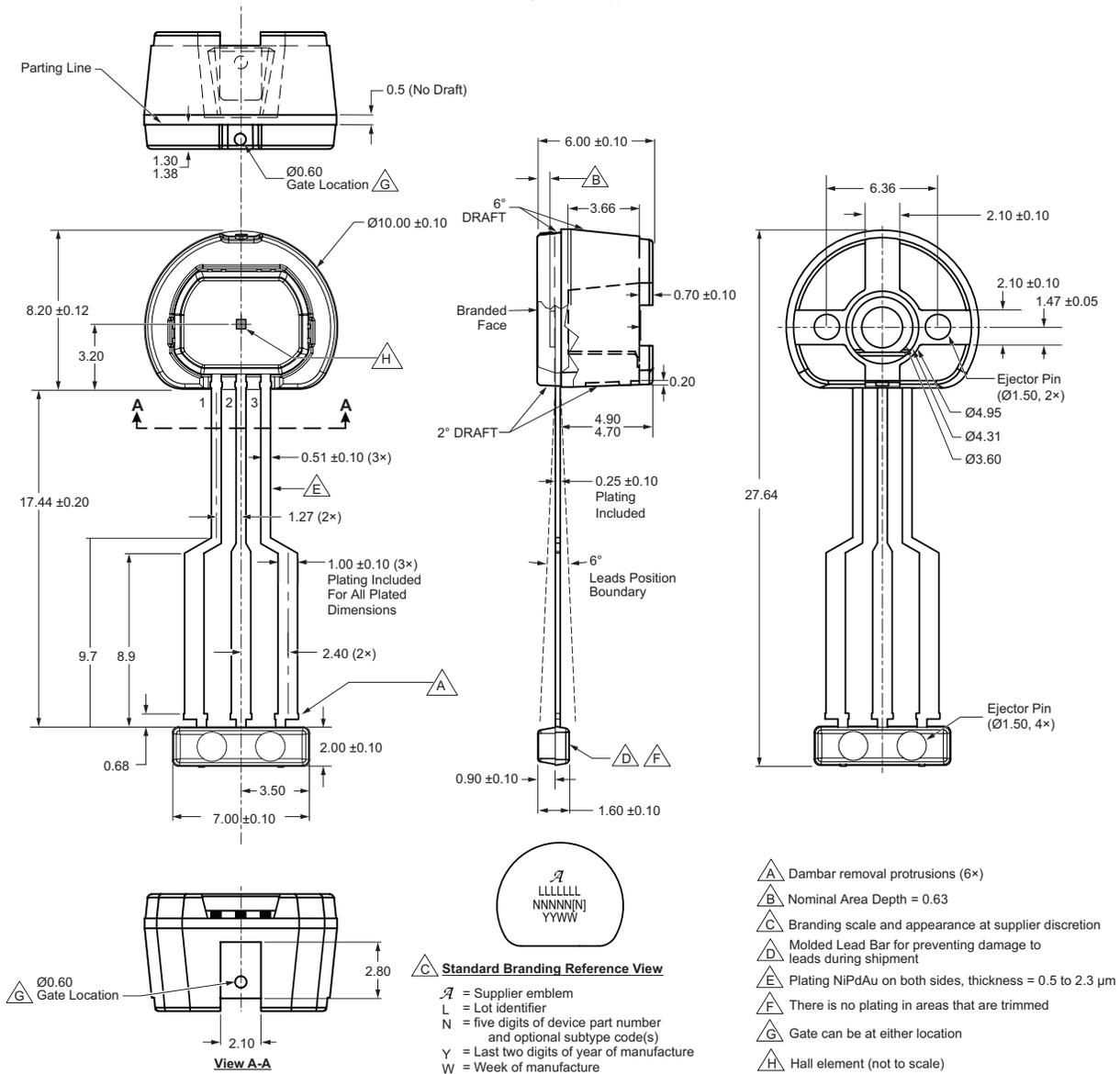
Parting Line

0.5 (No Draft)

1.30
1.38

Ø0.60
Gate Location /G\

6.00 ±0.10

6.36

Ø10.00 ±0.10

/B\

6°
DRAFT

3.66

2.10 ±0.10

8.20 ±0.12

0.70 ±0.10

2.10 ±0.10
1.47 ±0.05

3.20

Branded
Face

/H\

0.20

Ejector Pin
(Ø1.50, 2×)

A   1 2 3   A

2° DRAFT

4.90
4.70

Ø4.95
Ø4.31
Ø3.60

0.51 ±0.10 (3×)

0.25 ±0.10
Plating
Included

/E\

27.64

17.44 ±0.20

1.27 (2×)

1.00 ±0.10 (3×)
Plating Included
For All Plated
Dimensions

6°
Leads Position
Boundary

9.7   8.9

2.40 (2×)

/A\

0.68

2.00 ±0.10

Ejector Pin
(Ø1.50, 4×)

3.50

0.90 ±0.10

/D\ /F\

7.00 ±0.10

1.60 ±0.10

Ø0.60
Gate Location /G\

2.80

A
LLLLLLL
NNNNN[N]
YYWW

2.10

/C\ **Standard Branding Reference View**

View A-A

A = Supplier emblem
L = Lot identifier
N = five digits of device part number
    and optional subtype code(s)
Y = Last two digits of year of manufacture
W = Week of manufacture

/A\ Dambar removal protrusions (6×)

/B\ Nominal Area Depth = 0.63

/C\ Branding scale and appearance at supplier discretion

/D\ Molded Lead Bar for preventing damage to
    leads during shipment

/E\ Plating NiPdAu on both sides, thickness = 0.5 to 2.3 µm

/F\ There is no plating in areas that are trimmed

/G\ Gate can be at either location

/H\ Hall element (not to scale)

Figure 6: Package SL, 3-Pin SIP

Note: Package is manufactured with two steps. The molded magnet uses a hygroscopic nylon plastic material; therefore customer manufacturing process selection must take this factor into consideration. This package is designed for direct solder and welding attachment methods. If a reflowed solder attachment method is preferred, customers must utilize an MSL 6 handling protocol.

Revision History

Number	Date	Description
–	August 13, 2019	Initial release
1	February 18, 2021	Corrected plating material and thickness in package drawing (page 12)
2	March 8, 2023	Updated Operating Characteristics table (page 6)

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