Melexis

INNOVATION WITH HEART

APPLICATION NOTE

VA package handling and assembly in inverters (conventional Hall)

Revision 1.0 – January 2024

Advanced Customer Solutions

VA package handling and assembly in inverters

1. Scope
2. Sensor design and handling for THT assembly
3. Sensor design and handling for SMT assembly
4. Vibration robustness and plastic holder

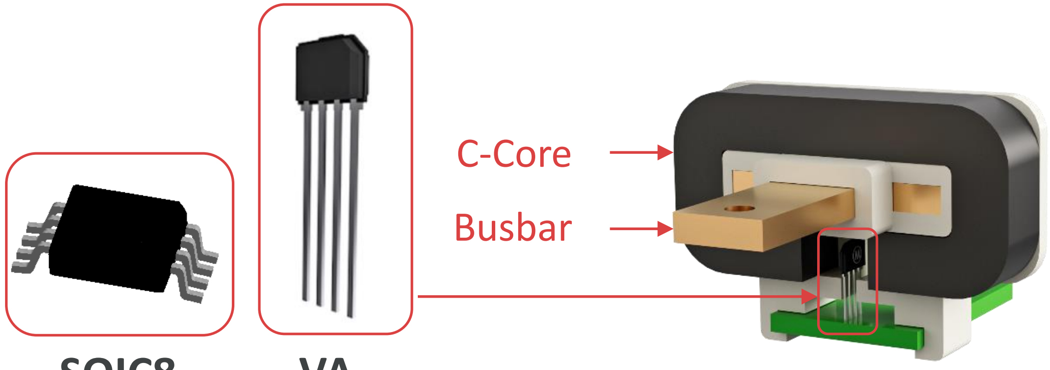
1. Scope

Inverter main architectures

Melexis current sensors come in two different packages, which allow for two different architectures when designing inverter modules:

- **VA package**: The busbar is placed within a magnetic C-shape core and the sensor is placed in the core gap. The magnetic flux is perpendicular to the IC active surface. This is usually referred as Conventional Hall
- **SOIC packages:** The busbar is placed inside a magnetic U-shield and the sensor is placed within the shield. The magnetic flux is parallel to the IC active surface.

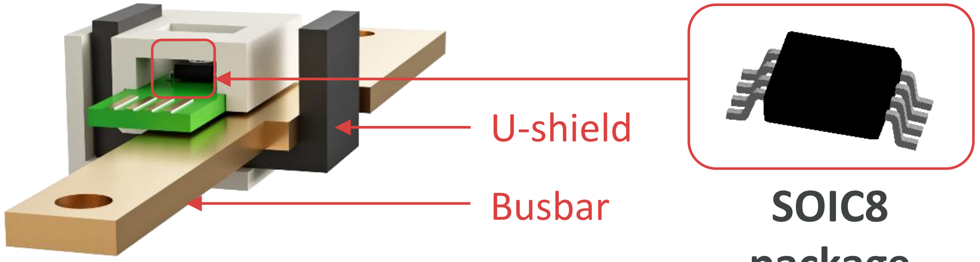
This Application Note is focused on conventional Hall inverters using VA package.



SOIC8 package

VA package

Conventional Hall (on C-Core)



U-Shield

SOIC8 package

1. Scope

Melexis current sensors in VA package

Typical inverter application requires that the current sensor body is assembled vertical on a defined height above the PCB in order to fit into the notch of the C-core.

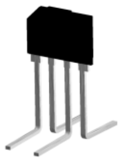
- VA package of Melexis current sensors is a straight leads (18mm length), TO-92S type. This sensor can be directly soldered with standard THT assembly after insertion into the PCB vias. Lead length shall be trimmed upfront to the desired height above the PCB.
- For SMT assembly the VA leads can be reverse T-shaped. Melexis offers several standard reverse T-shapes, delivered in an embossed tape for direct pick-and place on PCB, using a gripper tool.

In order to meet different dimension requirements, lead length trimming and/or T-shaping can be done by the customer or subcontractor. Refer to *Guidelines for leadforming of SIP Hall sensors in* ***www.melexis.com/ic-handling-and-assembly***

This Application Note is focused on sensor design for conventional Hall applications in a C-core in order to use safely Melexis VA package as well as to help customers to apply leadforming safely

Straight leads
(THT assembly)

Reverse T-shape 1.27mm
(SMT assembly)



Reverse T-shape 2.54mm
(SMT assembly)

VA package handling and assembly in inverters

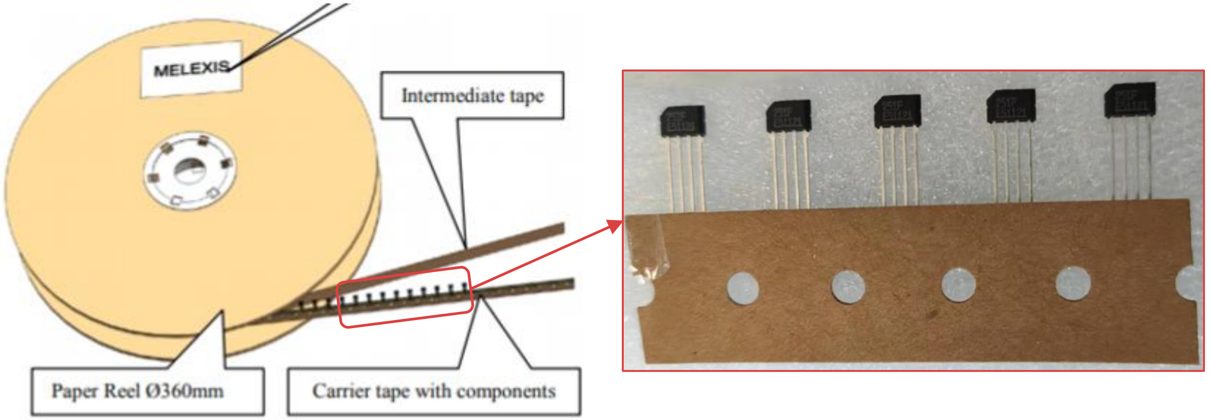
1. Scope
2. Sensor design and handling for THT assembly
3. Sensor design and handling for SMT assembly
4. Vibration robustness and plastic holder

2. Sensor design and handling for THT assembly

Radial tape handling

There are two delivery forms for current sensors in VA package:

- **Radial tape on reel (*-CR):** According to standard IEC 60286-2/EIA-481 and intended for automatic handling.
- **Bulk (*-BU):** The leads might be slightly deformed during shipping due to mechanical overstresses during transport. Intended for manual processing or automatic handling with the use of a vibrating bowl feeder



Reel
(Automatic processing)

Bulk in ESD-safe bag
(Manual or automatic processing)

2. Sensor design and handling for THT assembly

Reference flow for panel level soldering

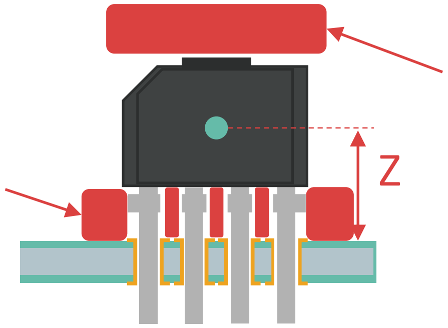
In case of TH assembly of sensor, lead length trimming should be made as a first step of PCB insertion process:

Hold IC by gripper → Cut from tape (desired length) → Insert onto PCB via (camera alignment needed) → Soldering

- Wave soldering
- Selective soldering
- PiP reflow soldering

The insertion onto PCB vias can use a spacer to define the target height. Alternatively, the dambar wings can be used if the height (Z) meets the requirements. Refer to *Guidelines for Through Hole Technology (THT) soldering* for more information

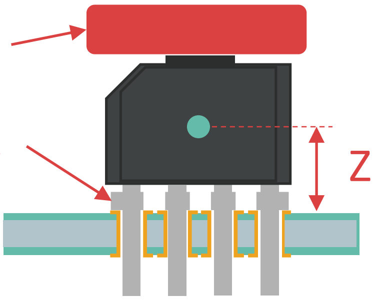
Temporary fixture with channels for dambar protrusion (removed after soldering) to guarantee part verticality



Spacer (higher Z)

Top plate to avoid IC lifting during soldering

Dambar wings



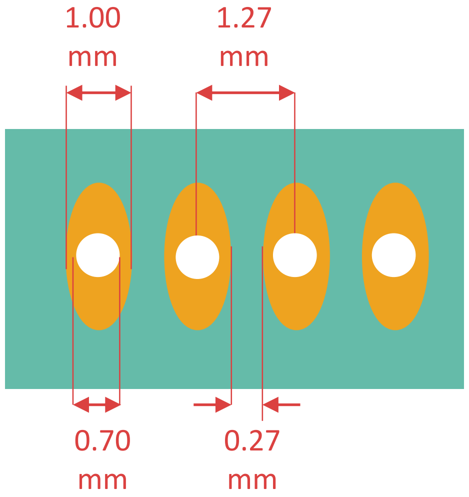
Stopper on dambar wings (low Z)

2. Sensor design and handling for THT assembly

PCB landpattern for VA straight leads

Minimum hole size can be calculated using *IPC-2222, 9.2.2 Plated-Through Holes*. The minimum pad size can be calculated using *IPC-2221, 9.1.1 Land requirements*. Both dimensions depend on technological capabilities of the PCB manufacturer. Clearance between lands should respect electrical clearances as per *IPC-2221, 6.3 Electrical Clearance*

The following numbers are calculated using the pin diagonal of the VA package:



Due to the size of the hole, the part might tilt during reflow soldering impacting the position of the Hall Plate. If tilting is not allowed, a spacer can be used to guarantee verticality of the IC.

VA package handling and assembly in inverters

1. Scope
2. Sensor design and handling for THT assembly
3. Sensor design and handling for SMT assembly
4. Vibration robustness and plastic holder

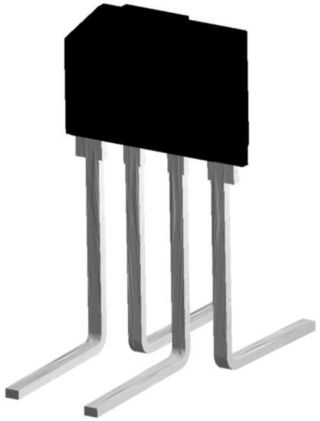
3. Sensor design and handling for SMT assembly

T-shapes for SMT soldering

There are two different reverse T-shapes, each one with a different pitch:

- **Reverse T-shape 1.27mm** Because of the asymmetrical nature of the pins, the orientation of the part is guaranteed both during transport in radial tape and soldering on the PCB. However, since the middle pins have a pitch of 1.27mm, bending has a higher requirement.
- **Reverse T-shape 2.54mm** All pins have a pitch of 2.54mm, which relaxes the specification for lateral displacement during bending. However, since the pins are symmetrical, orientation shall be controlled during placement onto PCB.

Reverse T-shape 1.27mm
Offered by Melexis

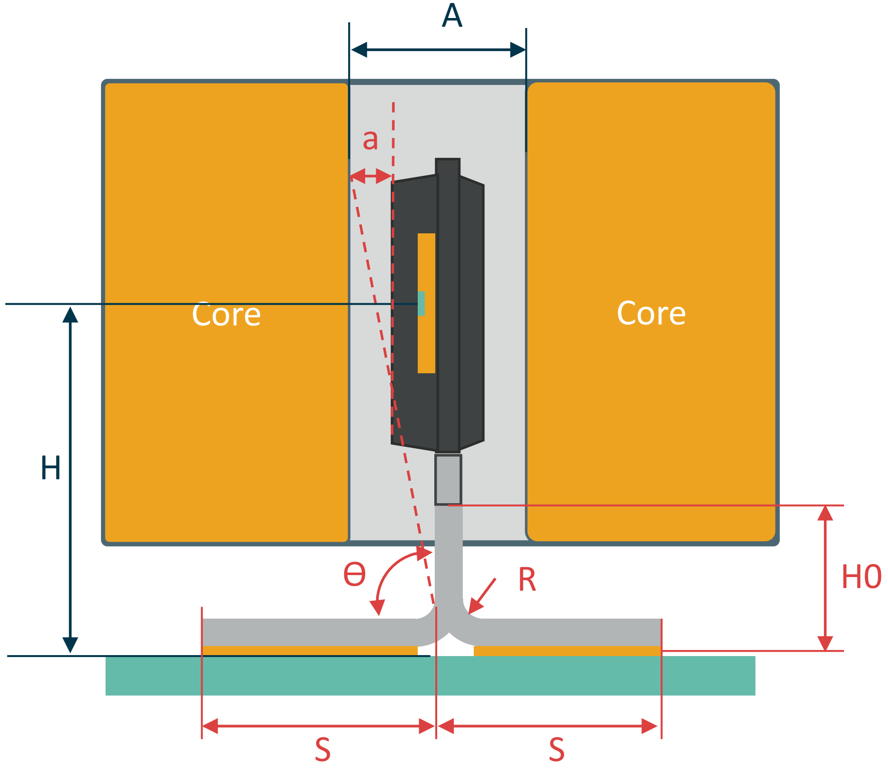


Reverse T-shape 2.54mm
Not offered by Melexis

3. Sensor design and handling for SMT assembly

Lead forming for customer requirements – sensor position vs PCB and core

The dimensions and tolerances of the reverse T-shape lead forming should meet customer designed sensor position versus the PCB after soldering (height) and versus magnetic current transformer core. The sensor sensitive spot shall be located within the homogeneity zone of the magnetic field and sensor mold body shall keep some physical clearance to the core.



Customer inverter design - key dimensions

- **A**: Magnetic core gap (minimum)
- **H**: Hall plate height – Min/Max acc. to core magnetic field homogeneity area
- Target solder paste (stencil) thickness

Resulting sensor lead forming dimensions:

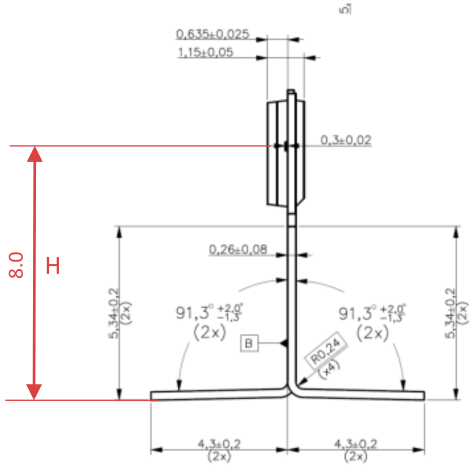
- **S**: Horizontal pin length
- **R**: Pin bending inner radius
- **ϴ**: Pin bending angle Min/Max
- **H0**: Vertical pin length Min/Max
- **a**: Maximum tilt at mold package top

3. Sensor design and handling for SMT assembly

Reverse T-shape options at Melexis

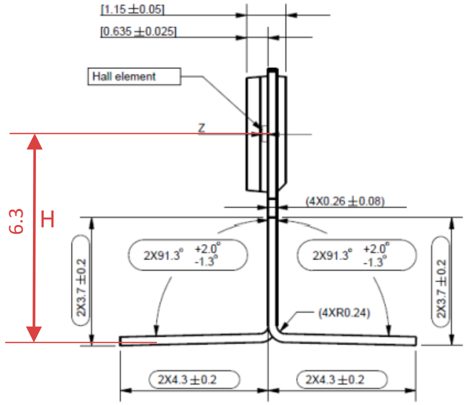
For different inverter designs, Melexis is producing 3 reverse T-shaped sensor variants STD2, STD3 and STD4. STD4 has the lowest sensor height and therefore the best vibration robustness.

Refer to the respective VA current sensor product datasheets for details.



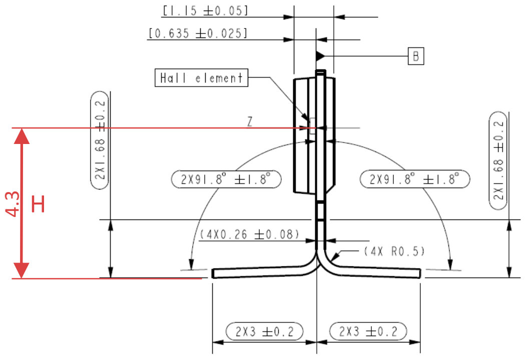
STD2

H = 8.0 mm



STD3

H = 6.3 mm



STD4

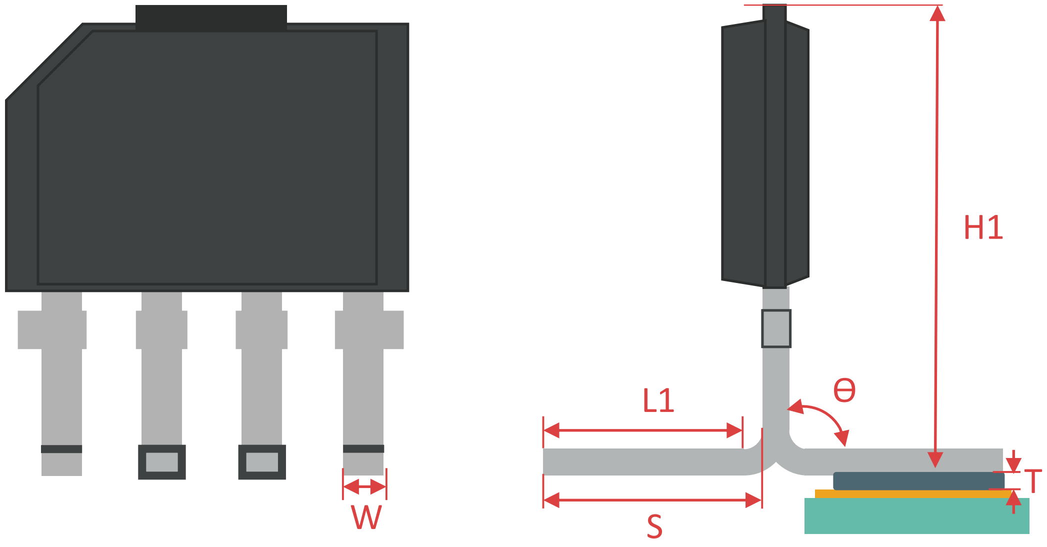
H = 4.3 mm

Evolution of sensor height H driven by vibration test requirement

3. Sensor design and handling for SMT assembly

Lead SMT solderability design considerations

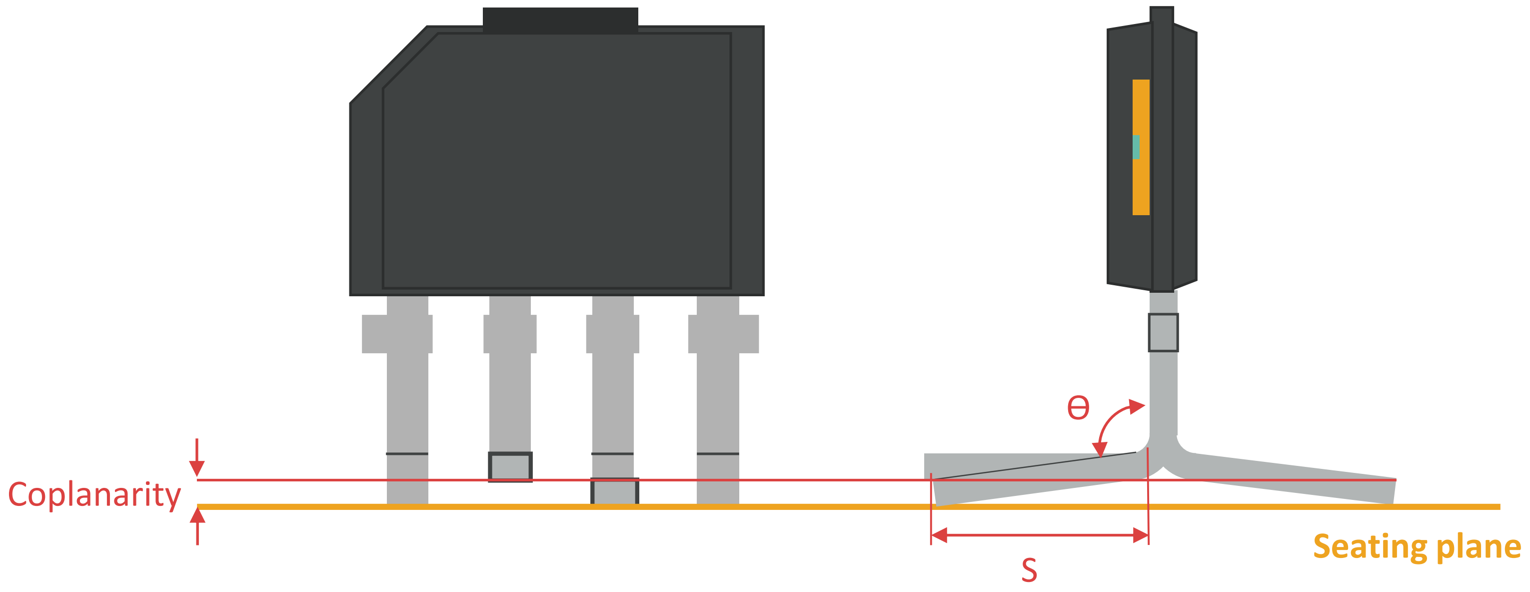
- Soldering of reverse T-shaped sensor by SMD reflow shall meet J-STD-001 and IPC-A-610 requirement. If it is a part of the common PCB with the switching circuitry, sensor solder paste type and printed thickness should align with the rest of components.
- JEDEC Gull wing lead design for SMT soldering
- Category SMT package (leads) – L1 > 3W
- Solder paste thickness (T): 6mil (152um)
- Horizontal length for stability on wet solder paste, 2xS > H1
- Lead bending angle (ϴ) shall be ≥ 90° for proper contact to printed solder paste



3. Sensor design and handling for SMT assembly

Definition of coplanarity and impact on the application

JESD22-B108 defines a methodology for measuring the coplanarity of SMD (Surface Mount Devices) using three pins to define a seating plane. Coplanarity is mostly defined by the bending angle ϴ variation. SMT soldering quality and final vertical tilt of the VA sensor are impacted by the coplanarity.

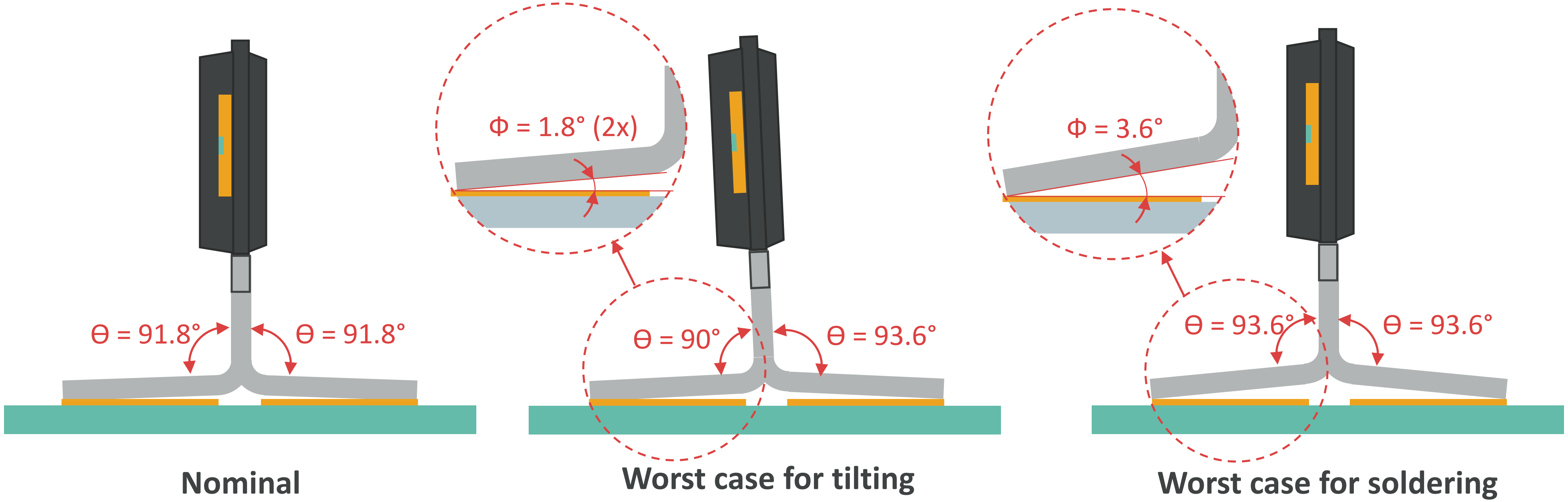


3. Sensor design and handling for SMT assembly

Worst cases by bending angle variation – STD4 example

The worst cases for both tilting and soldering depend on the resulting pin angle to seating plane.

Lead bending angle (Ө) shall be ≥ 90° for proper contact to printed solder paste

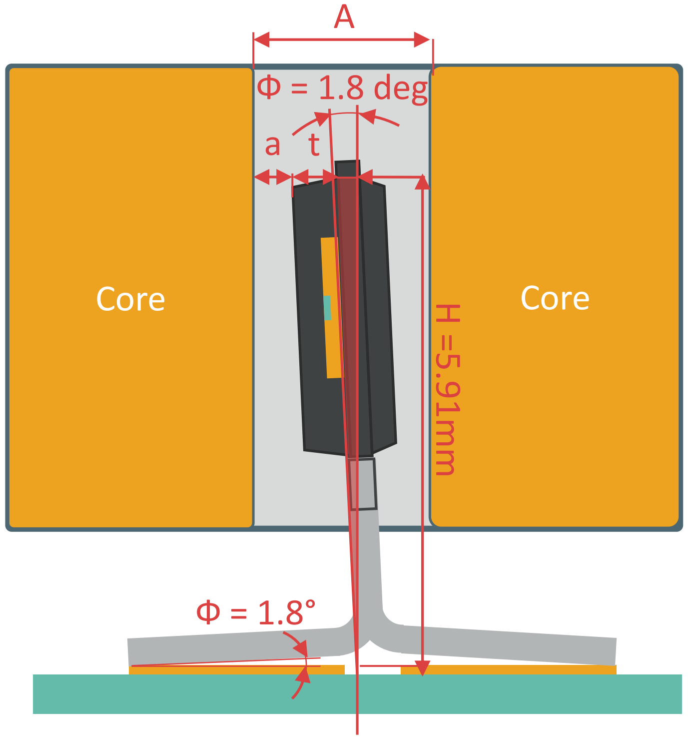


Bending angle
STD4: 91.8 ± 1.8°
STD2/3: 91.3 +2.0°/-1.3°

3. Sensor design and handling for SMT assembly

Worst case vertical tilt – STD4 example

Tilting is defined by the maximum angle to seating plane (Φ) and the IC height (H). The gap in the core (A) should be designed to accommodate for the maximum tilting of the device when the sensor is placed in the center of the gap.



Maximum tilt at mold package top (a)

- **STD4**: 0.186 mm
- **STD3**: 0.229 mm
- **STD2:** 0.276 mm

Minimum core gap (A)

- **STD4**: 1.69 mm
- **STD3**: 1.78 mm
- **STD2**: 1.87 mm

Recommended core gap with safety factor for vibrations (2x):

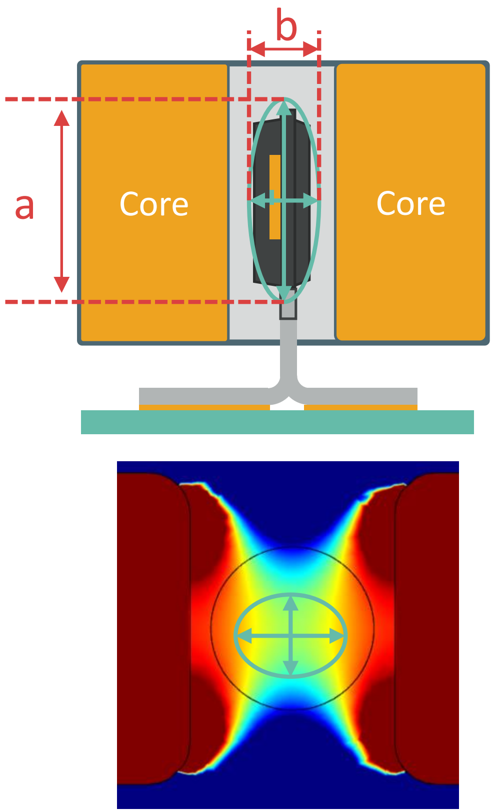
- **STD4**: 3.38 mm
- **STD3**: 3.56 mm
- **STD2**: 3.74 mm

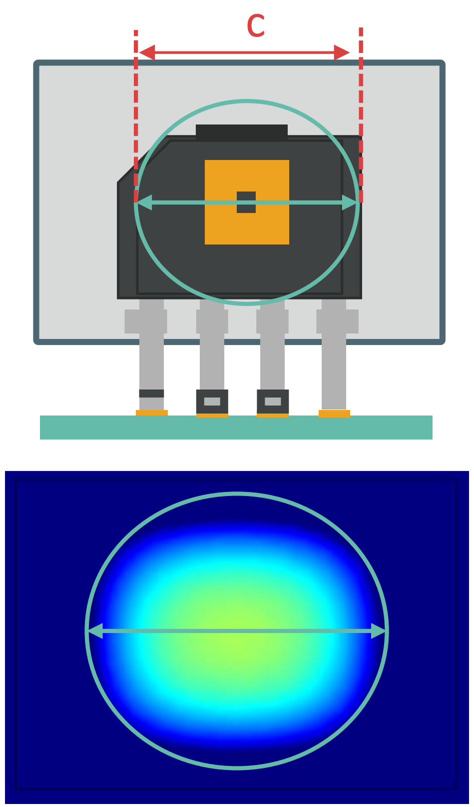
Note: The total tolerance stack-up shall include also core placement accuracy and core notch dimension tolerance

3. Sensor design and handling for SMT assembly

Homogeneity inside core airgap

Homogeneity zone can be defined as the volume where the magnetic field does not change by more than 2%





Dimension	Value [um]
a	700
b	1800
c	790

Simulation results

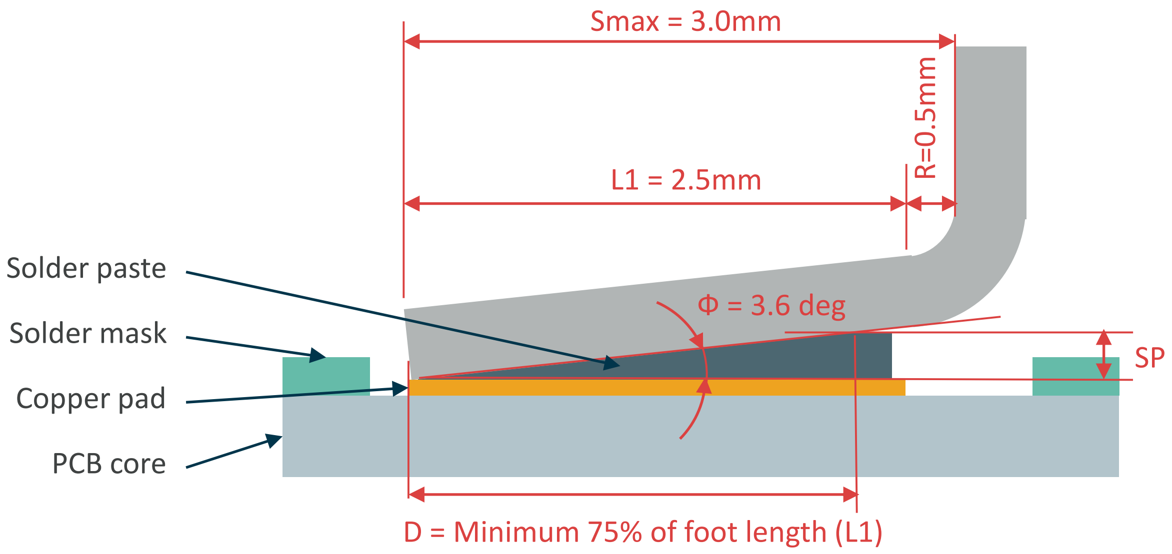
Note: 2% is a proposed value and can be changed based on application needs. Contact Melexis for more information

3. Sensor design and handling for SMT assembly

Worst case for pin contact to solder paste – STD4 example

Soldering quality (reflow process on printed solder paste) is defined by lead bending angle (Θ) and lead length (S).

IPC-A-610H 8.3.5.4 requires that effective soldering is applied at least to 75% of solderable foot length (L). Therefore the lead forming design target should be 75% of solderable foot length to come in contact with the solder paste at sensor placement onto PCB.



STD4: Minimum solder paste (SP) for 90% soldered length = 0.118 mm (**5 mil**)
STD2/3: Minimum solder paste (SP) for 90% soldered length = 0.175 mm (**7 mil**)

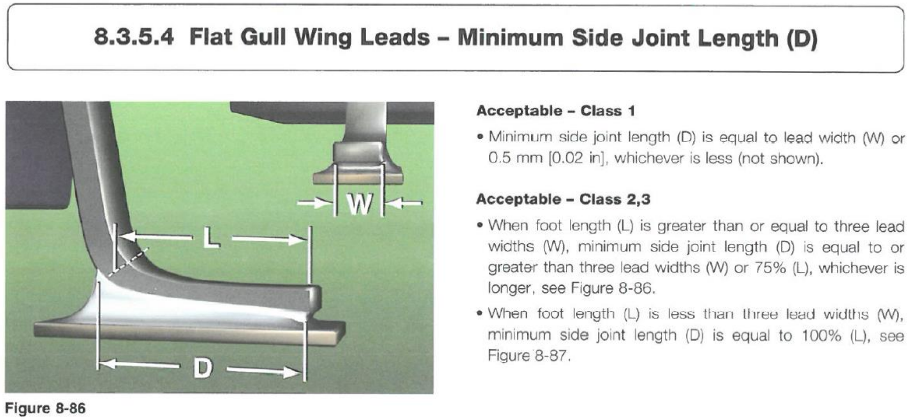
3. Sensor design and handling for SMT assembly

Lead forming for robust soldering to PCB

Soldering quality (reflow process on printed solder paste) is defined by lead bending angle (Ө) and solderable lead length (L).

IPC-A-610H requires effective soldering is applied at least to 75% of solderable foot length

Lead bending angle (Ө) shall be ≥ 90° for proper contact to printed solder paste with a solder paste (stencil) thickness



8.3.5.4 Flat Gull Wing Leads – Minimum Side Joint Length (D)

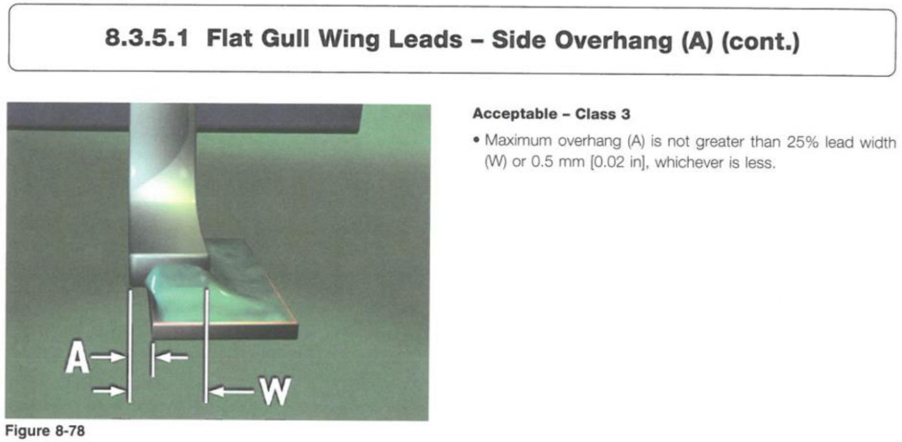
Acceptable – Class 1

- Minimum side joint length (D) is equal to lead width (W) or 0.5 mm [0.02 in], whichever is less (not shown).

Acceptable – Class 2,3

- When foot length (L) is greater than or equal to three lead widths (W), minimum side joint length (D) is equal to or greater than three lead widths (W) or 75% (L), whichever is longer, see Figure 8-86.
- When foot length (L) is less than three lead widths (W), minimum side joint length (D) is equal to 100% (L), see Figure 8-87.

Figure 8-86



8.3.5.1 Flat Gull Wing Leads – Side Overhang (A) (cont.)

Acceptable – Class 3

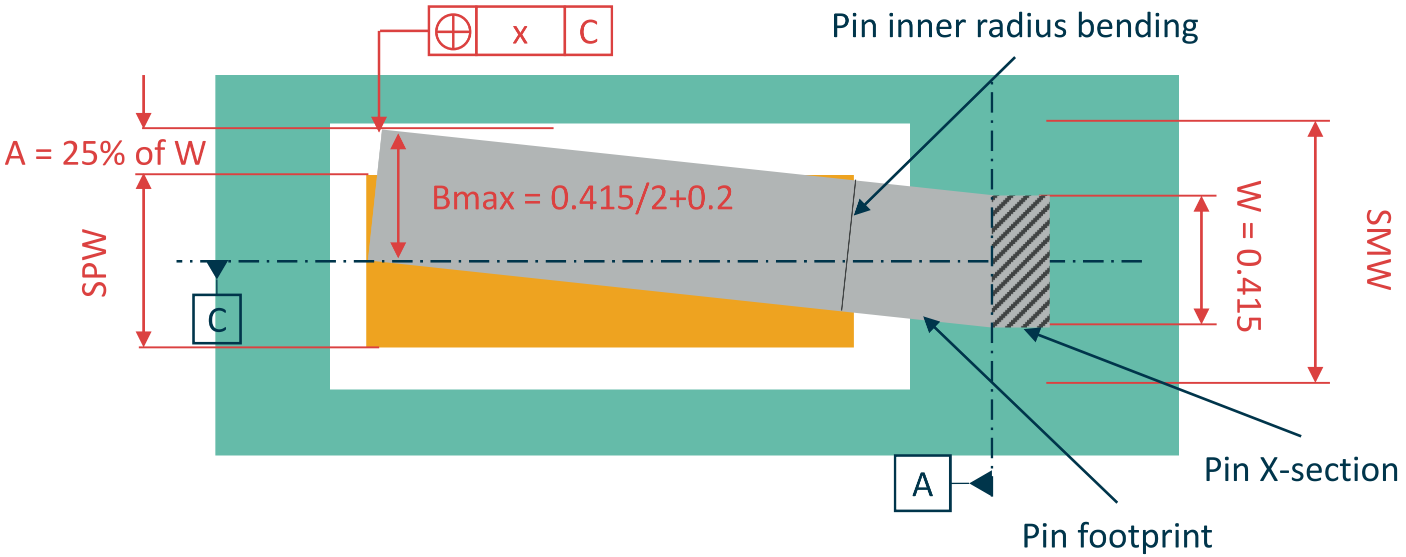
- Maximum overhang (A) is not greater than 25% lead width (W) or 0.5 mm [0.02 in], whichever is less.

Figure 8-78

3. Sensor design and handling for SMT assembly

Pin side bending limits to control pin side overhang in NSMD pad

IPC-A-610H 8.3.5.1 defines the maximum side overhang (A) as 25% of the lead width (W) for class 3 PCBAs. Parameter ‘A’ can be used to calculate the minimum solder pad width (SPW) and minimum solder mask width (SMW), with maximum allowed side bending pin apex position tolerance as +/- 0.2 mm (for reverse T-shapes with 1.27 mm pitch) or +/- 0.3 mm (for reverse T-shapes with 2.54 mm pitch). The pin apex should not step on the solder mask.



	Reverse T-shape, 1.27mm pitch	Reverse T-shape, 2.54mm pitch
Position tolerance (x)	0.40 mm	0.60 mm
SPW (minimum)	0.65 mm	0.75 mm
SMW (minimum)	0.90 mm	1.00 mm

Note 1: SPW guarantees that 75% of the area of the pin is solderable

Note 2: These numbers use a registration accuracy of SM(solder mask) is 0.1 mm, resolution of SP(Cu solder pad) is 0.05 mm

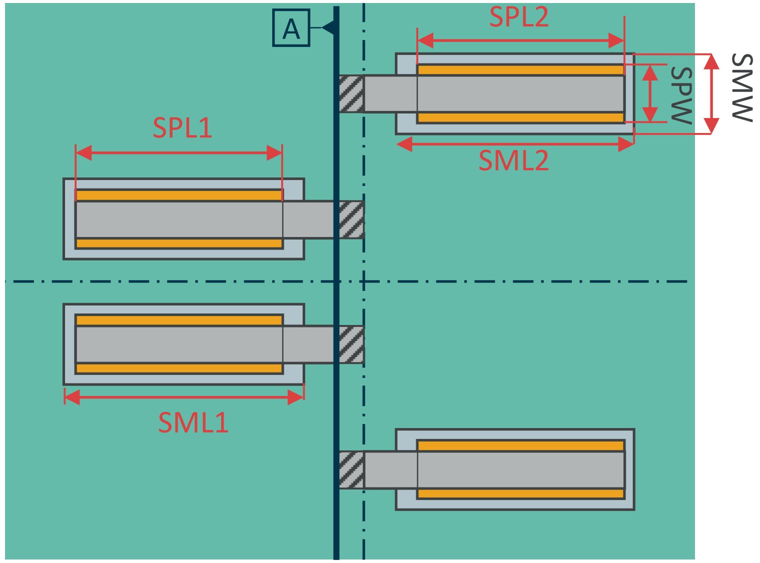
3. Sensor design and handling for SMT assembly

PCB solder pad design recommendations

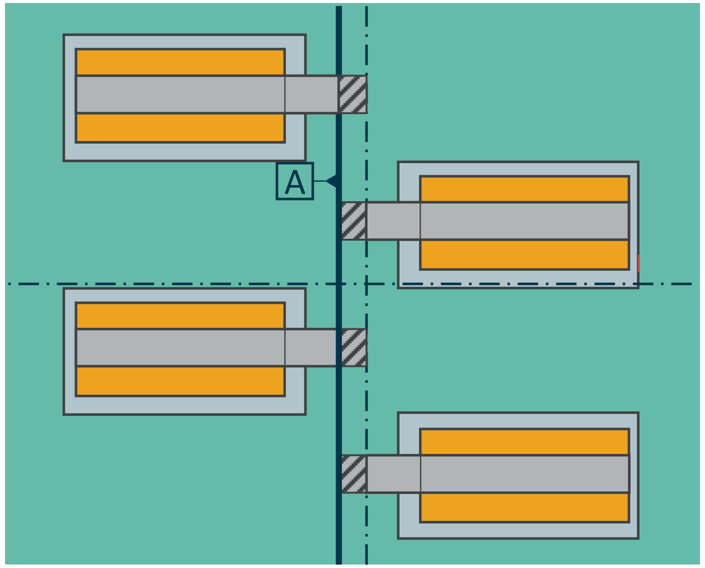
PCB solder pad design: Non-solder mask defined (NSMD)
PCB finish: OSP, ENIG recommended
Stencil opening for solder paste print: centered to solder pad, 90% of solder pad area
Stencil thickness: 5 mil (STD4) or 7 mil (STD2/STD3)

Dim.	Meaning	Reverse T-shape 1.27 STD4	Reverse T-shape 1.27 STD2/3	Reverse T-shape 2.54
SPW	**Solder Pad Width**	0.65	0.65	0.80
SMW	**Solder Mask Width**	0.90	0.90	1.00
SPL1	**Solder Pad Length 1**	2.50	4.05	*
SML1	**Solder Mask Length 1**	2.70	4.30	*
SPL2	**Solder Pad Length 2**	2.25	3.80	*
SML2	**Solder Mask Length 2**	2.50	4.00	*

**Based on the customer design for the lead length*



Reverse T-shape 1.27mm

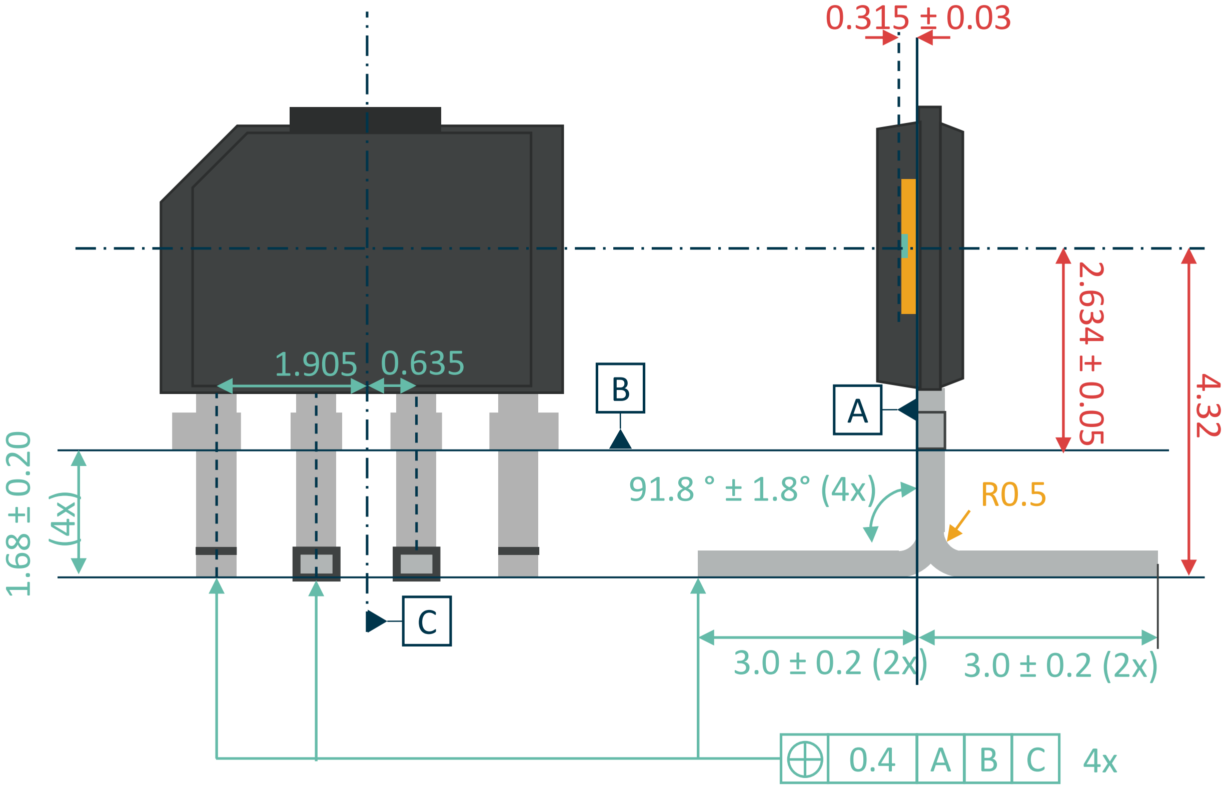


Reverse T-shape 2.54mm

3. Sensor design and handling for SMT assembly

Melexis lead forming process control by automatic optical inspection of dimensions

Coplanarity cannot be measured directly, but the two main dimensions defining it (bending radius and pin length) are checked during AOI (Automatic Optical Inspection)



Example - Dimensions and control of STD4

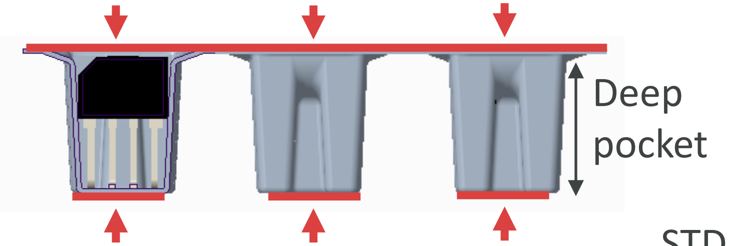
1. 2x90deg bending
2. Magnetic center height above sitting plane (PCB) is 4.32mm
3. Dimensions in **ORANGE** are only subject of tooling validation, not for 100% AOI
4. Dimensions in **GREEN** are subject of 100% AOI vs A, B, C
5. Dimensions in **RED** are guaranteed by Melexis assembly or customer design and are not subject of validation and/or inspection

3. Sensor design and handling for SMT assembly

Reel and tape handling risks

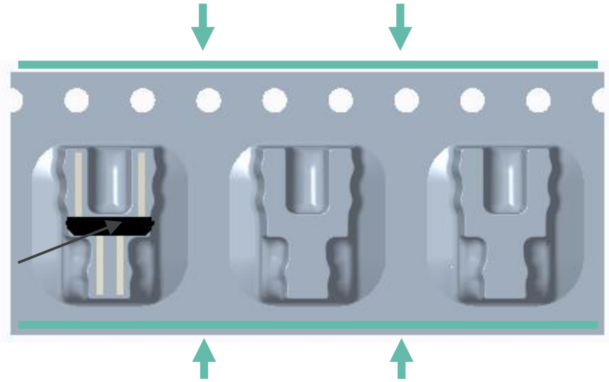
Reverse T-shape options are delivered in TOR (Tape On Reel) with deep pockets. EIA-481 standard does not foresee sensitive devices in deep pockets and the empty pocket leader might not be long enough for safe handling of the devices. Therefore the devices need to be protected during tape-on-feeder installation of the PnP machine to avoid smashing of the deep pockets and deformation of the pins: any manual handling should be limited to the edges of the tape.

SIDE VIEW OF TAPE

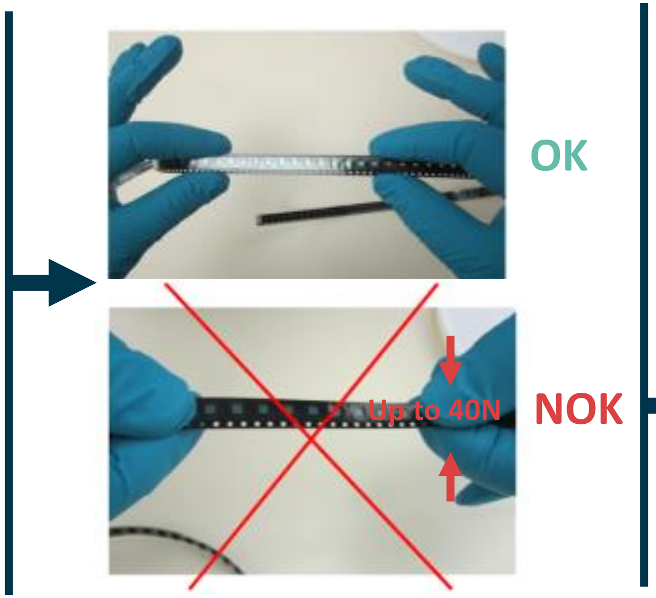


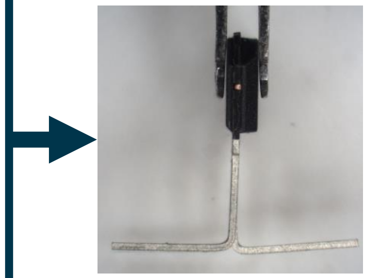
No force should be applied on the pockets, otherwise they might be smashed and the pins deformed

TOP VIEW OF TAPE



Force can be applied on the edges of the reel during manual handling





Lifted pins

Refer to *Guidelines for Surface Mount Technology (SMT) soldering* on Melexis website for more information on IC placement onto PCB. Contact Melexis for the TOR specification

3. Sensor design and handling for SMT assembly

Protection of reel during tape-on-feeder installation

The role of the empty pocket leader (at the beginning of the tape for PnP) is to avoid component stress risk during manual manipulation of loading the tape into the feeder unit of the PnP machine. Therefore, the length of the leader tape should be enough for secure insertion into the feeder.

The bend radius of the feeder shall be selected to accommodate the deep pockets of the tape: 9.9 mm for STD2, 8.4 mm for STD 3 and 6.3mm for STD4. It is recommended to use a minimum radius of 19 mm.

If the SMT line uses a multi-reel feeder, it is recommended to use to top floor if the leader tape is not long enough to install the reel on the lower floor without stressing the deep pockets of the reel. If in any case during installation the 1008mm is not enough for safe handling, please request a longer leader to Melexis.

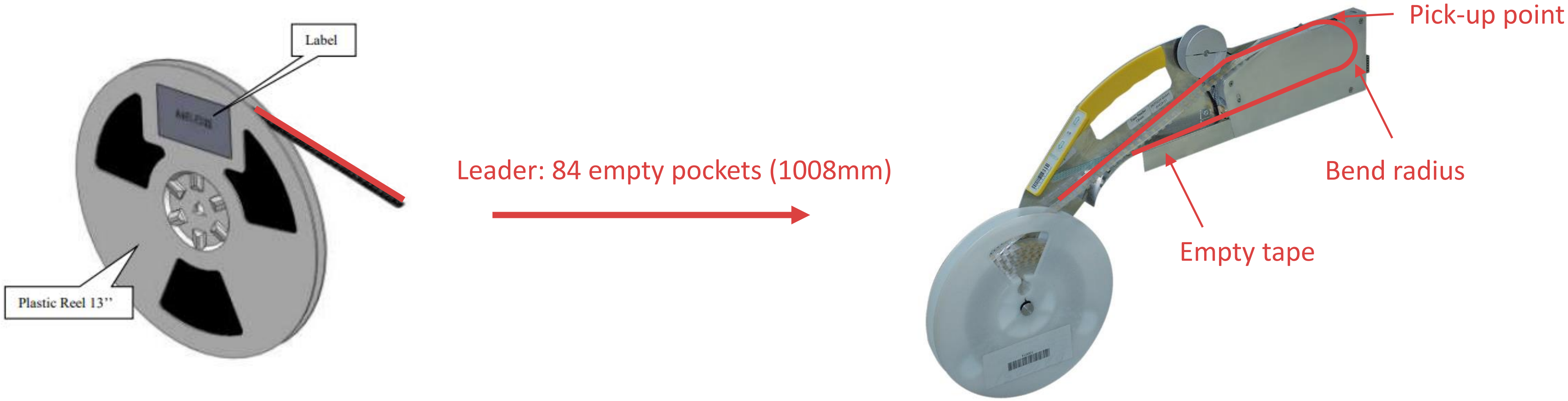
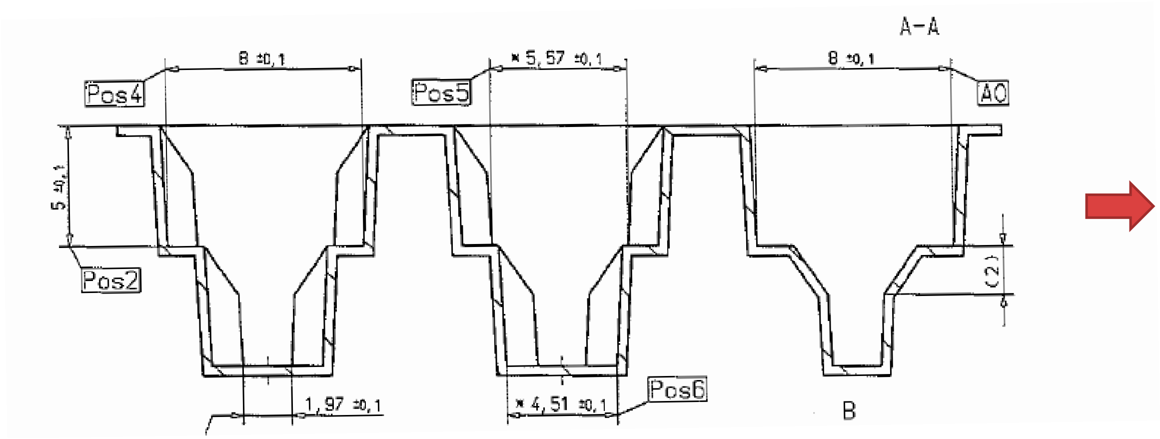


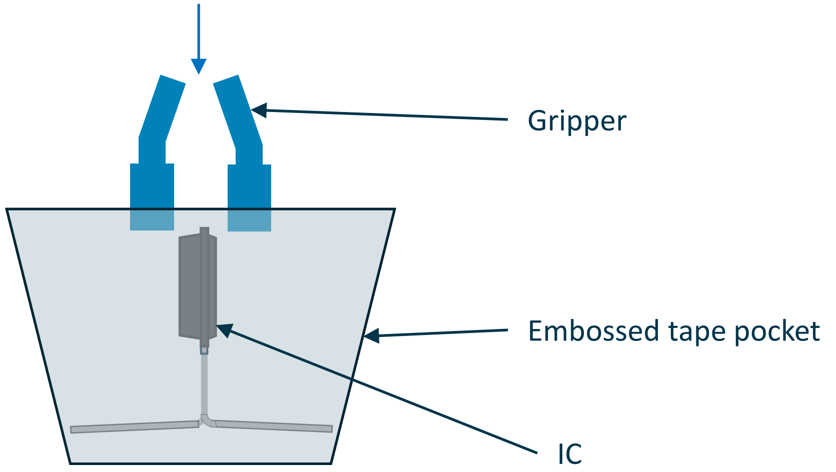
Photo courtesy of Fristsch SMT

3. Sensor design and handling for SMT assembly

Device pickup from embossed tape



Example of embossed tape on reel with pockets



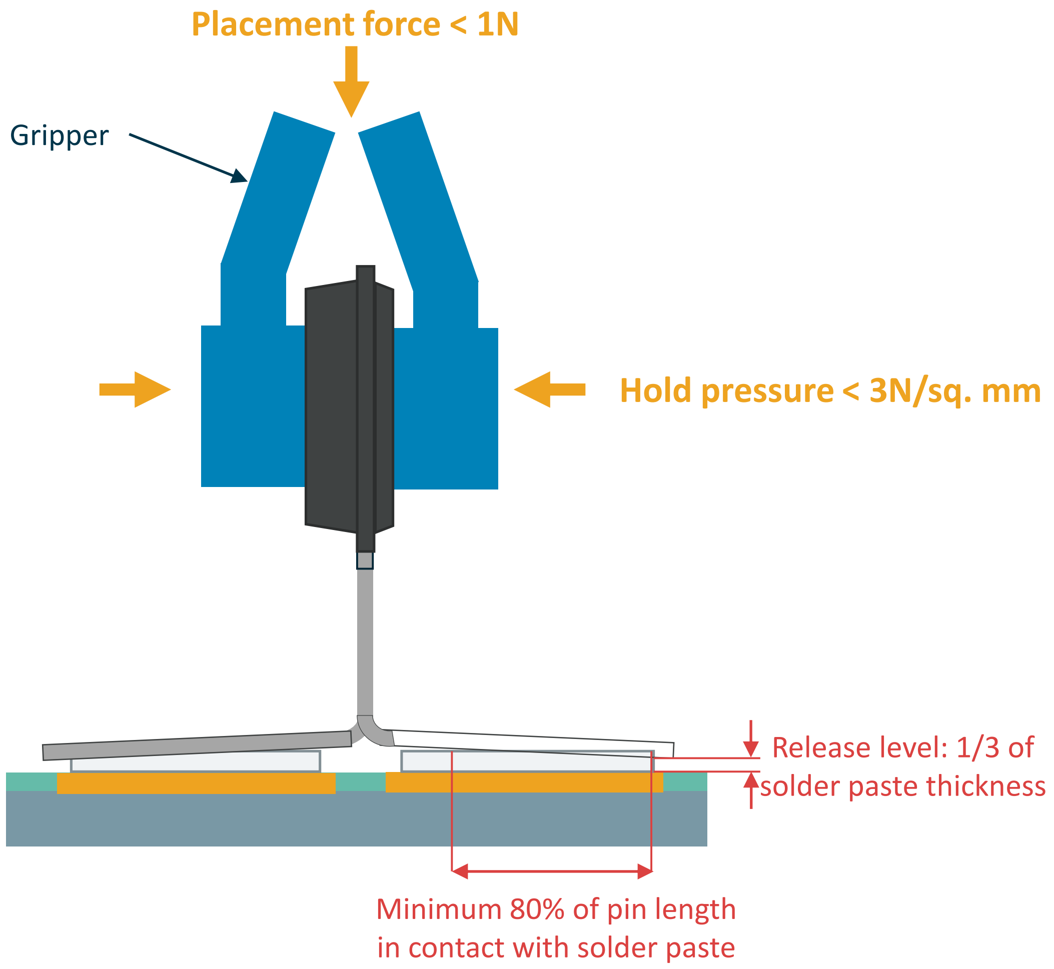
Example of nozzle gripper accessing pocket

The embossed tape on reel for SIP in SMD shape is custom made. Contact Melexis for the TOR (Tape On Reel) specification.

The nozzle gripper should be small enough to enter the pocket where the IC is placed.

3. Sensor design and handling for SMT assembly

Placement of SIP packages in SMD shape onto PCB by gripper

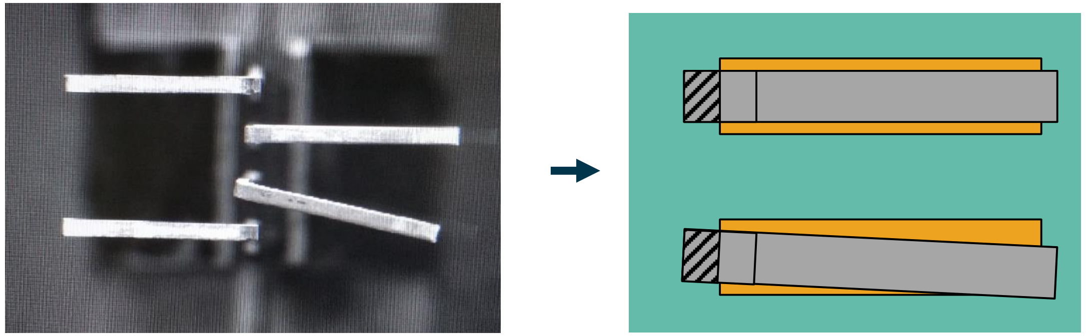


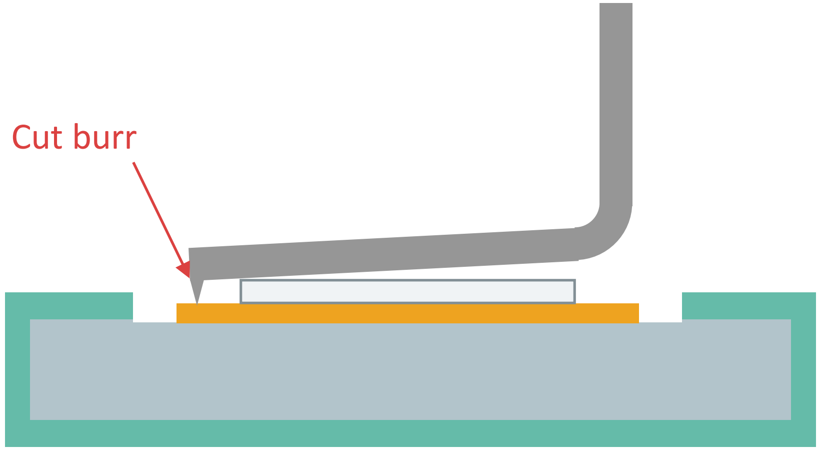
Exceeding the placement force might lead to extra bending of the leads and springback effect.

Exceeding the hold pressure of the gripper on the mold body might lead to mechanical damage of the package.

3. Sensor design and handling for SMT assembly

Known issues when soldering SIP in SMD shape





Risk of lead stepping on solder mask (if bending is out of spec)

If SMD solder pads are used, there is a risk that the lead steps on top of the solder mask due to non-parallelity of the leads. This will affect the positioning of the part and potentially the wetting by the solder

Risk of conflict with cut burr

If the solder pad is longer than the pin length, there might be a conflict with the cut burr present in two of the pins. This will affect the positioning of the part and potentially the wetting by the solder

VA package handling and assembly in inverters

1. Scope
2. Sensor design and handling for THT assembly
3. Sensor design and handling for SMT assembly
4. Vibration robustness and plastic holder

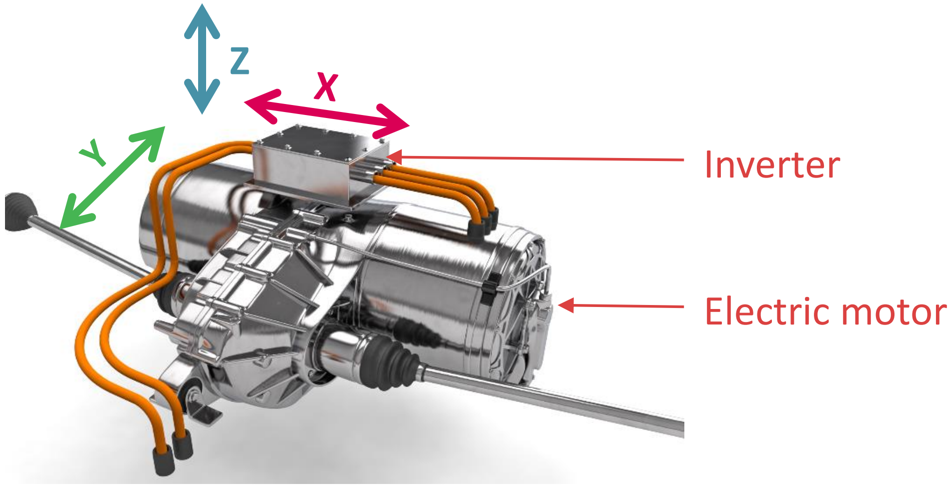
4. Vibration robustness and plastic holder

Vibration in inverter applications

Vibration robustness also depends on the inverter module position in the powertrain of a car. The vibration experimented by the inverter can be divided in three main components: X, Y and Z. From the IC point of view, the vibration in X axis is the worst case. When designing the inverter, the maximum energy axis for the module vibration should not match the IC X axis. This can be achieved by design:

- PCB orientation within the inverter and IC orientation on the PCB
- Dedicated PCB portion for IC without any switching circuitry (which requires heavy heat sinks prone to vibration)

Note: Attention to sensor vibration robustness should be paid early in the design phase to avoid failures during vibration testing

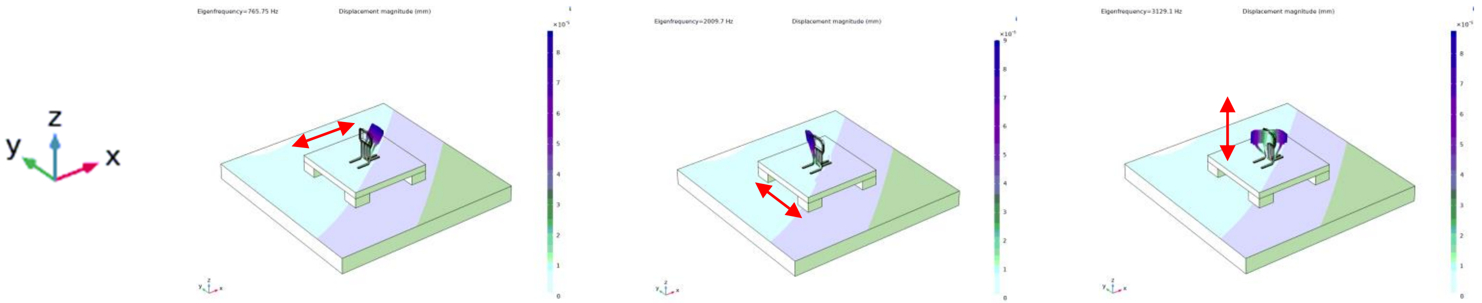


Axis of vibration in inverters modules

4. Vibration robustness and plastic holder

IC vibration robustness

Inverter assembly is a subject of vibration test with a specific frequency/amplitude/time profile. Melexis applies FEA simulations of soldered sensor reference model to establish natural (self-resonance) frequency in each axis X, Y, Z. As illustrated below, X-axis vibration is with the lowest natural frequency/highest amplitude and therefore represent the major vibration risk



X axis vibration **Y axis vibration** **Z axis vibration**

The natural frequency from FEA should be compared to the vibration test frequency range. Extra sensor fixation measures might be needed – adding sensor-to-PCB plastic holder, for example. Main factor for self resonant (natural) frequency of VA soldered sensor based on simulations:

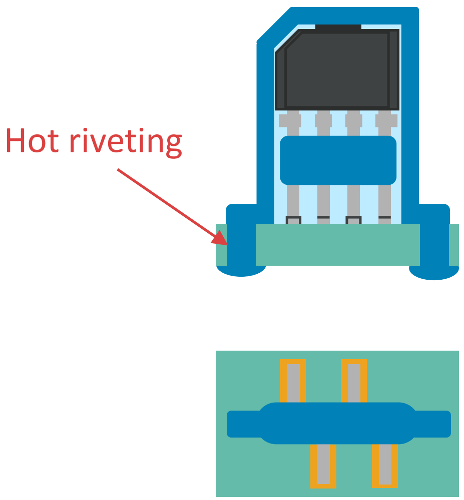
- **Primary** – Sensor height (H)
- **Secondary** – Bending radius (R), Horizontal pin length (S)

4. Vibration robustness and plastic holder

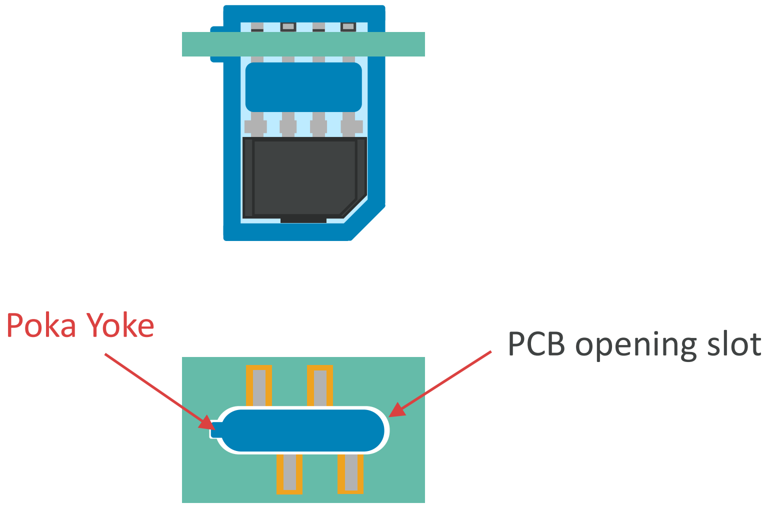
Plastic holder

The Plastic holder shall prevent (absorb) fatigue stress on the IC pins which is applied during vibration testing. Melexis does not have the core competency for design and manufacturing of plastic holders. However, some best practices on how to position the part on a plastic assembly can be found on *Guidelines for positioning and fixation of PCB-less devices.*

Use of plastic holder can accommodate PCB top side assembly and bottom side assembly (through a opening slot on the PCB). Below are examples for both approaches, only for reference.



Top side assembly



Bottom side assembly

Annex I: List of Abbreviations

AOI: Automatic Optical Inspection
ENIG: Electroless Nickel Immersion Gold
FEA: Finite Element Analysis
IC: Integrated Circuit
NSMD: Non-Surface Mask Defined
OSP: Organic Solderability Preservatives
PCB: Printed Circuit Board
PCBA: Printed Circuit Board Assembly
PnP: Pick And Place

SM: Solder Mask
SMD: Surface Mount Device
SMT: Surface Mount Technology
SOIC: Small Outline Integrated Circuit
TH: Through Hole
THT: Through Hole Technology
TO: Transistor Outline
TOR: Tape On Reel

Annex II: List of Standards

JESD22-B108 Coplanarity Test for Surface-Mount Semiconductor Devices

J-STD-033 *Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices*

IPC-A-610 Acceptability of Electronic Assemblies

IPC-2221 Generic Standard on Printed Board Design

IPC-2222 Sectional Design Standard for Rigid Organic Printed Boards

EIA-481 4 mm Through 200 mm Embossed Carrier Taping and 8 mm & 12 mm Punched Carrier Taping of Surface Mount Components for Automatic Handling

Annex III: List of Related Application Notes

For the latest revision of this document and related Application Notes, visit www.melexis.com/ic-handling-and-assembly

Guidelines for leadforming of SIP Hall sensors

Guidelines for positioning and fixation of PCB-less devices

Guidelines for Surface Mount Technology (SMT) soldering

Guidelines for Through Hole Technology (THT) soldering

Melexis

INNOVATION WITH HEART

The content of this document is believed to be correct and accurate. However, the content of this document is furnished "as is" for informational use only and no representation, nor warranty is provided by Melexis about its accuracy, nor about the results of its implementation. Melexis assumes no responsibility or liability for any errors or inaccuracies that may appear in this document. Customer will follow the practices contained in this document under its sole responsibility. This documentation is in fact provided without warranty, term, or condition of any kind, either implied or expressed, including but not limited to warranties of merchantability, satisfactory quality, non-infringement, and fitness for purpose. Melexis, its employees and agents and its affiliates' and their employees and agents will not be responsible for any loss, however arising, from the use of, or reliance on this document.
This document is subject to change without notice, and should not be construed as a commitment by Melexis. Therefore, before placing orders or prior to designing the product into a system, users or any third party should obtain the latest version of the relevant information.

Users or any third party must determine the suitability of the product described in this document for its application, including the level of reliability required and determine whether it is fit for a particular purpose.
This document as well as the product here described may be subject to export control regulations. Be aware that export might require a prior authorization from competent authorities. The product is not designed, authorized or warranted to be suitable in applications requiring extended temperature range and/or unusual environmental requirements. High reliability applications, such as medical life-support or life-sustaining equipment or avionics application are specifically excluded by Melexis. The product may not be used for the following applications subject to export control regulations: the development, production, processing, operation, maintenance, storage, recognition or proliferation of
1. chemical, biological or nuclear weapons, or for the development, production, maintenance or storage of missiles for such weapons;
2. civil firearms, including spare parts or ammunition for such arms;
3. defense related products, or other material for military use or for law enforcement;
4. any applications that, alone or in combination with other goods, substances or organisms could cause serious harm to persons or goods and that can be used as a means of violence in an armed conflict or any similar violent situation.
No license nor any other right or interest is granted to any of Melexis' or third party's intellectual property rights.
This disclaimer will be governed by and construed in accordance with Belgian law and any disputes relating to this disclaimer will be subject to the exclusive jurisdiction of the courts of Brussels, Belgium.
The invalidity or ineffectiveness of any of the provisions of this disclaimer does not affect the validity or effectiveness of the other provisions.
The previous versions of this document are repealed.

Melexis © - No part of this document may be reproduced without the prior written consent of Melexis. (2024)

IATF 16949 and ISO 14001 Certified