AS3213S.5 Application Note – AN06
Strain sensing with embedded strain sensor

Revision History

Revision	Date	Comment
1.0	2023-07-07	Initial version

Table of Contents

1. Abstract

The AS3213S.5 IC embeds both temperature and strain sensors and allows battery-less measurement of extension, compression and bending with a simple UHF RFID tag, without any external device (no need for strain gauges for instance).

The purpose of this document is to provide the user with:

- characterization results obtained with the AS3213S.5 internal strain sensor embedded on a reference tag design.
- general guidelines for the application development with this sensor.

2. AS3213S.5 sensor data and configurable parameters

The user can refer to application note AN04-1 for more information on how sensor data is organized in AS3213S.5 IC (temperature and strain):

https://as321x.asygn.com/clients/documentsbasic/AS321X_AN04-1_v2.0.pdf

In addition, the user can refer to the AS3213S.5 datasheet, where he will find in particular information on the configurable parameters available in the IC (pages 19 and 20):

https://as321x.asygn.com/clients/documentspremium/AS3213S.5_datasheet_v1.1.pdf

The default values of the two configuration words, CONFIG0 and CONFIG1 (at addresses 0x10 and 0x11 respectively in EPC bank) are as follows:

- CONFIG0 = 0x1800
- CONFIG1 = 0x1007

It is recommended that the user adjust CONFIG1<2:0> = STRAIN_GAIN according to the needs of the targeted application but keep the other parameters unchanged.

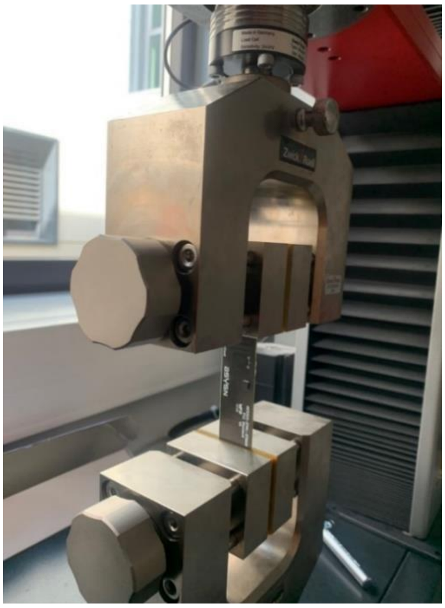
STRAIN_GAIN allows to adjust the gain of the amplifier of the acquisition channel. The higher STRAIN_GAIN, the higher the sensitivity of the strain sensor.

3. Results obtained on a practical case

3.1. Test bench

To perform this characterization, an extensometer bench has been used to elongate different types of tags, step by step. The constraints applied to the tags were uniaxial extension constraints and were measured by the equipment in µm/m.

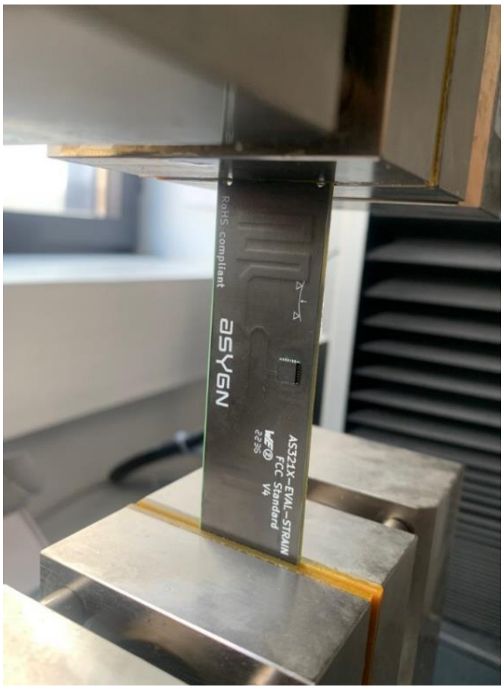
For these measurements, it has been chosen not to glue the tags on a support and to lengthen this support, but to lengthen the tags directly: the tags themselves were used as a support to test our IC. Therefore, tags have been placed directly on the extensometer and extension forces have been applied to them to stretch them (see picture below).



The use of this type of bench allows to know the elongation of the object in µdef (µm/m) without the need to use a reference sensor, such as a strain gauge for example. Indeed, this extension bench can perform a precise measurement of the distance between its two clamps, and therefore a precise measurement of the elongation caused by the constraint applied to the object.

During these measurements, the extension force applied to the tags has been increased step by step. For each step, both the elongation value indicated by the bench and the sensor data measured by the AS3213S.5 internal strain sensor has been stored. To measure this sensor data, a standard UHF RFID reader has been used.

On the picture below, for example, ASYGN demo tags placed on the extensometer for characterization can be seen.



Asygn demo tags are 1.6mm-thick PCB based tags, where the AS3213S.5 chip is used in a QFN package. It came that the uniaxial elongation of the PCB is not well transmitted to the component in this configuration. This PCB demo tag would be more convenient for bending application like weigh-scale.

The following section shows the results obtained on a reference PET inlay developed by one of our tag maker partners. On this inlay the AS3213S.5 component is used as a bumped bare die mounted in flip chip.

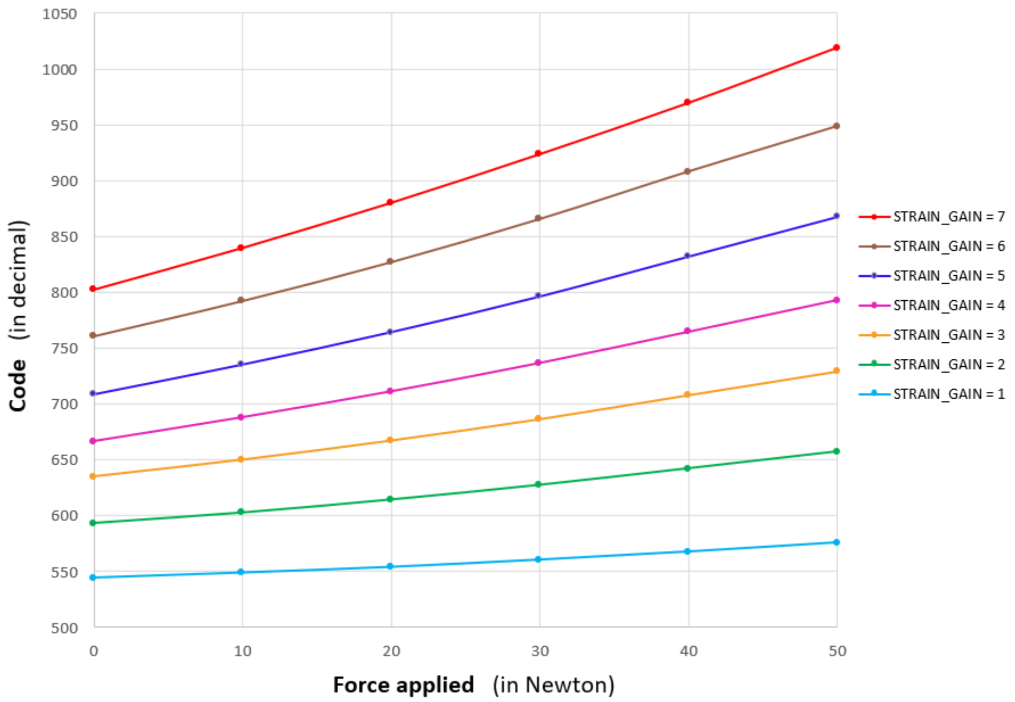
3.2. Measurement results obtained with the AS3213S.5 internal strain sensor on a PET inlay

Extension forces between 0 and 50N were applied. The elongation of the PET inlay tags caused by these forces is mentioned in the table below.

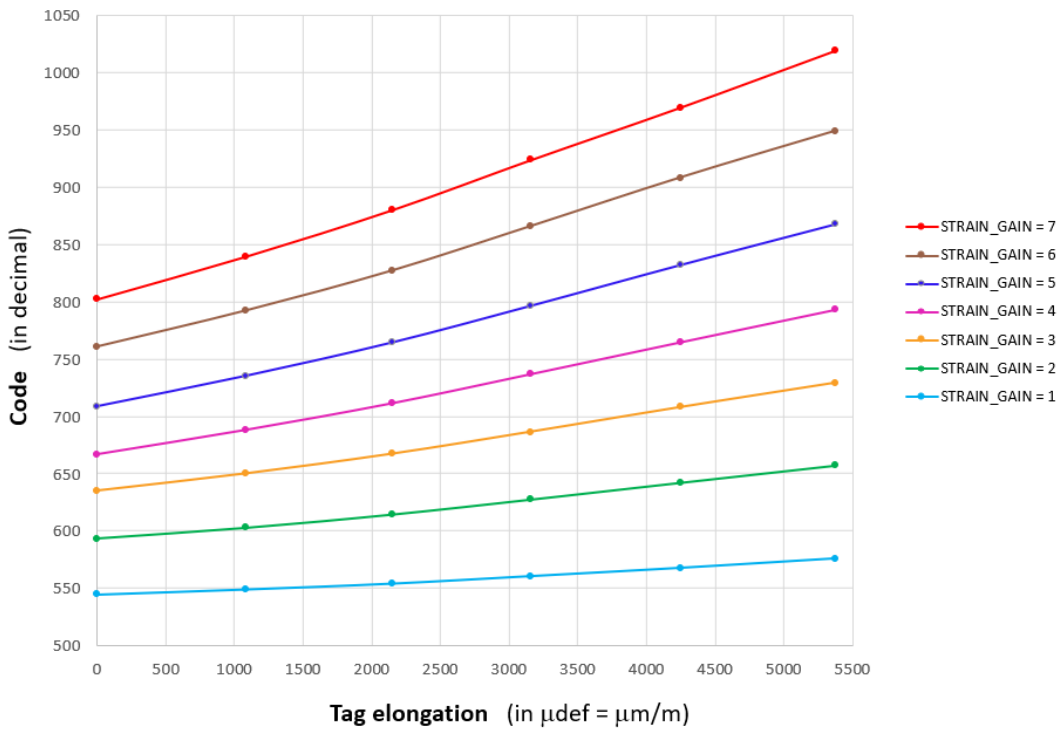
Extension force applied (in Newton)	Tag elongation measured (in µdef = µm/m)
10	1087
20	2148
30	3156
40	4249
50	5373

The curves below give the strain sensor data ("Code") measured by the AS3213S.5 IC of this tag as a function of the force applied: these measurements were made with the seven possible values of the STRAIN_GAIN parameter (from 1 to 7, natural values).

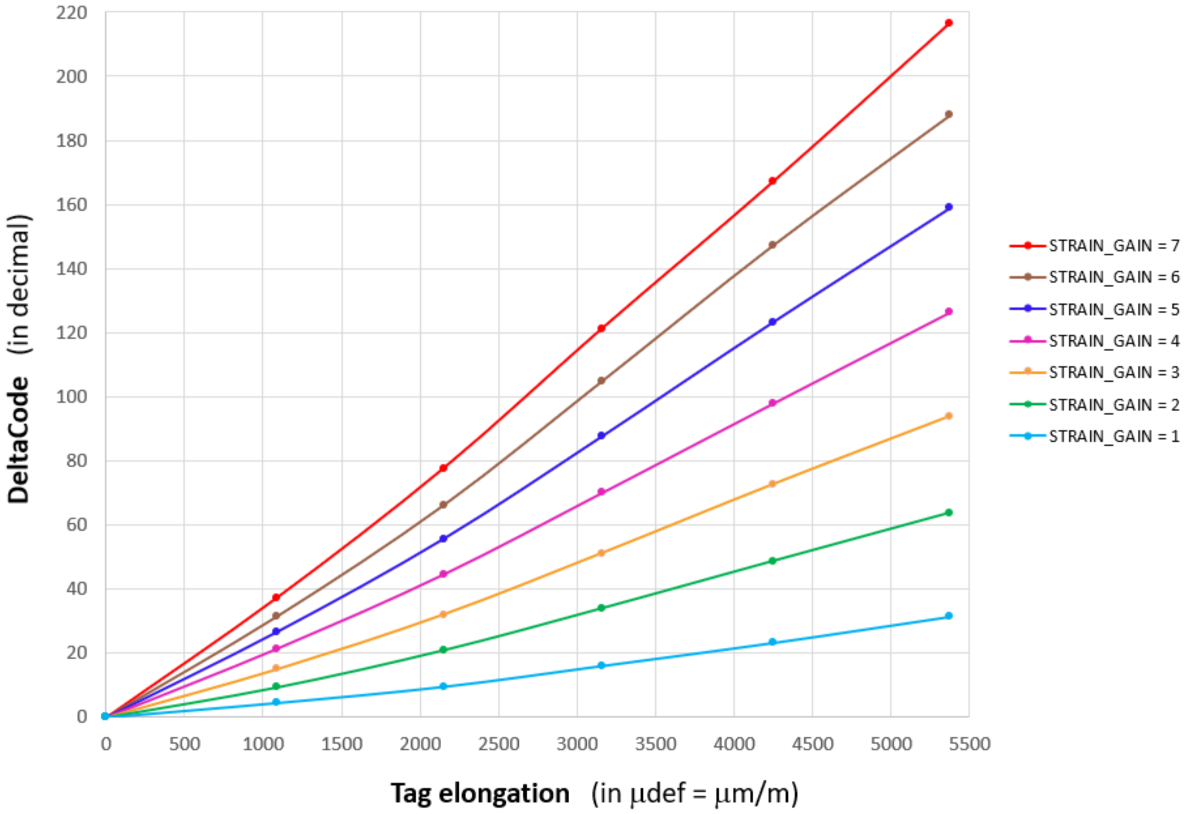
The acquisition channel ADC is a 10-bit ADC, so sensor data sent by the tag to the reader, when expressed in decimal, is a number between 0 and 1023.



Similar curves can be plotted to give strain sensor data as a function of the tag elongation (µdef) for the seven possible values of STRAIN_GAIN.



Finally, the curves below give "DeltaCode" as a function of the tag elongation: DeltaCode is the difference between the sensor data measured for a given deformation and the "zero deformation" sensor data, measured when no constraints are applied to the tag. It can be noted that DeltaCode evolves linearly with the tag elongation.



The following table recalls the value of DeltaCode obtained for the maximum elongation tested (5373 µdef) and specifies the sensitivity of the strain sensor and the value of the equivalent gage factor, GFeq, for the 7 possible values of STRAIN_GAIN.

Since the sensor data can vary between 0 and 1023, with therefore a median value equal to 512, this equivalent gauge factor can be expressed as follows:

GFeq = (DeltaCode/512) / (ΔL/L) with ΔL/L in m/m

By using the results obtained with the maximum deformation (5373 µdef), it comes:

STRAIN_GAIN	DeltaCode for a deformation of 5373 µdef	Sensitivity of the strain sensor (µdef/code)	GFeq
7	216.6	24.8	79
6	188	28.6	68
5	158.9	33.8	58
4	126.4	42.5	46
3	93.9	57.2	34
2	63.8	84.2	23
1	31.3	171.7	11.5

3.3. Some important comments about these results

It is important to emphasize that the measurements presented above are only an example of the results that can be obtained with the strain sensor embedded in the AS3213S.5 IC.

Not only the value of the sensor data measured without constraint, called the "zero deformation" sensor data, varies naturally from one IC to another (this offset is unavoidable as due to silicon dispersion and residual assembly stress), and the sensitivity of the sensor is also not strictly identical from one part to another, but also, and above all, the measurement results vary from one tag to another depending on the design of the tag, the method and material used to attach it to the object to be measured, as well as the specificities of this deformation (uniaxial or not).

It is therefore not possible to establish a single equation which would convert the strain sensor data into strain in μdef, as it is possible for temperature for example. As a consequence, to obtain accurate measurement results, it is essential that each tag be calibrated once installed in the application environment (see section 5 of this document).

Another point to highlight is that the sensitivity of the sensor, as measured during the tests presented above, is 24.8 μdef/code for this dedicated tag design where the IC is assembled in flipchip. However, laboratory tests carried out by sticking the AS3213S IC (bare die) directly on a support, applying bending stresses on this support, and using an external strain gauge as reference sensor, showed that the sensitivity of the IC is higher: sensitivities as high as 10 μdef/code could be measured.

Sensitivity and GF are therefore strongly dependent on tag design, IC assembly glue and substrate used. ASYGN can characterize the tag for any type of tag for any application providing sensitivity and law for a clearly defined application.

4. Compensation vs temperature

To optimize accuracy of the strain sensor measurements, it is recommended to take into account the influence of temperature: the AS3213S.5 IC is measuring both strain and temperature.

A characterization campaign was carried out in a thermal chamber: the "zero deformation" sensor data (sensor data without constraint) of 18 tags was measured from 0°C to 120°C (with STRAIN_GAIN = 7).

This characterization highlighted the linear evolution of the strain sensor data as a function of the temperature, with an average slope of **-0.9 code/°C** (when STRAIN_GAIN = 7).

5. General guidelines

This section explains how AS3213S.5 tags are characterized for any customer application and gives some guidelines for their calibration and use in the applications.

5.1. Introduction

As explained in section 3.3 of this document, the sensitivity of a strain tag varies depending on the design of the tag, the method used to attach it to the object to be measured, as well as the specificities of the deformation (uniaxial or not).

For the development of strain tags for a given application, it is therefore necessary to:

1) characterize about 30 tags under conditions as close as possible to the conditions of use in the application, in order to know the sensitivity of the tag strain sensor under these conditions → see section 5.2.

   NB: this characterization is a service that ASYGN is offering to its customer.

2) calibrate each individual tag once installed in the application --> see section 5.3.

By following these guidelines, the user will obtain measurement results as accurate as possible.

5.2. Characterization of the tags for a given application

5.2.1. Calibration of the AS3213S.5 ICs

During probing of the wafers, a calibration of each IC is carried out at the temperature ***CALIB_TEMP***, which is 30°C by default (please refer to AS3213S.5 AN09 application note). During this calibration, the following data are stored in the USER bank of the IC:

- → ***CALIB_TEMP***, stored in the USER Bank at address 0x5 (USER5): the temperature measured by a reference sensor during calibration process (by default: *CALIB_TEMP* = 30°C)

- → **CALIB_ACQ_TEMP**, stored in the USER Bank at address 0x6 (USER6): the temperature sensor data provided by the IC during calibration process.

- → ***CALIB_ACQ_STRAIN***, stored in the USER Bank at address 0x4 (USER4): the strain sensor data provided by the IC during calibration process.

NB: the use of *CALIB_ACQ_STRAIN*, measured during the probing of the wafers may be an option for applications which do not require a precise strain measurement (e.g. for detecting the crossing of an inaccurate threshold), but it is usually necessary, for most applications, to recalibrate the strain sensor data after the tag is installed in the application, as explained in section 5.3 below.

5.2.2. Characterization of the tags

For a given application, approximately 30 tags must be characterized. In this way, a mean and a standard deviation can be extracted from the results obtained.

For this characterization, it is important that the tags are used in conditions as close as possible to the conditions of use in the application (similar deformation stresses, similar solution used to fix the tags, etc...).

Prior to this characterization, it is also important that the user has configured the tags with the needed value of STRAIN_GAIN necessary for the application: the objective is to get the maximum dynamic range by setting this gain to the highest possible value, but without taking the risk that the sensor data saturates at 1023 in the application.

Reminder: STRAIN_GAIN = CONFIG1<2:0> with CONFIG1 available at address 0x11 in EPC bank.

NB: knowing the maximum deformation value that he wishes to measure in the application without reaching sensor saturation, the user can carry out some sensor data measurements on a few tags (before the complete characterization of the 30 tags) to determine the value of STRAIN_GAIN to use.

The operations carried out during the characterization of the 30 tags are as follows, for each tag:

1) Measurement without applying any stress:
   - Acquisition of the two sensor data, strain and temperature: *ACQ_STRAIN0* & *ACQ_TEMP0*
   - Conversion of *ACQ_TEMP0* into a temperature in °C: *temp0* (refer to AS3213S.5 AN09).
   - Compensation of the effect of temperature on the strain sensor data: the value of *ACQ_STRAIN0* is recalculated as if the temperature was *CALIB_TEMP* (i.e. 30°C by default):

     ACQ_STRAIN0_tcal = *ACQ_STRAIN0* – 0.9 x (*CALIB_TEMP* – *temp0*)

2) Measurement under a known stress (the highest possible):
   - Acquisition of the two sensor data: *ACQ_STRAIN* & *ACQ_TEMP*
   - Conversion of *ACQ_TEMP* into a temperature in °C: *temp*
   - Compensation of the effect of temperature on the strain sensor data:

     ACQ_STRAIN_tcal = *ACQ_STRAIN* – 0.9 x (*CALIB_TEMP* – *temp*)

3) Tag sensitivity calculation @*CALIB_TEMP*:

$$\boldsymbol{SENSI\_STRAIN\_tcal}\ (\boldsymbol{in}\ \mathbf{udef/code}) = \frac{STRAIN}{(ACQ\_STRAIN\_tcal\ - ACQ\_STRAIN0\_tcal)}$$

Where *STRAIN* = deformation caused by the stress applied (in µdef = µm/m)

IMPORTANT NOTICE

SENSI_STRAIN_tcal can be stored in the non-volatile memory of the chip, in USER3 for instance.

Another solution, **recommended when possible**, is to save this value, for each chip used in the application, in a database. By this way, reading *SENSI_STRAIN_tcal* in the ICs memory is not necessary for each sensor measurement.

5.3. Calibration of each tag in the application

For a given application, to obtain measurement results as accurate as possible, it is necessary to calibrate the strain sensor of each individual AS3213S.5 tag once installed in the application.

The procedure for this calibration is as follows:

1) Installation of the tag in the application.
2) Configuration of STRAIN_GAIN as determined during the characterization step (see 5.2.2 above).
3) Commissioning of the tag (without applying any stress):
   - Acquisition of the two sensor data, strain and temperature: *ACQ_STRAIN0* & *ACQ_TEMP0*
   - Conversion of *ACQ_TEMP0* into a temperature in °C: *temp0* (refer to AS3213S.5 AN09).
   - Compensation of the effect of temperature on the strain sensor data: the value of *ACQ_STRAIN0* is recalculated as if the temperature was *CALIB_TEMP* (i.e. 30°C by default):

     ACQ_STRAIN0_tcal = *ACQ_STRAIN0* – 0.9 x (*CALIB_TEMP* – *temp0*)
   - As for *SENSI_STRAIN_tcal*, if needed, *ACQ_STRAIN0_tcal* can be stored in the non-volatile memory of the chip (in USER2 for instance), but another solution, **recommended when possible**, is to save this value in a database. By this way, reading *ACQ_STRAIN0_tcal* is not necessary for each sensor measurement.

As a reminder, the following table lists the content of the USER bank of an AS3213S.5 tag after this commissioning:

Label	USER bank address	Function
USER7	0x7	RFU
USER6	0x6	CALIB_ACQ_TEMP: temperature sensor data measured during calibration
USER5	0x5	CALIB_TEMP: temperature of calibration (30°C by default)
USER4	0x4	CALIB_ACQ_STRAIN: strain sensor data measured during calibration
USER3	0x3	If necessary: SENSI_STRAIN_tcal = sensitivity of the **tag** as characterized for the application @CALIB_TEMP
USER2	0x2	If necessary: ACQ_STRAIN0_tcal = “zero” strain sensor data measured by the **tag** during its commissioning @CALIB_TEMP
ACQ_TEMP	0x1	Temperature sensor data (measured each time the tag is inventoried)
ACQ_STRAIN	0x0	Strain sensor data (measured each time the tag is inventoried)

5.4. How to use the AS3213S.5 tags in the application

The procedure to perform any strain measurement in the application is as follows:

- Acquisition of the two sensor data, strain and temperature: *ACQ_STRAIN* & *ACQ_TEMP*
- Conversion of *ACQ_TEMP* into a temperature in °C: *temp* (refer to AS3213S.5 AN09).
- Compensation of the effect of temperature on the strain sensor data: the value of *ACQ_STRAIN* is recalculated as if the temperature was *CALIB_TEMP* (i.e. 30°C by default):

  ACQ_STRAIN_tcal = *ACQ_STRAIN* – 0.9 x (*CALIB_TEMP* – *temp*)
- Conversion of *ACQ_STRAIN* into a strain value in µdef (µm/m):

  Strain (in µdef) = *SENSI_STRAIN_tcal* x (*ACQ_STRAIN_tcal* – *ACQ_STRAIN0_tcal*)