# 205mm Type 6.8 Linear Sensor

## Description

A precision linear resonant inductive position sensor with a measuring range of 205mm. Works with CambridgeIC's Central Tracking Unit (CTU) chips to provide high-quality position data to a host device.

The sensor has two sets of sensor coils: one for taking fine incremental measurements at high accuracy and resolution and another for coarse, absolute measurements. The sensor is Type 6, Subtype 8 (Type "6.8").

The sensor is connected to a CambridgeIC CTU chip, which combines the information from both sets of coils to deliver an absolute, high accuracy and high resolution output to a host system.

## Features

- Full absolute linear sensing
- 205mm Measuring Range
- 6-layer PCB process
- Compact sensor coils
- Target is sensed from the FRONT of the sensor PCB
- Tolerates aluminium close to REAR and sides

## Performance

- Linearity Error <0.05% at 0.5mm…2mm Gap
- Noise Free Resolution > 13 bits up to 2mm Gap
- Up to 0.5mm Y Misalignment

## Applications

- Inside extruded aluminium section
- Actuator position feedback
- Optical and magnetic scale replacement

**Product identification**

| Part no. | Description |
|---|---|
| 013-0035 | Assembled sensor, 10mm wide |
| 010-0094 | Sensor PCB design file, 19.8mm wide |
| 010-0093 | Sensor Blueprint |
| 013-1020 | 11mm E-Core Target |

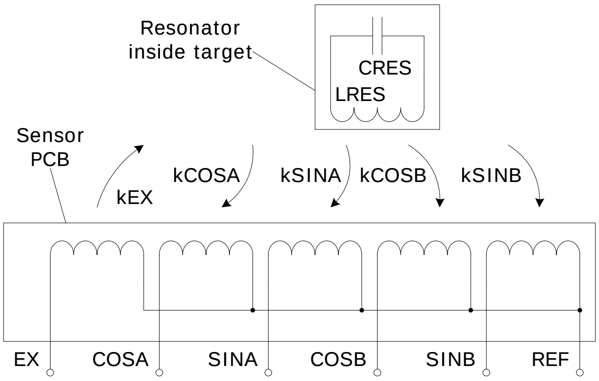


**Figure 1 equivalent circuit**

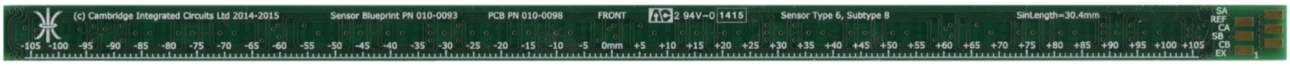


**Figure 2 Sensor PCB Assembly 013-0035, FRONT**

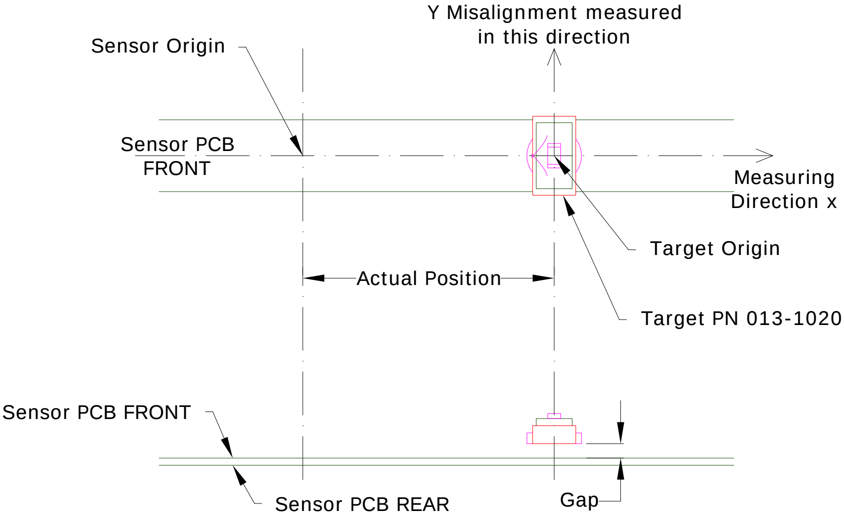


**Figure 3 Alignment of sensor PCB assembly 013-0035 with target 013-1020**

# 1 Assembled Sensor 013-0035 Mechanical Design

The 205mm Type 6.8 Linear Sensor is available as an assembled PCB including connector. Its FRONT side is illustrated in Figure 2. Figure 4 is a mechanical drawing.

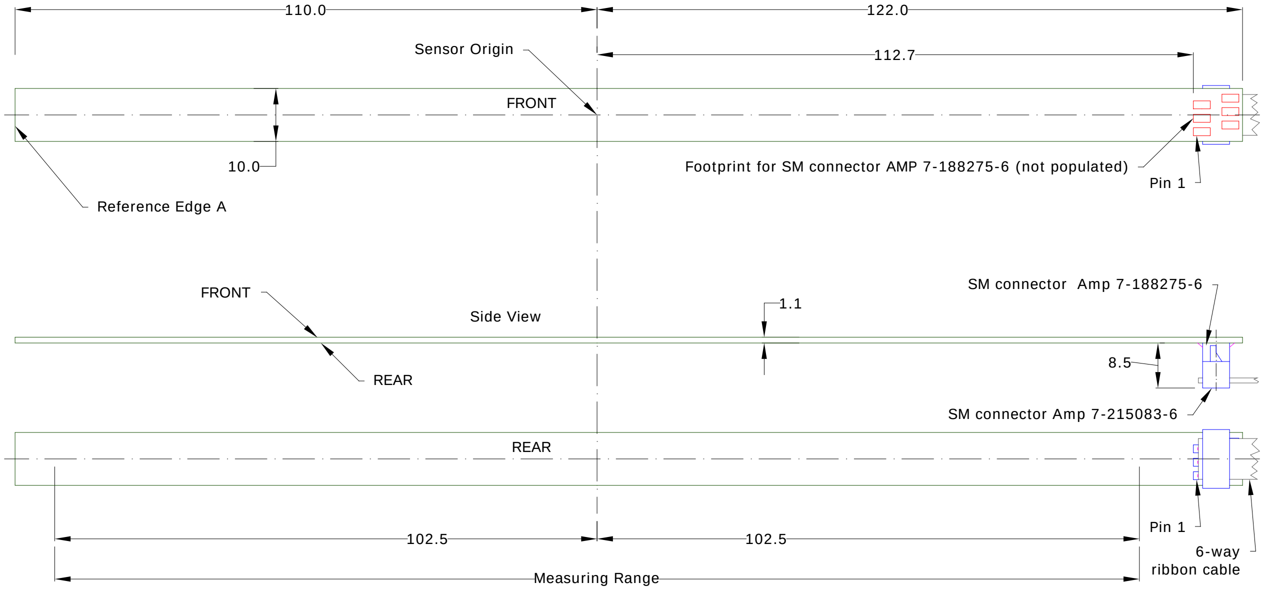


**Figure 4 Mechanical drawing, sensor PCB assembly 013-0035 shown with mating connector 013-6001**

There are footprints for an SM connector AMP 7-188275-6 on both the FRONT and REAR surfaces of the sensor PCB. Only the REAR is populated in part 013-0035. The pinout for both is shown in Table 1.

**Table 1 Sensor PCB electrical connections**

| Pin no | Signal name |
|---|---|
| 1 | EX |
| 2 | CB |
| 3 | SB |
| 4 | CA |
| 5 | REF |
| 6 | SA |

The 205mm Type 6.8 Linear Sensor assembly works with the 11mm E-Core Target, part number 013-1020. Their relative alignment is illustrated in Figure 3. The target must be adjacent the sensor's FRONT surface.

The sensor measures Actual Position relative to the Sensor Origin. The nominal location of the Sensor Origin is 110mm to the right of Reference Edge A as illustrated in Figure 4. This edge is created with a routing process which is inherently less accurate than an alignment hole, and the resulting Offset Error is on the order of ±0.3mm (section 4.4).

## 2 Sensor PCB 010-0094 Mechanical Design

The 205mm Type 6.8 Linear Sensor is available as a PCB design including mounting holes and with an overall width of 19.8mm. This is not available as an assembled sensor. If an assembled sensor is required, part 013-0035 is recommended, as described in section 1.

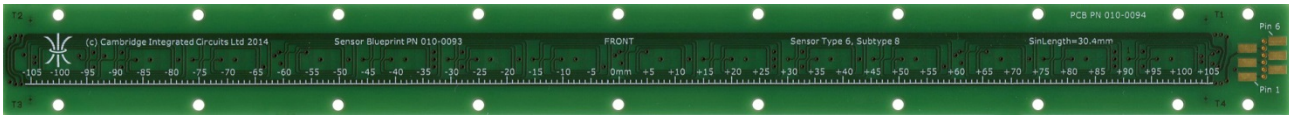


**Figure 5 Sensor PCB 010-0094, FRONT**

Figure 5 shows a PCB built according to the design of 010-0094, and Figure 6 is a dimensioned drawing of the sensor PCB:

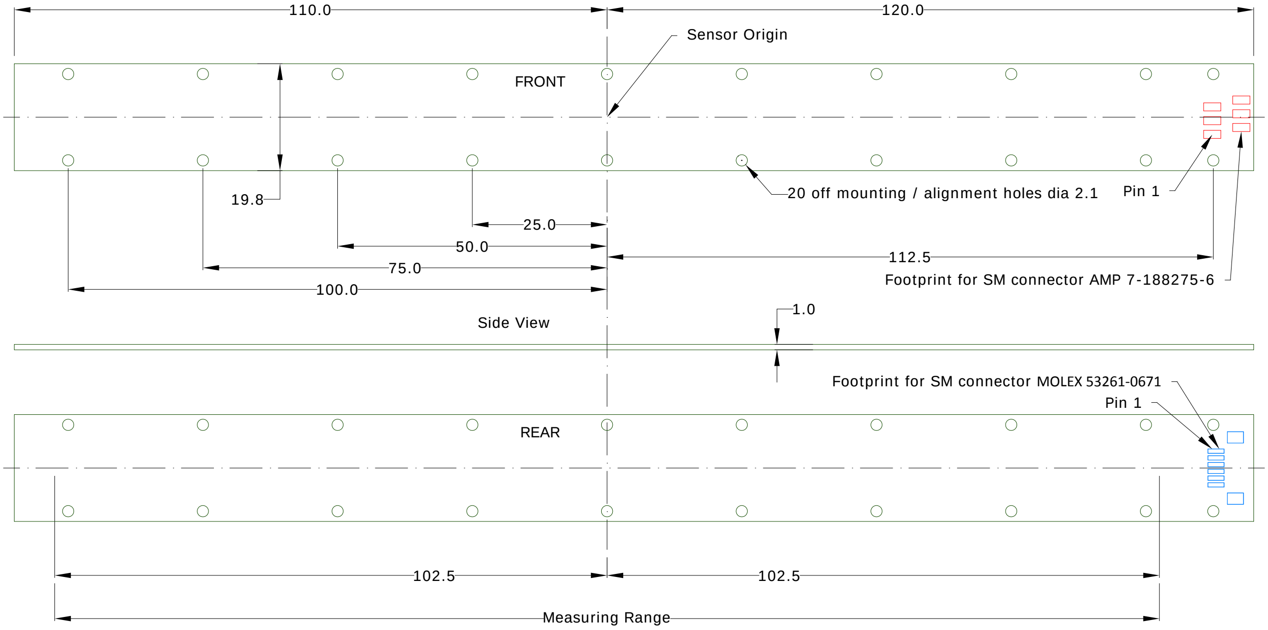


**Figure 6 Mechanical drawing, sensor PCB 010-0094**

The sensor coil pattern itself occupies only the central 9.4mm of the sensor PCB's width, see Figure 24. The remainder of the width is space for mounting, including holes.

The sensor includes 20 mounting/alignment holes. The sensor Origin is defined as mid-way between the central two holes as shown in Figure 6.

There are two different connector footprints, one on the FRONT for AMP 7-188275-6 and one on the REAR for MOLEX 53261-0671. They share coil connections and have the same pinout shown in Table 2. Note the numbering direction of the REAR connector may not be the same as the one used by its manufacturer.

**Table 2 Sensor PCB electrical connections**

| Pin no | Signal name |
|---|---|
| 1 | EX |
| 2 | CB |
| 3 | SB |
| 4 | CA |
| 5 | REF |
| 6 | SA |

The 205mm Type 6.8 Linear Sensor PCB works with the 11mm E-Core Target, part number 013-1020. Their relative alignment is illustrated in Figure 7. The target must be adjacent the sensor's FRONT surface.

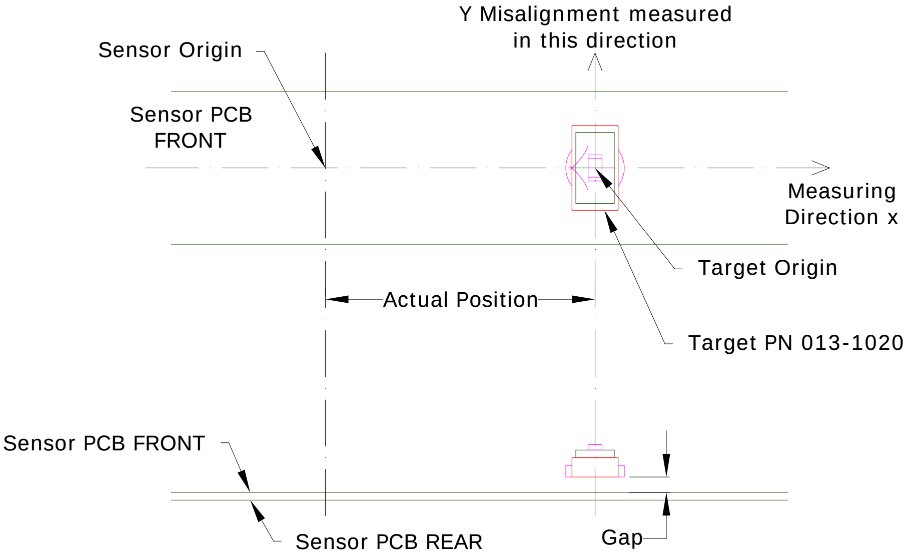


**Figure 7 Alignment of sensor PCB 010-0094 with target 013-1020**

# 3 Principle of Operation

## 3.1 Electronic Interrogation

The 205mm Type 6.8 linear sensor is connected to a CambridgeIC CTU chip (e.g. the CAM204) and its associated circuitry. To take a position measurement the CTU chip first generates a few cycles of AC current in the EX coil matching the resonant frequency of the resonator. This current forces the resonator to resonate. When the excitation current is removed the resonator continues to resonate, with its “envelope” decaying exponentially as shown in Figure 8. This decaying signal generates EMFs in the 4 sensor coils. The CTU chip detects the relative amplitude of the decaying resonator signal in each coil. It uses the amplitude information to determine position, as described below in section 3.2.

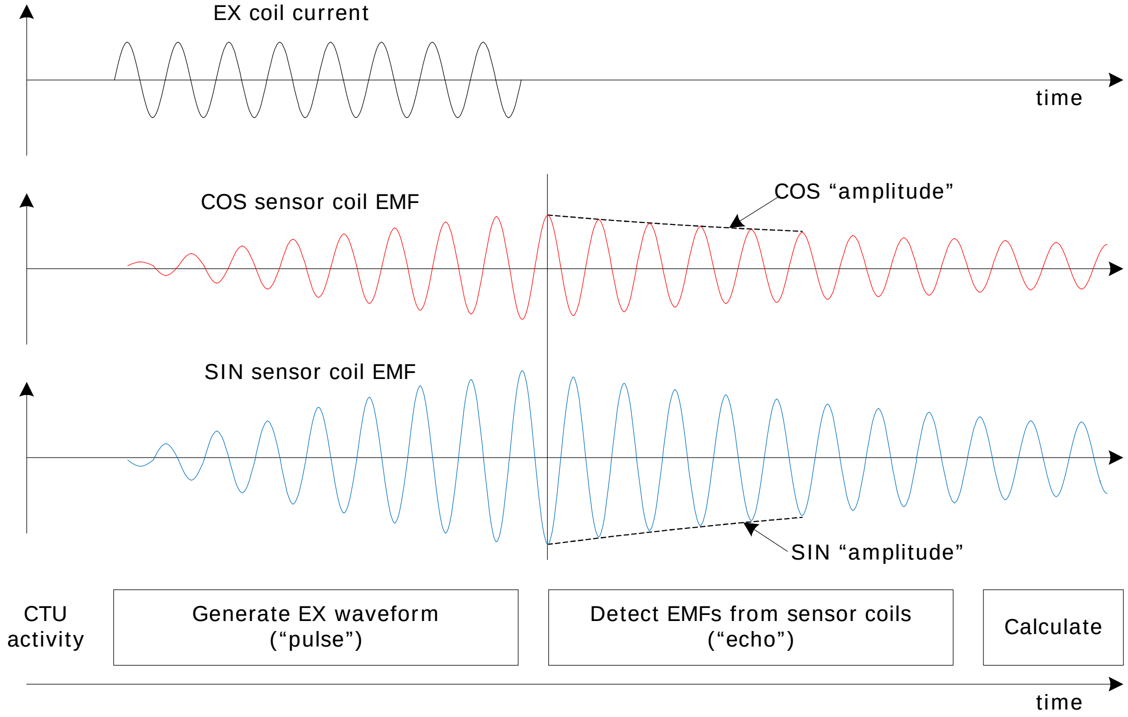


**Figure 8 Electronic interrogation process**

## 3.2 Sensor Coils and Position Calculation

Section 3.1 described how the CambridgeIC CTU chip detects the relative amplitude of the signals induced by the resonator in the sensor's 4 sensor coils. These measured amplitudes are proportional to the coupling factors between the resonator and each of the 4 sensor coils, kCOSA, kSINA, kCOSB, kSINB. This subsection describes how these coupling factors change with position, and the calculation the CTU chip performs to determine this position.

Figure 9 illustrates each of the 5 coils in the sensor individually, one above the other. In reality, they are all overlain.

The EX coil is rectangular and extends beyond the measuring range, so that its coupling to the resonator is largely uniform. This means the resonator signal at the end of the excitation process is approximately uniform along the sensor's measuring range.

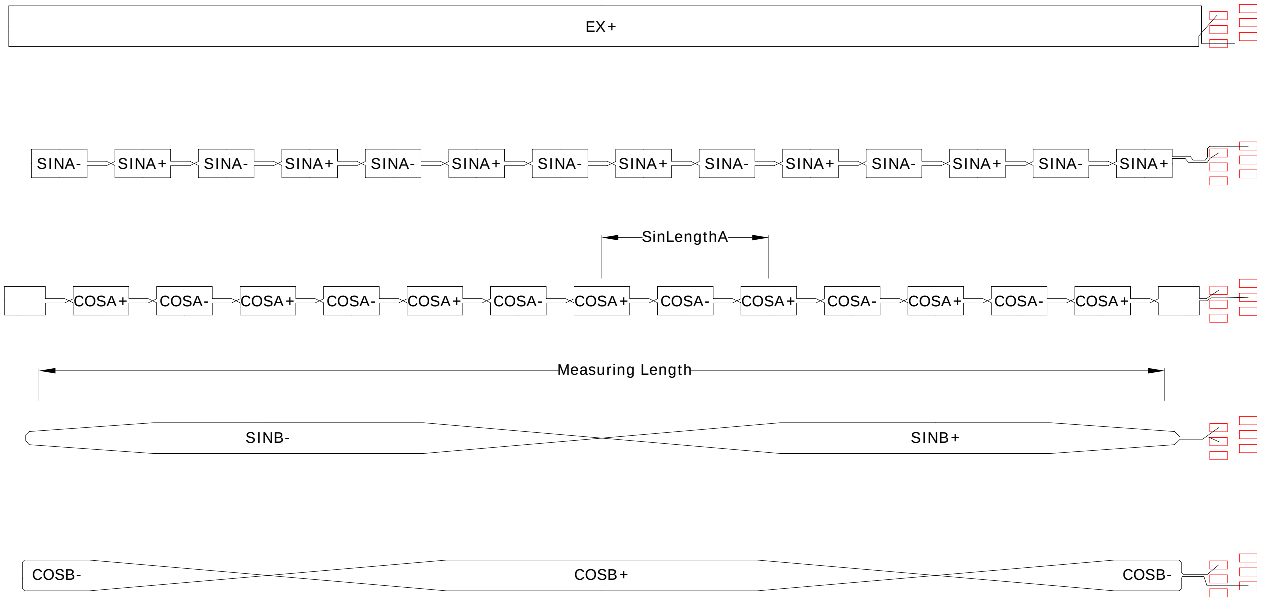


**Figure 9 Coil designs, simplified for clarity**

The COSA and SINA coils are fine sensor coils. The coupling factor between resonator and fine coils varies sinusoidally with position with just under 8 repeating periods along the measuring range, as illustrated in Figure 10. Their sinusoidal period is denoted SinLengthA. The kCOSA and kSINA coupling factors are in phase quadrature. The CTU chip measures these coupling factors, and performs a 4-quadrant inverse tangent calculation on them to determine *Fine Position*. This calculation is fully ratiometric, so that changes in absolute signal levels due to variations in power supply voltage, temperature and so on do not affect the measurement.

The Fine Position measurement is a precise measure of position. However it is ambiguous: there are several locations along the sensor that have the same Fine Position due to the repeating nature of the fine sensor coil pattern.

To resolve this ambiguity, the CTU chip also takes readings from the coarse sensor coils COSB and SINB. These yield the Coarse Position measurement. These are also sinusoidally patterned but have a longer period, SinLengthB. The coarse coils also have fewer turns, which together with the longer period yield much lower measurement precision. However this precision is still more than adequate to resolve the Fine Position ambiguity.

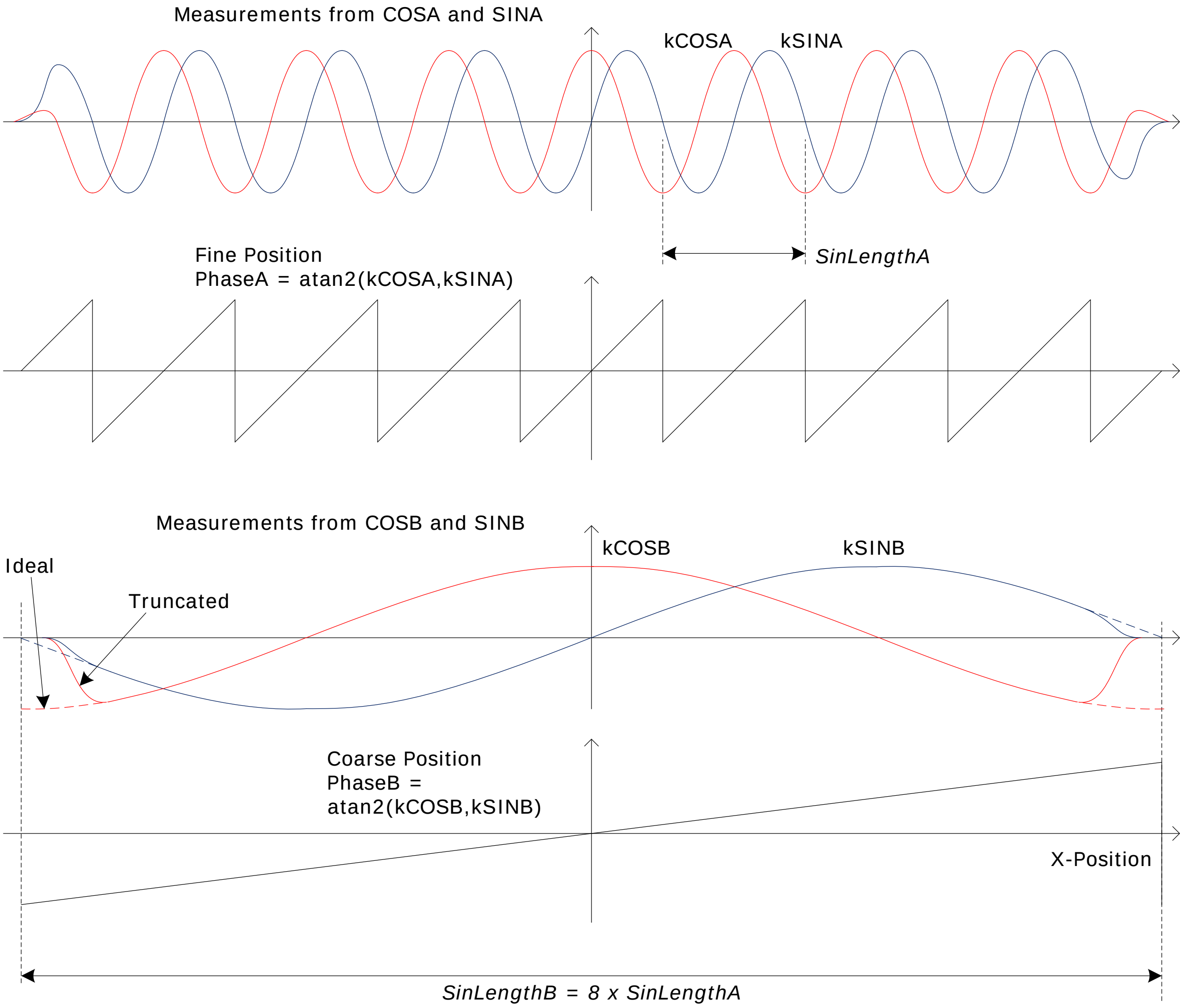


**Figure 10 Sensor Coil coupling factors**

The CTU chip measures both Fine and Coarse Position, and combines both measurements to deliver a full absolute value of reported position to the host. This has the precision and accuracy of the Fine sensor coils, and is absolute like the coarse sensor coils.

The Fine Pitch parameter SinLengthA, also denoted just *SinLength* defines how reported position is scaled into physical units.

The Coarse Pitch parameter SinLengthB is 8 times SinLengthA, and the number 8 corresponds to the sensor's Subtype. Both the sensor's Type (6) and Subtype (8) must be communicated to the CTU chip for correct operation. Please refer to the datasheet for the appropriate part.

# 4 Definitions

## 4.1 Coordinate System

Figure 7 illustrates the coordinate system for the sensor, with the X-Axis running along the measuring direction and the Y-Axis perpendicular and also in the plane of the sensor PCB.

The Gap dimension is the distance between the resonator and the sensor PCB. This is measured between the nearest faces of the coil and sensor PCB as shown in Figure 3 and Figure 7.

The Target Origin should run centrally along the sensor as shown. Y Misalignment is defined as the distance between the target Origin and the sensor's centre line in the Y-Axis direction.

## 4.2 Transfer Function and Performance Metrics

The sensor is connected to a CTU chip which reports position as a 32-bit signed integer, here denoted *CtuReportedPositionI32*. The CTU chip also reports a VALID flag to indicate when the resonator is in range. These vary with Actual Position as illustrated in Figure 11.

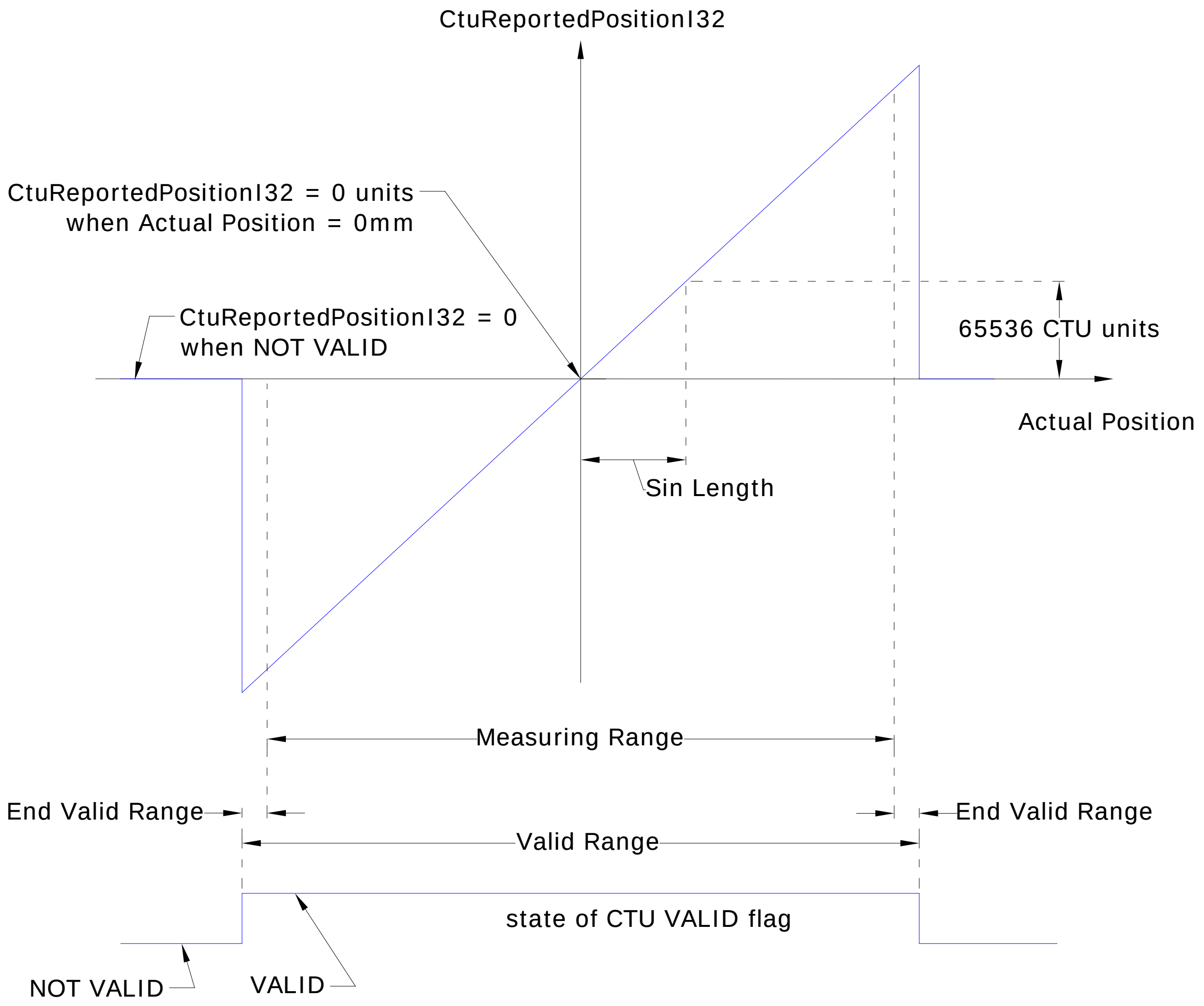


**Figure 11 Transfer function**

The VALID Range is the distance over which the CTU reports VALID. When VALID, CtuReportedPositionI32 varies linearly with Actual Position as shown. The slope of the transfer function is defined by the SinLength parameter (SinLengthA). The Measuring Range is the distance over which full performance is quoted. The Valid Range exceeds the Measuring Range by an amount End Valid Range each side, so that the sensor's output can be VALID throughout the Measuring Range.

The CTU chip’s position output may be converted to reported position in physical units using:

$$Reported\ Position = \frac{CtuReportedPositionI32}{65536} \times SinLength$$

**Equation 1**

This figure is nominally equal to the Actual Position defined in section 4.1. The figures differ due to random noise, Linearity Error and Offset Error:

$$Reported\ Position - Actual\ Position = Random\ Noise + Linearity\ Error + Offset\ Error$$

**Equation 2**

## 4.3 Random Noise and Resolution

Random noise is inherent in any analog measurement. The random noise present in the CTU’s reported measurements can be considered Gaussian (*well behaved noise*). There are two general measures of Random Noise, Peak to Peak Noise and Standard Deviation. Defining Peak to Peak Noise such that it encompasses 99.9% of samples (100% is physically impossible due to the statistical nature of noise) yields the following relationship:

$$Peak\ to\ Peak\ Noise = 6.6\ \times Standard\ Deviation$$

**Equation 3**

Another common measure of noise used in encoders is Noise Free Resolution, which is related to Peak to Peak Noise as follows:

$$Noise\ Free\ Resolution = \log_2 \frac{Measuring\ Range}{Peak\ to\ Peak\ Noise}$$

**Equation 4**

Noise Free Resolution can be improved by averaging raw samples from a CTU, or applying some other digital filter to the samples. Averaging $2^N$ samples increases Noise Free Resolution by N/2 bits. So averaging 4 samples (N=2) improves Noise Free Resolution by 1 bit, and averaging 16 (N=4) samples improves Noise Free Resolution by 2 bits. Measurements of Linearity Error and Offset Error are separated from Random Noise by averaging in this way.

## 4.4 Linearity Error and Offset Error

Linearity Error is the deviation of the transfer function from a best fit straight line. Strictly, the figures quoted in this datasheet are based on a best fit straight line whose slope and offset are adjusted to minimise the maximum magnitude of Linearity Error, so that the maximum positive and negative linearity departures have equal magnitude.

The slope of the best fit straight line is the SinLength parameter quoted below. Its value can also change due to a small stretch error inherent in the PCB manufacturing process.

There are two main contributions to Offset Error: one from the sensor and one from the target.

The target’s contribution to Offset Error is the mechanical tolerance with which the Target Origin can be located relative to appropriate alignment features, and therefore depends on how these features are designed.

The sensor’s contribution to Offset Error is mainly due to the PCB manufacturing process, in particular linear misregistration of copper layers relative to chosen registration features. Again these are application specific. For example, if PCB holes are used for registration, an Offset Error of ~±0.15mm can be expected for a conventional PCB process. If a routed edge is used, as with assembled sensor 013-0035, the tolerance is typically ±0.3mm, which is greater due to the routing process.

# 5 Performance

Figures below are representative of assembled sensor PCBs 013-0035, sensor PCBs built to design 010-0094 and to Sensor Blueprint 010-0093. Measurements are taken with a typical target PN 013-1020, and Type 6 CAM204 CTU Circuitry (see CAM204 datasheet, grade A components), at room temperature and in free space unless otherwise stated. Sensors are mounted flush against a flat surface for test purposes.

Measurements are presented as a function of Gap, which is defined in Figure 7. Unless otherwise stated, values presented below are worst case across Y misalignment of up to 0.5mm.

## 5.1 End Valid Range

End Valid Range is the distance each side of the Measuring Range over which the CTU chip's output remains VALID, as shown in Figure 11. It is a function of Gap as illustrated in Figure 12 below.

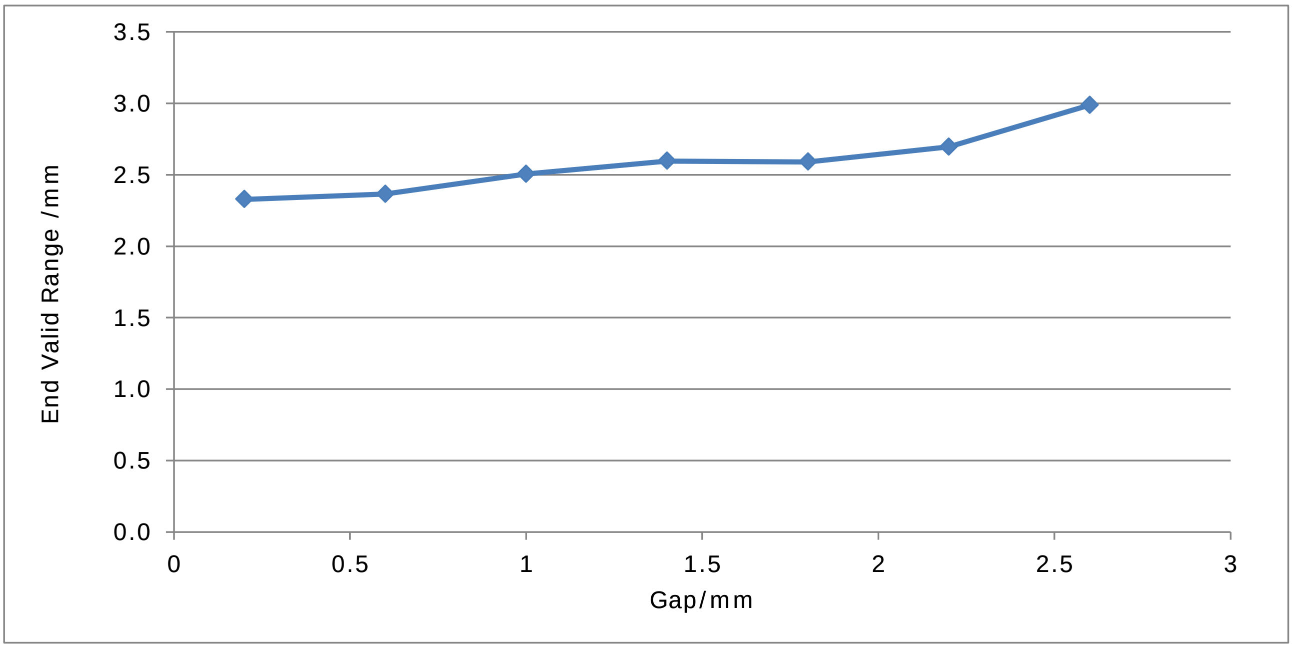


**Figure 12 End Valid Range as a function of Gap**

## 5.2 Linearity Error

Linearity Error is defined in section 4.4. Its value is also a function of Gap, as shown in Figure 13.

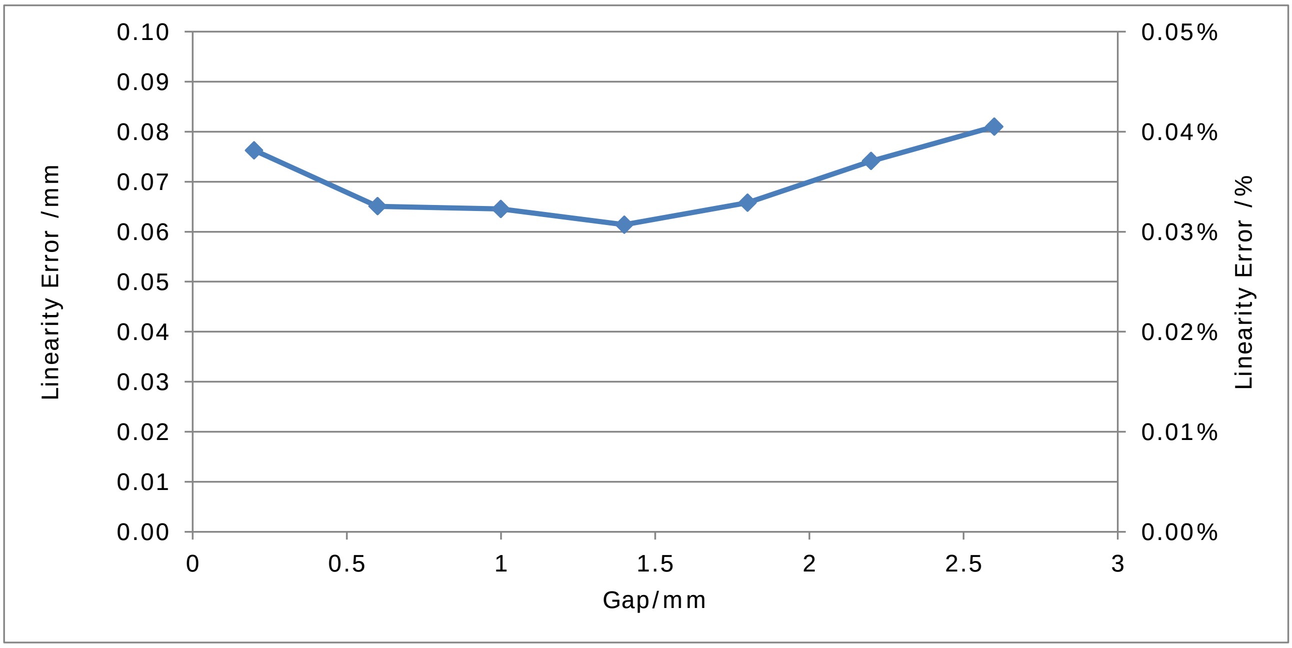


**Figure 13 Linearity Error as a function of Gap**

## 5.3 SinLength Value

The SinLength parameter is the sinusoidal pitch of the fine sensor coil coupling, SinLengthA, as illustrated in Figure 10. Its value is mainly defined by the layout of the fine sensor coils. However the exact best fit value for use in Equation 1 is also a weak function of Gap, as illustrated in Figure 14.

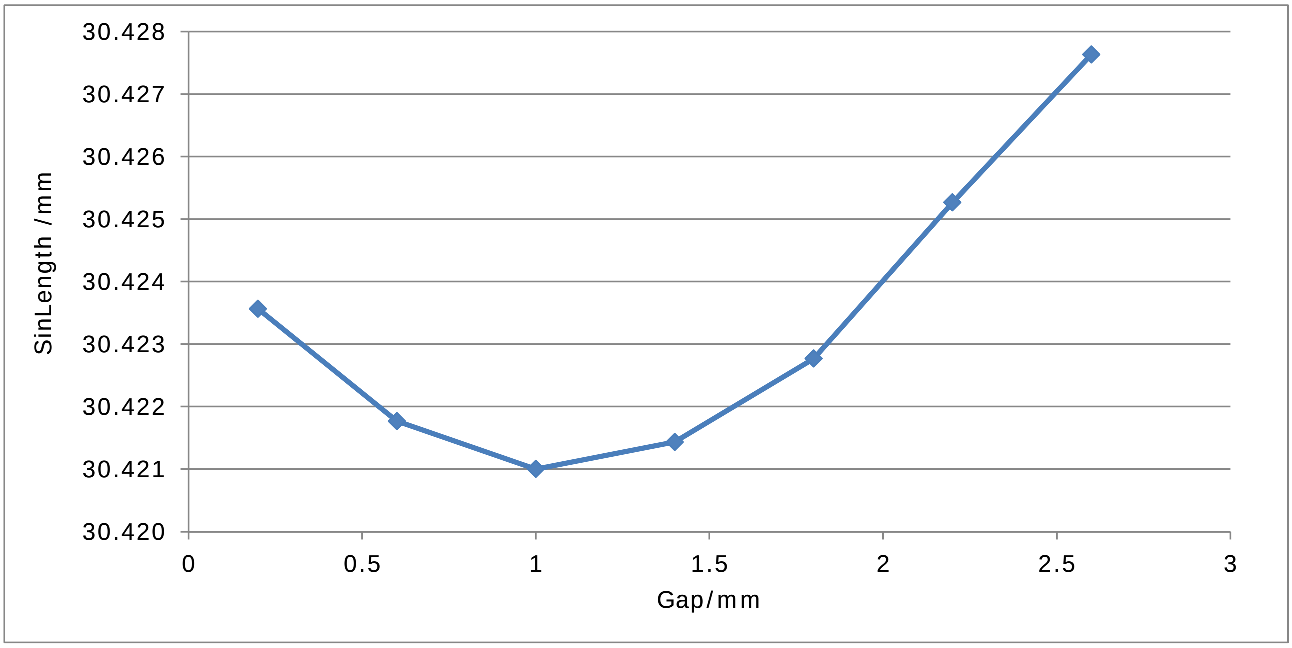


**Figure 14 SinLength value as a function of Gap**

The exact SinLength value is also subject to ~±0.1% error due to stretch error in the PCB fabrication process. Thermal expansion also affects the length of the PCB and hence the SinLength value. Its magnitude is ~13ppm/°C, assuming FR4 PCB material that is allowed to expand.

## 5.4 Amplitude

In addition to reporting position, the CTU chip also reports Amplitude. Amplitude is a useful measure of system health, and reduces with Gap as shown in Figure 15. Amplitude also reduces with the presence of nearby metal, and sensor installations should be checked to ensure any reduction is not excessive.

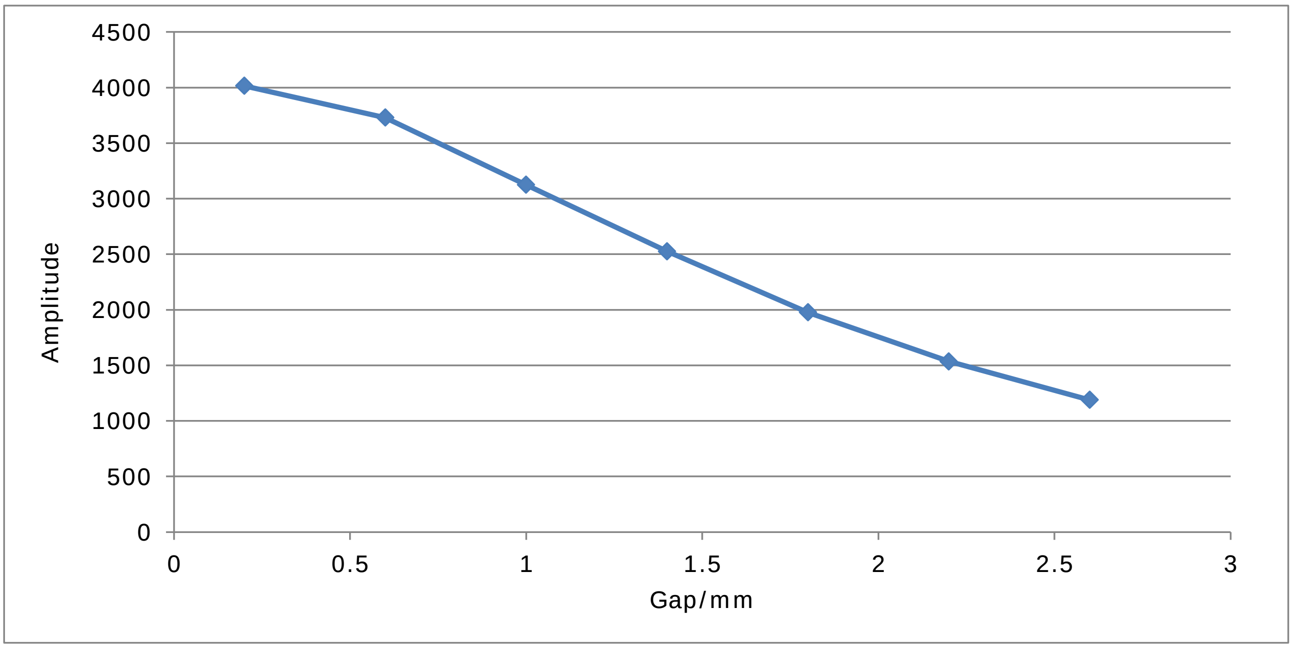


**Figure 15 Minimum Reported Amplitude as a function of Gap, free space**

## 5.5 Noise Free Resolution

Noise Free Resolution is defined in section 4.3. It is a function of the signal level detected by the CTU chip. It therefore reduces with Gap in a similar way to Reported Amplitude as illustrated in Figure 16.

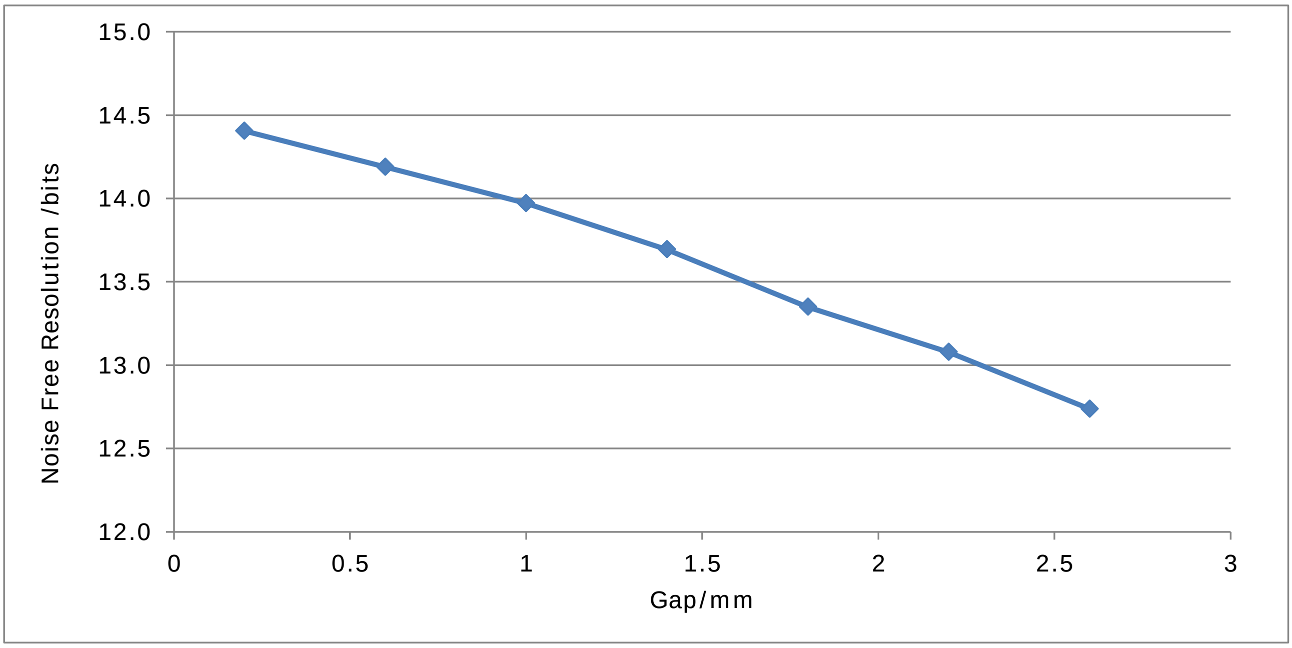


**Figure 16 Noise Free Resolution as a function of Gap, CAM204 CTU chip, free space**

Quoted Noise Free Resolution is based on single measurements from a CTU chip. The host may average (or otherwise digitally filter) measurements to yield a higher resolution than shown above, at the expense of greater latency.

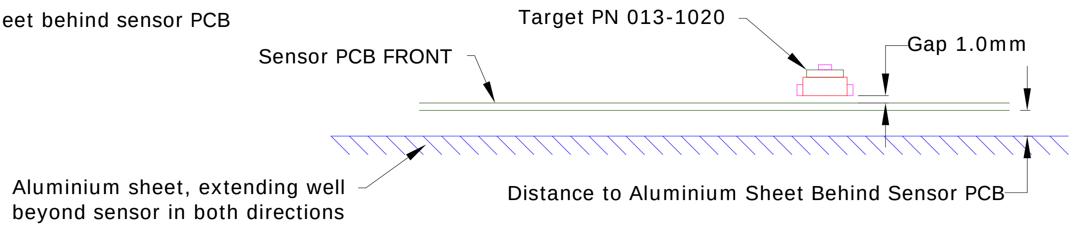
# 6 Effect of Nearby Aluminium

This section illustrates the effect of aluminium near the sensor and target.

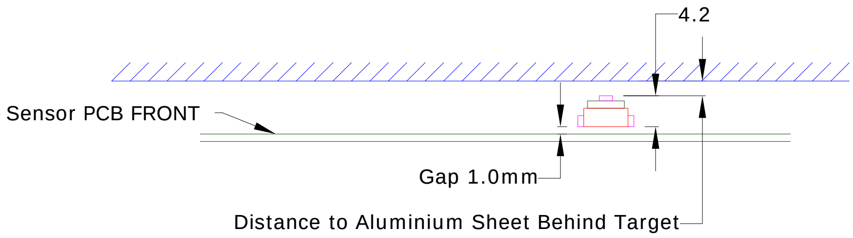
## 6.1 Mechanical Arrangements

Figure 17 illustrates three different test arrangements. In each case, a sheet of aluminium is placed next to the sensor and target, with variable distance between the parts. The aluminium sheet is large, extending well beyond the extents of the sensor PCB in all directions. The target is held at a constant gap of 1mm to the sensor PCB.

(a) Aluminium sheet behind sensor PCB



(b) Aluminium sheet behind Target



(c) Aluminium sheet to the side

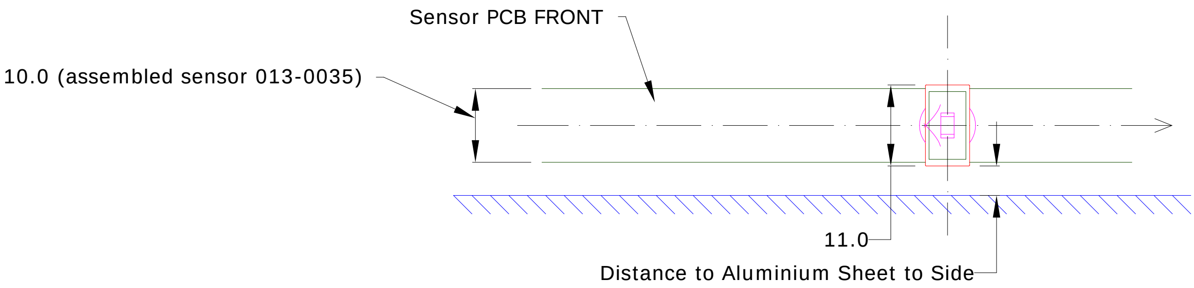


**Figure 17 Aluminium test arrangements**

In Figure 17(a), the aluminium sheet is placed behind the sensor PCB. In Figure 17(b), it is above the target, the other side of the sensor PCB. In Figure 17(c) it is to one side.

For test purposes a sheet 2mm thick was used, but measurements presented below are also valid for sheets of 0.2mm thick upwards. Thinner sheets of aluminium, including aluminium foil (typically ~20µm), tend to have a significantly greater detrimental effect due to greater eddy current losses, and should be avoided.

## 6.2 Effect of Aluminium on Amplitude

Amplitude is reported by the CTU chip connected to the sensor. It is an important indication of system health, and in general reduces when metal is nearby.

Figure 18 illustrates how Amplitude reduces as the distance between the sensor and aluminium sheet reduces, as illustrated in Figure 17(a).

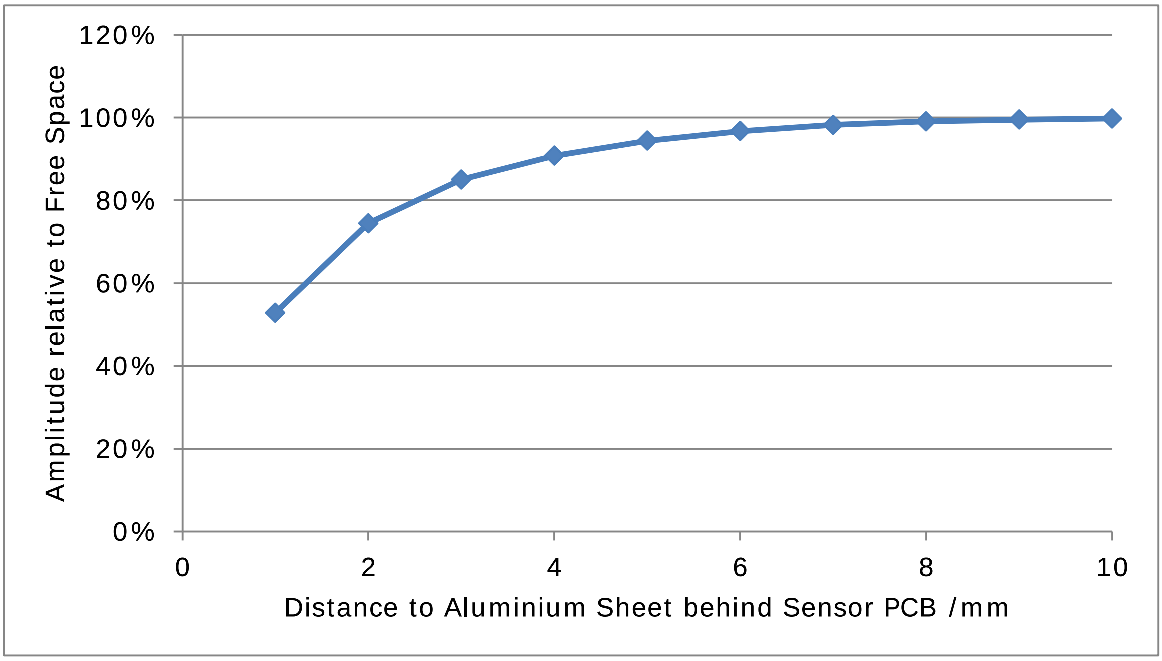


**Figure 18 Amplitude reduction due to aluminium behind sensor PCB**

Figure 19 illustrates how the Amplitude reported by a CAM204 IC connected to the sensor reduces as the distance between the target and aluminium sheet reduces, as illustrated in Figure 17(b).

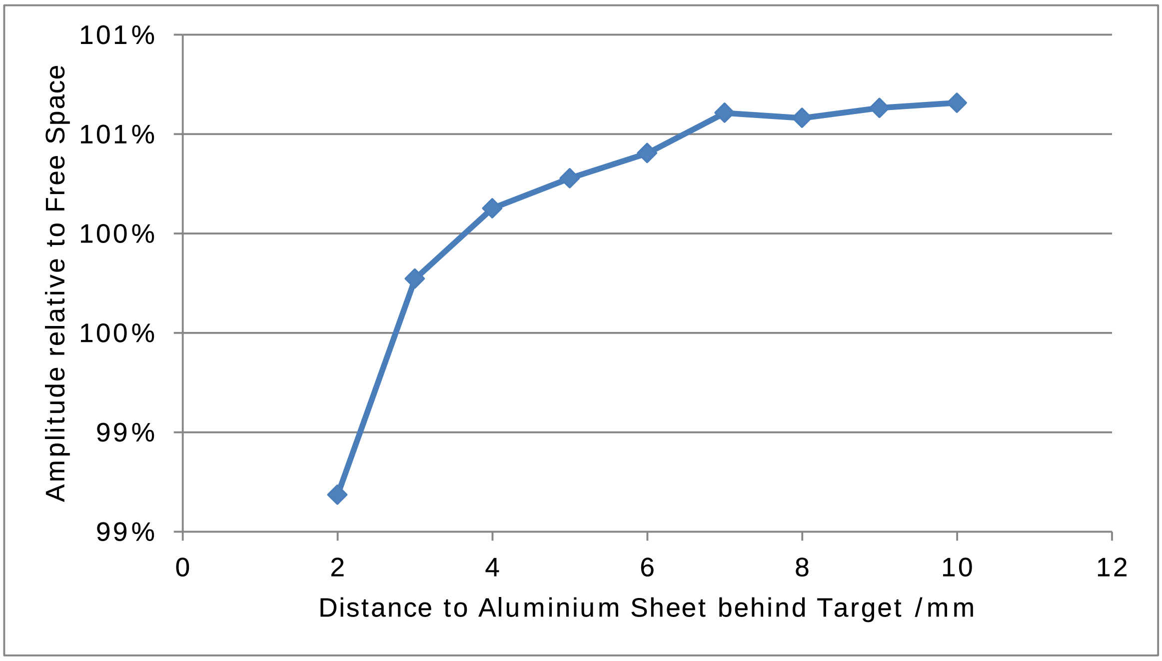


**Figure 19 Amplitude reduction due to aluminium behind Target**

Figure 20 illustrates how the Amplitude reported by a CAM204 IC connected to the sensor reduces as the distance between the target and aluminium sheet to one side reduces, as illustrated in Figure 17(c).

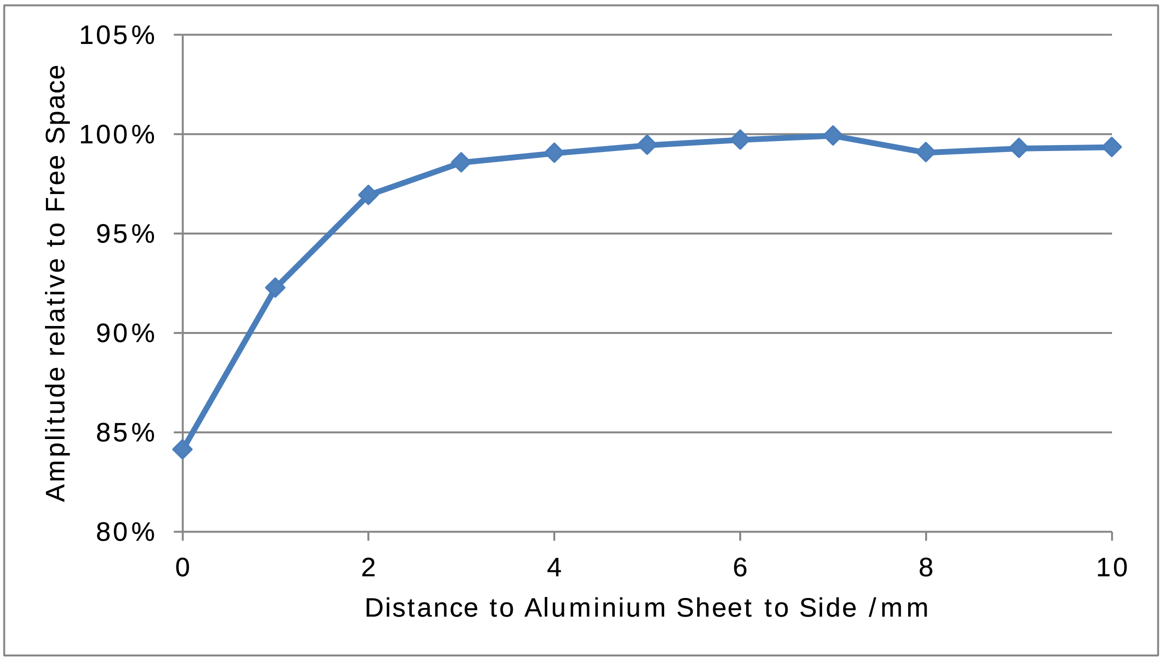


**Figure 20 Amplitude reduction due to aluminium to the side**

The most significant effect of a reduction in Amplitude is to increase the level of random noise present in the position data returned by the system, or equivalently to reduce the noise free resolution. If Amplitude is reduced to 50% of its free space value then position noise will increase by approximately a factor of 2, and hence Noise Free Resolution will reduce by 1 bit.

Care must also be taken to ensure that the presence of metal does not reduce Amplitude below the minimum detectable level specified for the CTU chip to be used across temperature, typically ~1000.

The effect of aluminium present on two or more sides of the sensor and oval coil may be estimated by combining the effects for each side the aluminium is present. For example, aluminium 2mm behind the sensor PCB reduces Amplitude to 74% of its free space value, and aluminium 3mm from the side of the target to 98%. The combination of aluminium 2mm behind the sensor and 3mm to each side of the target is then approximately 74% x 98% x 98% = 71% Amplitude relative to free space.

For a more values, or where the metal environment is uneven, it is important to check with a physical system.

## 6.3 Effect of Aluminium on Resonator Frequency

The CTU chip connected to the sensor reports the frequency difference between the resonator and the CTU chip’s centre frequency. Changes in relative frequency make little difference to system function when the frequency difference is inside the CTU’s tuning range. However the CTU IC may not report VALID if the frequency is outside this range, so it is important to ensure the resonator frequency will remain within this range across all targets and CTU ICs, and across temperature. The target’s datasheet includes manufacturing and temperature tolerances, and this section describes the expected effect of nearby aluminium.

The target’s resonant frequency will increase as aluminium approaches. Figure 21 illustrates the increase with aluminium behind the sensor PCB, Figure 22 with aluminium behind the target and Figure 23 with aluminium to the side.

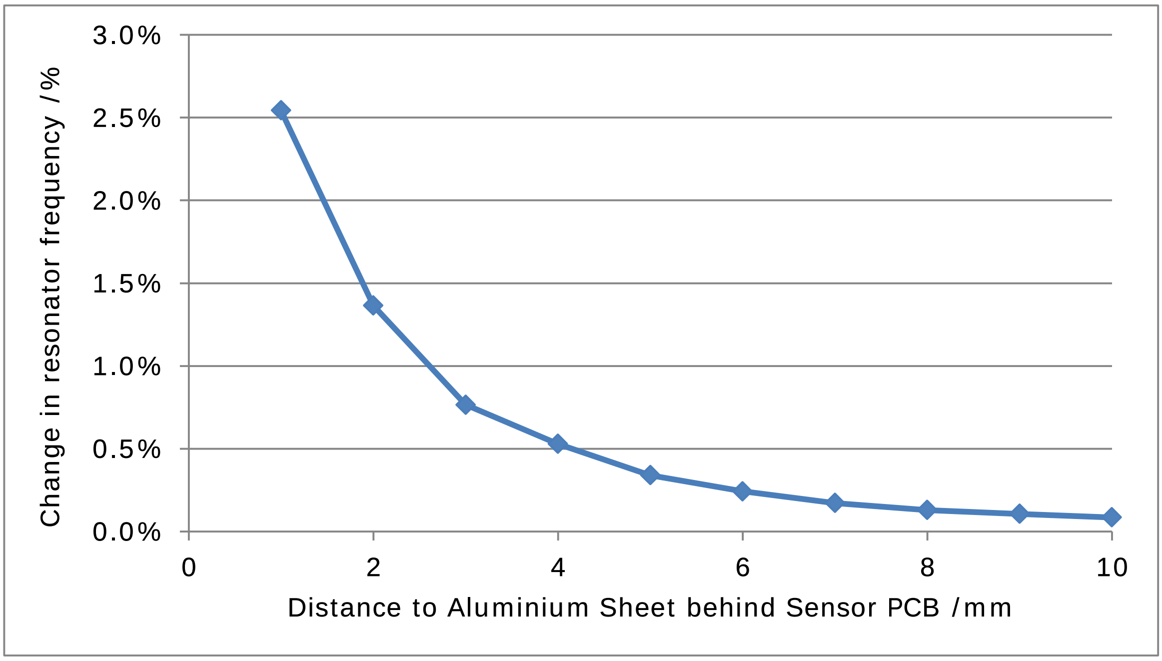


**Figure 21 Resonator frequency change due to aluminium behind sensor PCB**

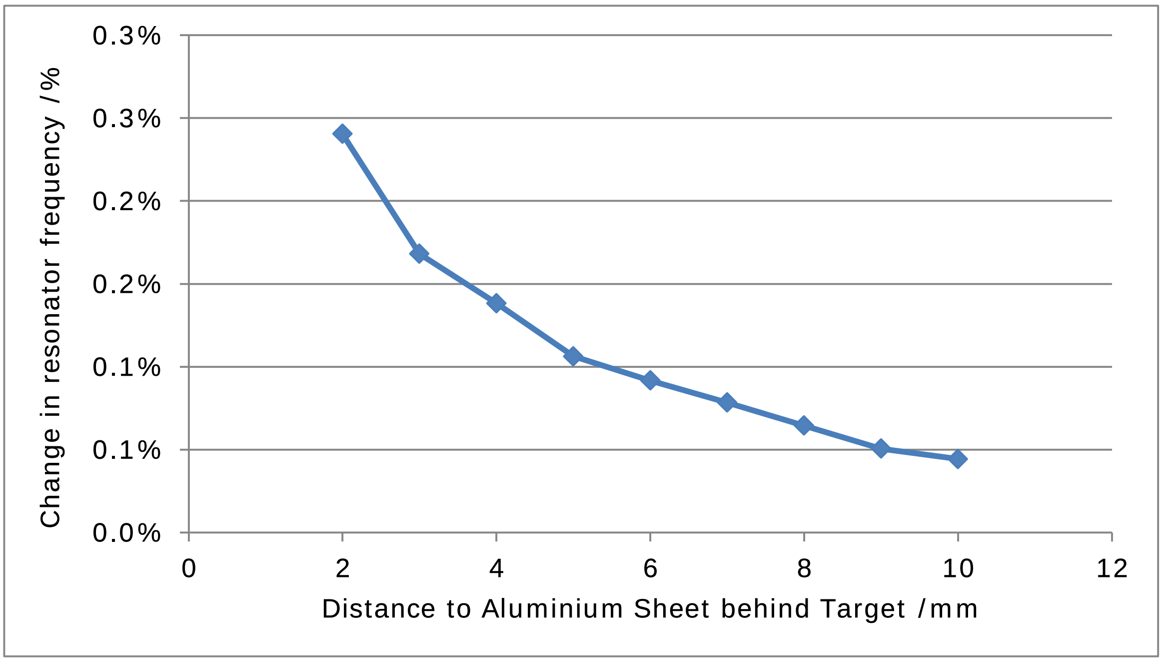


**Figure 22 Resonator frequency change due to aluminium behind Target**

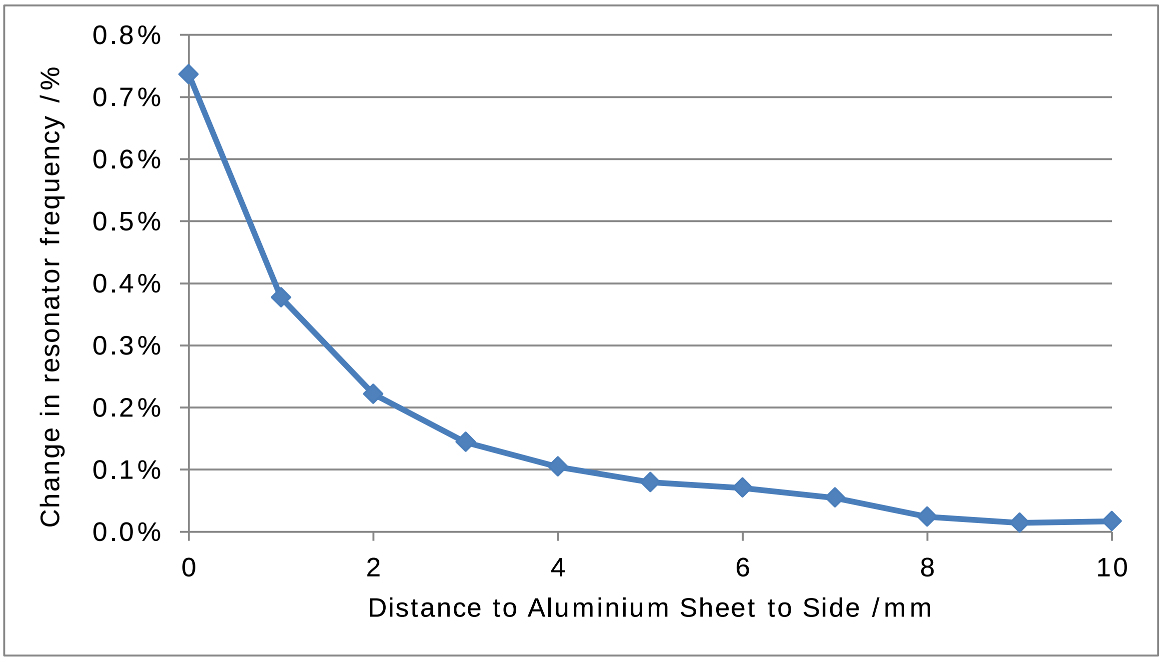


**Figure 23 Resonator frequency change due to aluminium to the side**

The effect of aluminium present on two or more sides of the sensor and target may be estimated by combining the effects for each side the aluminium is present. For example, aluminium 2mm behind the sensor PCB increases frequency by 1.4% relative to free space, and aluminium 3mm to the side of the target increases frequency by 0.15%. The combination of aluminium 2mm behind the sensor and 3mm to each side of the target is then approximately 1.4% + 2 x 0.15% = 1.7% frequency increase.

For more accurate values, or where the metal environment is uneven, it is important to check with a physical system.

# 7 Sensor Blueprint 010-0093

## 7.1 Purpose

A Sensor Blueprint is data defining the pattern of conductors for building the sensor onto a PCB. A customer may build their own sensors for use with CambridgeIC's CTU chips, either as stand-alone sensors or combined with their own circuitry.

## 7.2 Fabrication Technology

Sensor Blueprint 010-0093 is fabricated on a 6-layer PCB. Recommended copper thickness is shown in Table 3.

**Table 3**

| **Copper thickness** | **oz** | **µm** |
|---|---|---|
| Minimum | 0.8 | 28 |
| Recommended | 1 | 35 |

## 7.3 PCB Design Parameters

**Table 4**

| **PCB Design Rules** | **Minimum values used** | |
|---|---|---|
| | mm | inches |
| Track width | 0.2 | 0.0079 |
| Gap between tracks | 0.2 | 0.0079 |
| Via land outer diameter | 0.8 | 0.031 |
| Drill hole diameter | 0.4 | 0.016 |

## 7.4 PCB Integration

Figure 24 illustrates the extent of the copper pattern required to build the sensor on a PCB. The shaded area is the sensor itself. The coil pattern may be rotated or flipped to fit a customer's assembly, in which case the position reported by the CTU will be transformed accordingly.

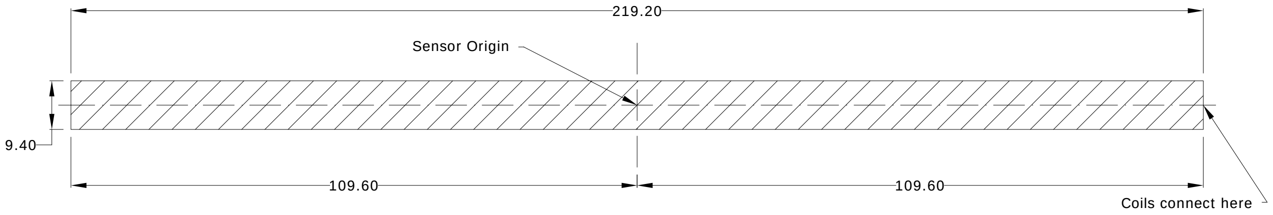


**Figure 24 Copper extent, Sensor Blueprint 010-0093**

When integrating with other electronic circuitry, a keep-out of 3mm is recommended all around the sensor's conductors. Copper traces surrounding the sensor must not include a complete loop, otherwise these may appear as a "shorted turn" to the sensor's excitation coil and Amplitude may be reduced dramatically.

## 7.5 Data Format

The Sensor Blueprint is supplied as Gerber data in RS-274-X format with the following settings: imperial, 2.4 precision and leading zero suppression. Coordinates are relative to the Sensor Axis.

## 7.6 Trace Connections

There are 5 pairs of tracks (EX, COSA, SINA, COSB, SINB and their respective VREF connections), which should be connected to the respective CTU circuit connections with the minimum practical trace lengths.

Please refer to the CTU datasheet for recommendations on track design for connecting sensors to CTU circuitry.

# 8 Environmental

Assembled sensor part number 013-0035 conforms to the following environmental specifications:

| Item | | Comments |
|---|---|---|
| Minimum operating temperature | -40°C | Sensor limited by the connector |
| Maximum operating temperature | 85°C | |
| Maximum operating humidity | 95% | Non-condensing |

The maximum operating temperature of the sensor PCB may be increased if a customer manufactures their own sensor PCB to CambridgeIC's design, and uses an alternative, higher temperature, connecting method.

# 9 RoHS Compliance

CambridgeIC certifies, to the best of its knowledge and understanding that part number 013-0035 is in compliance with EU RoHS, China RoHS and Korea RoHS.

# 10 Document History

| Revision | Date | Comments |
|---|---|---|
| 0001 | 6 January 2015 | First draft |
| 0002 | 10 April 2015 | Added details of assembled sensor 013-0035<br>Quoted 0.5mm minimum gap for ±0.05% linearity error<br>Expanded SinLength performance section to include PCB stretch error and effect of thermal expansion |
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# 12 Legal

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