Description

A resonant inductive position sensor for measuring over a full 360° of rotation. 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 6 (Type "6.6").

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

Sensor

- Full absolute sensing over 360°
- 6-layer PCB process
- Sensor coil pattern 77.8mm inside diameter
- Target can be sensed from front or rear of PCB

Target

- Simple design using 4 SMD transponder coils
- Balanced for immunity to misalignment
- Buy from CambridgeIC or build from components

Performance

Table 1

	Condition	
	Best	**Realistic installation tolerances**
Gap sensor PCB to target	0.5mm	1.0±0.5mm
Radial Misalignment	0mm	0.5mm
Angular Misalignment	0°	±0.2°
	Result	
Max Linearity Error	±0.08°	±0.13°
Noise Free Resolution	15.5 bits	15 bits

Applications

- Lab automation equipment
- Azimuth and tilt sensing for surveillance cameras
- Motion control
- Actuator position feedback
- Valve position sensing
- Absolute Optical Encoder replacement
- Motor control, with CAM502 CTU chip

Product identification

Part no.	Description
013-0042	Assembled sensor
013-6013	6-way M80 sensor connecting cable
010-0109	Sensor Blueprint
013-1026	Assembled Target, 182.5kHz
013-1704	20mm Transponder Coil

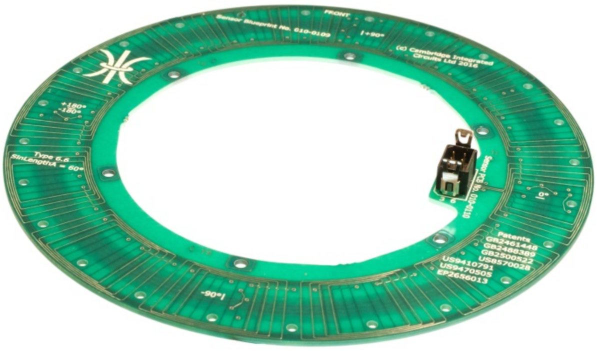

Figure 1 Sensor assembly 013-0042

Figure 2 Target assembly 013-1026

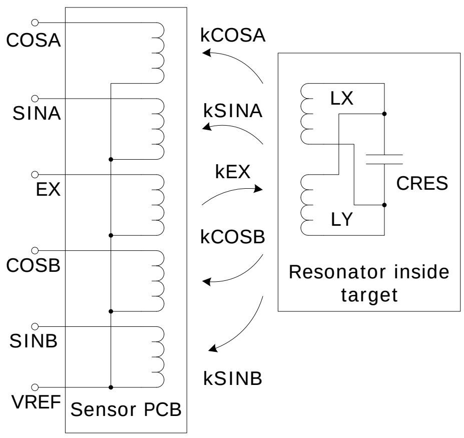

Figure 3 equivalent circuit

Document part no 033-0063_0001

1 Assembled Sensor

Figure 4 is a dimensioned drawing of the assembled sensor PCB part number 013-0042.

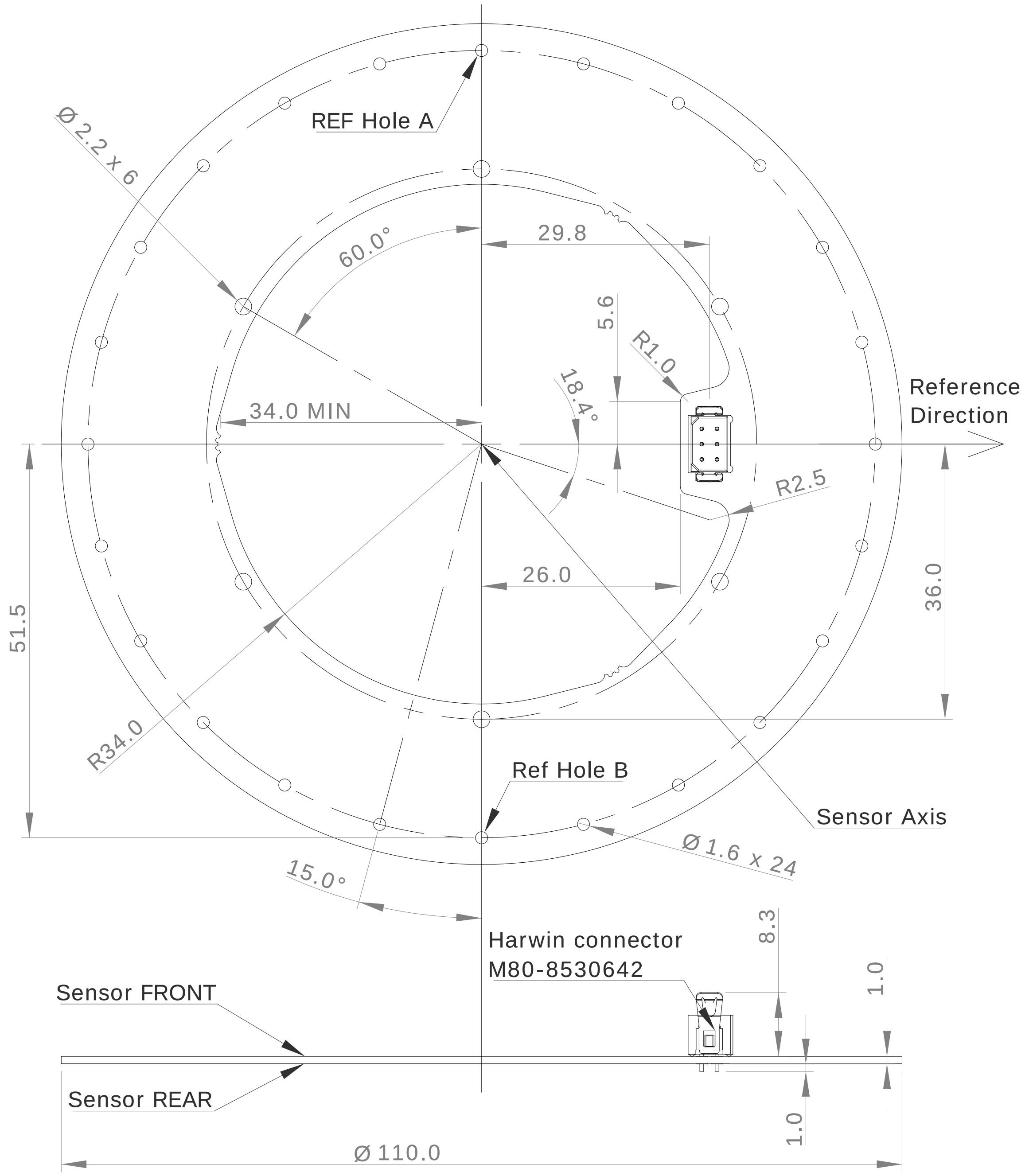

Figure 4 Assembled Sensor 013-0042

The Reference Direction is perpendicular to the line joining Ref Holes A and B. The nominal location of the Sensor Axis is the mid-point of the Ref Holes.

The actual location of the Sensor Axis may be up to 0.2mm from the Nominal Sensor Axis due to hole location tolerances relative to the copper sensing pattern inherent in the PCB production process. When performance is quoted at a Radial Misalignment of 0.5mm, for example in Table 1, this 0.5mm is *in addition* to the 0.2mm misalignment between actual and Nominal Sensor Axis. In this case an allowance of 0.7mm has been made for the radial misalignment between the centroid of the copper pattern and the Target Axis.

The assembled sensor part number 013-0042 includes a connector mounted on the front, located as shown in Figure 4. Table 2 shows signal names and their pin allocations.

Table 2 Sensor Assembly electrical connections

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

2 Principle of Operation

The 110mm Type 6.6 Rotary Sensor measures the full, absolute angle of a target without contact, with high resolution and accuracy and with minimal influence of misalignment. This section illustrates how these features are achieved.

2.1 Overview

The sensor PCB comprises 5 printed coils: COSA, SINA, COSB, SINB and EX. Its equivalent circuit is illustrated in Figure 3. All 5 coils couple to a resonant circuit positioned above the sensor. The resonant circuit is the functional element of the target, and rotates relative to the sensor.

The EX coil is for exciting this resonator. The magnetic coupling between excitation coil and resonator is uniform with rotation angle, so that the excitation coil powers the resonator whatever the rotation angle.

The other 4 coils are sensor coils, and are patterned so that their coupling factors to the resonator vary sinusoidally, as shown in section 2.3. The CTU circuit connected to the sensor detects the coupling factors and uses them to determine position.

The resonator comprises four 20mm Transponder Coils placed symmetrically either side of the Target Reference Direction, shown in Figure 11. This balanced arrangement is for immunity to misalignment, see section 2.4.

2.2 Electronic Interrogation

The sensor is connected to a CambridgeIC CTU chip (e.g. the CAM204 or CAM502) 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 5. 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 2.3.

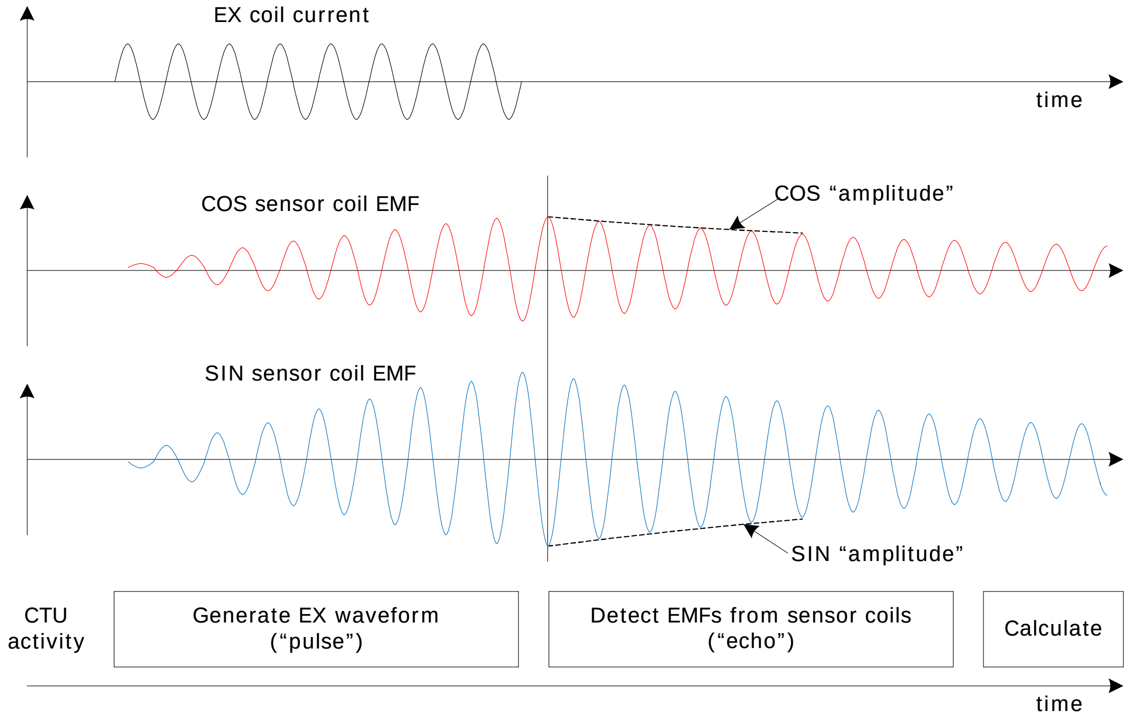

Figure 5 Electronic interrogation process

2.3 Sensor Coils and Position Calculation

Section 2.2 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 measured angle, and the calculation the CTU chip performs to determine this angle.

Figure 6 is a simplified illustration of the sensor board's excitation coil (EX). The CTU circuit energises the target by driving a current in the EX coil. This generates a magnetic field perpendicular to the plane of the sensor which is negative ("-") inside the inner loops, and positive ("+") outside. The target's transponder coils lie across the excitation coil, angled so that excitation field flows through them from the outside to the inside of the sensor. The ends of the transponder coils are thus magnetised by the excitation field, with the outer portions of the transponder coils having positive polarity and the inner having negative polarity. The coupling between the excitation coil and the transponder coils is uniform with Actual Angle, so that the target is uniformly powered irrespective of angle.

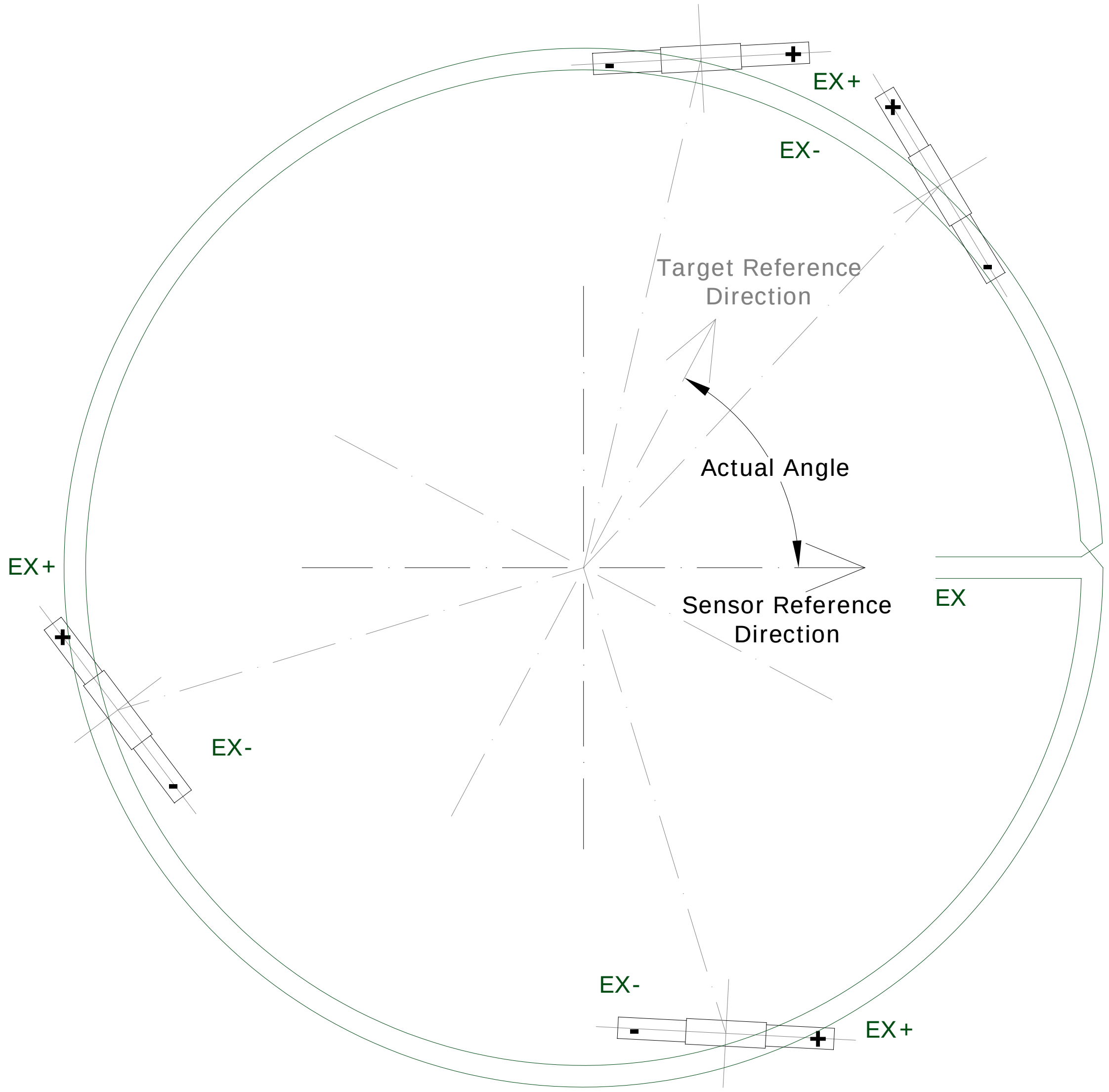

Figure 6 EX Coil, simplified

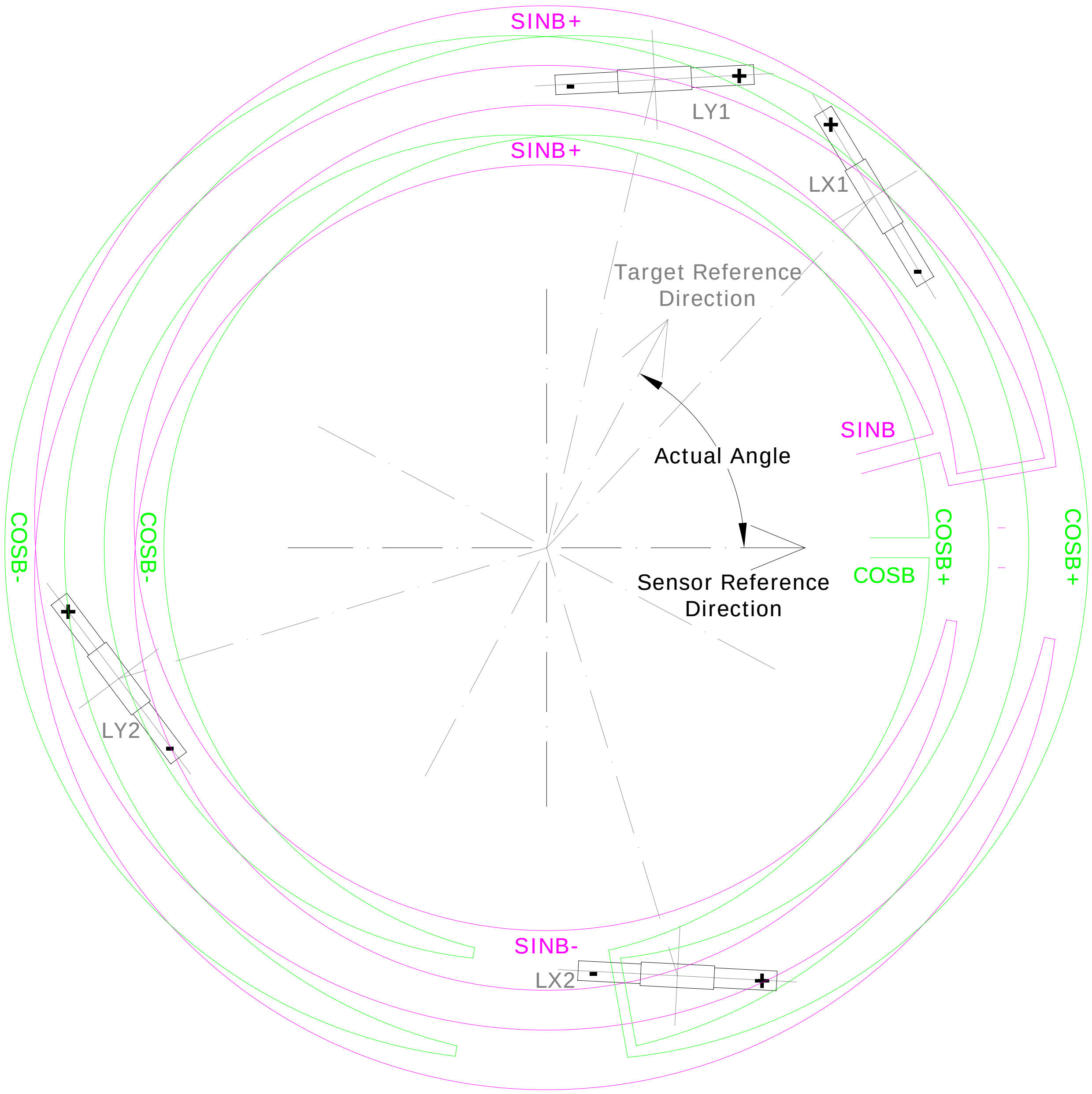

Figure 7 COSB and SINB coils, simplified

A simplified version of the COSB and SINB coils are shown in Figure 7 together with the transponder coils of the target. The COSB coil is patterned to generate an output whose amplitude varies sinusoidally with Actual Angle, and having one sinusoidal repeat per circle (*SinLengthB*=360°). The SINB coil is similar, only mechanically rotated by 90° to generate an output in the SINB coil whose amplitude varies in phase quadrature with the Actual Angle.

The net coupling factors kCOSB and kSINB vary in a sinusoidal fashion with Actual Angle as shown in Figure 9. The CTU chip measures kCOSB and kSINB and determines *coarse position* from a 4-quadrant inverse tangent function. Coarse position is an approximate measure of angle. It is absolute across 360°.

The coarse coils COSB and SINB are arranged in two concentric regions, so that their sensitivity to field from the target peaks twice with radius, once inside the inner loops and once inside the outer loops. In between, the sensitivity is lower. LX1 and LY1 are positioned at a greater radius than LX2 and LY2. The combined effect of these features is that the + end of transponder coils LX1 and LY1 couple more strongly with the outer loops of the coarse coils, and the – end of transponder coils LX2 and LY2 to couple more strongly with the inner loops. Since LX1 and LY1 are on opposite sides of the rotation axis to LX2 and LY2, this makes the target's coupling to the coarse coils strongly positive in the Target Reference Direction, and strongly negative in the opposite direction. Since the coarse coils have equal and opposite sensitivity on opposite sides of the rotation axis, the coupling contributions made by LX1 and LY1 reinforce those of LX2 and LY2. Furthermore, the symmetry improvement afforded by coupling contributions coming from all four transponder coils around the rotation axis makes the coarse position reading largely insensitive to misalignment between target and sensor axes.

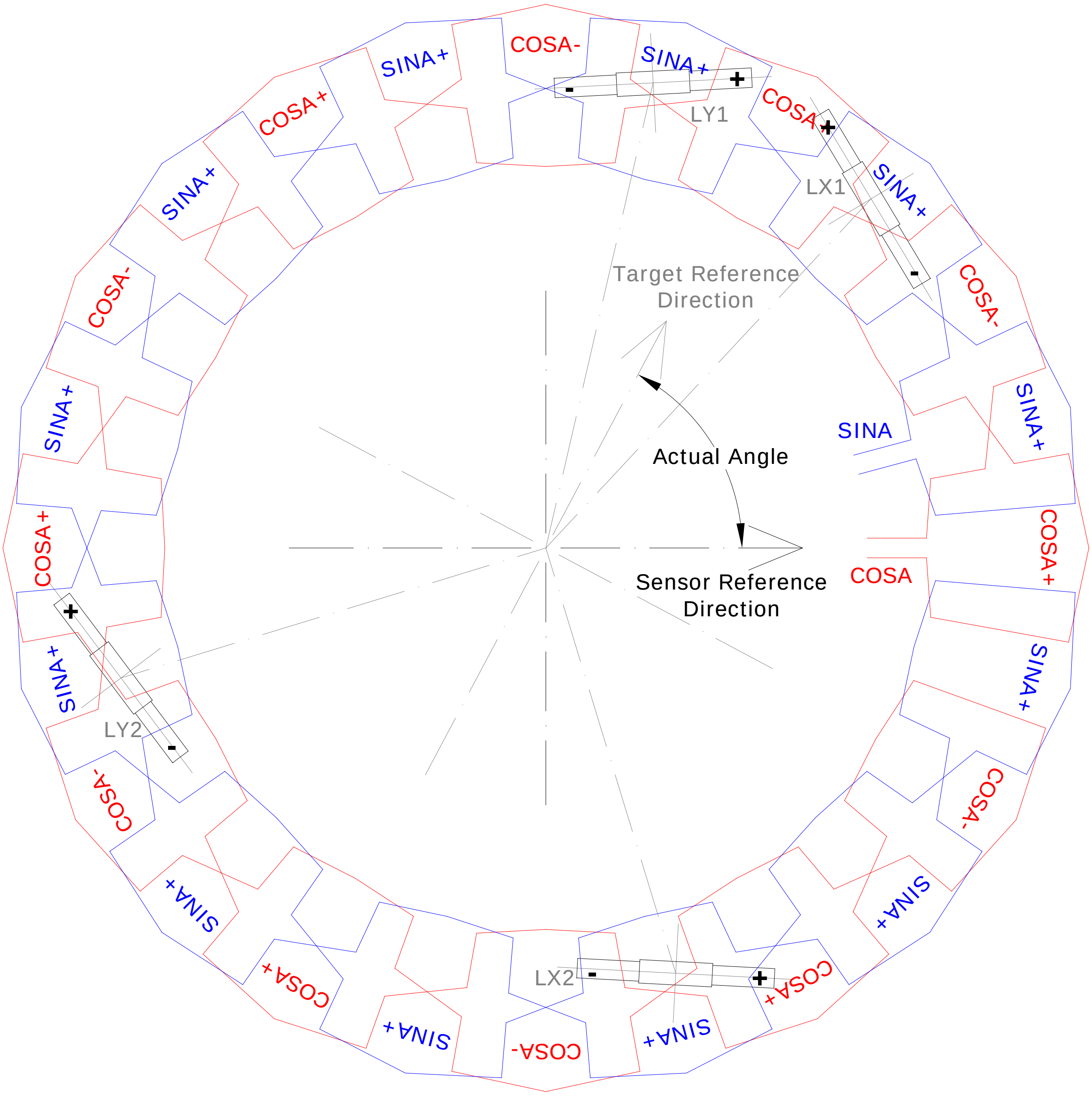

Figure 8 COSA and SINA coils, simplified

The fine sensor coils, COSA and SINA, are shown simplified in Figure 8. They are superimposed on the EX, COSB and SINB coils. They are patterned for sinusoidal variation in coupling with angle, but this time with 6 sinusoidal repeats per 60° (SinLengthA = 60°). This number, 6 sinusoidal repeats per circle, is the sensor's Subtype.

At the Actual Angle illustrated in Figure 8, the signal amplitude measured in the COSA coil is large and positive, because all of the + ends of the transponder coils are almost perfectly aligned with COSA+ portions of the COSA coil, and the – ends are aligned with the COSA- portions. The signal amplitude measured in the SINA coil is small, since the + and - ends of each transponder coil are almost mid-way between SINA+ and SINA- lobes.

The net coupling factors kCOSA and kSINA vary with Actual Angle as shown in Figure 9. The CTU chip measures kCOSA and kSINA and determines *fine position* from a 4-quadrant inverse tangent function. Fine Position is a precise measure of Actual Angle, but it is incremental across 360°, repeating 6 times (SinLengthA = 60°). The 4-quadrant inverse tangent calculation is ratiometric so that the system is immune to changes in amplitude, for example due to changes in gap and temperature.

The CTU chip combines fine and coarse position indications, so that its final output to the host has the accuracy and resolution of the “fine” reading and full absolute information from the “coarse”.

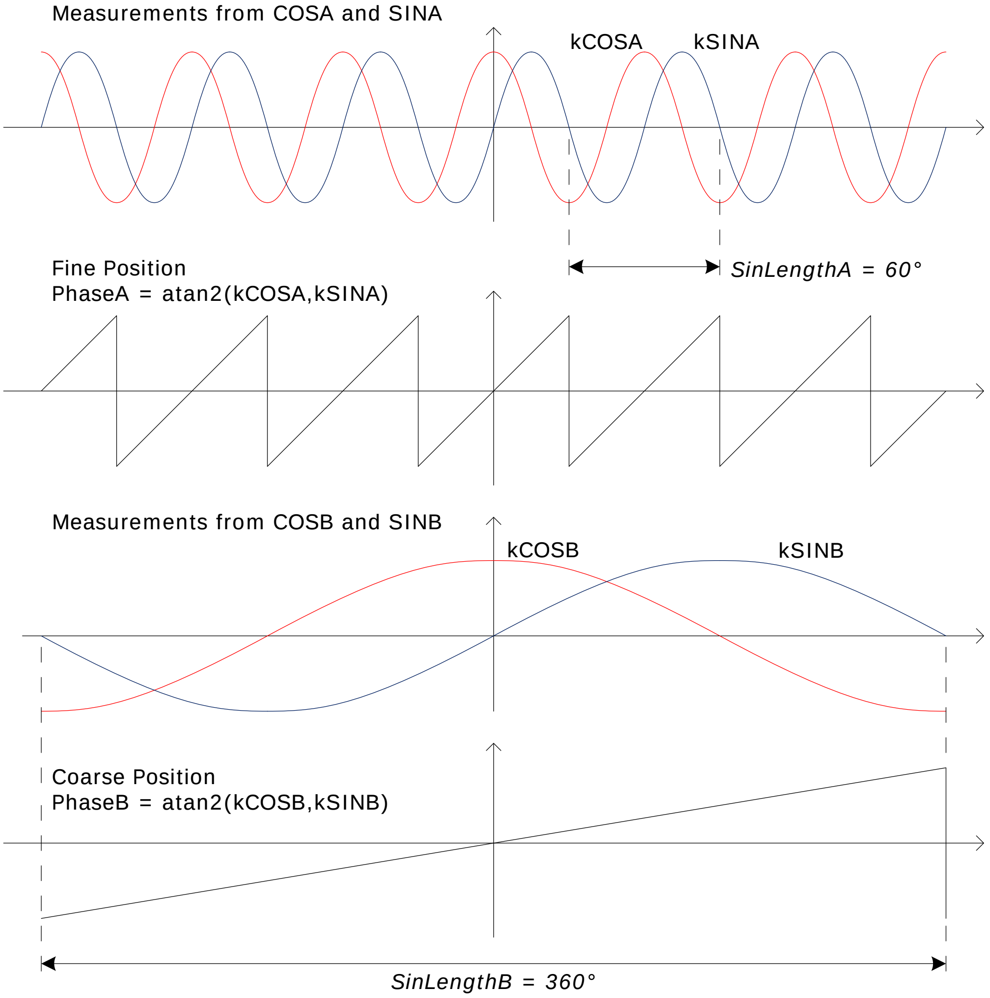

Figure 9 sensor coil coupling factors and position calculation for Type 6.6 sensor

2.4 Immunity to Misalignment

The target described in section 3 comprises 4 transponder coils which are distributed around the Sensor Axis. Each transponder coil makes an approximately equal contribution to the coupling between target and each of the COSA and SINA coils. They are all positioned at the same angle relative to the repeating fine coil pattern, albeit in different periods. This means that the calculation of fine position gives approximately equal weight to the angular position of each of the transponder coils. Radial misalignment between the Target Origin and Sensor Axis can shift the apparent angular position of each individual transponder coil. However the apparent angular shift for transponder coils LX1 and LX2 is equal and opposite to that of LY1 and LY2. The CTU chip “sees” the combined effect of all of the transponder coils added together, so the net effect of radial misalignment is that reported position is hardly affected.

The effect of radial misalignment is higher in the presence of angular misalignment between the target and sensor. Angular misalignment in the positive AYr direction (defined in Figure 13) tends to decrease the gap between sensor and LX1 and LY1, and increase it for LX2 and LY2. Similarly, angular misalignment in the positive AXr direction tends to decrease the gap between sensor and LX1 and LX2, and increase it for LY1 and LY2. The exact angle of each transponder coil has been carefully optimised so that the effect of angular misalignments in both the AYr and AXr directions is minimised. Due to the symmetry of the target design about the Reference Direction, cancellation of angular misalignment in the AXr direction is better than misalignment in the AYr direction.

The sensor’s performance is determined in the presence of both radial and angular (AYr) misalignment to yield practical, worst-case figures (Table 1 and section 5).

Radial Misalignment causes a larger change in coarse position than fine, because the design has been optimised for fine sensor coil performance. However coarse position is still relatively immune to misalignments. In any case, small residual errors in coarse position have no effect on the reported position, because the coarse coils are only used to detect position to within one fine period. Absolute position reported by the CTU chip comes only from the fine sensor coils, and there is minimal change in reported position for small lateral misalignments.

3 Target Design

3.1 Electrical

The 110mm Type 6.6 Rotary Sensor is designed to work with an inductively coupled resonant target comprising 4 off 20mm Transponder Coils LX and LY connected to capacitance CRES as illustrated in Figure 10.

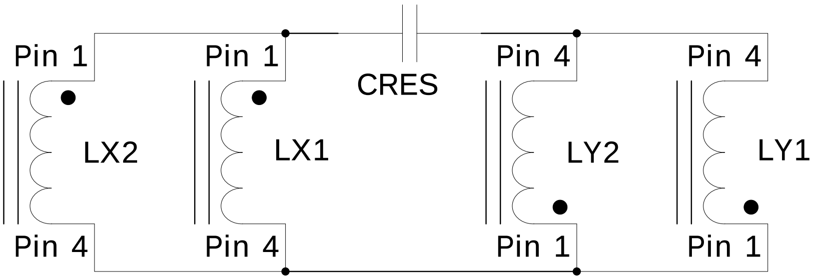

Figure 10 Schematic for target

Resonant frequency, Fres, should usually match the Nominal Operating Frequency of the CTU chip processing the sensor. Fres given by Equation 1.

$$Fres = \frac{1}{2\pi\sqrt{CRES \times LRES}}$$

Equation 1

CRES is the total resonating capacitance (the sum of the parallel connected resonating capacitors if more than one capacitor is used).

LRES is the combined inductance of the parallel connected transponder coils. The nominal inductance of each transponder coil LX1, LY1, LX2 and LY2 is the same, and denoted Ltc, measured in free space. When connected together according to Figure 10 and located as in Figure 11 the combined inductance is given by…

$$LRES = Ltc \times 0.986$$

Equation 2

The factor 0.986 accounts for the mutual coupling between inductors, mainly LX1 and LY1, which tends to reduce the value of their combined inductance.

When the target is integrated with metal parts, LRES should be the inductance in the presence of metal. CRES may comprise two or more capacitors connected in parallel. CRES should be formed with a stable, high Q-factor dielectric capacitor(s) such as NPO or COG, and have an operating voltage of at least 200V. The combined capacitance and inductance tolerance, including temperature effects, must yield values of Fres within Tuning Range of the CTU chip. Please refer to the CambridgeIC white paper “Resonant Frequency Centering” for more details.

3.2 Transponder Coil Locations

To function correctly with the 110mm Type 6.6 Rotary Sensor and deliver the specified performance, locations and angles of the Transponder Coils must be as illustrated in Figure 11, and they must be mounted flush with the target PCB.

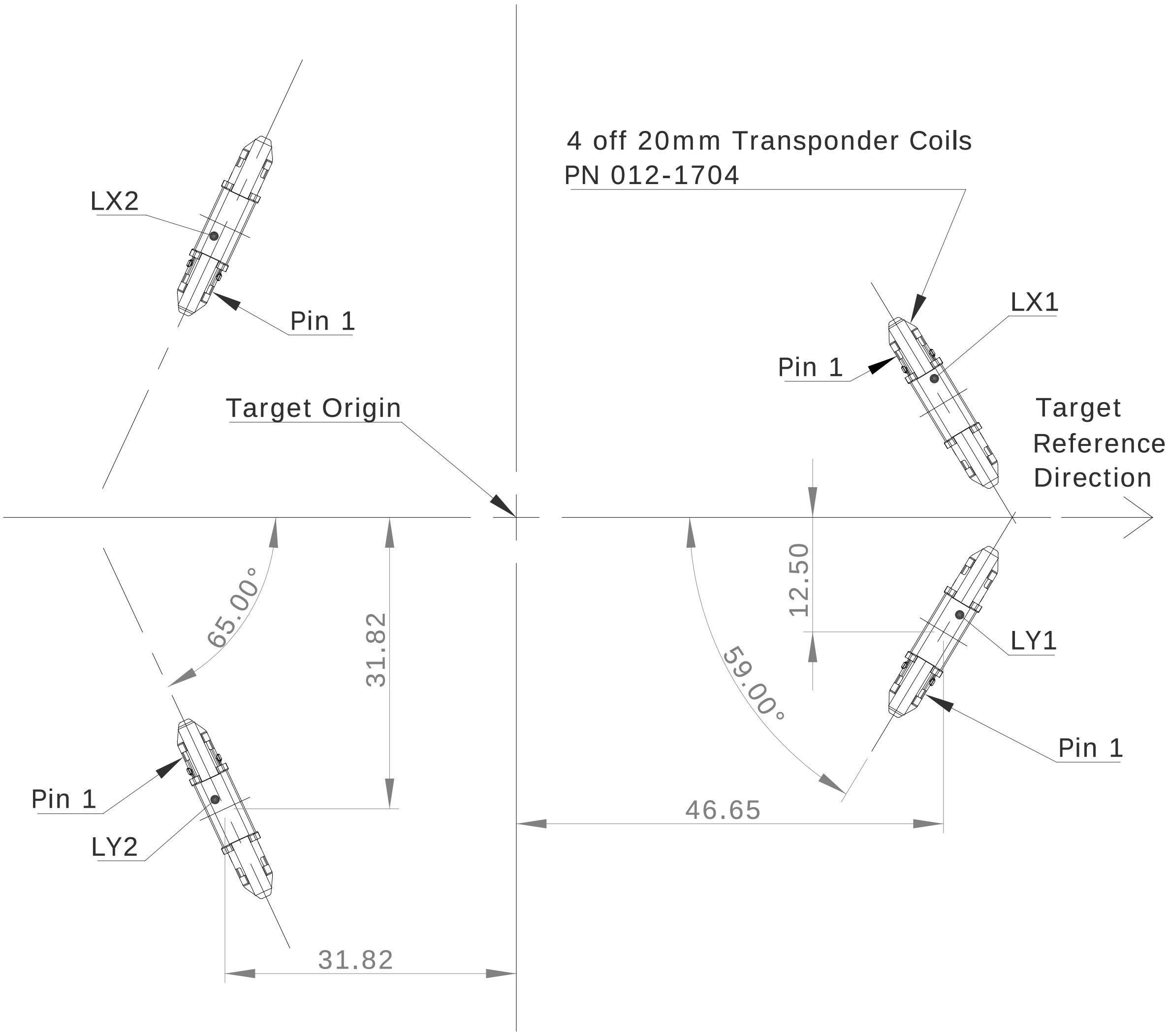

Figure 11 Transponder Coil locations

The electrical winding direction of the two transponder coils is shown in Figure 10, with pin 1 of each part connected together. The mechanical orientation of the transponder coils is illustrated in Figure 11. It is essential that the parts are connected and oriented this way round for the target to work.

20mm Transponder Coils are surface mounted components (SMD), to enable targets to be manufactured by customers using a conventional PCB process. Please refer to their datasheet for more details. They are available to buy from CambridgeIC.

3.3 Assembled Target

Assembled targets are also available from CambridgeIC, as illustrated in Figure 2. The mechanical design of assembled targets is shown in Figure 12.

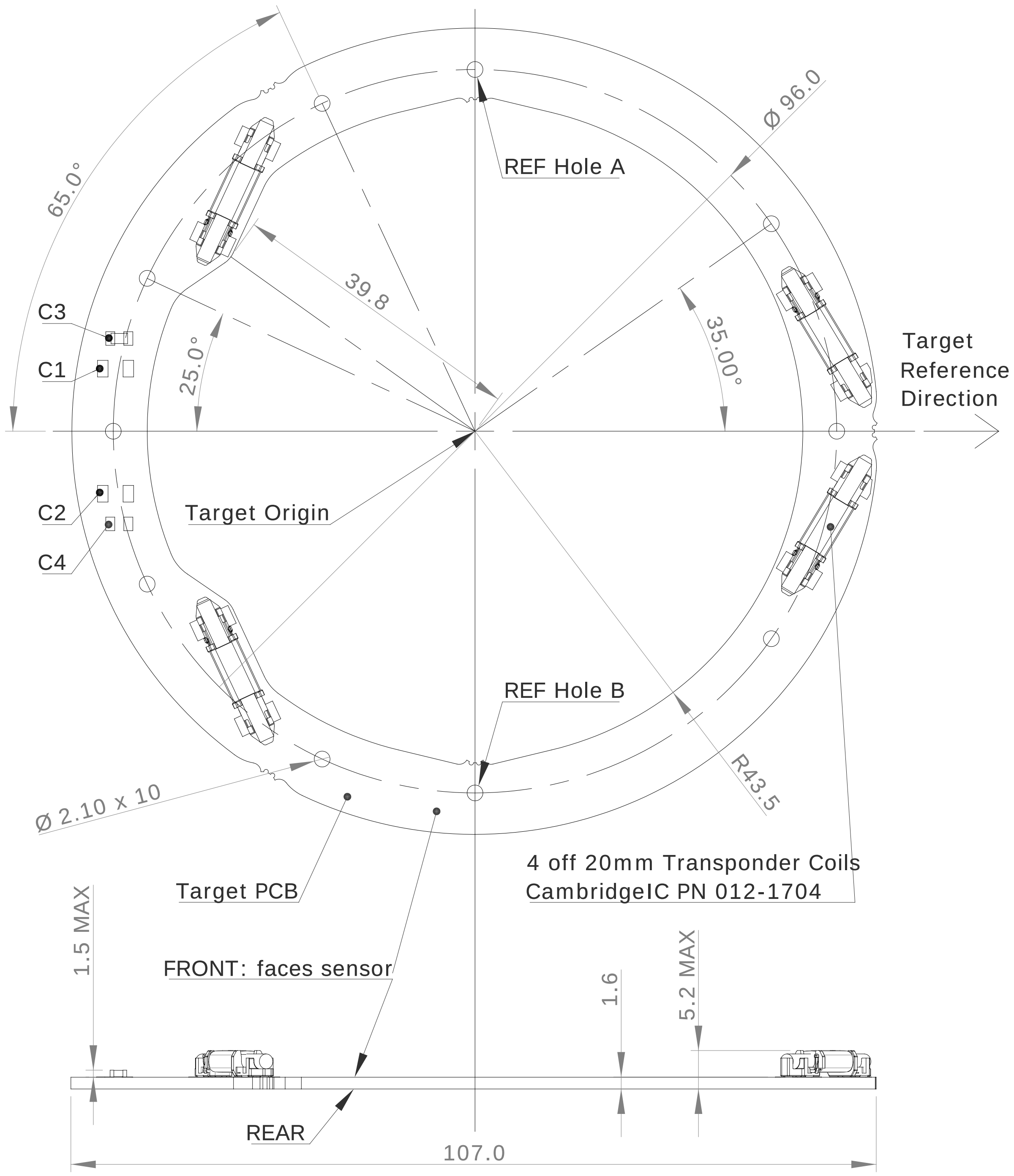

Figure 12 Assembled Target 013-1026 mechanical design

The Target Origin is defined as mid-way between the centre of Ref Hole A and Ref Hole B. The Reference Direction is perpendicular to a line joining their centres. There are a total of 10 holes that may be used for mounting and/or alignment.

Assembled targets may be fitted with different values of capacitors, for different free space resonant frequency and hence compatibility with different metal environments. Their corresponding part numbers are shown in Table 3.

Table 3 Assembled Targets

Part Number	**013-1026**
Fres, free space	182.5kHz (1)
Fres tolerance, 20°C	±2.5%
Fres tolerance, -40°C to +85°C	±4.5%
LX1, LX2, LY1, LY2	CambridgeIC PN 012-1704
C1	Not fitted
C2	Not fitted
C3	820pF COG/NPO 250V
C4	Not fitted

Note (1) For operation with the CAM204 across -40°C to +85°C in metal environments that increase resonator frequency by up to 5%.

Please contact CambridgeIC to enquire about assembled targets with different nominal values of Fres.

4 Definitions

4.1 Coordinate System

The sensor system measures the angle of a target relative to a sensor. The Target Reference Direction is defined in Figure 12. For assembled sensors, the Sensor Reference Direction is defined relative to REF Holes A and B shown in Figure 4. The Actual Angle is the angle between the two. Strictly, since the target may be slightly tilted relative to the sensor, Actual Angle is the angle between the projection of the Target Reference Direction onto the sensor's XY plane and the Sensor Reference Angle. This is shown in Figure 13.

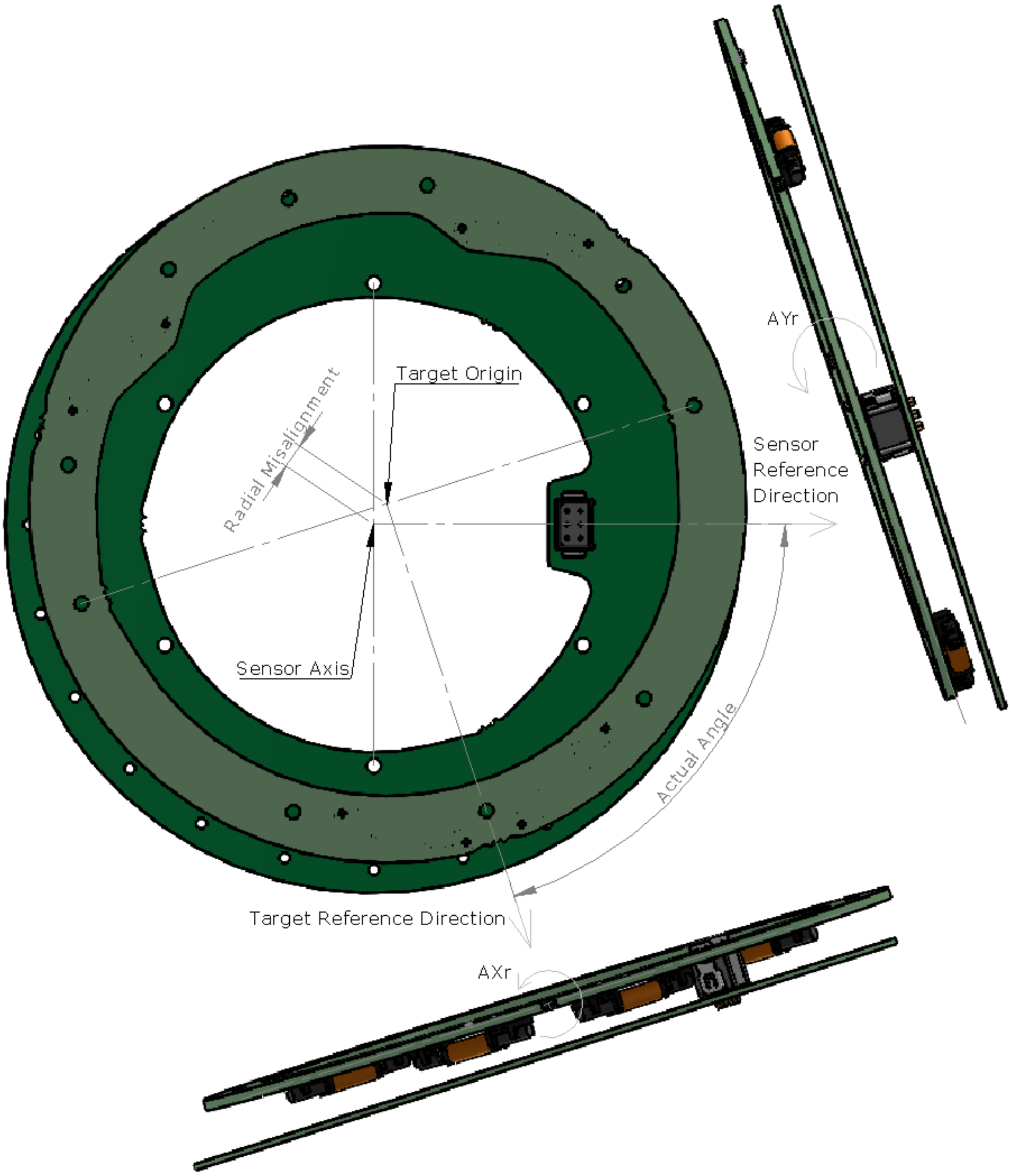

Figure 13 Coordinate System

The target's X-Axis is denoted Xr and coincides with the Target Reference Direction. The target's Y-Axis, Yr, is orthogonal to Xr and also in the plane of the Target PCB. Tilt of the target relative to the sensor is defined about the

Xr and Yr axes, denoted AXr and AYr, and illustrated in the auxiliary views of Figure 13 References to Angular Misalignment below are either AXr or AYr, whichever has the worst effect on linearity.

Radial Misalignment is the distance between the Target Origin and Nominal Sensor Axis.

4.2 Gap Definition

Figure 14 shows how Gap is defined. It is the average distance between sensor PCB and target PCB FRONT surfaces minus 3.5mm. That way, Gap equals the physical gap when the transponder coils are their nominal height of 3.5mm.

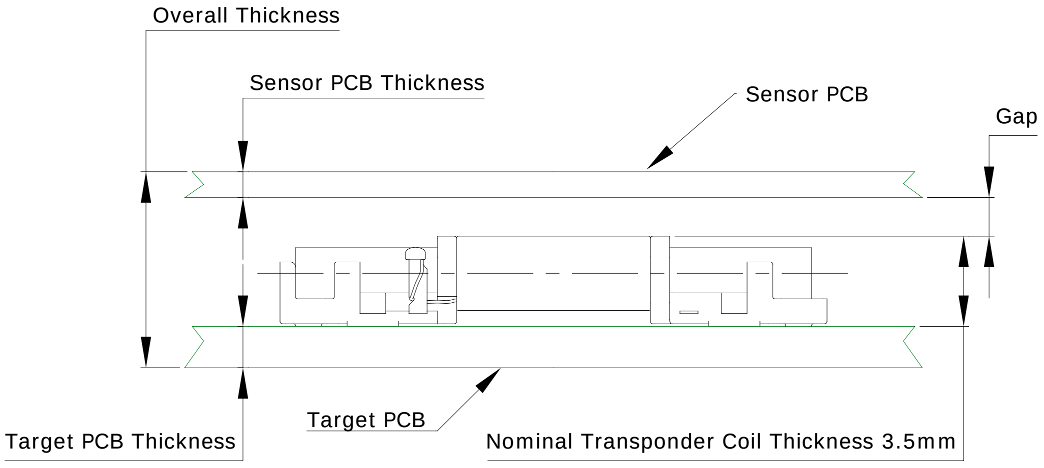

Figure 14 Definition of Gap

4.3 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 sensor's *Sin Length* parameter is 60°. The reported position may be converted to degrees using:

$$Reported\ Angle\ in\ Degrees = \frac{CtuReportedPositionI32}{65536} \times 60°$$

Equation 3

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

$$Reported\ Angle - ActualAngle = RandomNoise + LinearityError + OffsetError$$

Equation 4

4.4 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 5

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

$$Noise\ Free\ Resolution = \log_2 \frac{360°}{Peak\ to\ Peak\ Noise\ in\ °}$$

Equation 6

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.

4.5 Linearity Error and Offset Error

Linearity Error is the peak deviation of the transfer function from a straight line. In this case the slope of the straight line is fixed at 360° per 360° because of the continuous rotary nature of the sensor. So Linearity Error simply measures deviations relative to an Offset Error.

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 mainly due to the location and symmetry of its transponder coils relative to the Target Reference Direction.

The sensor's contribution to Offset Error is mainly due to the PCB manufacturing process, in particular angular misregistration of layers 2, 3, 4 and 5 relative to the holes defining the Sensor Reference Angle.

4.6 Sensitivity to Radial Misalignment

Sensitivity to Radial Misalignment is measured by comparing Reported Position values with and without Radial Misalignment, and expressing the result in "angle per distance" units using…

$$Measured\ Sensitivity\ to\ Radial\ Misalignment = \frac{Reported\ Position(with\ Radial\ Misalignment) - Reported\ Position\ (no\ Radial\ Misalignment)}{Radial\ Misalignment}$$

Equation 7

This depends on Actual Angle, Angular Misalignment, Gap and so on, so typically a worst case value is presented.

When applied to an optical or magnetic encoder without the benefit of a balanced design, the worst case sensitivity is given by...

$$Imbalanced\ Sensitivity\ to\ Radial\ Misalignment = \frac{180°}{\pi} \times \frac{1}{Code\ Radius}$$

Equation 8

…where Code radius is the working radius of the code disc's optical or magnetic patterning. When comparing performance between the 110mm Type 6.6 Rotary Sensor and an optical or magnetic encoder of similar size, the Code Radius is taken to be the average of the outer and inner radii of the sensor…

$$Imbalanced\ Reference\ Sensitivity\ to\ Radial\ Misalignment = \frac{180°}{\pi} \times \frac{2}{(Outer\ Radius + Inner\ Radius\ )}$$

Equation 9

The Radial Misalignment Rejection Ratio can then be defined, comparing measured performance to expected performance for an alternative encoder system that does not benefit from balance…

$$Radial\ Misalignment\ Rejection\ Ratio = \frac{Imbalanced\ Reference\ Sensitivity\ to\ Radial\ Misalignment}{Measured\ Sensitivity\ to\ Radial\ Misalignment}$$

Equation 10

5 Performance, Free Space

Figures below are representative of assembled sensors (as described in section 1) and of sensors built to the same specification. Measurements are taken with a typical target (built according to section 3) and Type 6 CAM204 CTU Circuitry (see CTU 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.

Performance figures in this section are presented as a function of Gap, and this is defined in Figure 14.

5.1 Linearity Error

Linearity Error is defined in section 4.5. It is minimised when there is no Radial or Angular Misalignment. Figure 15 shows how Linearity Error changes with Gap and when misalignments are introduced. The quoted misalignment is *in addition* to ±0.2mm of misalignment between copper and REF Holes.

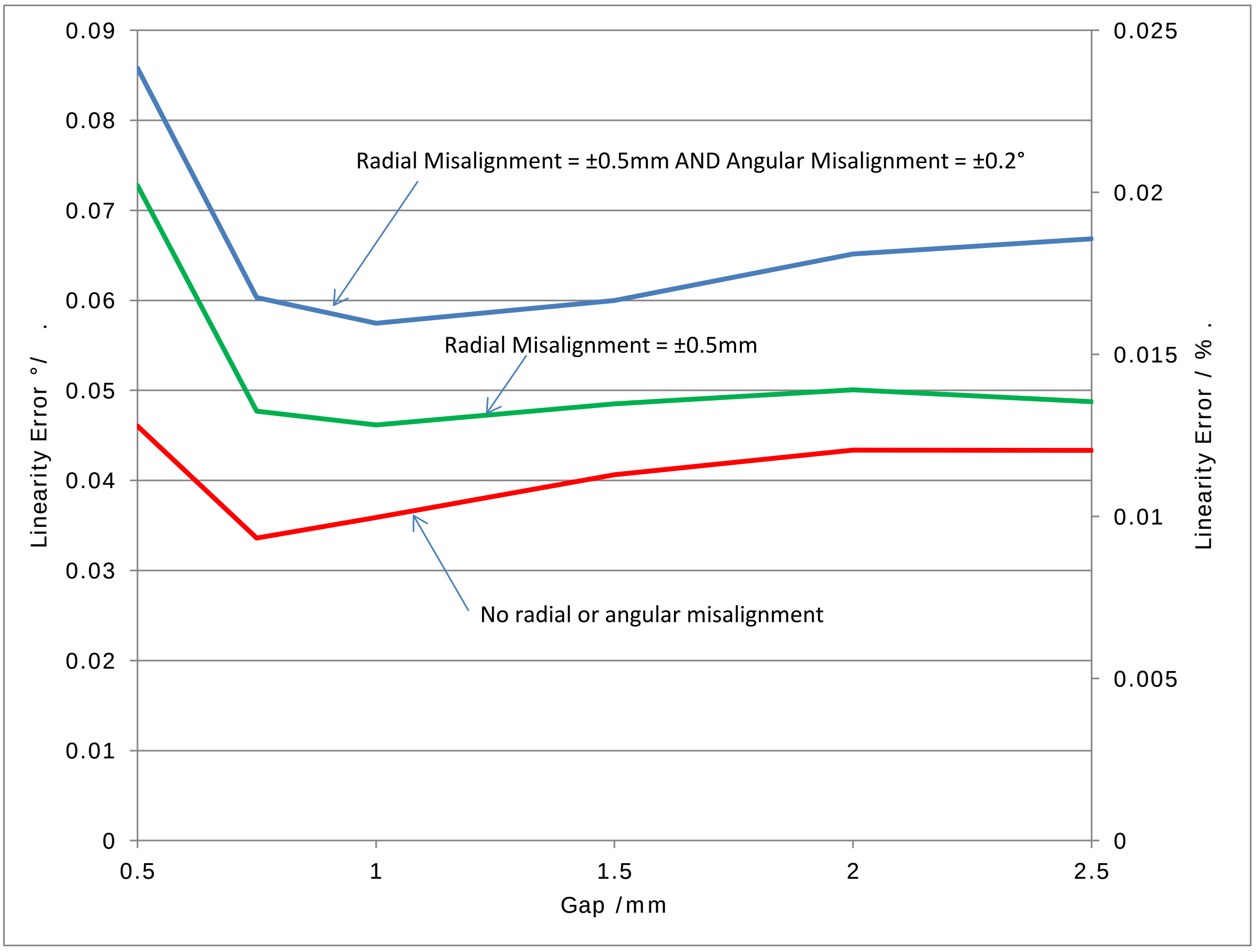

Figure 15 Linearity Error as a function of Gap and misalignment, free space

5.2 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 16.

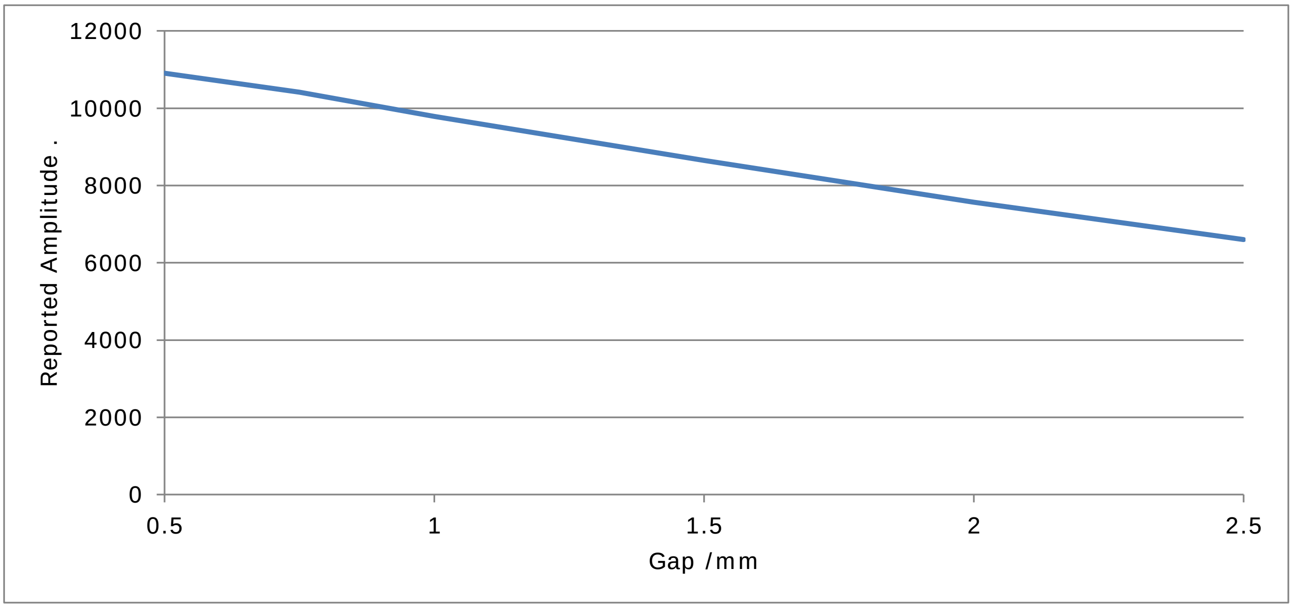

Figure 16 Minimum Reported Amplitude as a function of Gap, free space

Care should be taken to avoid Amplitude values greater than about 11000, for example caused by small gap. Please see section 5.5.

5.3 Noise Free Resolution

Noise Free Resolution is defined in section 4.4. 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 17.

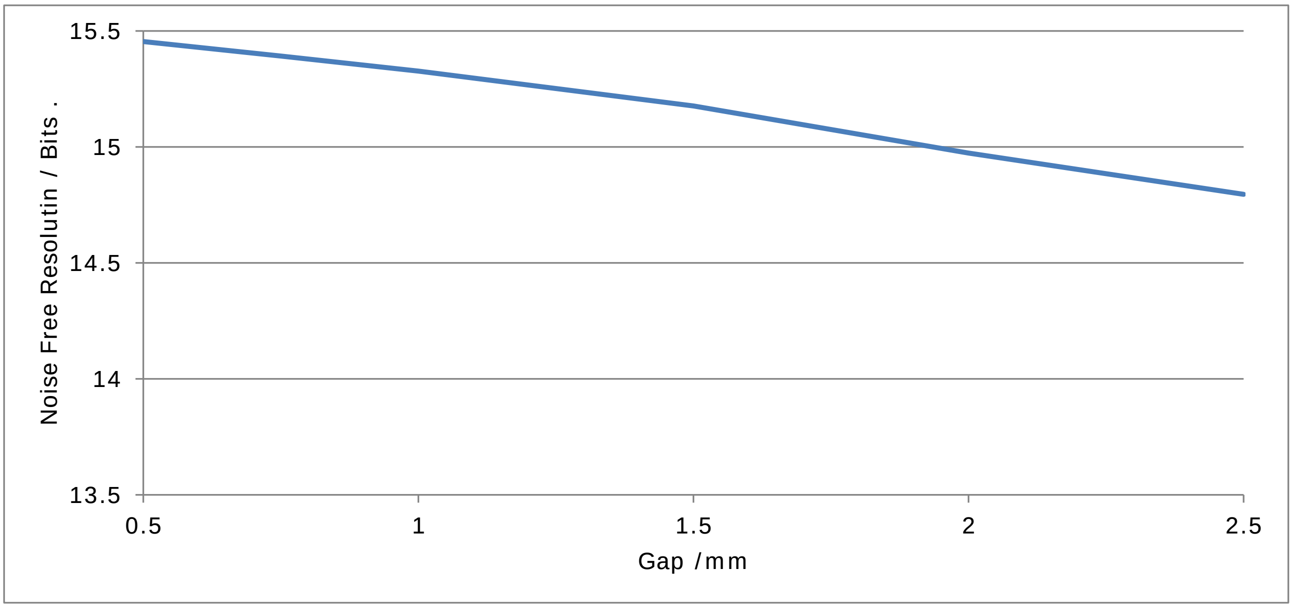

Figure 17 Noise Free Resolution as a function of Gap, CAM204 CTU chip, free space

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.

5.4 Immunity to Misalignment

Section 4.6 defines how immunity to radial misalignment between target and sensor axes can be quantified, and results for the 110mm Type 6.6 Rotary Sensor are presented in Table 4.

Table 4 Immunity to Misalignment

Parameter	**Value at 0.5mm gap**	**Worst case 0.75mm…1.5mm gap**
Measured Sensitivity to Radial Misalignment, worst case across Actual Angle, misalignment direction, and Angular Misalignment up to 0.2°	0.1°/mm	0.08°/mm
Radial Misalignment Rejection Ratio	6	8

5.5 Maximum Misalignment and Amplitude

Table 5 shows maximum allowable misalignments. If radial or angular misalignment exceeds these values, for example when held by hand during demonstration, reported position may include an error of ±60°, or become invalid.

Table 5 Maximum misalignment between target and sensor, free space

Parameter	**Maximum**
Radial Misalignment	0.5mm
Angular Misalignment	0.5°
Gap	1.5mm

For this particular sensor, Amplitude is relatively high when used in Free Space. Care should be taken to avoid Amplitude values above about 11000, since signal voltages input to the CTU chip may exceed supply rails causing clipping and hence additional linearity error. A maximum value of 10000 is recommended. High Amplitudes can be caused by use at small gaps and with the CAM502 processing chip in pipeline mode. In these cases it may be necessary to operate with some mechanism to reduce signal Amplitude so that clipping does not occur. Please contact CambridgeIC for suggestions.

6 Metal Integration

6.1 Background

As with all resonant inductive sensors, the 110mm Type 6.6 Rotary Sensor and its target can be integrated near metal providing the metal's influence is not excessive.

Nearby metal can cause additional linearity error, although the effect is usually small, especially when the metal is placed symmetrically around the sensor.

The metal must not dampen the resonator's Q-factor excessively, and distort fields such that coupling factor is reduced excessively, otherwise Amplitude will be significantly reduced. Low Amplitude causes low Noise Free Resolution. When Amplitude is reduced to 50% of its original value, Noise Free Resolution will reduce by approximately 1 bit. In extreme cases Amplitude may fall below the CTU chip's minimum Amplitude for reporting VALID.

The 110mm Type 6.6 Rotary Sensor delivers relatively high Amplitude in free space. If the target is mounted to or near a large area of aluminum, this may actually increase Amplitude. Caution should be taken to avoid Amplitude greater than 11000, when there is a risk of incoming signal voltages outside supply rail range, causing clipping and hence additional linearity error. It is recommended to aim for integrations with Amplitude no more than 10000. If the target is to be mounted direct to aluminium, measures should be taken to reduce Amplitude, for example by mounting the sensor above aluminium too. This situation is described in section 6.2.

The target's resonant frequency Fres when integrated with the customer's product must also remain within the tuning limits of the CTU it will be used with, typically 187.5kHz ±7% for the CAM204. Fres is a function of the metal environment inside the product. When there is very little metal nearby, Fres will equal the target's free space resonant frequency. When there is metal nearby, Fres will shift. For non-ferrous, highly conductive materials such as aluminium and brass, Fres increases as metal approaches. If the shift is substantial, it may be necessary to alter the nominal free space resonant frequency so that when integrated with the product Fres remains within the CTU's tuning range. The free space resonant frequency may be lowered by increasing the target's resonating capacitance CRES of Figure 10.

Small metal objects such as fixing screws have less effect than larger objects and metal surfaces. The sensor 013-0042 and target 013-1026 can both be mounted using steel M2 screws with no effect on Amplitude, for example.

The effect of a product's fixed metal environment is highly reproducible and can be established by experiment, for example using CambridgeIC's CTU Demo application and appropriate sensor, target and CTU Development Board.

Large areas of aluminium, brass or copper near the sensor and target can be tolerated, as illustrated in the following subsections. However these materials must be at least 0.2mm thick, otherwise their conductivity is insufficient to repel magnetic fields efficiently and Amplitude is reduced more than the values illustrated.

The sensor and its target tolerate aluminium and brass nearby much better than steel, iron, titanium or stainless steel. It is recommended to cover any large areas of iron, titanium or stainless steel near the sensor and target with an aluminium screen at least 0.2mm thick. For example if there is a steel shaft passing through the middle of the sensor and target, it should preferably be shrouded in an aluminium tube with wall thickness 0.2mm or more.

Please refer to the CambridgeIC white paper "Resonant Frequency Centering" for more details, including practical approaches for testing and analysis.

The following sections illustrate the effect of aluminium parts near the sensor and target. Brass and copper will behave similarly.

6.2 Between Aluminium Plates, Sensor 2mm Above Aluminium

In the example illustrated in Figure 18 the sensor is mounted 2mm above an aluminium sheet. A parallel aluminium sheet is positioned behind the target.

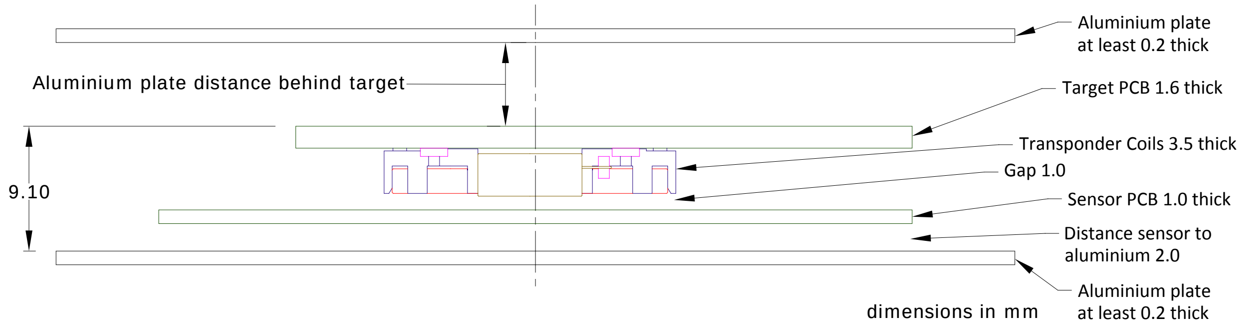

Figure 18 Between Aluminium Plates, Sensor 2mm Above Aluminium

Figure 19 shows how reported Amplitude and frequency change with distance of the aluminium sheet behind the target.

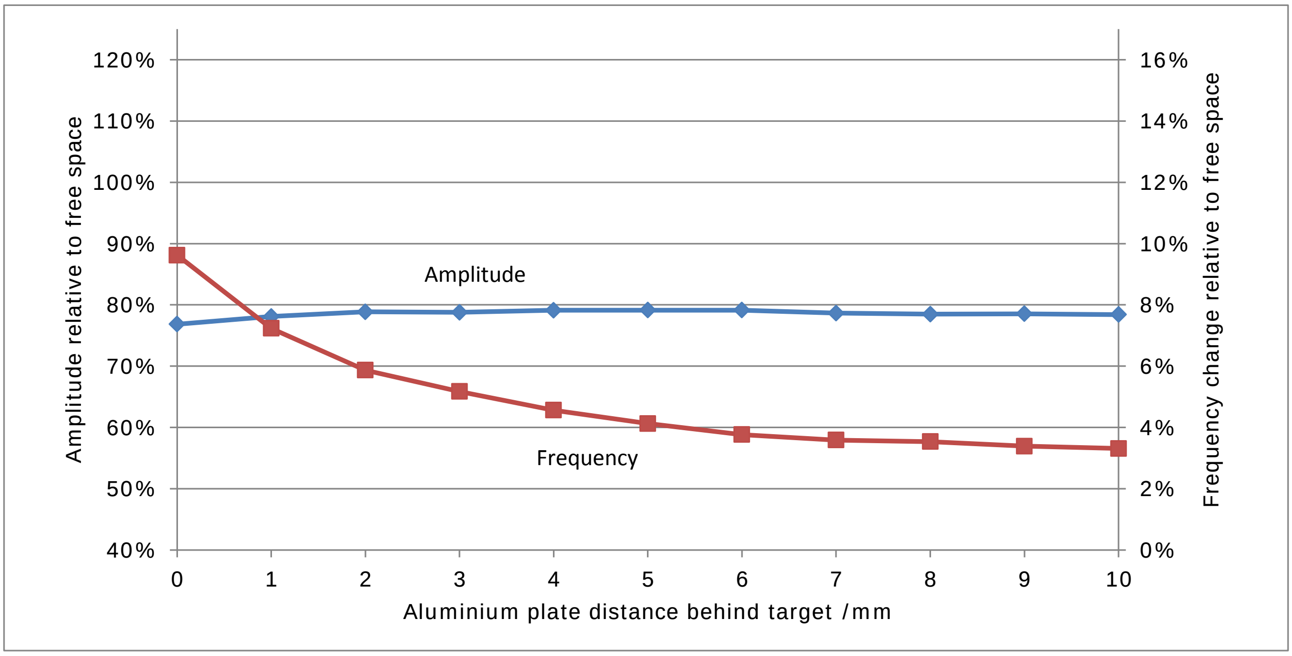

Figure 19 Effect of nearby aluminium on Amplitude and Resonant Frequency

A gap of 0mm represents the target in contact with an aluminium plate (e.g. target mounted to aluminium).

6.3 Metal Integration Example

This subsection provides an example where the sensor is integrated 3mm above an aluminium plate, and there is a steel bearing inside the target. It is illustrated in Figure 20.

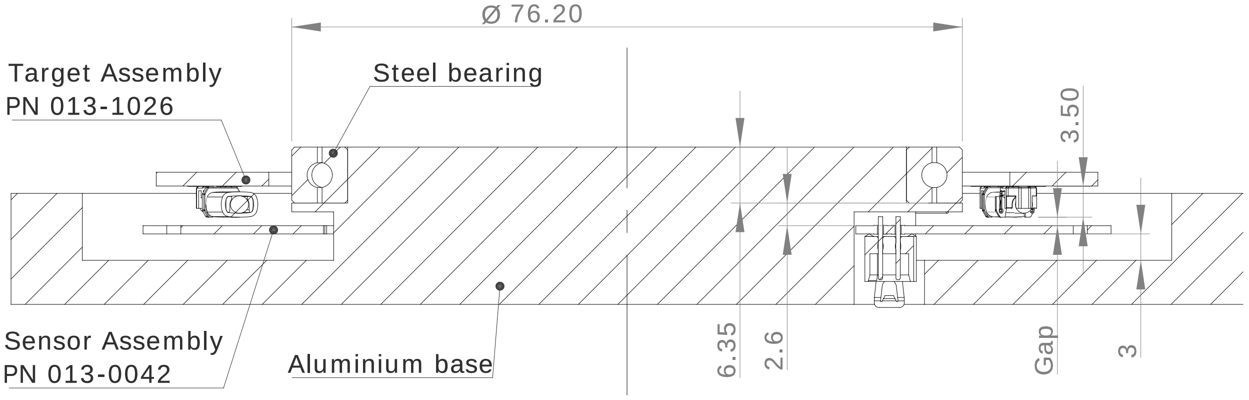

Figure 20 Example metal integration including aluminium behind sensor and steel bearing inside target

Figure 21 shows linearity measurement results for this metal integration example. Values at 0.5mm are very similar to those for free space operation shown in Figure 15. Linearity error is then about 0.02° greater for gaps of 1mm and more.

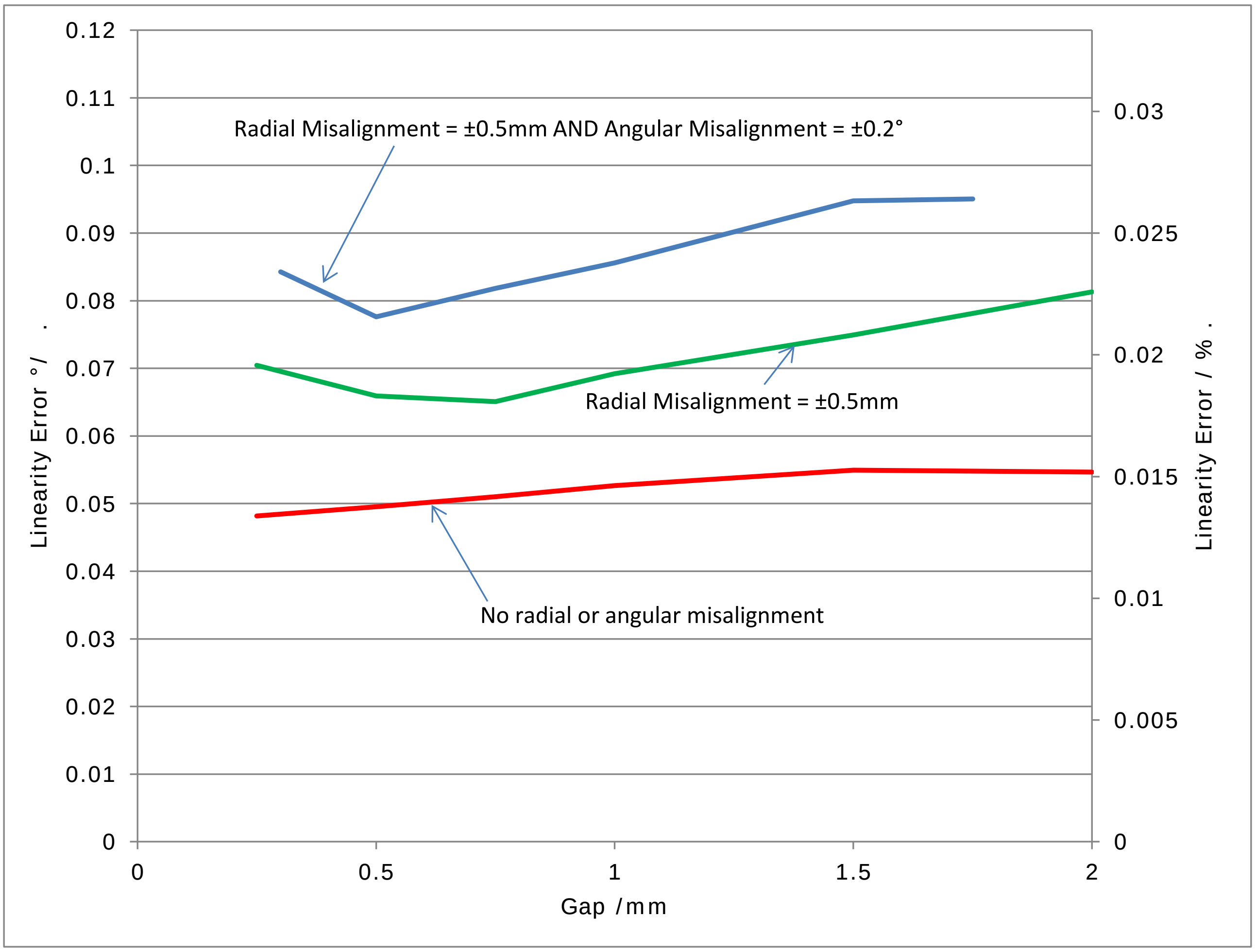

Figure 21 Linearity Error as a function of Gap and misalignment, metal example

Figure 22 shows how minimum Amplitude changes with gap. Amplitude is about half the free space values shown in Figure 16. The reduction is caused by a combination of the proximity of the aluminium plate behind the sensor, and a reduction in the target's Q-factor due to the damping effect of the steel in the bearing.

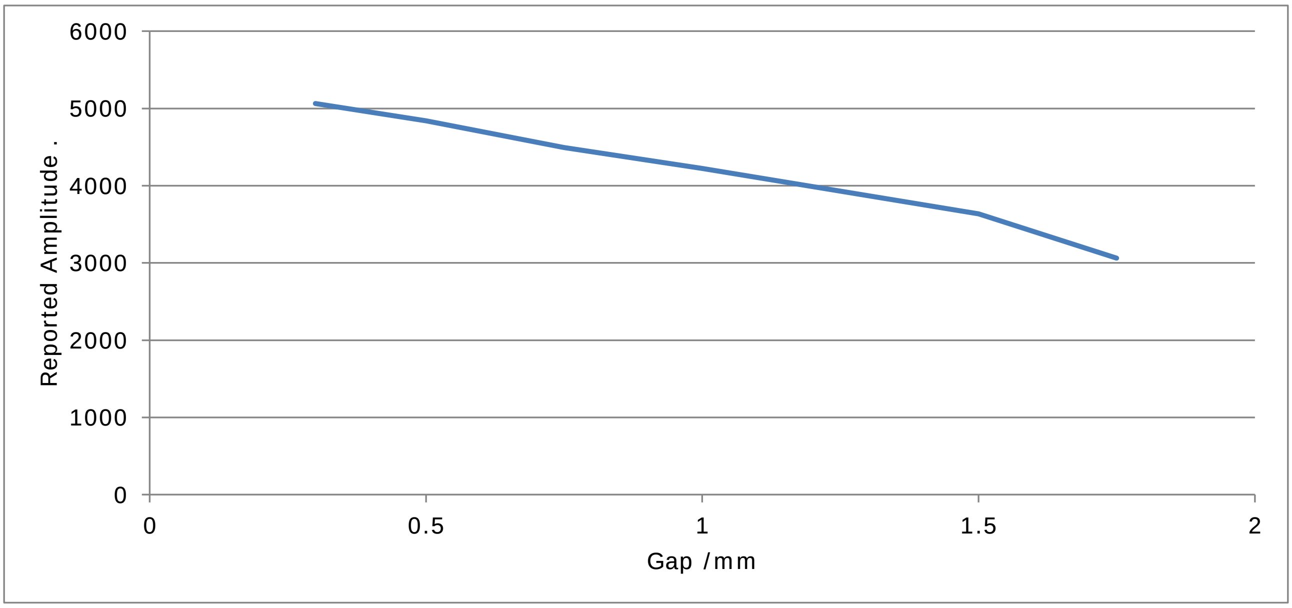

Figure 22 Minimum Reported Amplitude as a function of Gap, metal example

Figure 23 shows how Noise Free Resolution changes for gap for this metal integration example. Values are approximately 1 bit less than the free space values of Figure 17. This is because Amplitude was approximately halved.

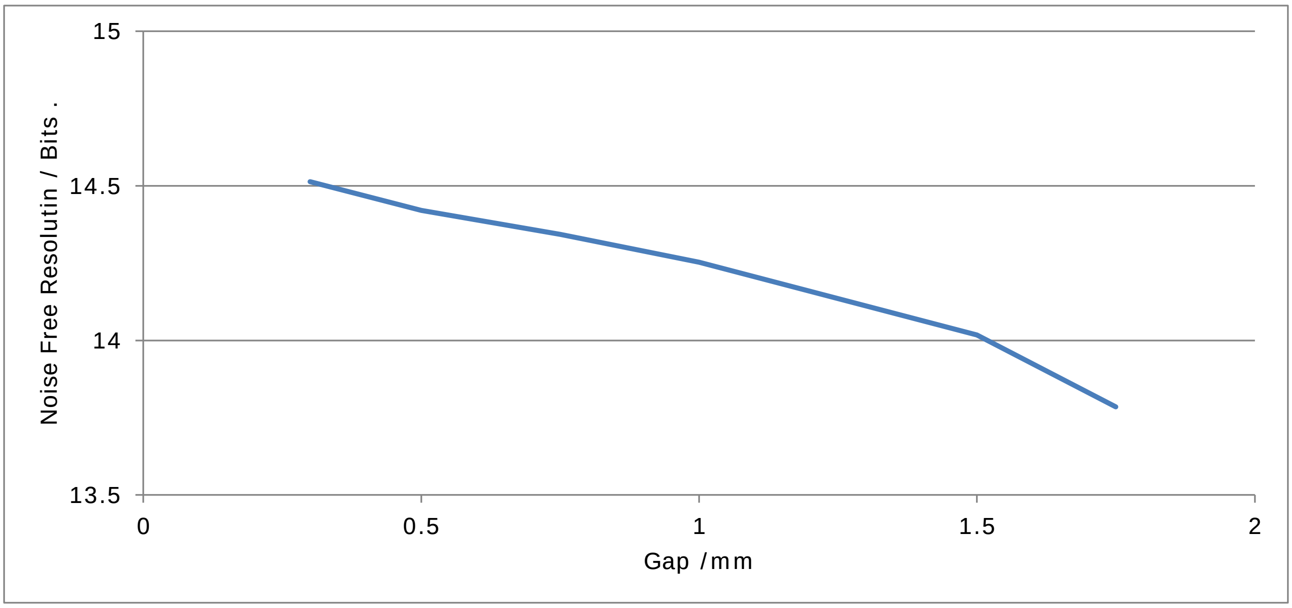

Figure 23 Noise Free Resolution as a function of Gap, CAM204 CTU chip, metal example

Integration with the metal environment of Figure 20 delivers high performance. Although the Amplitude is reduced significantly relative to free space, the resulting values are still higher than for most sensors of the same Type, because the free space Amplitude was so high to start with.

7 Sensor Blueprint 010-0109

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, as stand-alone sensors or combined with their own circuitry.

7.2 Fabrication Technology

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

Table 6

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

7.3 PCB Design Parameters

Table 7

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, with coil connections shown to the upper right. 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.

The sensor coil pattern includes space for 24 off 1.6mm diameter holes, as shown in Figure 24. These may be used for alignment. They may also be used for mounting, for example using M1.6 countersunk screws. However this is not recommended because the screws may clash with the target at small gaps. The holes may be omitted if they are not needed.

Sensor Blueprint 010-0109 has sensor connections to the inside of the sensor pattern. This means it suits applications where processing electronics is positioned inside the sensor pattern, or where the customer's connector is placed inside. Please contact CambridgeIC to enquire about a version with connections to the outside.

When integrating with other electronic circuitry, a keep-out of 3mm is recommended all around the sensor's conductors.

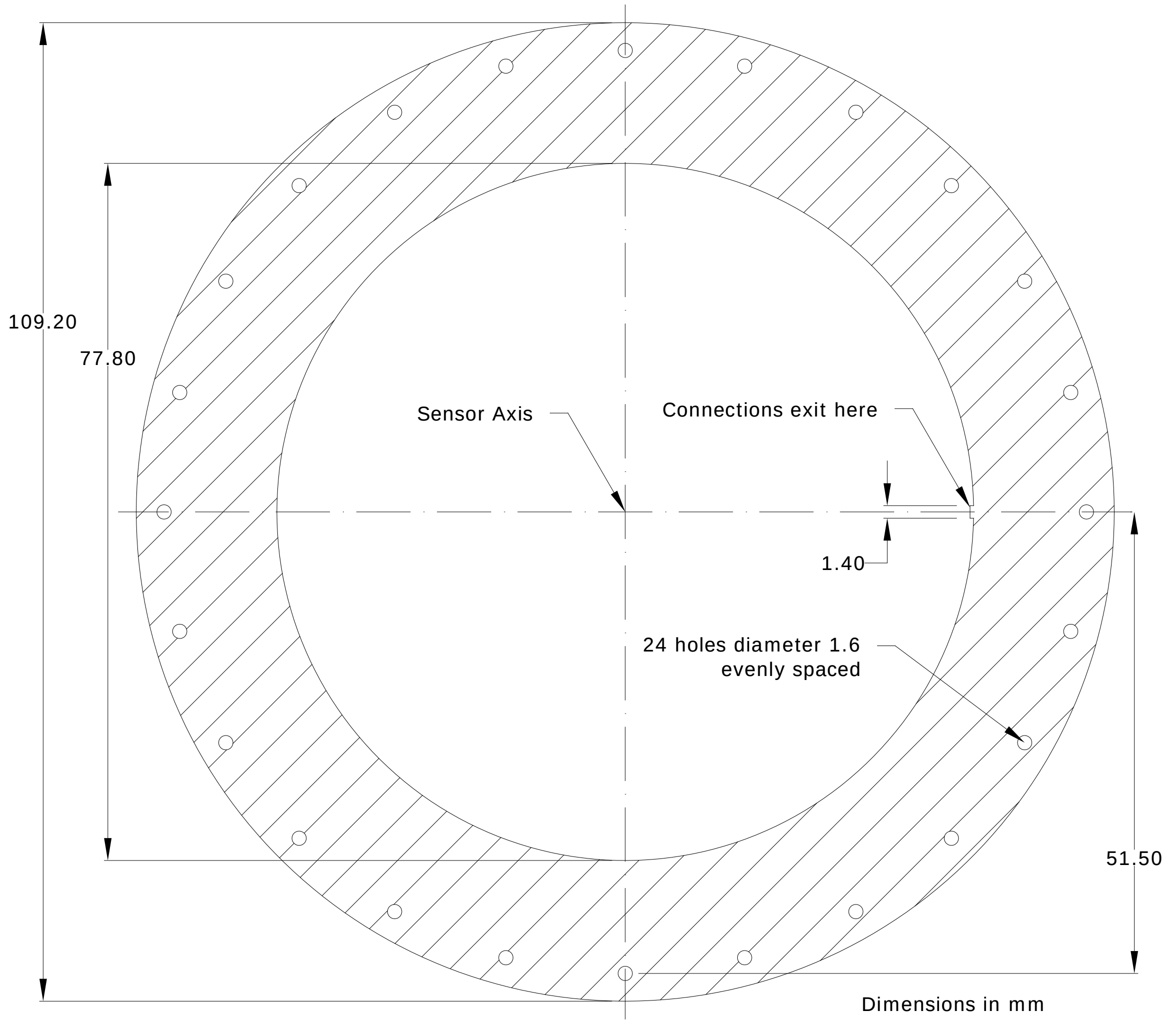

Figure 24 Copper extent

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 CAM204 datasheet for recommendations on track design for connecting sensors to CTU circuitry.

8 Environmental

Assembled sensor part number 013-0042 and target 013-1026 conform to the following environmental specifications:

Item	Value	Comments
Minimum operating temperature	-40°C	Limited by the wire used for connections
Maximum operating temperature	85°C	
Maximum operating humidity	85%	Non-condensing

The maximum operating temperature 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 numbers 013-0042 and 013-1026 are in compliance with EU RoHS directive 2011/65/EU, China RoHS and Korea RoHS.

10 Document History

Revision	Date	Comments
0001	3 November 2016	First draft

11 Contact Information

Cambridge Integrated Circuits Ltd
21 Sedley Taylor Road
Cambridge
CB2 8PW
UK

Tel: +44 (0) 1223 413500

info@cambridgeic.com

12 Legal

The parts described in this datasheet are subject to the following patents: US8570028, US9410791, US9470505, EP2656013, GB2461448, GB2488389 and GB2500522.