62-42mm Type 6.7 Rotary Sensor

Description

A resonant inductive position sensor for measuring angle 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 7 (Type "6.7").

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°
- 4-layer PCB process
- 42mm hole, e.g. for through shaft
- 61.2mm diameter copper coil pattern

Target

- Simple design using 4 x SMD transponder coils
- Balanced for immunity to misalignment

Table 1 Free Space Performance, with CAM204

	Condition	
	Best	**Realistic installation tolerances**
Gap Sensor to Target Coils	0.5mm	1.0±0.5mm
Radial Misalignment	0mm	0.5mm
Angular Misalignment	0°	±0.3°
	Result	
Max Linearity Error	±0.06°	±0.18°
Noise Free Resolution	14.5 bits	13.9 bits

Applications

- Azimuth and tilt sensing for surveillance cameras
- Motion control
- Actuator position feedback
- Valve position sensing
- Absolute Optical Encoder replacement

Product identification

Part no.	Description
013-0033	Assembled sensor, FRONT connector
012-1703	20mm Transponder Coil
013-1018	Assembled Target, 177kHz
013-6011	6-way PicoBlade sensor cable
010-0095	Sensor Blueprint

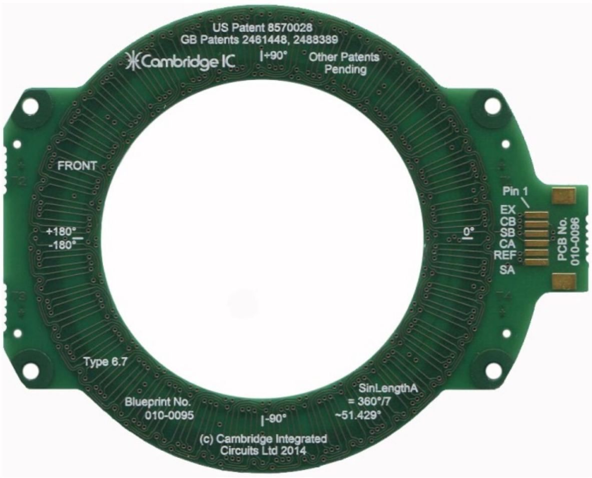

Figure 1 Assembled Sensor 013-0033, FRONT

Figure 2 Assembled Target 013-1018, FRONT

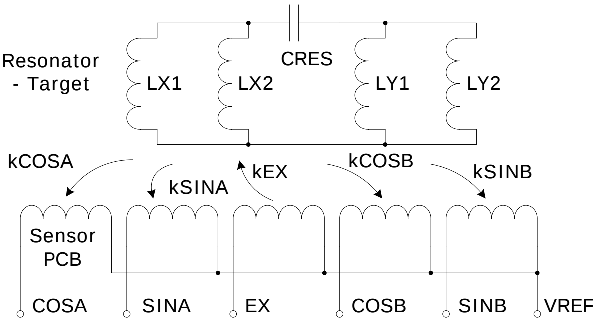

Figure 3 equivalent circuit

1 Assembled Sensor

Figure 4 is a dimensioned drawing of the assembled sensor PCB part number 013-0033.

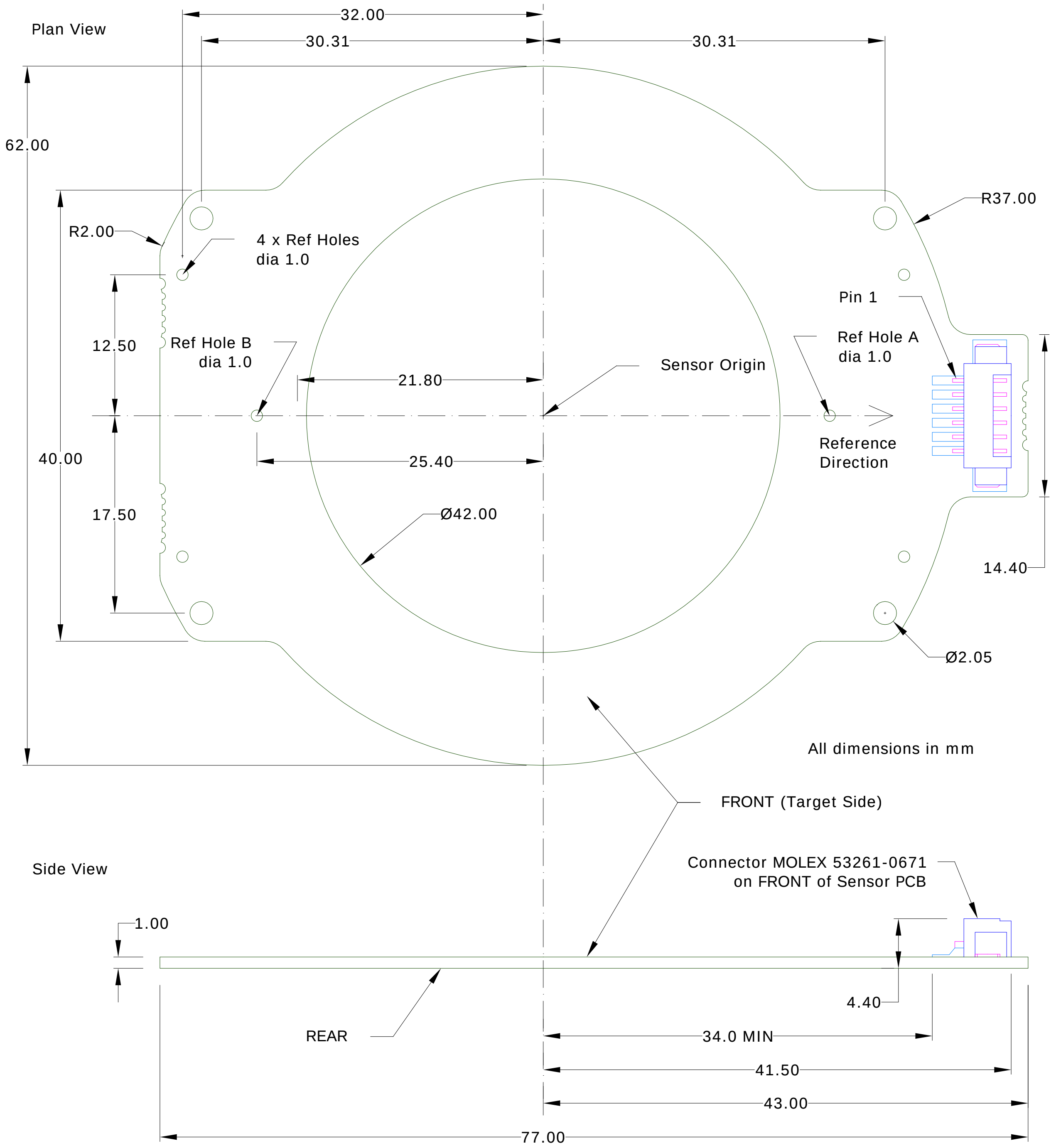

Figure 4 Assembled Sensor 013-0033

The sensor PCB is not symmetric FRONT to REAR, and the target must face the sensor's FRONT surface as in Figure 15.

The Sensor Origin is defined as mid-way between the centres of Ref Hole A and Ref Hole B. The Reference Direction is defined as the line joining the same two hole centres.

The actual location of the Sensor Origin may be up to 0.2mm from the Nominal Sensor Origin 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 Origin. 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 013-0033 includes a connector mounted on the FRONT. Figure 4 shows its location and defines pin 1. 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 Assembled Targets

The 62-42mm Type 6.7 Rotary Sensor is designed to work with an inductively coupled resonant target comprising 4 off 20mm Transponder Coils LX1, LX2, LY1 and LY2 connected to capacitance CRES as illustrated in Figure 5.

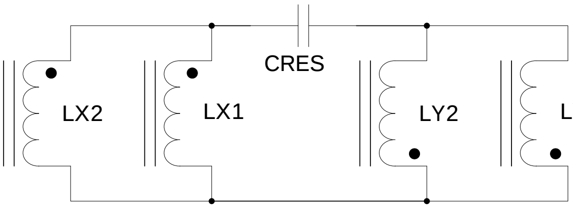

Figure 5 Schematic for target

Resonant frequency, Fres, should usually match the Nominal Operating Frequency of the CTU chip processing the sensor. Fres given by Equation 1, where LRES is the inductance of the transponder coils and CRES is the total resonating capacitance.

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

Equation 1

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.

To function correctly with the 62-42mm Type 6.7 Rotary Sensor and deliver the specified performance, locations and angles of the Transponder Coils must be as illustrated in Figure 6, and they must be mounted flush with the target PCB.

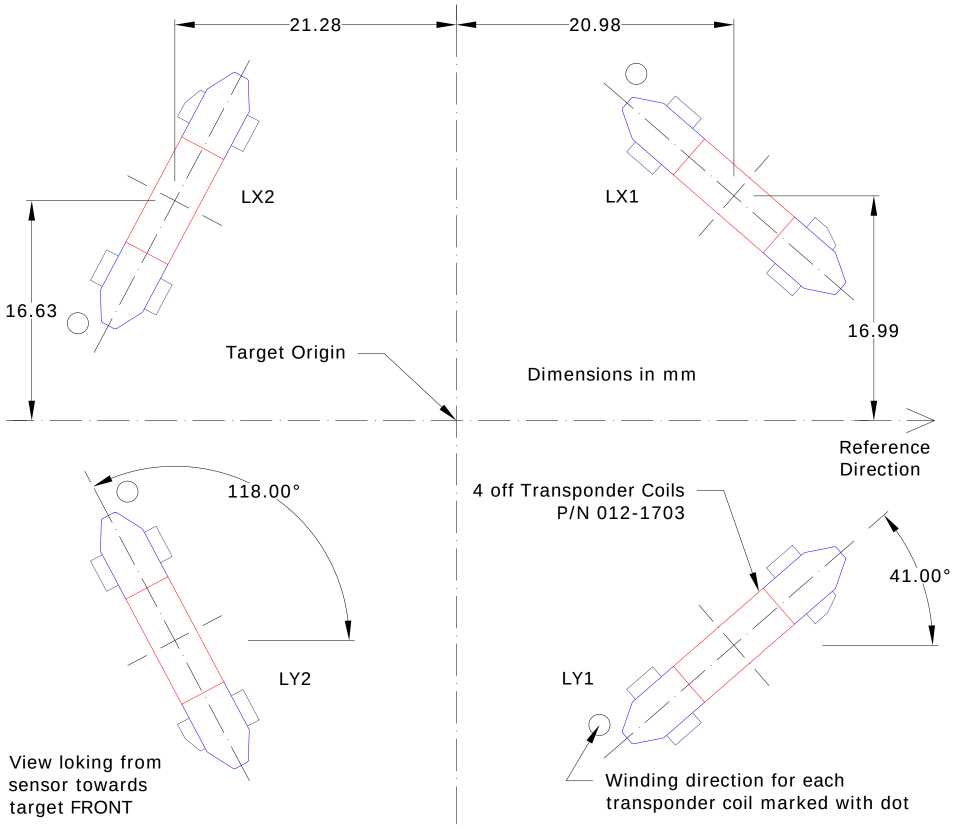

Figure 6 Transponder Coil locations

The winding direction of transponder coils is marked with a dot in Figure 5 and Figure 6, and it is essential that the parts are connected 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. Assembled targets are also available from CambridgeIC, as shown in Figure 2. The mechanical design of assembled targets is illustrated in Figure 7.

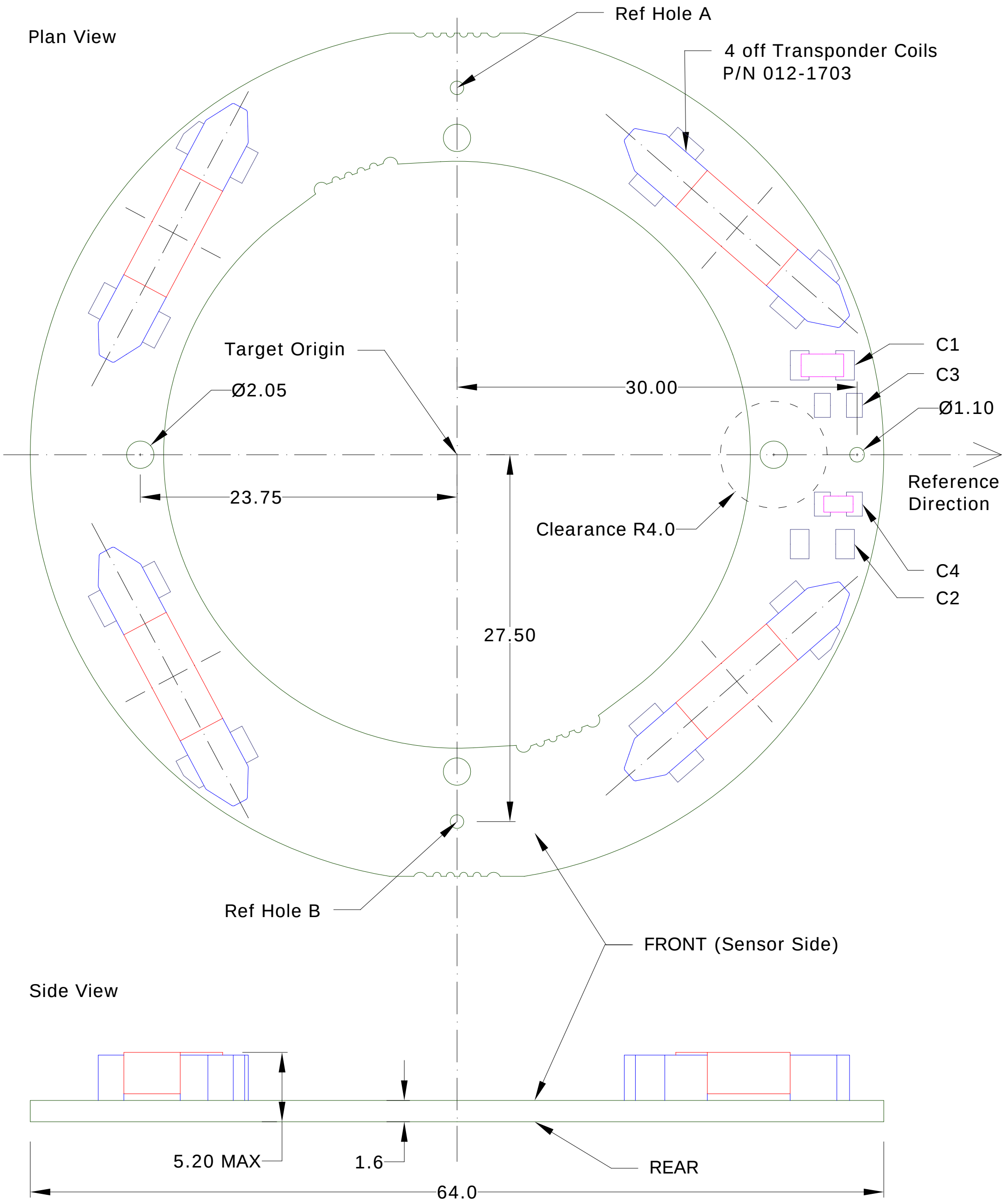

Figure 7 Assembled Target mechanical design

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 4 mounting holes towards the inner radius of the assembled target, and an additional hole shown to the right that helps identify the Reference Direction when viewed from the REAR of the part.

Assembled targets may be fitted with different values of capacitors for compatibility with different metal environments, and their corresponding part numbers are shown in Table 3.

Table 3 Assembled Targets available

Part Number	**013-1018**
Fres, free space	177.0kHz
Fres tolerance, 20°C	±4%
Fres tolerance, -40°C to +125°C	±6%
Comments	For integration near aluminium, for example as in Figure 19. Aluminium increases Fres for compatibility with CAM204/CAM502 CTU chips.

3 Principle of Operation

The 62-42mm Type 6.7 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.

3.1 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 inside 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 3.3. The CTU circuit connected to the sensor detects the coupling factors and uses them to determine position.

The resonator comprises 4 wound transponder coils positioned symmetrically around the sensor, shown in Figure 6. This balanced arrangement is for immunity to misalignment, see section 3.4.

3.2 Electronic Interrogation

The 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 3.3.

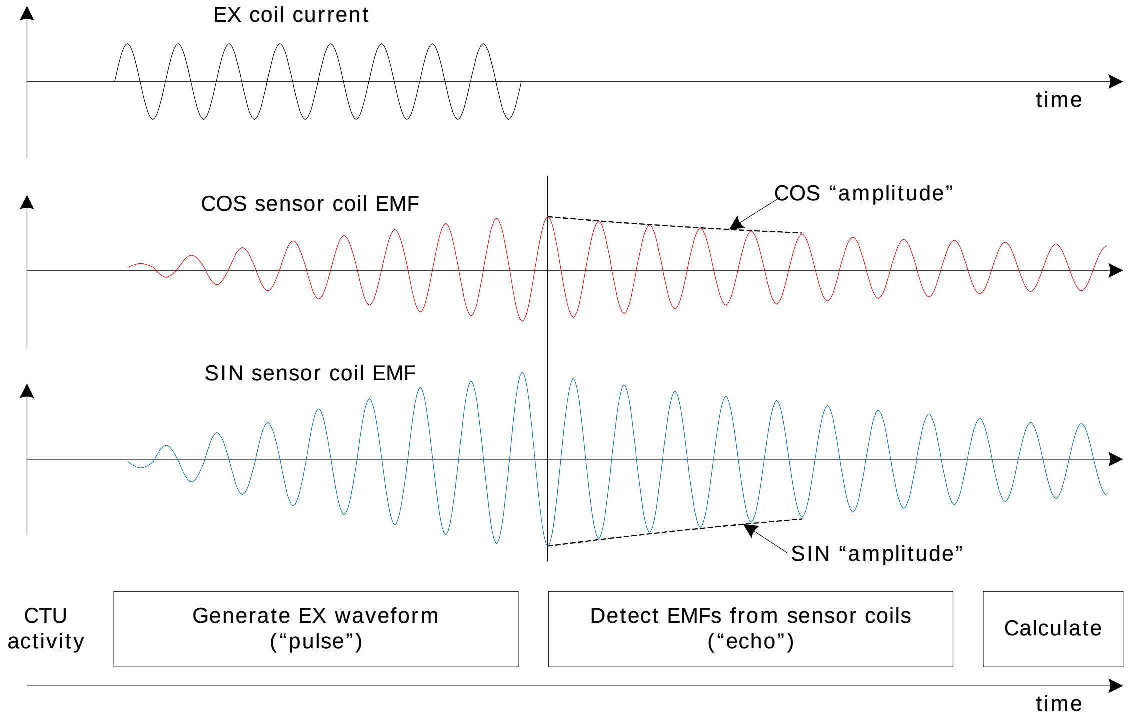

Figure 8 Electronic interrogation process

3.3 Sensor Coils and Position Calculation

Section 3.2 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 9 is a simplified illustration of the sensor board's excitation coil (EX) and the target's transponder coils. The CTU circuit energises the target by driving a current in the EX coil. This generates a magnetic field which is positive ("+") outside the inner loops, and negative ("-") inside. The target's transponder coils lie across the excitation coil, angled so that excitation field flows through them from the inside to the outside of the sensor. The ends of the transponder coils are thus magnetised by the excitation field, with the inner portions of the transponder coils having negative polarity and the outside having positive polarity. The coupling between the excitation coil and the target's transponder coils is uniform with Actual Angle, so that the target is uniformly powered irrespective of angle.

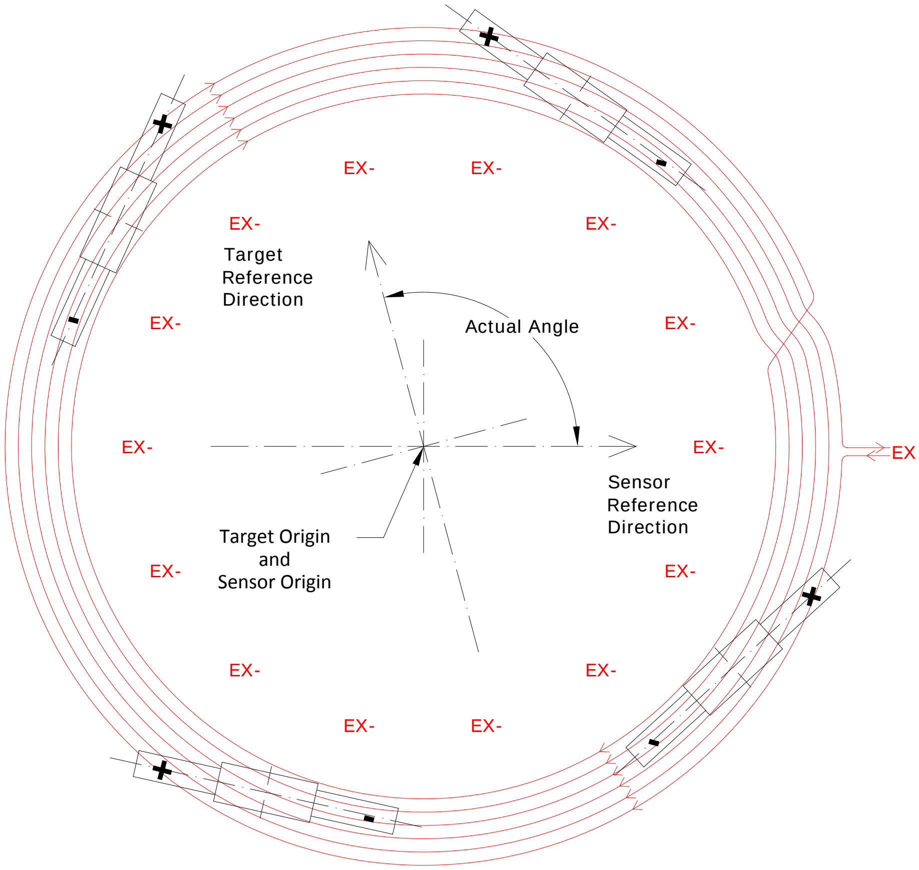

Figure 9 EX Coil, simplified

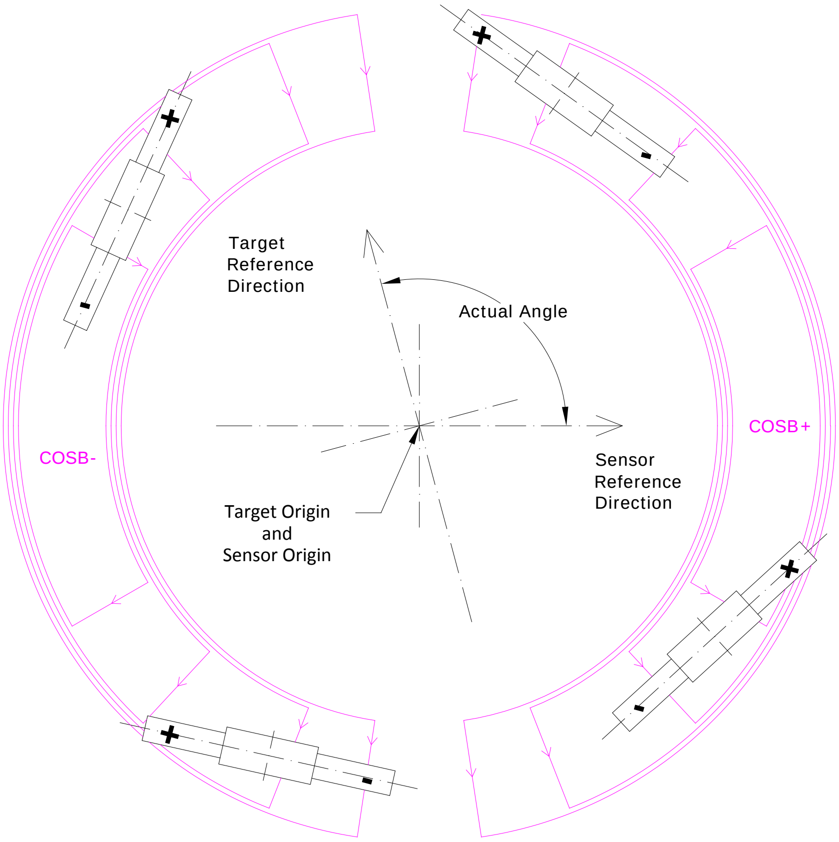

Figure 10 COSB coil, simplified

A simplified version of the COSB coil is shown in Figure 10 together with the target's transponder coils. 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 12. 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°.

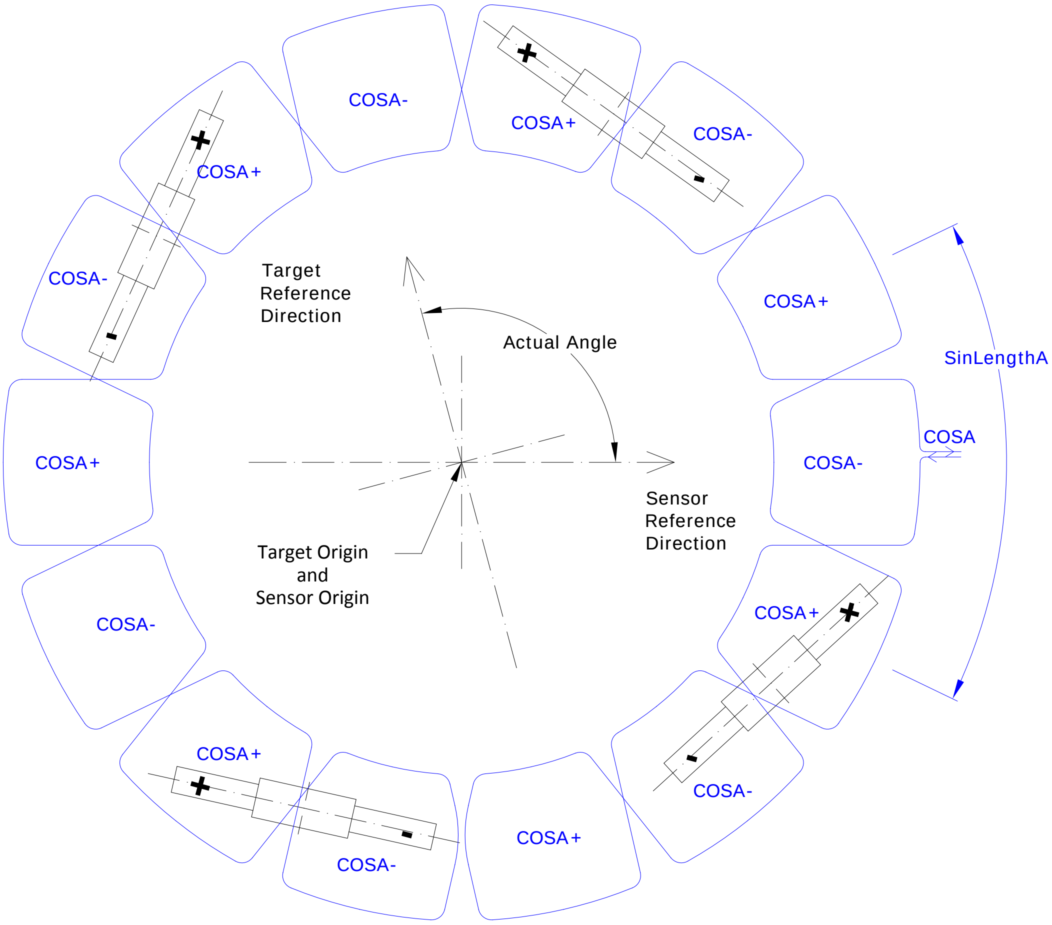

Figure 11 COSA coil, simplified

The COSA fine sensor coil is shown simplified in Figure 11. It is patterned for sinusoidal variation in coupling with angle, but this time with 7 sinusoidal repeats per 360° (SinLengthA = 360°/7 = 51.42857°). This number, 7 sinusoidal repeats per circle, is the sensor's Subtype.

At the Actual Angle illustrated in Figure 11, the signal amplitude measured in the COSA coil is positive, since the + ends of the transponder coils are close to the COSA+ lobes, and the – ends of the transponder coils are close to the COSA- lobes.

The SINA coil, not shown, is the same design but rotated by 1/28th of a circle, so that kSINA varies in phase quadrature with kCOSA, as shown in Figure 12. kSINA is close to zero at the angle illustrated since the + and - ends of each transponder coil are approximately mid-way between SINA+ and SINA- lobes.

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 7 times (SinLengthA = 360°/7). 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".

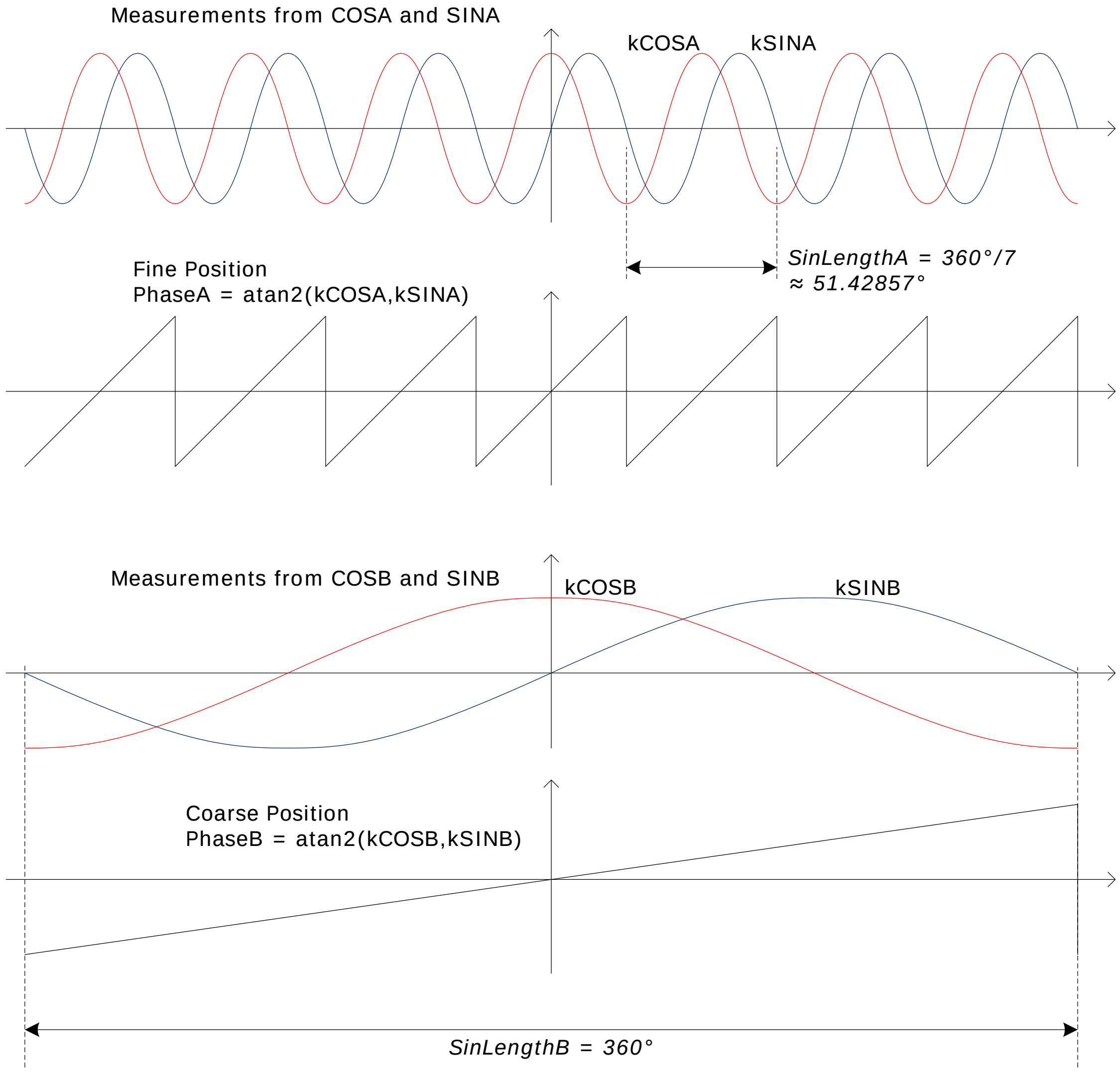

Figure 12 sensor coil coupling factors and position calculation for Type 6.7 sensor

3.4 Immunity to Misalignment

The target described in section 2 comprises 4 transponder coils arranged around the Sensor Axis. This makes the system largely immune to Radial Misalignment between the Target Origin and Sensor Origin. The reason for this immunity is illustrated in Figure 13. This illustrates the target's transponder coils viewed towards the sensor, flipped 180° about the x-axis relative to Figure 6. When misaligned (dashed transponder coils), the effective angles of transponder coils Y1 and Y2 decrease (dAY1, dAY2 clockwise) while the effective angles of transponder coils X1 and X2 increase (dAX1, dAX2 anticlockwise). The sensor and target are designed so that the increases and decreases largely cancel, irrespective of the Actual Angle and the direction of radial misalignment. This cancellation is aided by changes in the relative amplitude contributions of the outer and inner ends of the transponder coils with radial misalignment.

The system does not independently measure the effective angle of each transponder coil; by design it measures the average of the four because they are all connected together as in Figure 5.

The effect of Radial Misalignment is greater in the presence of angular misalignment between the target and Sensor Axes, in the AYr direction (AYr is defined in Figure 14). In this case transponder coils X2 and Y2 are no longer the same distance to the sensor as X1 and Y1, so that their relative contributions to the system's angle measurement are no longer equal and the cancellation of angle shifts is longer so precise. This is why the sensor's performance is determined in the presence of both radial and angular misalignment to yield practical, worst-case figures (Table 1, section 5).

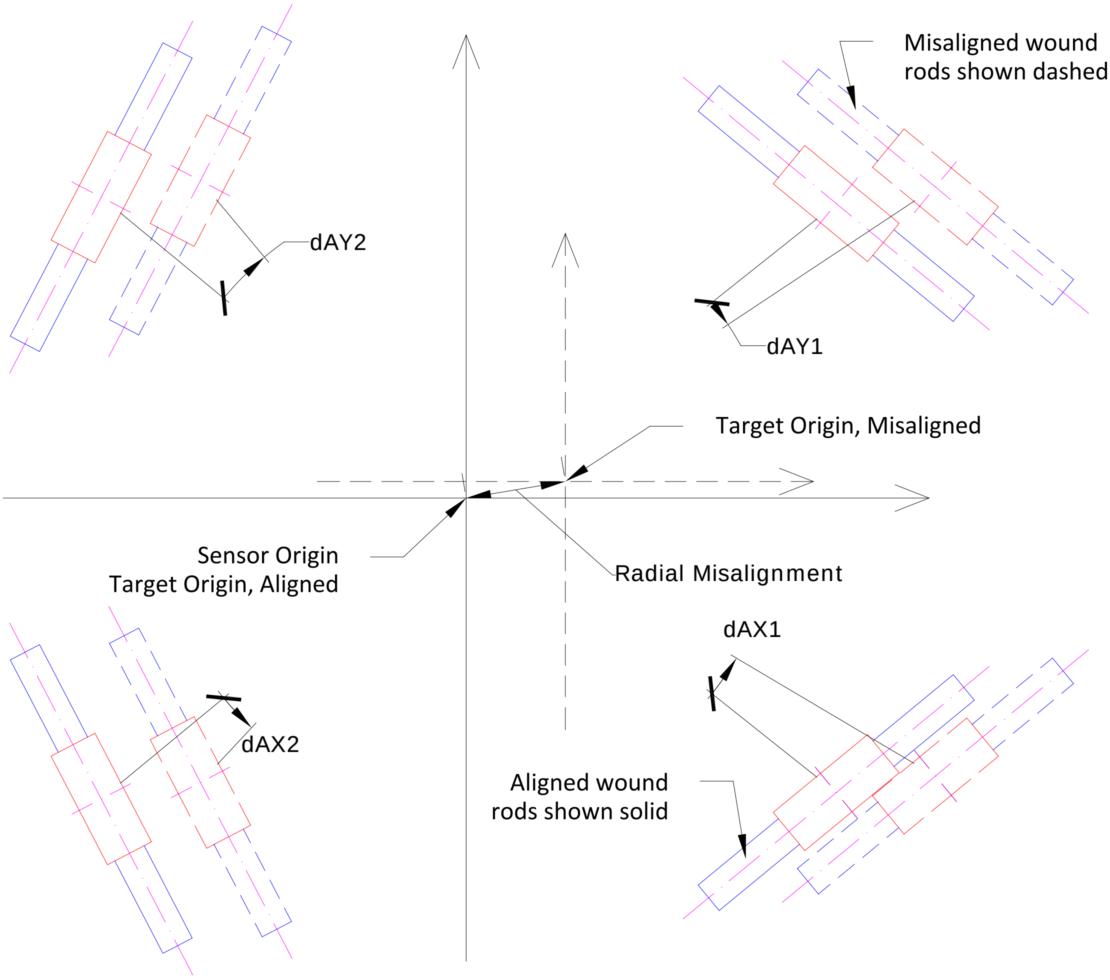

Figure 13 Immunity to misalignment (excessive misalignment for clarity)

Radial Misalignment causes a larger change in coarse position, since the coarse sensor coils are not balanced to the same extent. However this has 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. However very large misalignments can cause errors in reported position readings (section 5.4), and the sensor and target should be mounted to avoid these extremes.

4 Definitions

4.1 Coordinate System

The sensor system measures the angle of a target relative to a sensor. The Target Reference Direction is the symmetry axis of the target shown in Figure 6 and Figure 7. 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 denoted Actual Angle below.

The sensor's X Axis coincides with the Sensor Reference Direction, and its Y-Axis is orthogonal and in the plane of the sensor. The Z-Axis is orthogonal to X and Y Axes.

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. Xr and Yr are in the plane of the FRONT of the Target PCB, which is the seating plane of the transponder coils. Tilt of the target relative to the sensor is defined about Xr and Yr. It is convenient to define tilt about the target axes, since the effect of angular misalignment in the AXr direction is significantly smaller than in the AYr direction. References to Angular Misalignment below are therefore in the AYr direction, so that the worst case is presented.

Radial Misalignment is the distance between the Target Origin and Nominal Sensor Origin, measured in the plane of the sensor PCB.

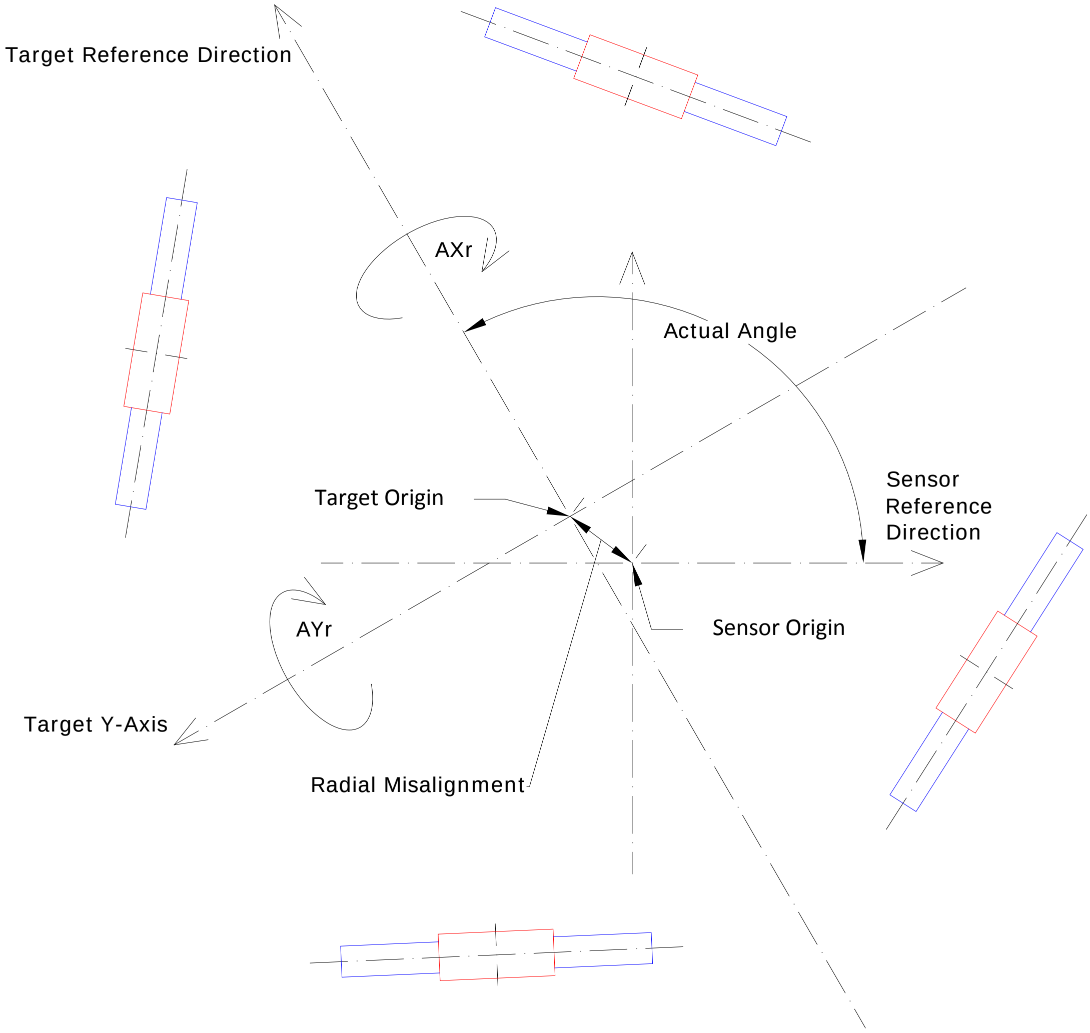

Figure 14 Coordinate System

4.2 Gap Definition

Figure 15 shows how Gap is defined. It is the 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.

Side View of Sensor PCB and Target

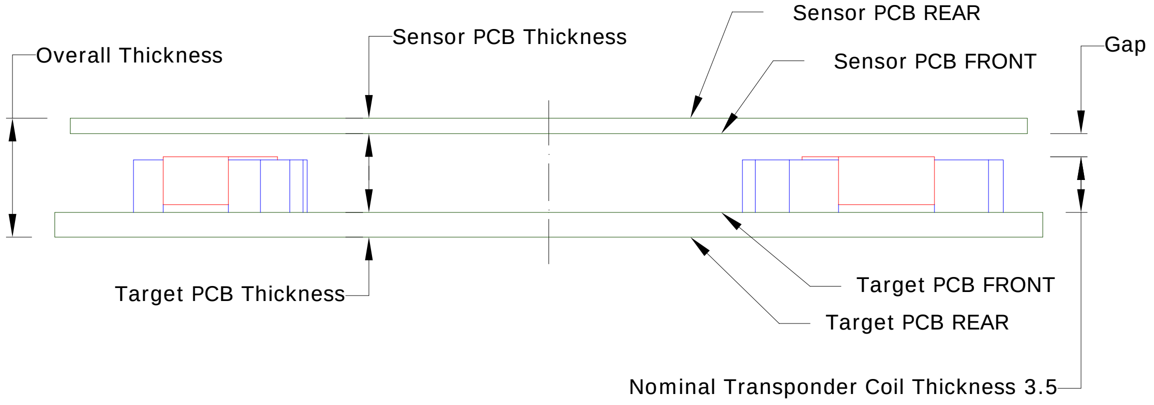

Figure 15 Definition of Gap

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 360°/7 = 51.42857°. The reported position may be converted to degrees using:

$$Reported\ Angle\ in\ Degrees = \frac{CtuReportedPositionI32}{65536} \times \frac{360°}{7}$$

Equation 2

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 3

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 4

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 5

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 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 layer 1 copper relative to the holes defining the Sensor Reference Diretion.

5 Performance, Free Space

Figures below are typical of assembled sensors as described in section 1 operating with assembled targets described in section 2, and sensors and targets built to the same specifications. They are taken with typical Type 6 CAM204 CTU circuitry (see CTU datasheet, grade A components), at room temperature and in free space unless otherwise stated. Sensors and targets are mounted flush against a flat surface for test purposes.

Measurements are presented as a function of Gap, which is defined in Figure 15.

5.1 Linearity Error

Linearity Error is defined in section 4.5. It is minimised when there is no Radial or Angular Misalignment. Figure 16 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.

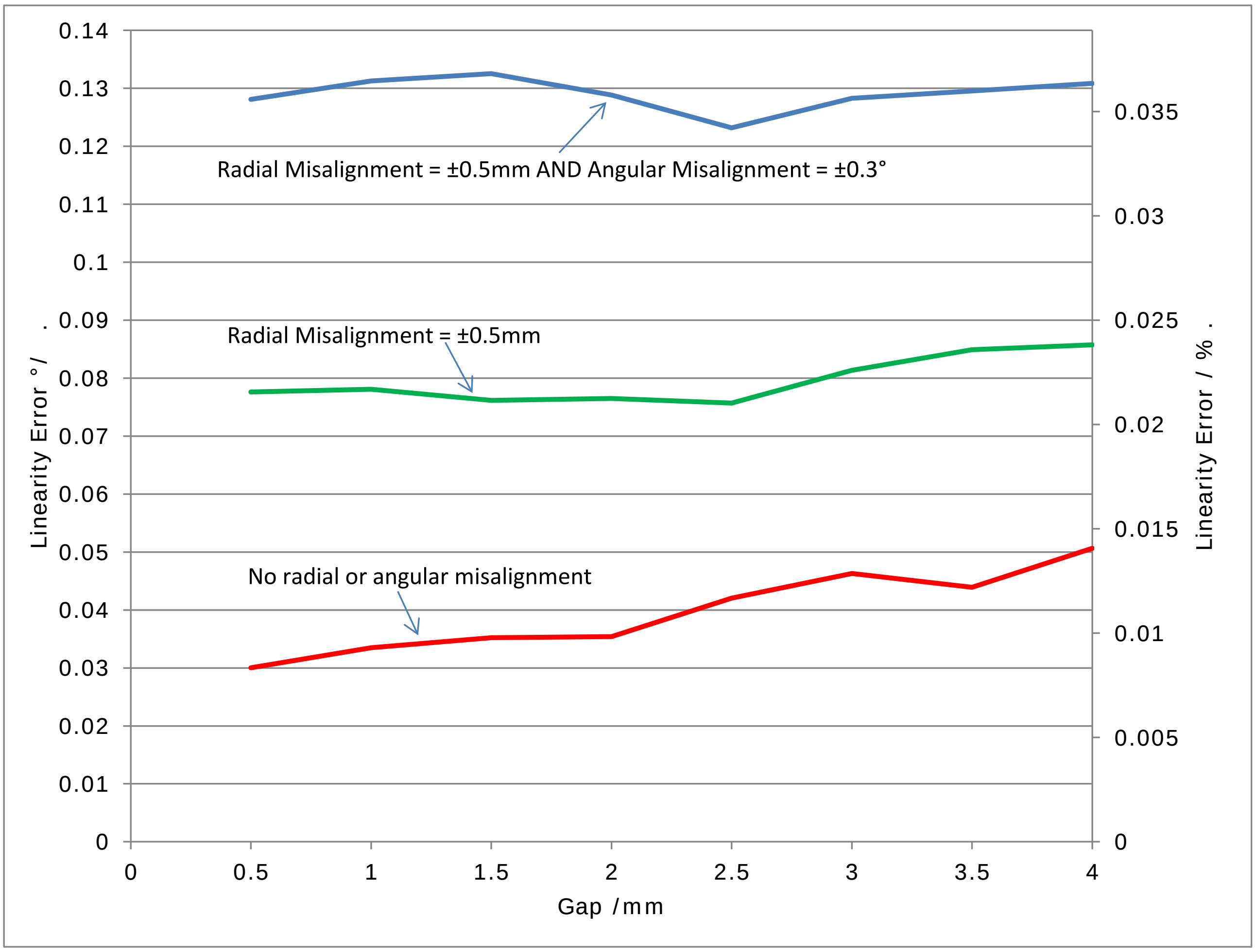

Figure 16 Linearity Error as a function of Gap and misalignment

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 17. Amplitude also reduces with the presence of nearby metal, and sensor installations should be checked to ensure any reduction is not excessive. Amplitude also reduces at high temperature.

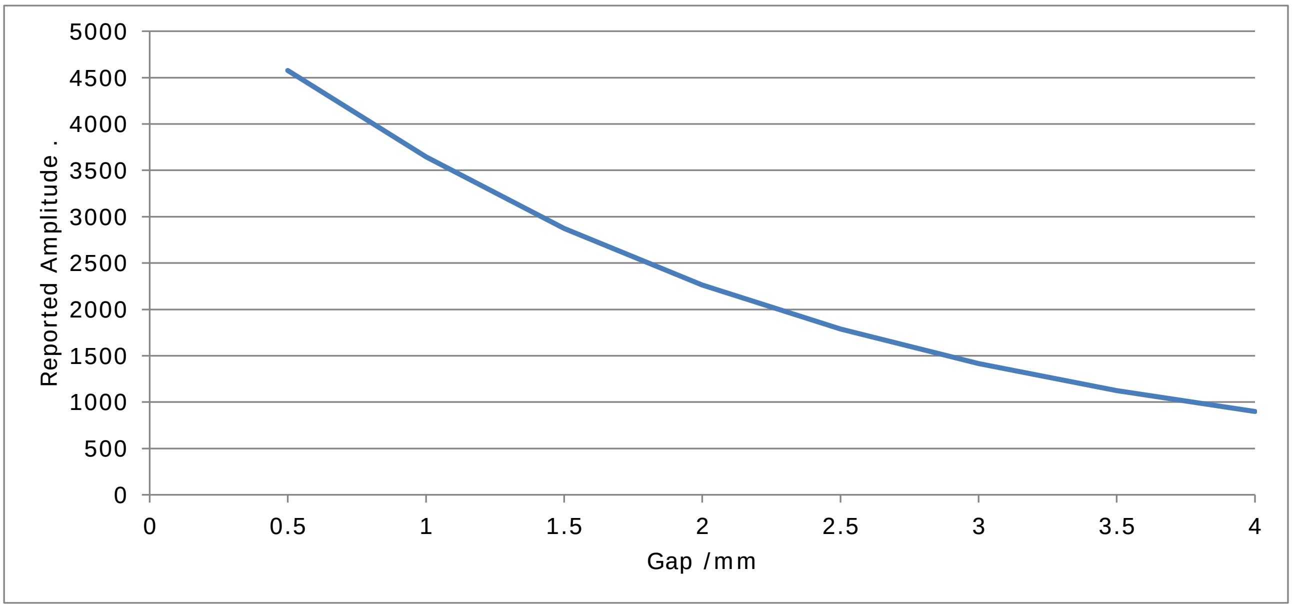

Figure 17 Minimum Reported Amplitude as a function of Gap, free space

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 18.

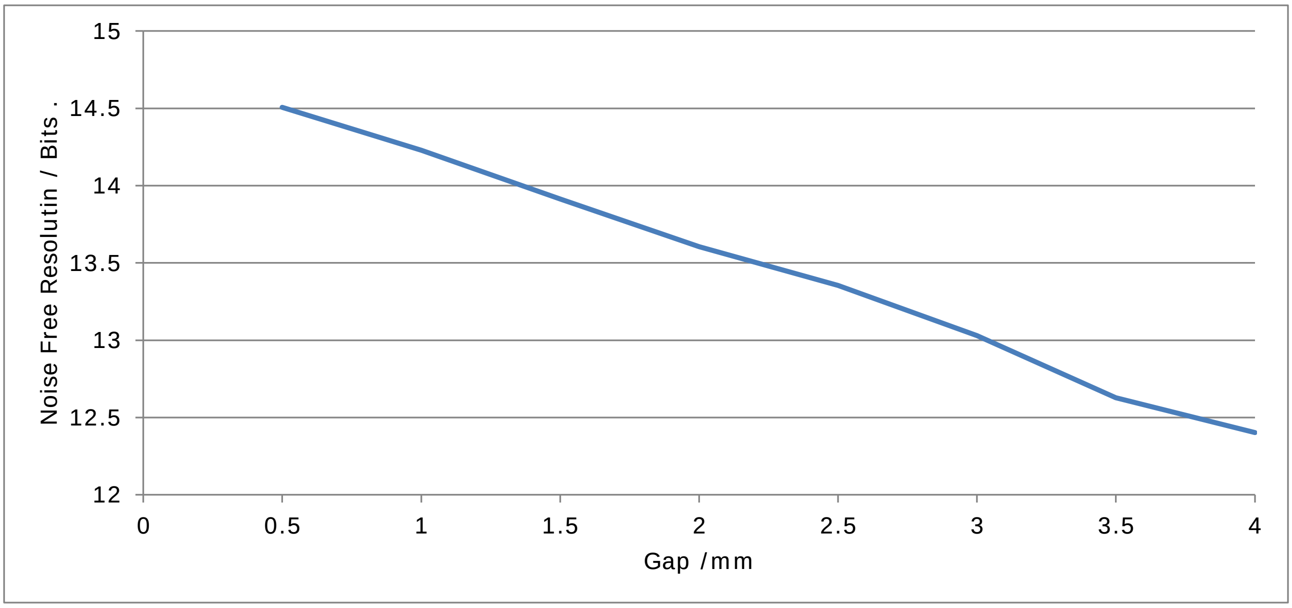

Figure 18 Noise Free Resolution as a function of Gap, CAM204 CTU chip, free space

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 Maximum Misalignment

The sensor will report angle correctly even when the target and sensor are badly misaligned. Table 4 shows the maximum allowable misalignments, and the resulting maximum linearity error. If radial or angular misalignment exceeds these values, for example when held by hand during demonstration, reported position may become nonsensical.

Table 4 Maximum misalignment between target and sensor, Free Space

Parameter	**Maximum**
Radial Misalignment	1.0mm
Angular Misalignment	0.8°
Gap	3.5mm (CAM204 CTU chip) 2.5mm (CAM502 CTU chip)
Linearity Error at max alignments	0.5°

6 Metal Integration

The 62-42mm Type 6.7 Rotary Sensor and target may be integrated near metals, but care must be taken to ensure the metal does not reduce Amplitude excessively, or cause resonator frequency to shift outside the tuning range of the selected CTU chip.

Small pieces of metal, for example screws up to M3, can be placed as close as 2mm to the sensor's printed coils and the target's transponder coils. Larger pieces should be tested for compatibility, by observing the Amplitude and frequency reported by the CTU chip in an experimental set-up.

Larger pieces of metal near the sensor and target have only a small effect on linearity providing they are rotationally symmetric about the rotation axis.

6.1 Screening Steel with Aluminium

Steel and stainless steel tend to reduce Amplitude significantly more than aluminium. For operation near steel and stainless steel, it is usually preferable to clad these materials with aluminium sheet, which should be at least 0.1mm thick.

6.2 Aluminium Integration Example

Figure 19 shows an example of how the sensor and target may be integrated with aluminium components. The target is mounted directly to aluminium, the sensor is mounted a small distance above aluminium, and a 38mm diameter aluminium tube passes through both.

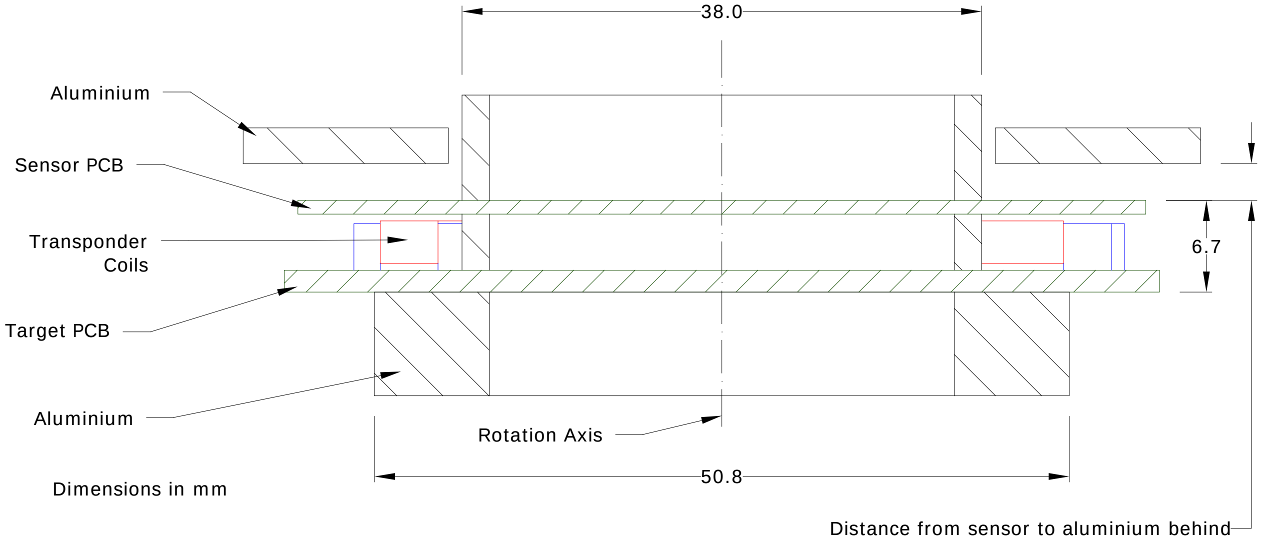

Figure 19 Aluminium integration example

Figure 20 shows how Amplitude depends on the distance between the sensor and aluminium behind for the arrangement of Figure 19. The closer the aluminium, the greater the reduction in Amplitude. At 3mm, a 20% reduction in Amplitude causes approximately 0.3 bits reduction in Noise Free Resolution.

Figure 21 shows how Frequency depends on the distance between the sensor and aluminium behind for the arrangement of Figure 19. Frequency increases as distance is reduced. At 3mm the increase in frequency is 7%. When this increase is applied to the nominal frequency and combined with the frequency tolerance, the resulting frequency range must lie within the chosen CTU chip's Tuning Range. The target's resonator frequency Fres may be modified with changes to tuning capacitance CRES according to Equation 1. Assembled targets are available with the standard free space nominal frequencies shown in Table 3.

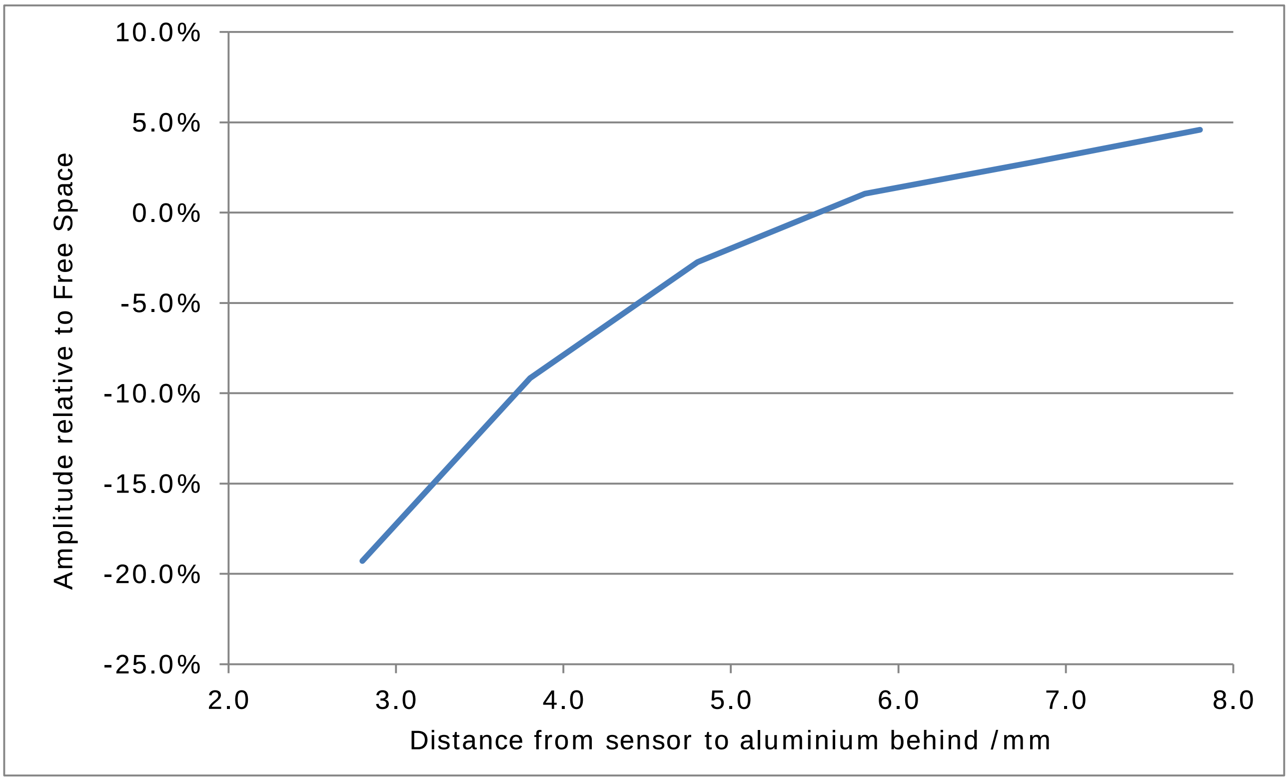

Figure 20 Effect of aluminium on Amplitude as a function of distance

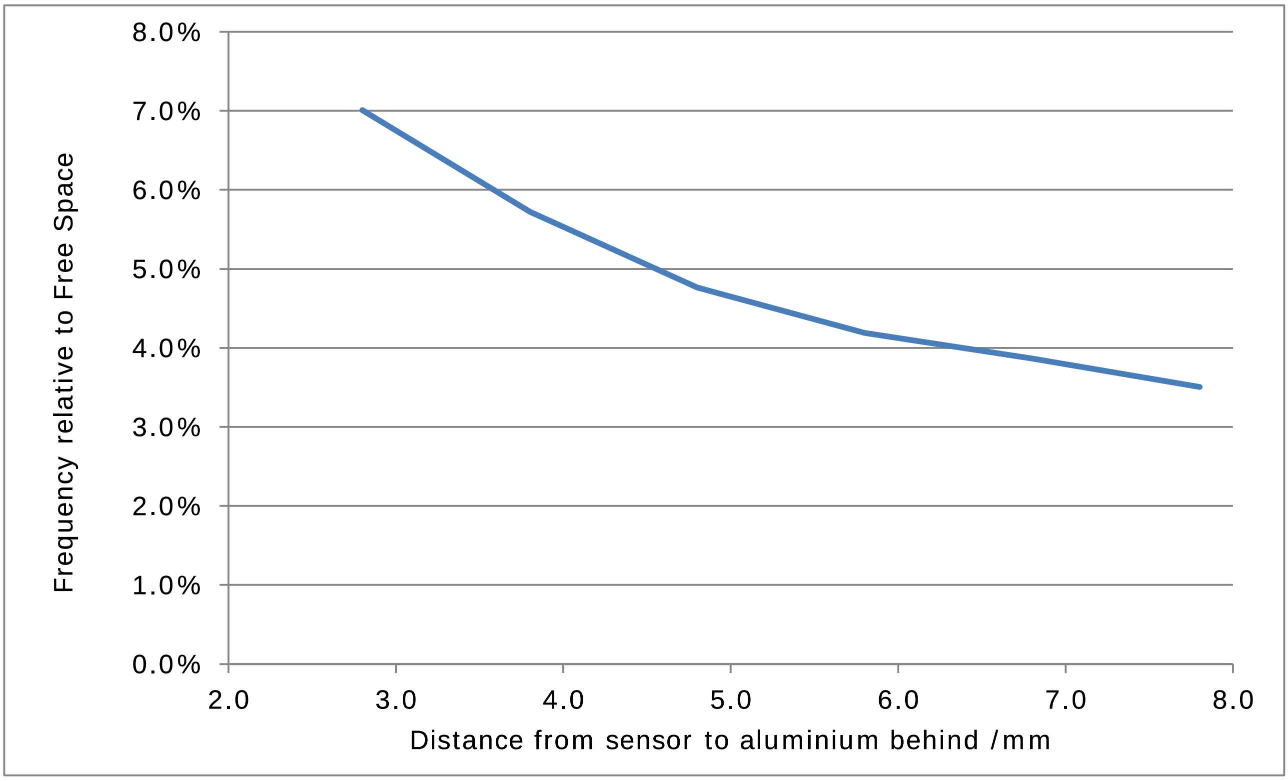

Figure 21 Effect of aluminium on frequency as a function of distance

7 Sensor Blueprint 010-0095

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 4-layer PCB. Recommended copper thickness is shown in Table 5.

Table 5

Copper thickness	oz	µm
Minimum	0.8	28
Recommended	1	35

7.3 PCB Design Parameters

Table 6

PCB Design Rules	Minimum values used	
	mm	inches
Track width	0.160	0.0063
Gap between tracks	0.159	0.0063
Via land outer diameter	0.640	0.025
Drill hole diameter	0.30	0.012

7.4 PCB Integration

Figure 22 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 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. Note that the FRONT of the sensor PCB (layer 1 copper) must face the target.

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

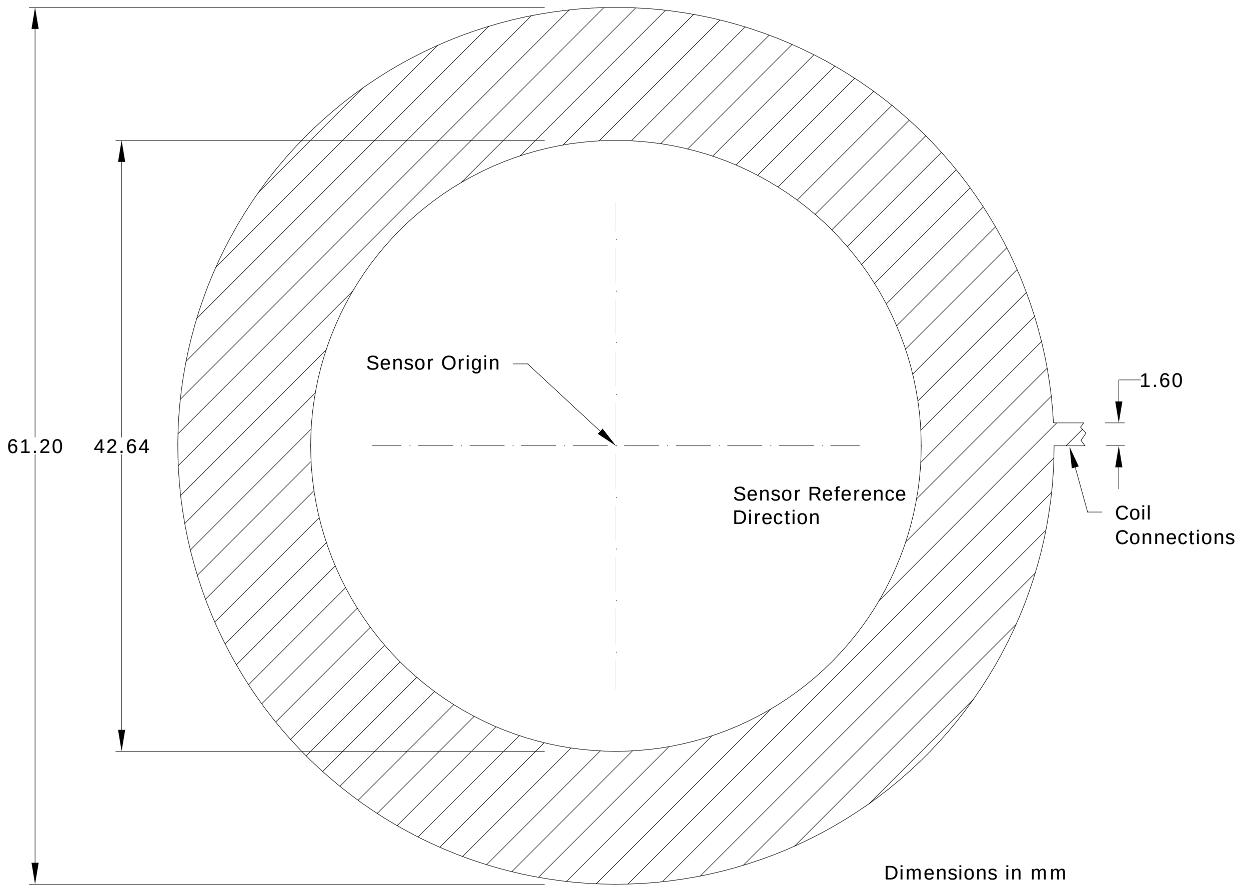

Figure 22 Sensor Blueprint Copper Extent

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

8 Environmental

Assembled sensor part number 013-0033 conforms to the following environmental specifications:

Item	**Sensor PCBs**	**Assembled Targets**	**Comments**
Minimum operating temperature	-40°C	-40°C	Sensor limited by the connector
Maximum operating temperature	85°C	+125°C	
Maximum operating humidity	95%	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 013-0033 is in compliance with EU RoHS, China RoHS and Korea RoHS.

10 Document History

Revision	**Date**	**Comments**
0001	16 January 2015	First draft based on datasheet 033-0043 for sensor assembly 013-0029, which describes a similar sensor but with 44mm ID and lower Amplitude

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12 Legal

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The design of the sensor, comprising each of the patterned copper layers, drill locations, silk screens, assembly layers and board outline are protected by copyright.

The parts described in this datasheet are subject to the following patents: US8570028, GB2461448 and GB2488389. Other patents are pending.