30mm B3 Precision Rotary Sensor

Description

A resonant inductive position sensor and target for measuring full absolute angle across 360°. The sensor connects to a Resonant Inductive Encoder IC such as the CAM622 to provide high-quality position and velocity data to a host device.

The sensor design includes two pairs of PCB coils for detecting the target. Fine coils provide high accuracy and resolution and repeat 3 times around 360°. Coarse coils repeat once around 360° for full absolute measurement of angle.

The matching non-contact target design includes a PCB printed resonator coil and SMD capacitor(s). These form a resonant circuit, powered without electrical contact by the sensor's excitation coil. The resonator coil design is patterned to minimise the effect of misalignments on reported angle.

The sensor and target are Type "B3". "B" refers to the resonator frequency band centred on 833kHz. "3" is the number of fine sensor coil periods per coarse.

This document should be read together with the Type B Sensor Reference Manual.

Features

- Robust, non-contacting, environmentally immune
- Coil patterns fit inside 30mm PCB diameter
- 13.6mm centre hole to take shafts up to 13mm OD
- Sensor PCB built on 4 PCB layers, target on 6
- Up to 17 bits of noise free resolution with CAM622 depending on gap, environment, filter level
- PCB Gerbers available to customers

Alignment	Typical Linearity
1mm gap, aligned	±0.05°
0..2.5mm gap, ±0.3mm radial misalignment, ±0.3° tilt	±0.1°

Product identification	
Part no.	**Description**
010-0162	Sensor PCB Design
010-2003	Target PCB Design
013-0069	Sensor Assembly, Rear Connector
013-1040	Target Assembly, 840kHz
013-6017	6-way 60mm PicoBlade Sensor Cable

Applications

- High-speed closed loop motion control
- Traction motor velocity feedback and commutation
- Pan and tilt sensing for surveillance cameras
- Valve position sensing
- Optical Encoder replacement (more robust)
- Magnetic encoder replacement (more performance)

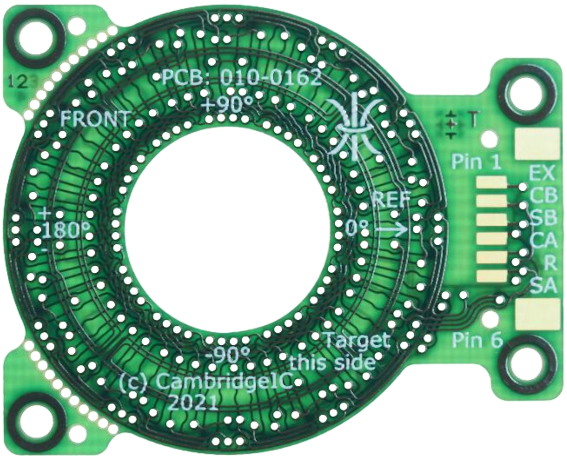

Figure 1 Sensor PCB 010-0162 Front

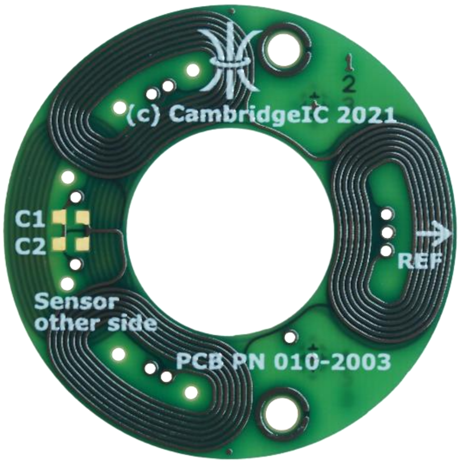

Figure 2 Target PCB 010-2003 Front

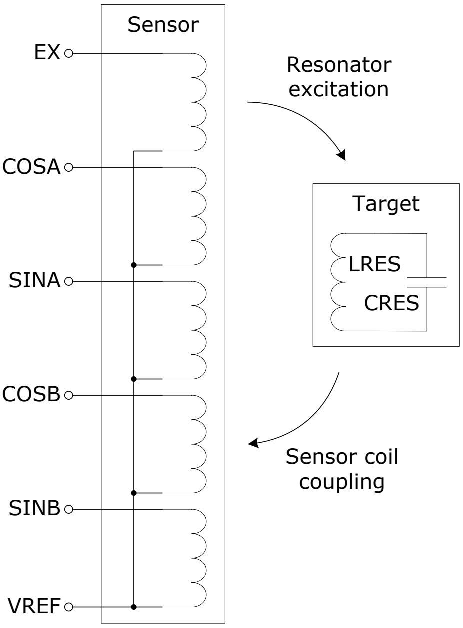

Figure 3 equivalent circuit

1 Sensor Design

A sensor assembly is available for evaluation and early prototyping. The sensor PCB design is also available as Gerber and Altium files, to allow customers to have their own parts built for production. Customers may modify the PCB design, for example how it is mounted, the connection scheme and board outline. Customers may also integrate the sensor design onto their own processor PCB, so that it shares the PCB with other electronics.

1.1 Assembled Sensor Part 013-0069

Figure 4 is a dimensioned drawing of the 30mm B3 Precision Rotary Sensor Assembly part number 013-0069. This comprises PCB part number 010-0162 with a MOLEX 53261-0671 connector mounted on the REAR.

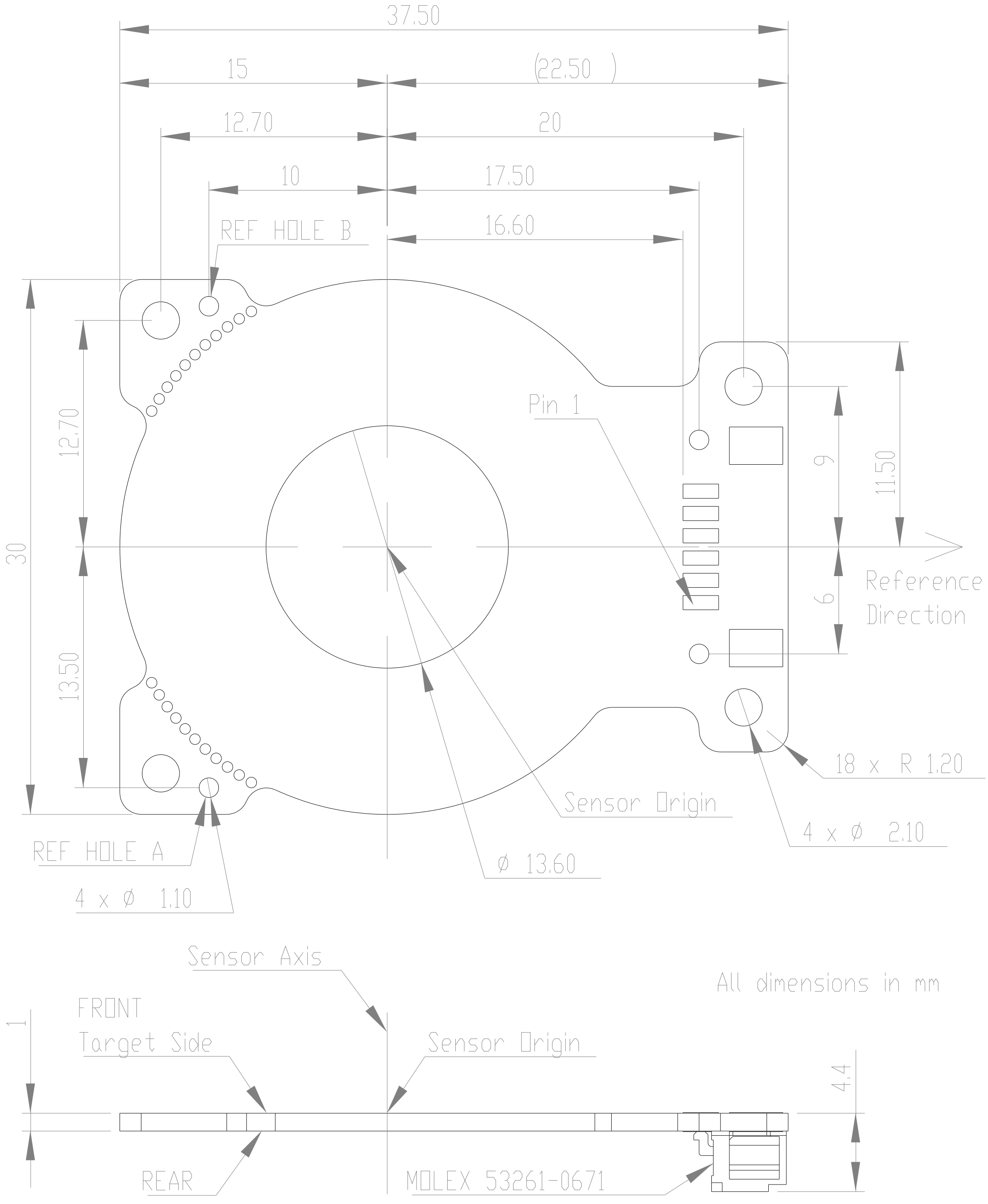

Figure 4 Assembled Sensor 013-0069

The target must be positioned adjacent to the Sensor's Front. This is the opposite side to the connector in Sensor Assembly 013-0069.

The Sensor Reference Direction is defined as perpendicular to a line joining REF Holes A and B. The Sensor Origin is defined as 10.00mm to the right of their midpoint in the plane of the Front surface. The Sensor Axis is defined as perpendicular to the Sensor PCB through the Sensor Origin.

The accuracy of the sensor is at its best when the radial misalignment between the Sensor Origin and the rotation axis is minimised. For best alignment with a customer's hardware, it is recommended to align the sensor assembly using 1.0mm dowel pins through REF Holes A and B.

The connector's location, orientation and the pin 1 position are shown in Figure 4. Table 1 shows signal names and their pin allocations. The same pinout applies to connector footprints on both the Front and Rear. Only the rear connector is fitted in Sensor Assembly 013-0069.

Table 1 Sensor Assembly electrical connections

Pin no	Signal name
1	SINA
2	REF
3	COSA
4	SINB
5	COSB
6	EX

1.2 Sensor PCB Design and Customisation

Sensor PCB design 010-0162 is built on 4 PCB layers, each with 35µm copper ("1oz per square foot"). It includes a Sensor Coil Area illustrated in Figure 5. PCB features inside the hatched area must not be modified when a customer adapts the design to their own application. There is no available space for adding mounting or registration holes to the hatched area.

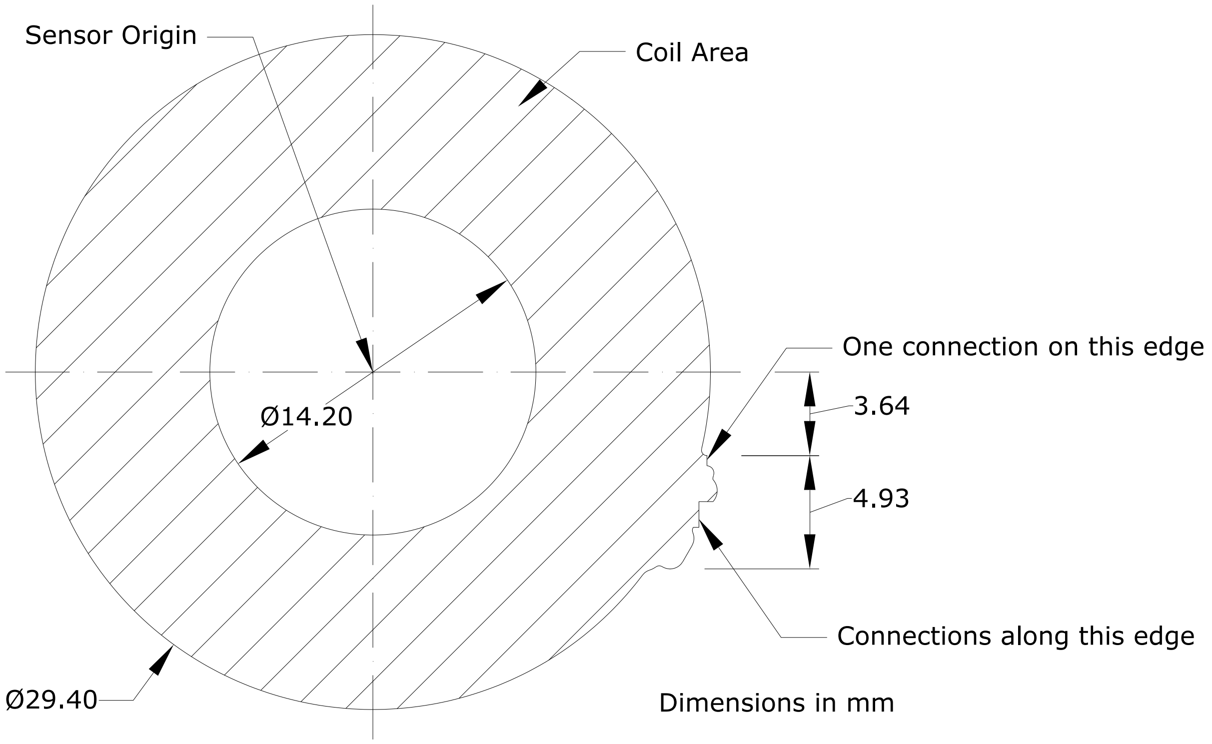

Figure 5 Sensor Coil Area and connections

The sensor PCB design includes connector footprints on the Front and Rear of the PCB, both with the same pinout shown in Table 1. If a customer wishes to modify how the sensor coils are connected to processing circuitry then these connectors and their connecting traces may be removed, up to the point they enter the hatched area. This will leave a set of traces having end coordinates and functions shown in a table in the sensor PCB's AssemblyInfo Gerber file.

The target must be positioned adjacent the Sensor PCB's Front, which may be identified by the ident text "Target this side" on the top silk layer, and is adjacent copper layer 1.

Table 2 lists the design rules used for the sensor PCB.

Table 2 Sensor PCB design rules

Minimum values used	**mm**	**inches**
Track width	0.16	0.0063
Gap between tracks	0.16	0.0063
Via land outer diameter	0.64	0.0252
Drill hole diameter	0.3	0.012

The Sensor PCB design includes an assembly layer with specification tables, and those specifications must be met in order for the sensor to work with the performance specified in this datasheet.

2 Target Design

A target assembly is available for evaluation and early prototyping. The target PCB design is also available as Gerber files, to allow customers to have their own parts built for production. Customers may modify the PCB design, for example how it is mounted, the board outline and the location and diameter of holes for alignment and balancing.

2.1 Assembled Target Part 013-1040

Figure 6 is a dimensioned drawing of the 30mm B3 Precision Rotary Target Assembly part number 013-1040. This comprises PCB part number 010-2003 with up to two capacitors mounted on the FRONT.

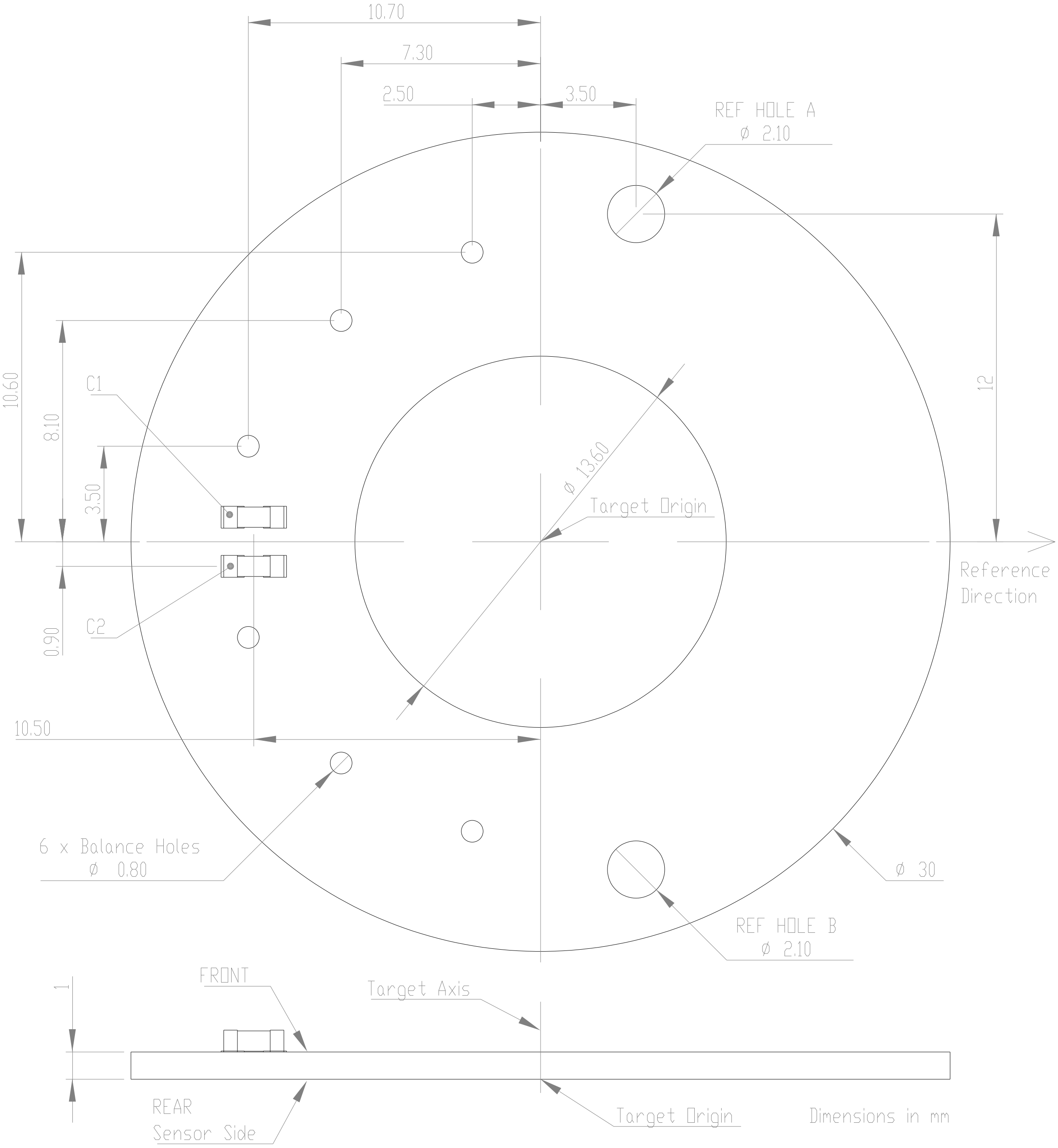

Figure 6 Assembled Target 013-1040

The sensor must be positioned adjacent the Target's Rear, which is the opposite side to the capacitors.

The Target Reference Direction is defined as perpendicular to a line joining REF Holes A and B. The Target Origin is defined as 2.10mm to the left of their midpoint in the plane of the Rear surface. The Target Axis is defined as perpendicular to the Target PCB through the Target Origin. Note that the large centre hole is routed, and its alignment relative to the Sensor Origin is not as accurate as drilled holes. Where possible drilled holes should be used for alignment relative to the rotation axis.

The accuracy of the system is at its best when the radial misalignment between the Target Origin and the rotation axis is minimised. For best alignment with a customer's hardware, it is recommended to align the target assembly using 2.0mm dowel pins through REF Holes A and B.

Mechanical properties of the assembled target are listed in Table 3.

Table 3 Target Assembly mechanical properties

Parameter	Value	Units	Comments
Mass	1.2	g	Typical
Moment of Inertia	150	$g.mm^2$	Based on PCB inner and outer radii and mass
Static Imbalance	<0.3	g.mm	Calculated based on capacitor mass and location, balance holes and up to 5% PCB thickness variation across PCB

Table 4 lists the specifications for the capacitors fitted in positions C1 and C2.

Table 4 Fitted components

Location	Value	Description
C1	1000pF	200V ±5% COG/NPO capacitor, 0603 footprint
C2	47pF	200V ±5% COG/NPO capacitor, 0603 footprint

These capacitor values yield the frequency specifications given in Table 5.

Table 5 Frequency specifications

Parameter	Value	Comments
Resonant Frequency	840kHz	Free space value, no metal nearby. Matches CAM622 centre frequency.
Resonant Frequency tolerance	±4%	

2.2 Target PCB Design and Customisation

Target PCB design 010-2002 is built on 6 PCB layers, each with 70µm copper ("2oz per square foot"). Design rules for the PCB are shown in Table 6.

Table 6 Target PCB Design Rules

Minimum values used	mm	inches
Track width	0.2	0.0078
Gap between tracks	0.2	0.0078
Via land outer diameter	1.0	0.039
Drill hole diameter	0.5	0.012

The majority of the area of the PCB illustrated in Figure 6 is covered in traces, leaving little scope for adding or moving holes or other features. The main flexibility available is to add PCB area inside or outside the existing board outline. Please review Gerber files to check whether desired modifications are possible.

2.3 Selection of Resonator Capacitor(s)

Table 7 shows the expected nominal value of LRES and its tolerance for PCBs manufactured to design 010-2003.

Table 7 Resonator coil inductance

Parameter	Value	Comments
LRES, nominal	32.9µH	Free Space, based on 1.0mm finished thickness and 0.2mm cores
CSELF	40pF	Approximate self-capacitance
LRES tolerance	±2%	Simulated, based on finished thickness tolerance of ±10%

The capacitor values fitted to Target Assembly 013-1040 are shown in Table 4. The sum of these capacitors plus target PCB self-capacitance CSELF is denoted CRES, the total resonating capacitance. CRES, is resonant with the nominal value of LRES given in Table 7 at the resonant frequency shown in Table 5. This resonant frequency matches the CAM622 IC's centre frequency when the part is in free space far from metal.

Nearby metal affects performance and resonator frequency. Please refer to the Type B Sensor Reference Manual for details of how to select resonator capacitors, especially if the target is mounted near metals.

3 Performance, Free Space

Figures below are representative of assembled sensors part 013-0069 (as described in section 1) and of sensors built to the same specification. Measurements are taken with a typical target 013-1040 (built according to section 2) and CAM622 Circuitry (see 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.

Performance figures in this section are presented as a function of Gap, Radial Misalignment and Angular Misalignment. These terms are defined in the Type B Sensor Reference Manual, together with definitions of Linearity Error, Expected Noise Free Resolution and other terms used to quantify performance.

3.1 Linearity Error

Linearity Error is minimised when there is no Radial or Angular Misalignment. Figure 7 shows how Linearity Error changes with Gap and when misalignments are introduced. The quoted misalignment of ±0.3mm is *in addition* to ±0.1mm of misalignment between the sensor's copper traces and its REF Holes, and ±0.1mm of misalignment between the target's copper traces and its REF Holes.

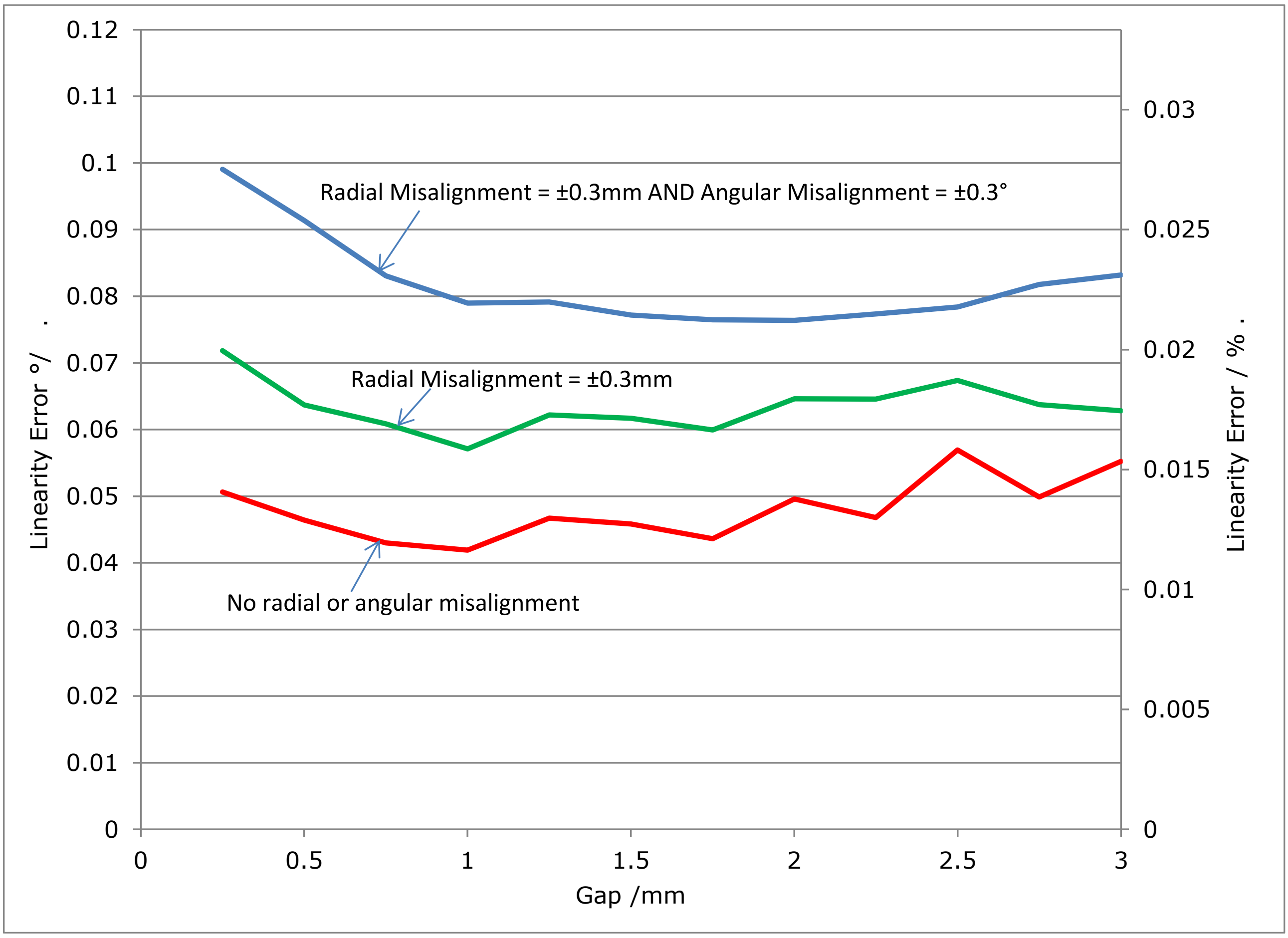

Figure 7 Linearity Error as a function of Gap and misalignment, free space

3.2 Amplitude

Resonant Inductive Encoder ICs report Amplitude over a diagnostic interface. Amplitude is a useful measure of system health, and reduces with Gap as shown in Figure 8.

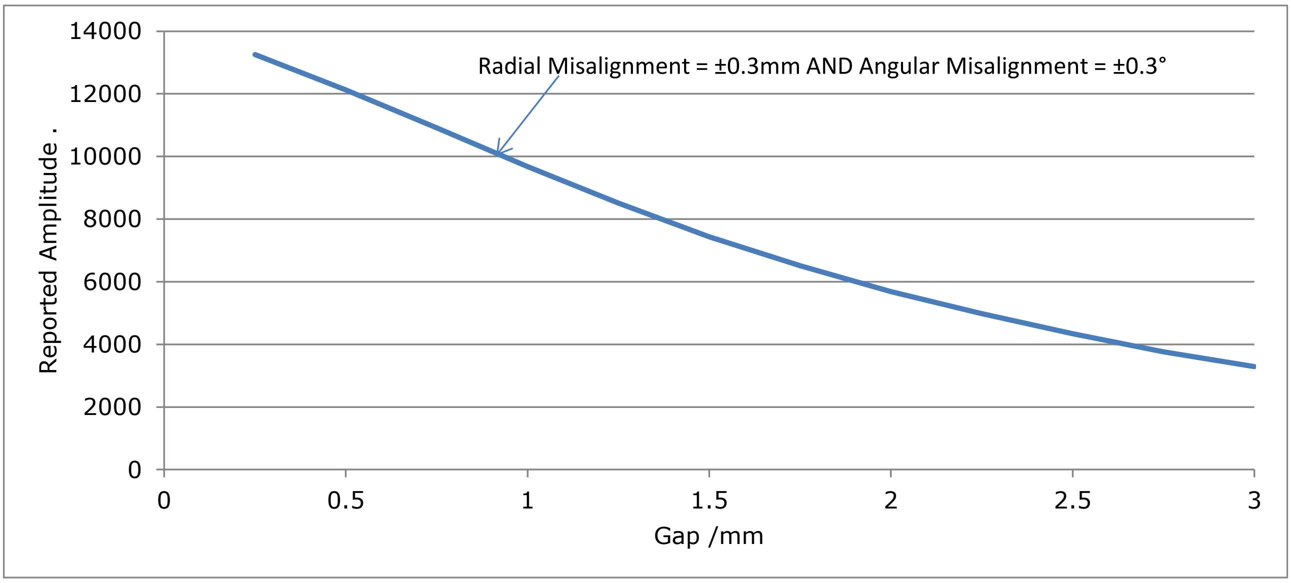

Figure 8 Minimum Reported Amplitude as a function of Gap, free space

3.3 Expected Noise Free Resolution

Expected Noise Free Resolution is a function of Amplitude. It therefore reduces with Gap in a similar way, as illustrated in Figure 9.

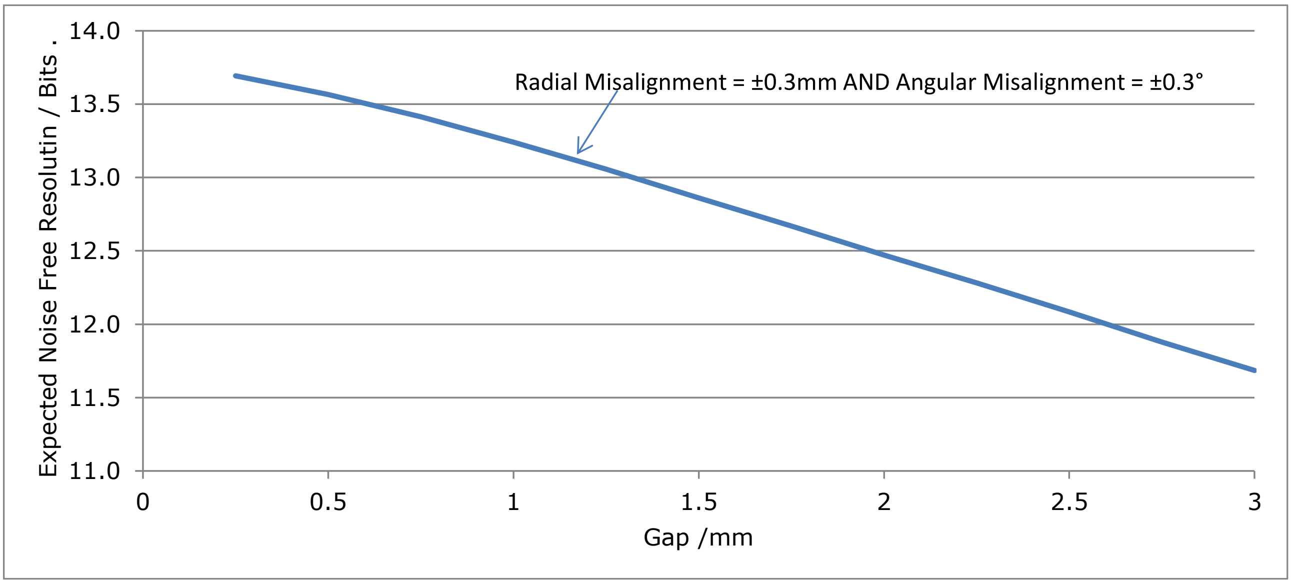

Figure 9 Noise Free Resolution as a function of Gap, CAM622 chip, free space

Figure 9 is based on raw data, with no filtering and delay compensation disabled. The Noise Free Resolution in the position output of a Resonant Inductive Encoder IC can be improved substantially by adding on-chip filtering.

3.4 Differential Non-Linearity

Differential Non-Linearity (DNL) is a measure of how well the sensor can measure instantaneous velocity. Figure 10 is a plot of the worst case DNL across Radial Misalignment up to ±0.3mm and Angular Misalignment up to ±0.3° for a typical sensor, across Gap. Slope was calculated from measurements at 3° intervals.

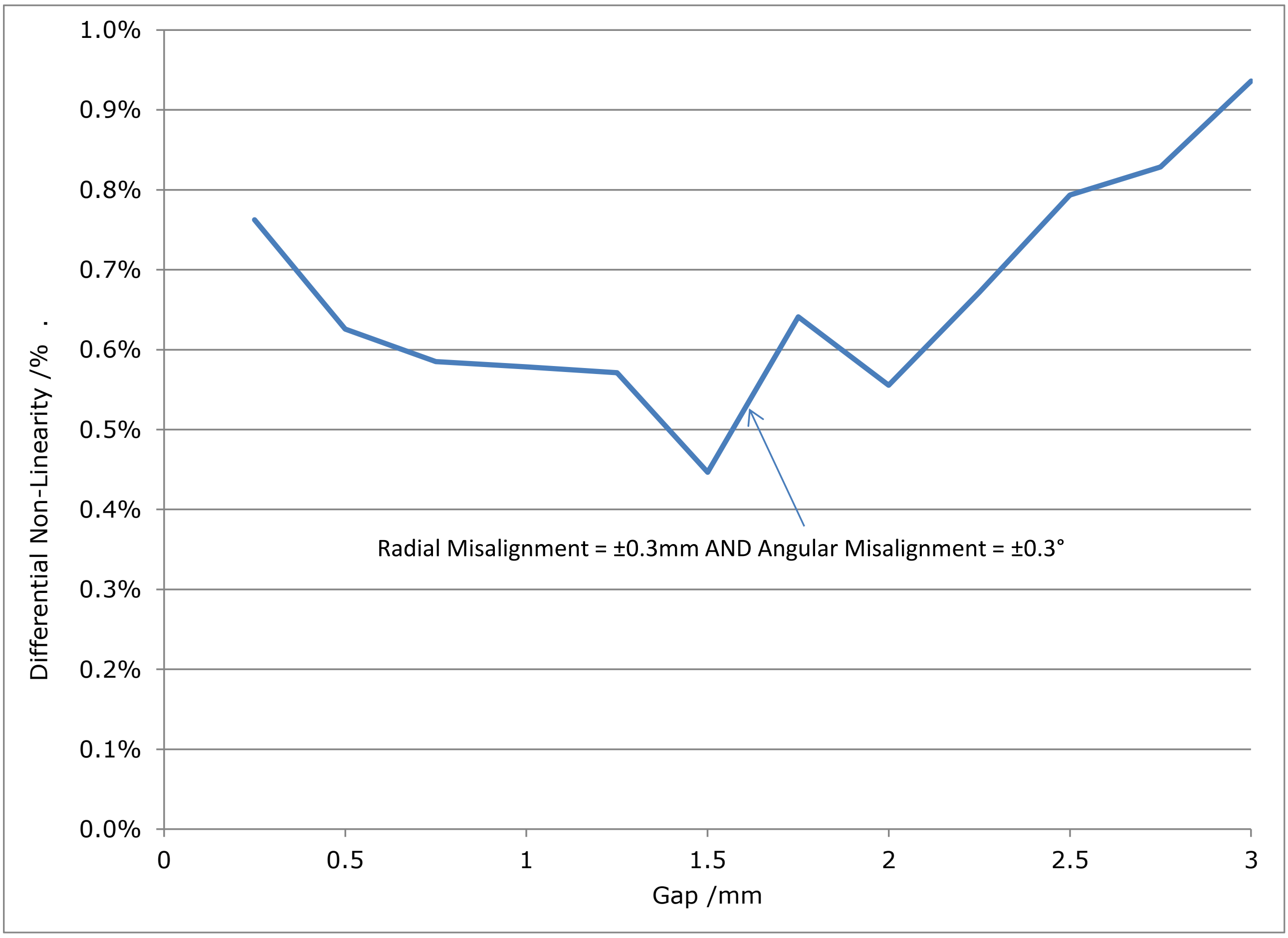

Figure 10 Differential Non-Linearity

Note that the vertical scale is NOT % of 360°. It is the fractional error in the slope of the linearity function, which is a measure of instantaneous velocity error. Note also that the DNL figure is not a lower bound on achievable velocity accuracy. There are tactics for achieving much better velocity accuracy if required. Please refer to the Type B Sensor Reference Manual for more detail.

3.5 Immunity to Misalignment

The Type B Sensor Reference Manual defines how immunity to radial misalignment between target and sensor axes can be quantified, and results for the 30mm B3 Precision Rotary Sensor are presented in Table 8.

Table 8 Immunity to Misalignment

Parameter	Worst case 0mm…2mm gap
Measured Sensitivity to Radial Misalignment, worst case across Actual Angle, misalignment direction, and Angular Misalignment up to 0.3°	0.12°/mm
Radial Misalignment Rejection Ratio	42

Radial Misalignment Rejection Ratio is a measure of the 30mm B3 Precision Rotary Sensor's immunity to radial misalignment when compared to an optical encoder of a similar size.

4 Performance with Metal Nearby

This section presents examples of how nearby metal affects the sensor system. Please refer to the Type B Sensor Reference Manual for definitions of the terms used in this section, and for more details of the effect of nearby metals.

Unless otherwise noted, measurements in this section are made with a Gap between sensor and target of 1mm.

4.1 Metal Plate Behind Sensor

Aluminium behind the sensor tends to reduce Amplitude less than steel…

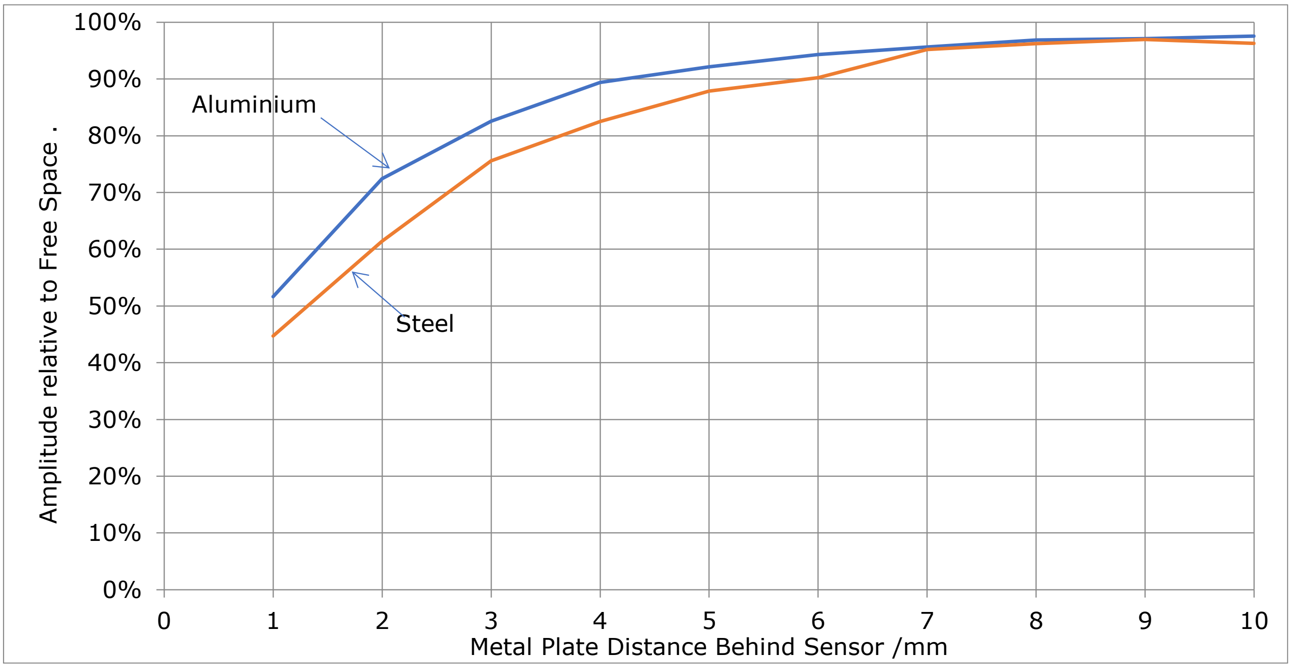

Figure 11 Effect of metal plates behind the sensor on Amplitude

On the other hand, aluminium tends to increase the target’s resonant frequency more than steel does…

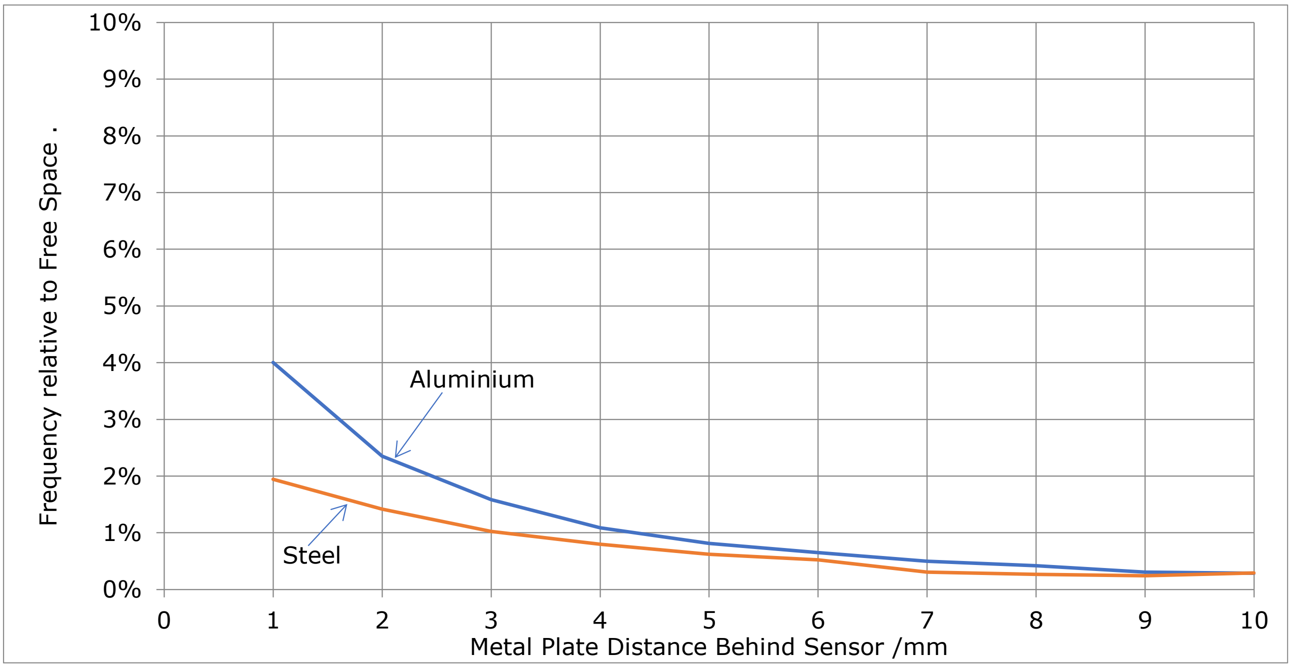

Figure 12 Effect of metal plates behind the sensor on resonator frequency

4.2 Metal Plate Behind Target

Steel near the target has a somewhat greater effect than when it is the same distance behind the sensor, because steel reduces the Q-factor of the target's resonator substantially.

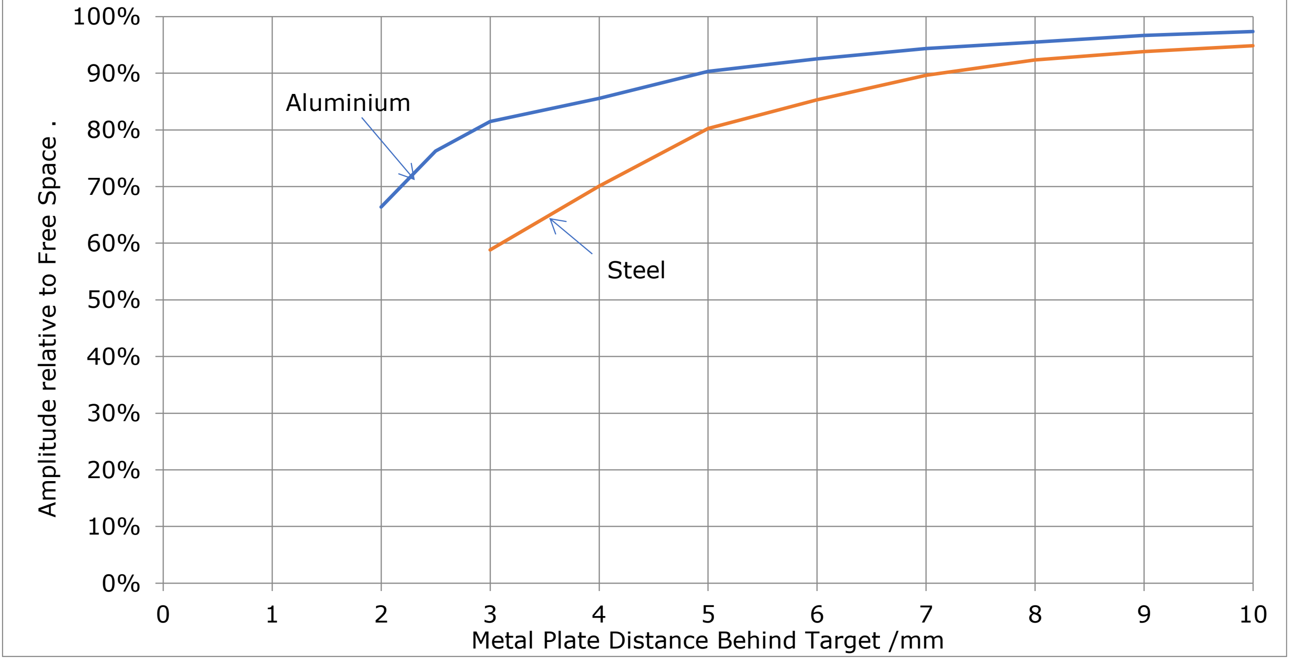

Figure 13 Effect of metal plates behind the target on Amplitude

Metals behind the target have a greater effect than when they are the same distance behind the sensor, because it is mainly the metal's proximity to the target that matters.

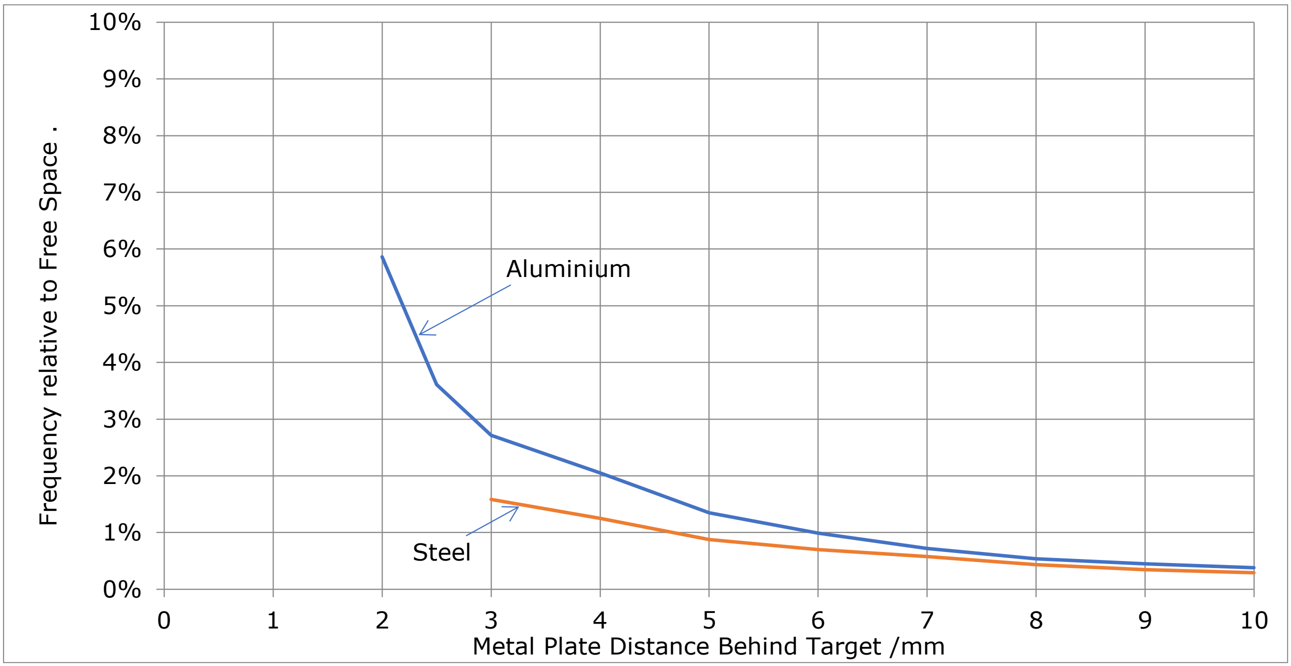

Figure 14 Effect of metal plates behind the target on resonator frequency

4.3 Metal Shaft Through Sensor and Target

The sensor and resonator designs are specially optimised to avoid significant influence of metal shafts through their centre holes. Shafts result in very little disturbance as illustrated below.

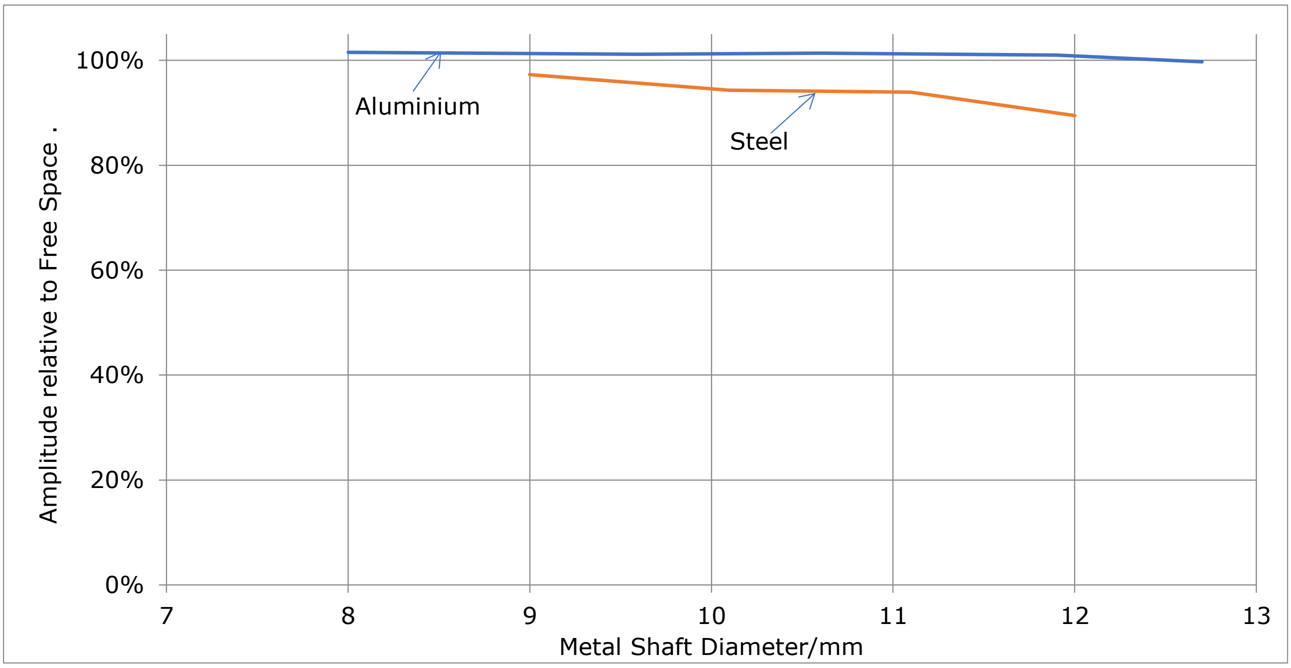

Figure 15 Effect of metal shaft through sensor and target on Amplitude

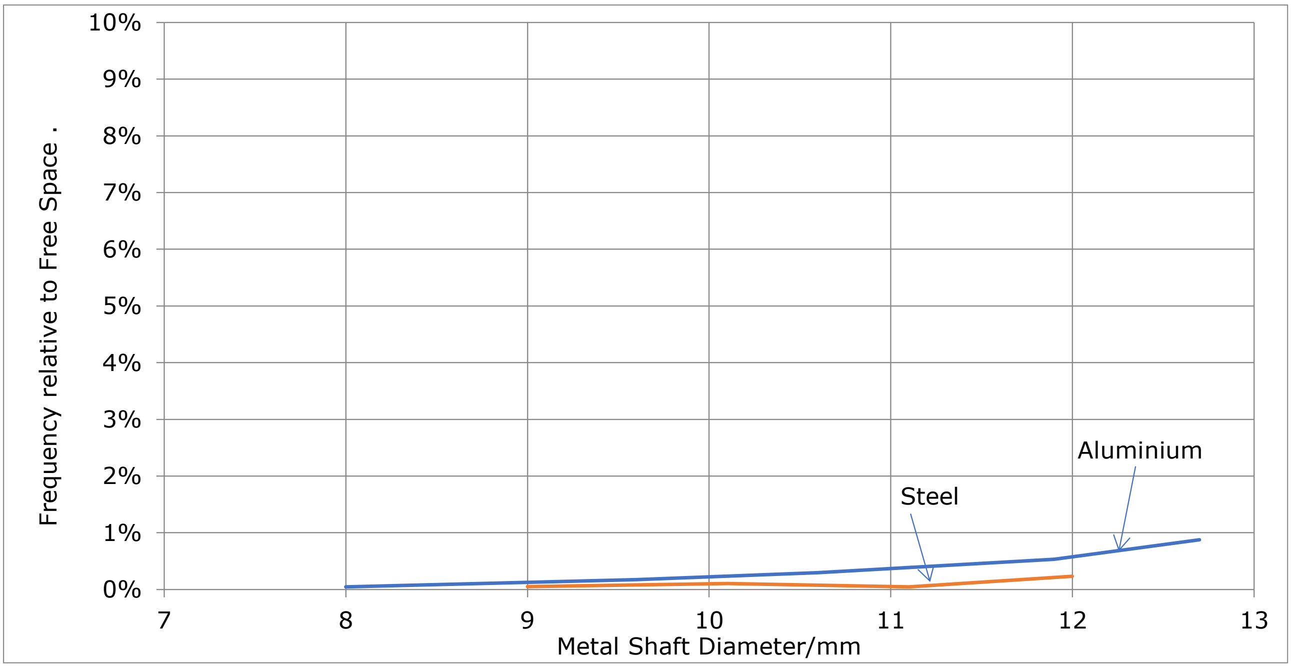

Figure 16 Effect of metal shaft through sensor and target on resonator frequency

4.4 Copper Ground Plane Around Sensor

The sensor coils may be implemented on a PCB that is shared with electronic components. In this case the electronics will usually require a ground plane that may surround the sensor coils. Figure 17 and Figure 18 illustrate the effects of surrounding the sensor with a ground plane. The data is based on a single copper ground plane layer 35µm thick with a circular cut-out for the sensor. There are two plots in each graph. One is for a continuous ground plane that forms a "shorted turn" around the sensor. The other is the same except it includes a cut that prevents current flowing all around the ground plane.

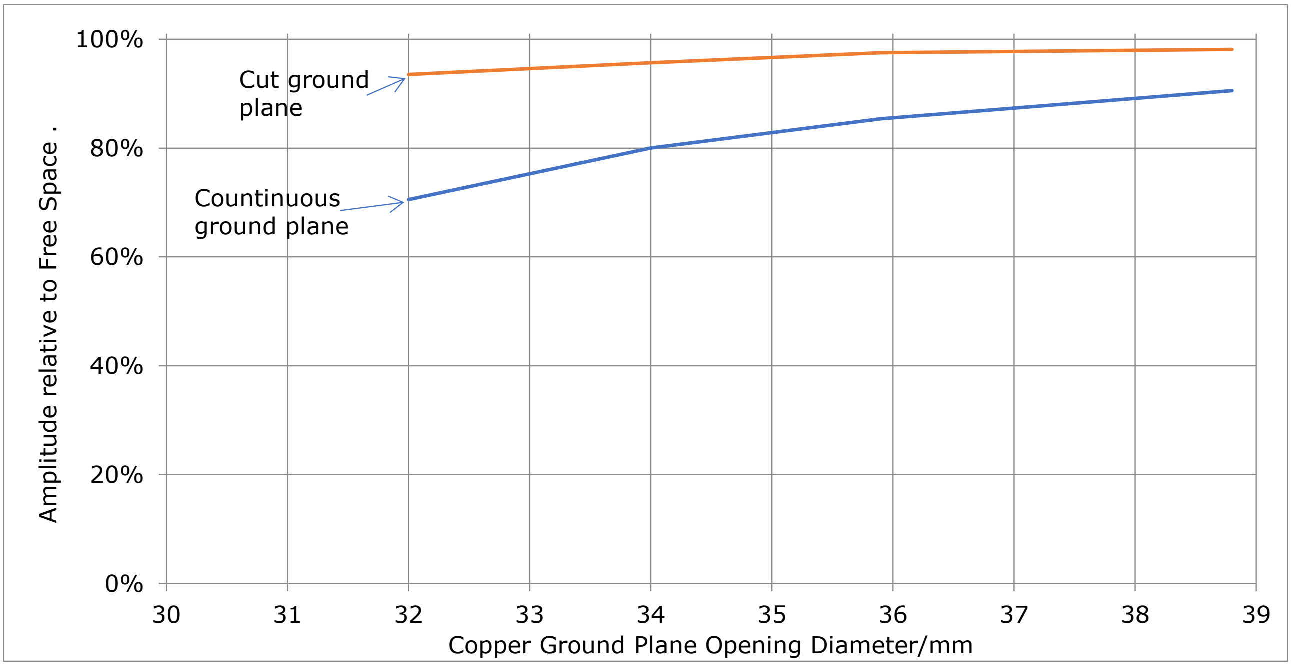

Figure 17 Effect of copper ground plane surrounding sensor on Amplitude

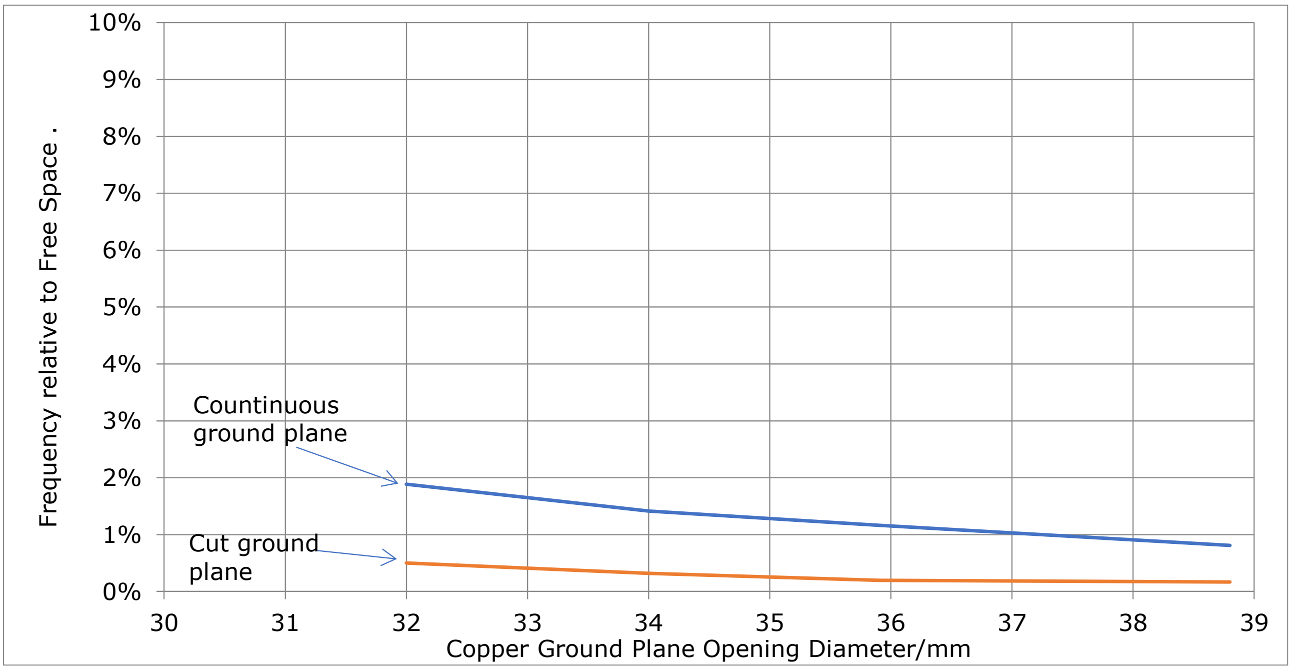

Figure 18 Effect of copper ground plane surrounding sensor on frequency

The adverse effects of the coper ground plane reduce as the opening diameter increases. Nevertheless, a ground plane with opening 32mm or greater may be used if absolutely necessary.

5 Environmental

Assembled sensor part number 013-0069 and target 013-1040 conform to the following environmental specifications:

Item	Value	Comments
Minimum operating temperature	-40°C	
Maximum operating temperature, sensor assembly 013-0069	105°C	Limited by MOLEX connector
Maximum operating temperature, target assembly 013-1040	125°C	Limited by FR4 PCB martial
Maximum operating humidity	85%	Non-condensing

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

The maximum operating temperature of both parts may be further increased by using PCB materials and components rated to higher temperatures. The ultimate limit is that the target resonator's Q-factor must remain above the minimum specified for the Resonant Inductive Encoder IC.

6 Document History

Revision	Date	Comments
0001	14 Feb 2023	First draft
0002	31 Oct 2024	Added target PCB coil self capacitance CSELF Published rear connector version of sensor assembly, removed front connector Corrected the target's moment of inertia value Removed "CONFIDENTIAL" Changed B3 target centre frequency to 833kHz

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8 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.

Patents relating to the parts described in this datasheet are pending.