Description

A range of linear resonant inductive position sensors for measuring linear position. Sensors work with CambridgeIC's Central Tracking Unit (CTU) family of single chip processors to provide high-quality position data to a host device.

Sensors are available as blueprints in Gerber format, to enable integration with a customer's own PCB. They are also available as assembled sensors for evaluation, customer prototyping and low-volume production.

Sensor Part Numbers		Measuring Length
Assembled	**Blueprint**	
013-0007	010-0003	25mm
	010-0047	36mm
013-0008	010-0004	50mm
013-0009	010-0005	100mm
013-0013	010-0033	150mm
013-0010	010-0006	200mm
013-0019	010-0041	300mm

Features

- Simple non-contact target
- Full absolute sensing
- Standard 4-layer PCB process
- Stable across temperature
- Highly repeatable

Performance

- Up to 5mm Target Gap
- < ±0.25% Linearity Error at optimum Target Gap
- Δ< ±0.2mm -40°C...85°C, ≤ 3.5mm Target Gap
- < ±0.25mm Position Offset Error
- Up to ±1mm Y Misalignment
- Can be installed 2mm from aluminium sheet

Applications

- Motion control
- Actuator position feedback
- Precision front panel controls
- Valve position sensing
- Industrial potentiometer replacement
- LVDT replacement

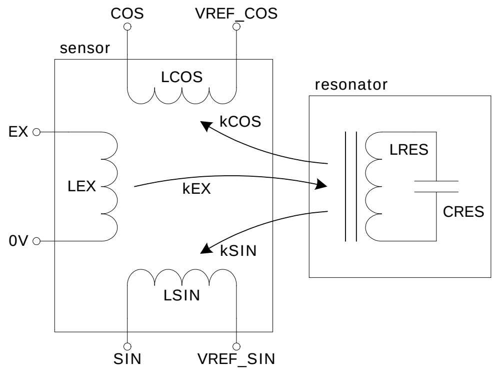

Figure 1 equivalent circuit

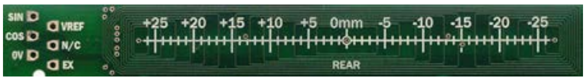

Figure 2 50mm assembled sensor, approximate actual size, viewed from rear

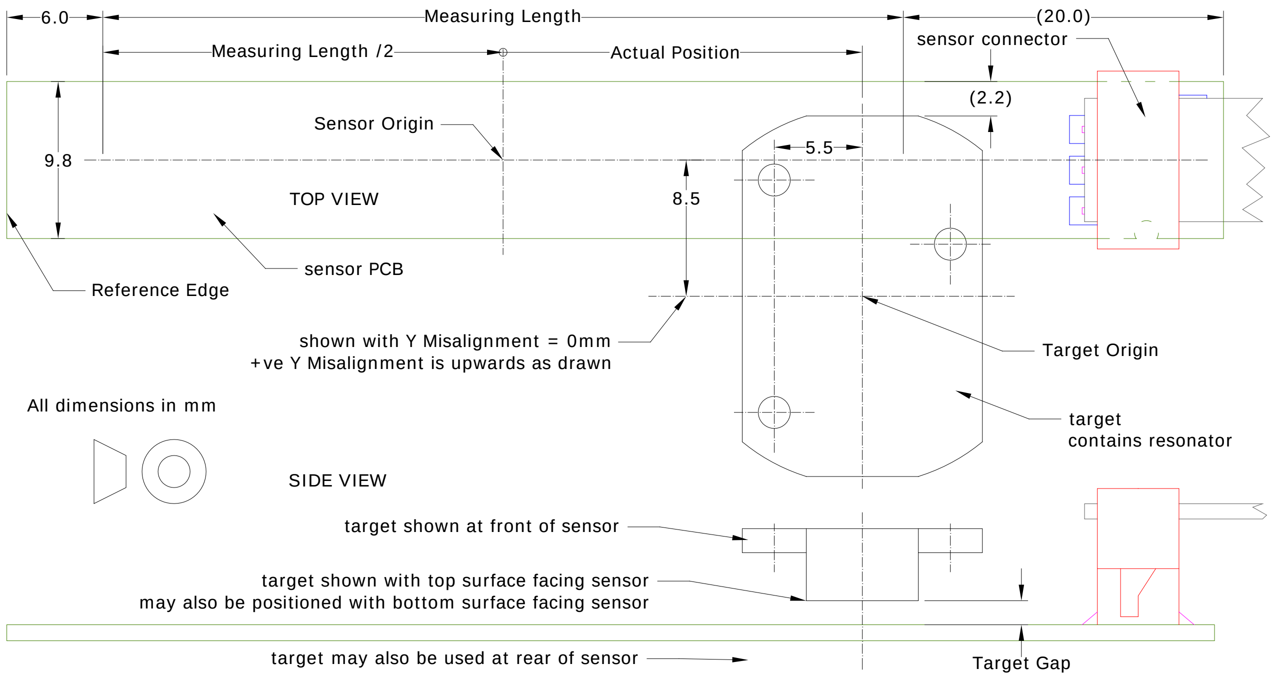

Figure 3 assembled sensor shown with target part number 013-1005

1 Assembled Sensors

Sensor designs are similar to each other, except for the difference in Measuring Length. Figure 4 shows a sensor with general Measuring Length, and Table 1 shows how Overall Length depends on Measuring Length.

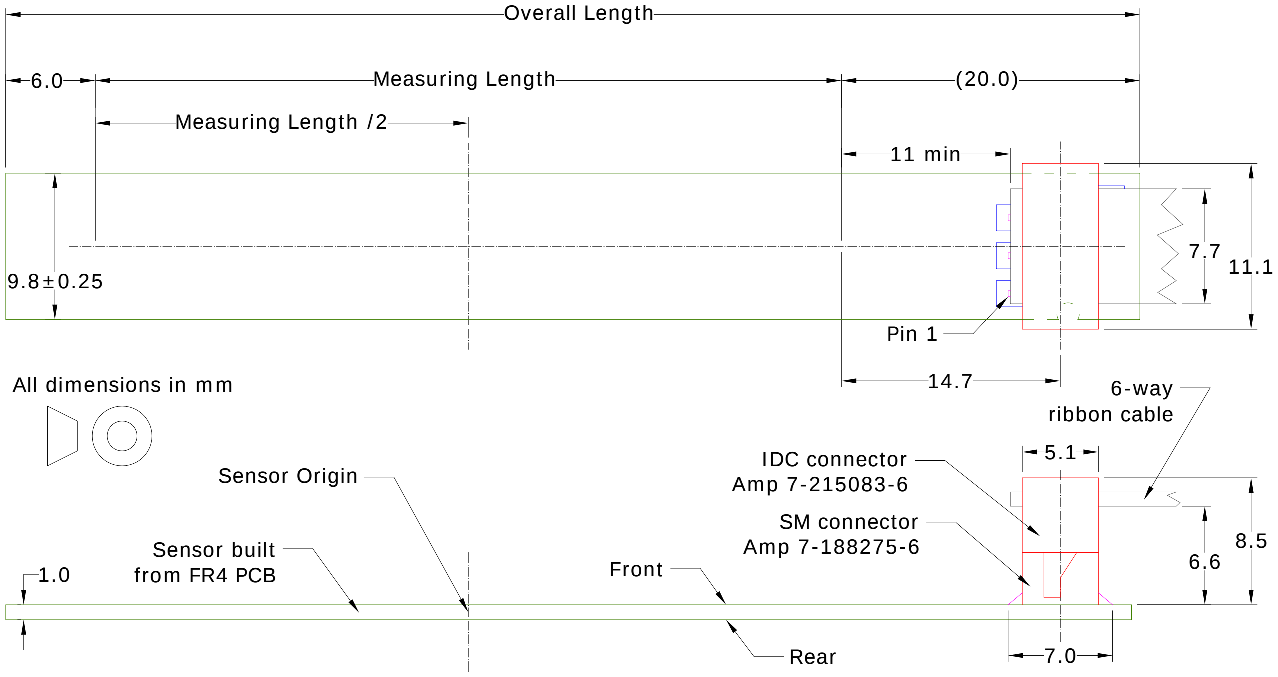

Figure 4 assembled sensor, shown with connector 013-6001 attached

Table 1

Assembled sensor part number	**Measuring Length**	**Overall Length**
013-0007	25mm	51mm ±0.25mm
013-0008	50mm	76mm ±0.25mm
013-0009	100mm	126mm ±0.25mm
013-0013	150mm	176mm ±0.25mm
013-0010	200mm	226mm ±0.25mm
013-0019	300mm	326mm ±0.25mm

Figure 4 *defines* the position of the Sensor Origin, which is nominally the origin of the Sensor Blueprint data. The sensor is also available in the form of a Sensor Blueprint (section 3).

2 Performance

This section illustrates performance of the linear sensors. Figures are representative of assembled sensors available from CambridgeIC (as described in section 1) and of sensors built according to CambridgeIC's blueprint (section 3). Measurements are taken with a typical target (part number 013-1005) and CTU Development Board (part number 013-5006 using CambridgeIC's CAM204A chip).

2.1 Transfer Function

The CTU reports position as a 16-bit signed number: *CtuReportedPositionI16*. It also outputs a VALID flag to indicate when the target is in range. Figure 5 illustrates how these outputs change with the Actual Position of the target (Actual Position is defined in Figure 3).

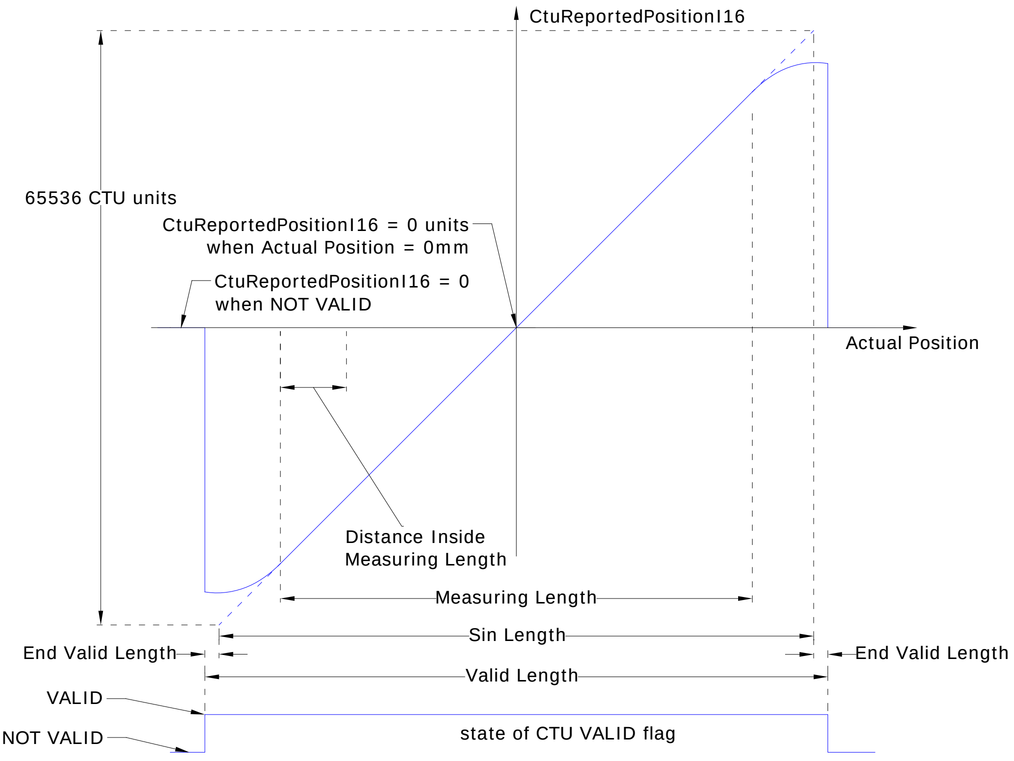

Figure 5 CTU outputs versus position

The *Measuring Length* defines a central region where performance is defined. The CTU reports position beyond this region at lower accuracy and resolution, over a distance of *End Valid Length* at each end. The distance over which the CTU reports VALID is the *Valid Length*.

Sin Length defines how CtuReportedPositionI16 can be scaled into distance units:

$$ReportedPosition = \frac{CtuReportedPositionI16}{65536} \times SinLength + PositionOffsetError$$

Equation 1

Sin Length is shown greater than ValidLength in Figure 5. This is not always the case; it depends on signal levels.

Sin Length is nearly constant for a given sensor design, and can be approximated by its value when the target is at its Nominal Target Gap and there is no Y Misalignment: *Nominal Sin Length*. Sin Length changes slightly with Target Gap (Figure 13) and with metal nearby (Figure 20 and Figure 25).

The system is designed so that *Position Offset Error* is nominally zero. Position Offset Error is almost entirely due to mechanical tolerances of the sensor and target. In some cases Position Offset Error may be known (e.g. through a “zero calibration”), in which case the known value may be used to improve the estimate of Reported Position.

2.2 Performance Metrics

Absolute Position Error is the difference between Reported Position and Actual Position. A fixed, quoted value for Sin Length is used (typically Nominal Sin Length), and a value of 0 is used for Position Offset Error:

$$AbsolutePositionError = ReportedPosition - ActualPosition \ \text{[value of Sin Length fixed, Position Offset Error = 0]}$$

Equation 2

According to this definition, Absolute Error includes the error in position alignment between the resonator inside the target and the features used to define the Target Origin (two mounting holes in the case of target 013-1005). This document concerns the sensor alone, and performance is quoted excluding this Target Position Offset.

Absolute Position Error may also be quoted as a percentage of the Measuring Length:

$$AbsolutePositionError\% = \frac{AbsolutePositionError}{MeasuringLength} \times 100\%$$

Equation 3

Linearity Error is defined in the same way as Absolute Position Error, except that the values of Sin Length and Position Offset Error are modified to minimise the maximum error. This definition corresponds to Independent Linearity (INL).

$$LinearityError = ReportedPosition - ActualPosition \ \text{[values of Sin Length and Position Offset Error variable]}$$

Equation 4

Note that Independent Linearity is scaled to the same position units as Absolute Position, by definition. It may also be quoted as a percentage:

$$LinearityError\% = \frac{IndependentLinearity}{MeasuringLength} \times 100\%$$

Equation 5

Unless otherwise stated, all measurements are based on the average of a sufficiently large number of individual CTU samples so that the effect of CTU noise is negligible. Noise (and resolution) are mainly functions of the CTU, although they do become smaller as Amplitude decreases (see section 2.12).

2.3 End Valid Length

End Valid Length is the distance each side of the Measuring Length over which the system reports VALID, as shown in Figure 5.

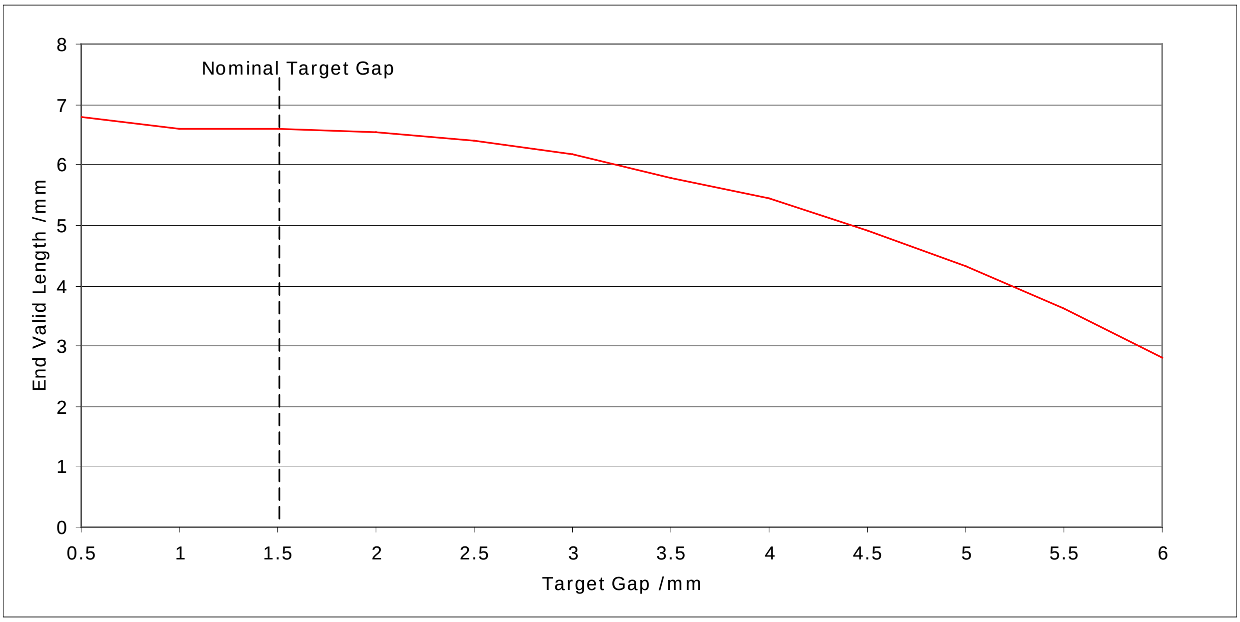

Figure 6 End Valid Length as a function of Target Gap

2.4 Linearity Error

Linearity Error is a measure of accuracy defined above in Equation 4 and Equation 5. The *Worst Linearity Error* refers to the worst error magnitude measured across the Measuring Range. Figure 7 and Figure 8 show how Worst Linearity Error depends on Target Gap for typical sensors, measured with Y Misalignment = 0mm.

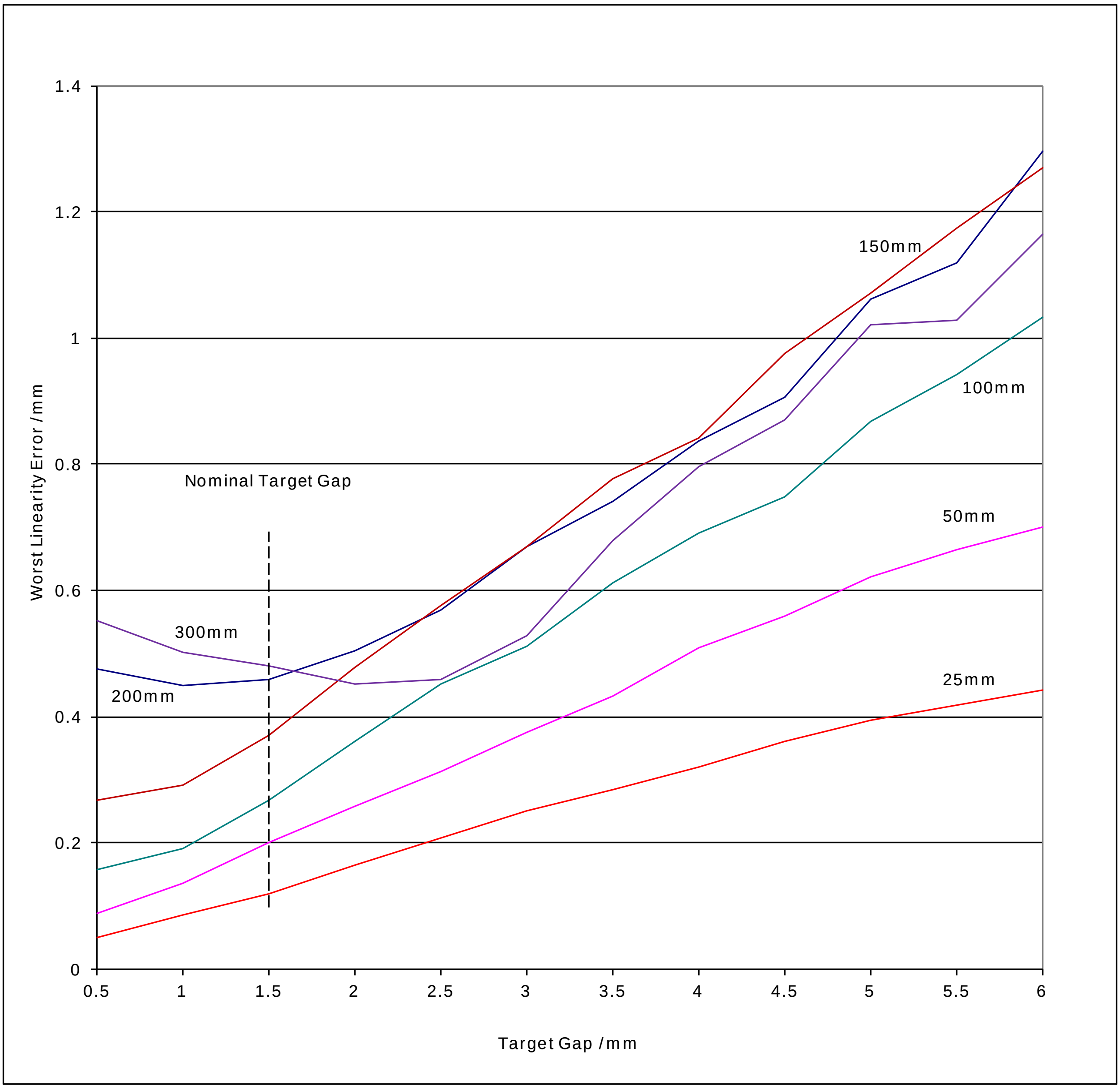

Figure 7 Linearity Error in mm as a function of Target Gap for different Measuring Lengths

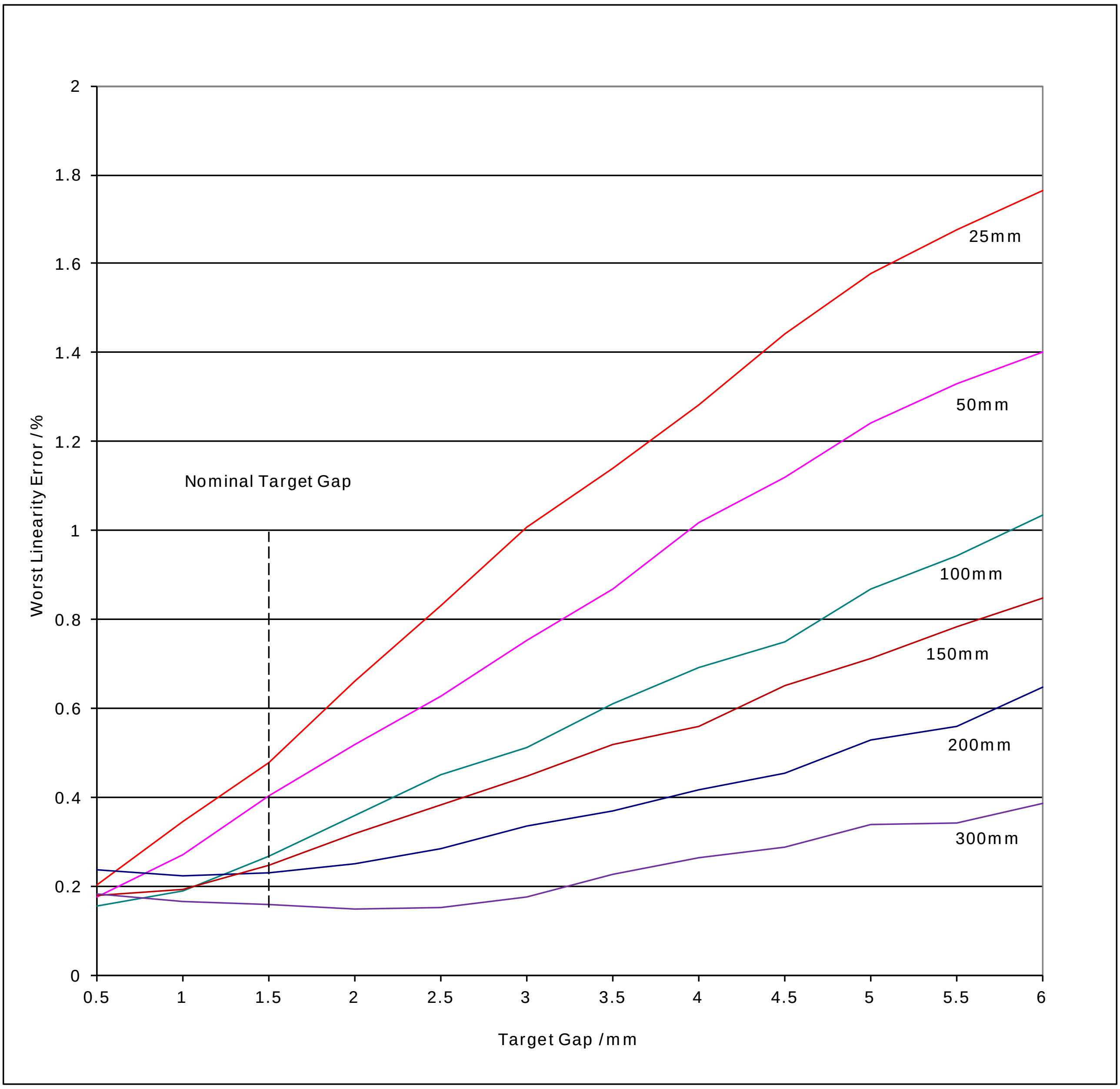

Figure 8 Linearity Error in % as a function of Target Gap for different Measuring Lengths

Figure 7 is in mm, and Figure 8 is in %. Sensors with longer measuring lengths tend to have larger values of Linearity Error expressed in mm, but smaller values in %.

2.5 Linearity Improvement with Reduced Measuring Length

Section 2.4 illustrates how Linearity Error gets worse as Target Gap increases. Since the worst errors occur at the ends of the sensors in these cases, it is possible to achieve significant improvements in Linearity Error by not using the extreme ends of the sensor, using a sensor with a longer Measuring Length than the desired travel.

Figure 9 to Figure 15 illustrate the improvement for different Measuring Lengths. In each case, the vertical axis is Linearity Error %, calculated using data points centered around the Sensor Origin with Measuring Range equal to *Reduced Measuring Range*.

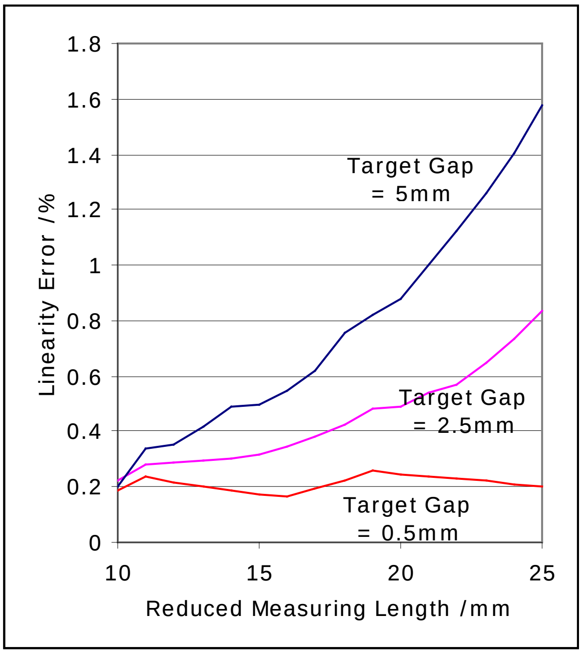

Figure 9 25mm sensor

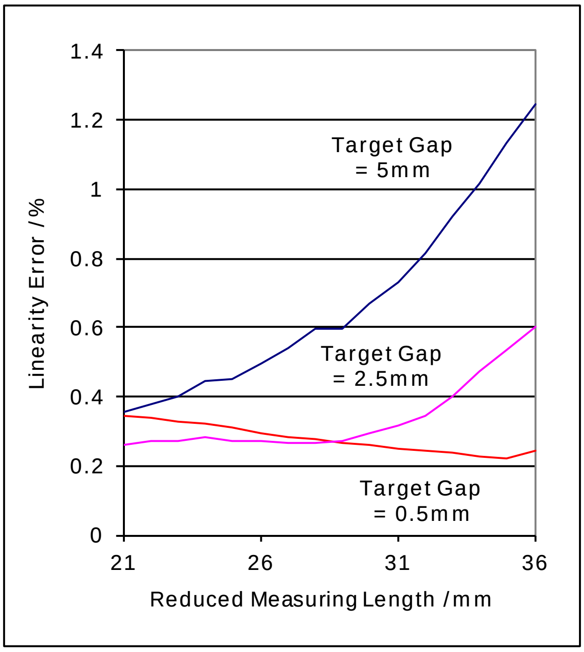

Figure 10 36mm sensor

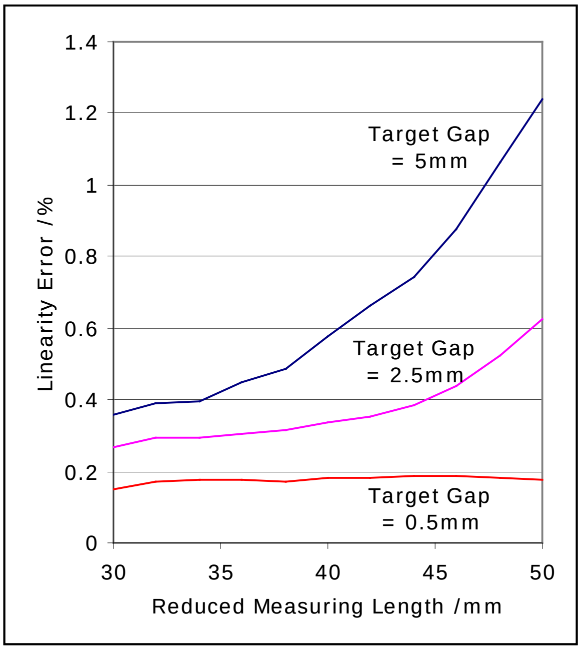

Figure 11 50mm sensor

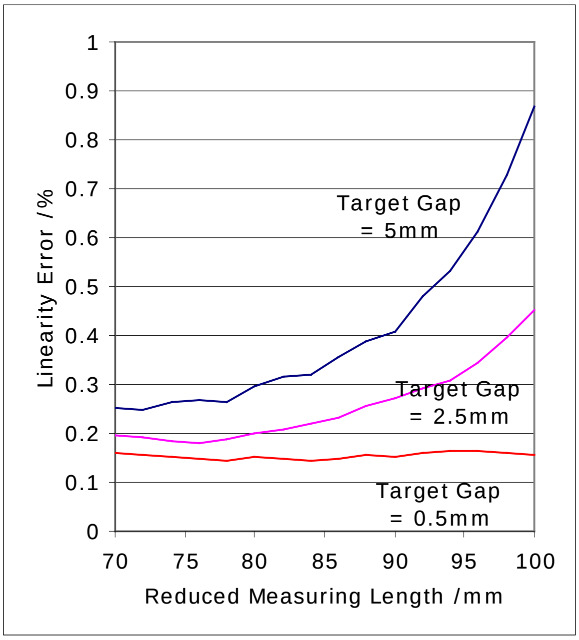

Figure 12 150mm sensor

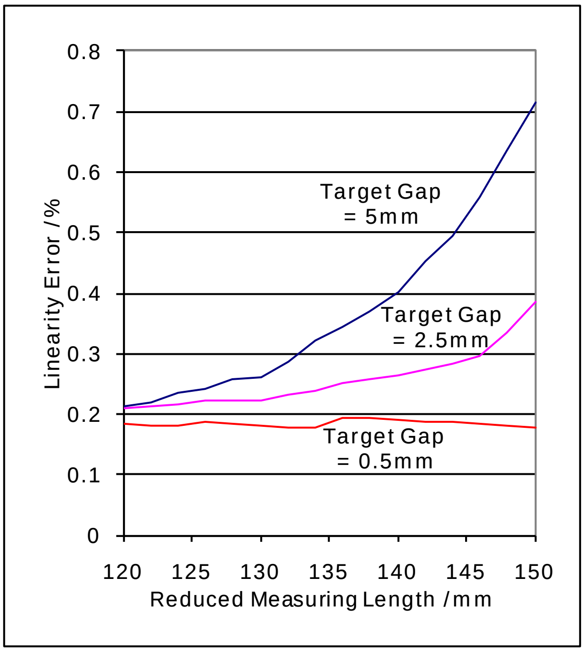

Figure 13 150mm sensor

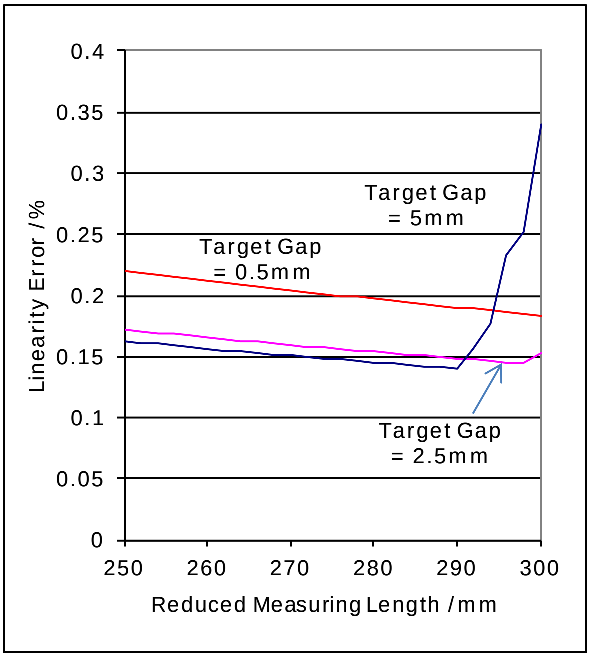

Figure 15 300mm sensor

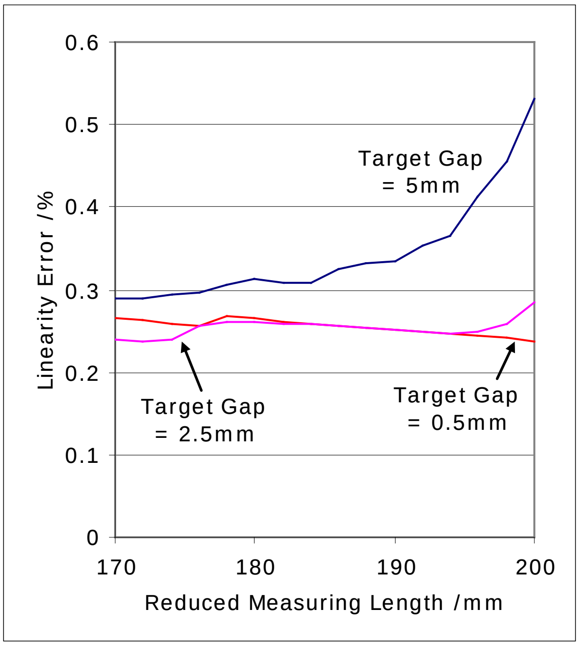

Figure 14 200mm sensor

The benefit of operating over a reduced measuring length is greater at larger operating gaps and for shorter sensors.

2.6 Sin Length at Nominal Target Gap

Sin Length scales the position reported by the CTU to position units, according to Equation 1. Its values at Nominal Target Gap and room temperature are given in Table 2.

Table 2

Assembled sensor part number	Blueprint part number	Measuring Length	Nominal Target Gap	Sin Length
013-0007	010-0003	25mm	1.5mm	37.9mm
	010-0047	36mm		48.6mm
013-0008	010-0004	50mm		63.0mm
013-0009	010-0005	100mm		113.2mm
013-0013	010-0033	150mm		163.4mm
013-0010	010-0006	200mm		213.1mm
013-0019	010-0041	300mm		313.1mm

2.7 Sin Length Dependence on Target Gap

The value of Sin Length required to minimise Linearity Error changes slightly with Target Gap. Figure 13 illustrates the change in Sin Length from its value at Nominal Target Gap.

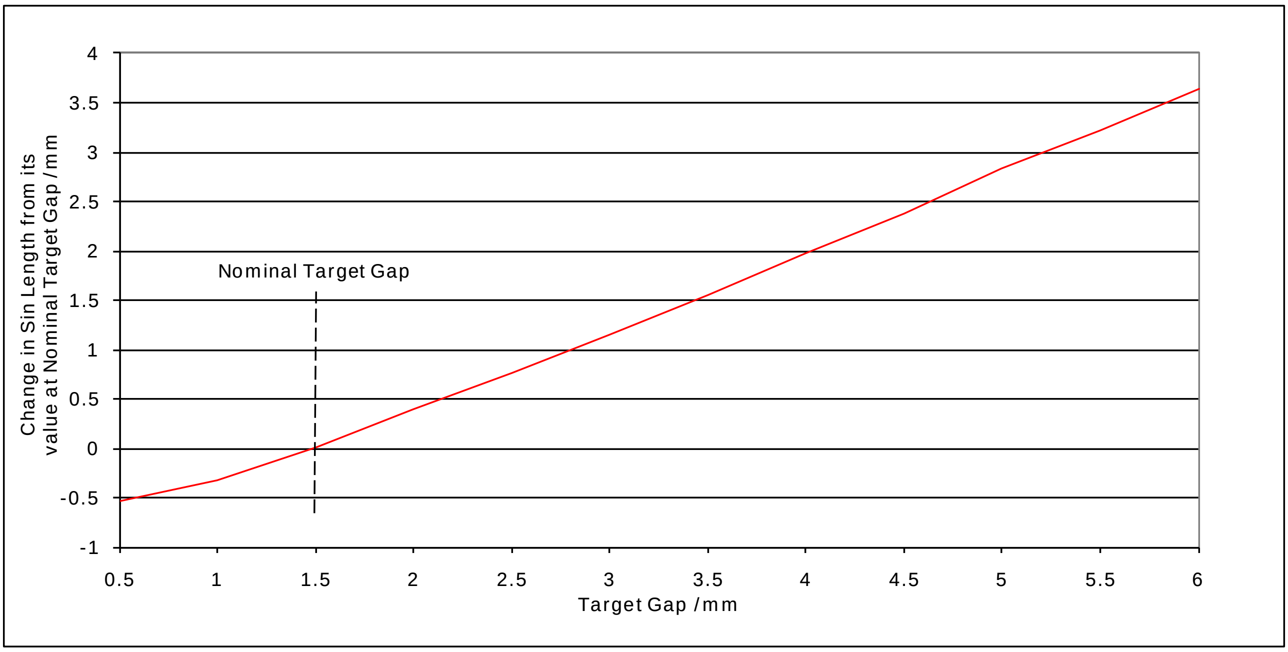

Figure 16 Sin Length dependence on Target Gap

2.8 Immunity to Y Misalignment

The target should be operated with its Target Origin the specified distance below the Sensor Origin as illustrated in Figure 3. Deviations in the Y direction (upwards in the top view) are denoted Y Misalignment. The sensors use a ratiometric measuring technique to minimise sensitivity to Y Misalignment. Table 3 lists the residual sensitivity for different Measuring Lengths, for 1mm Y Misalignment at Nominal Target Gap.

Table 3

Assembled sensor part number	Blueprint part number	Measuring Length	Worst change in Reported Position magnitude due to 1mm Y Misalignment at Nominal Target Gap	
			mm	% of Measuring Length
013-0007	010-0003	25mm	0.04mm	0.15%
	010-0047	36mm	0.06mm	0.16%
013-0008	010-0004	50mm	0.06mm	0.12%
013-0009	010-0005	100mm	0.13mm	0.13%
013-0013	010-0033	150mm	0.19mm	0.13%
013-0010	010-0006	200mm	0.26mm	0.13%
013-0019	010-0041	300mm	0.2mm	0.13%

2.9 Immunity to Target Gap

Ratiometric measurement means the sensors are largely immune to changes in Target Gap, especially away from the ends of the Measuring Range. When *Distance Inside Measuring Length* (as defined in Figure 5) is small, changes in Target Gap have greater effect, as illustrated in Figure 14.

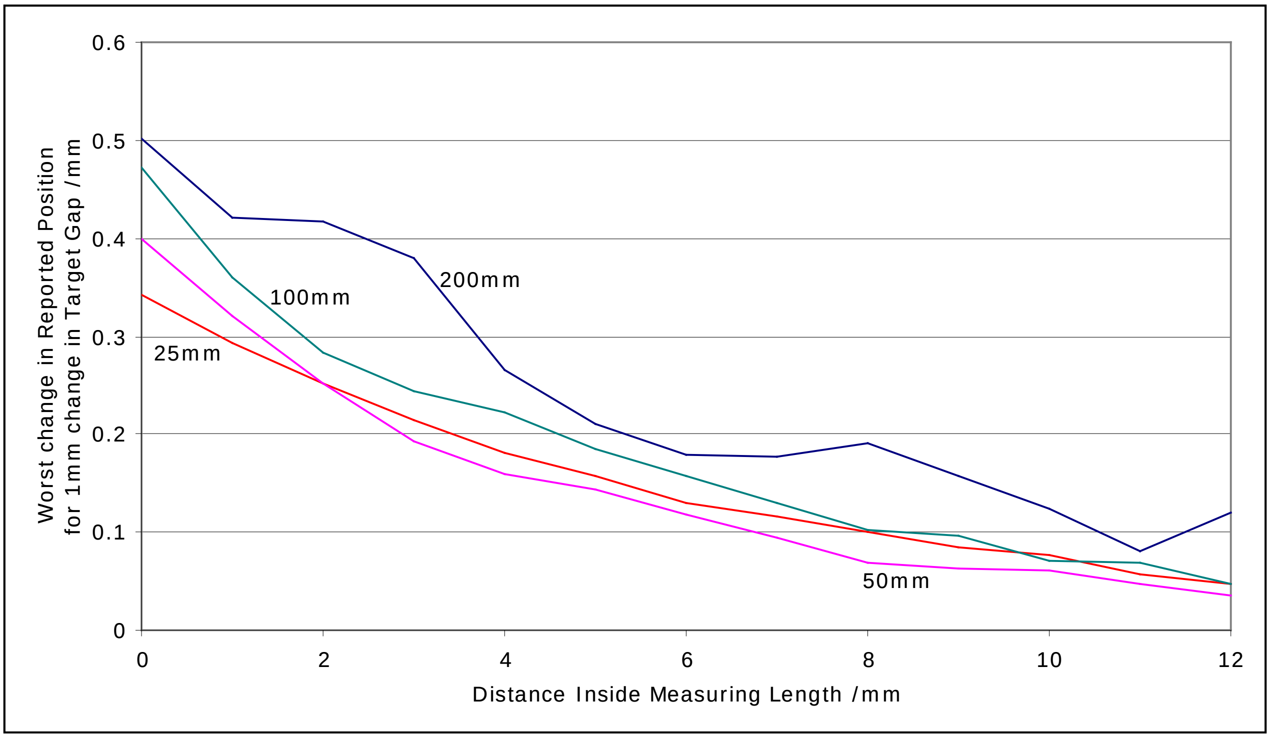

Figure 17 Effect of 1mm change in Target Gap from Nominal

2.10 Sensor to Sensor Repeatability

The use of PCB fabrication technology means that the sensors are highly repeatable. The largest source of sensor to sensor variability at Nominal Target Gap is a difference in Position Offset Error between sensors which results directly from the accuracy with which PCB copper traces are positioned relative to the sensors' Reference Edges (Figure 3): **±0.25mm** for assembled sensors.

2.11 Effect of Temperature

The following graphs how the system's reported position output changes with its temperature, relative to room temperature. Here, the system comprises a typical CAM204A, target and sensor. Sensors are built from FR4 material with a coefficient of linear expansion of +13ppm/°C, and effect of thermal expansion of the sensors is included.

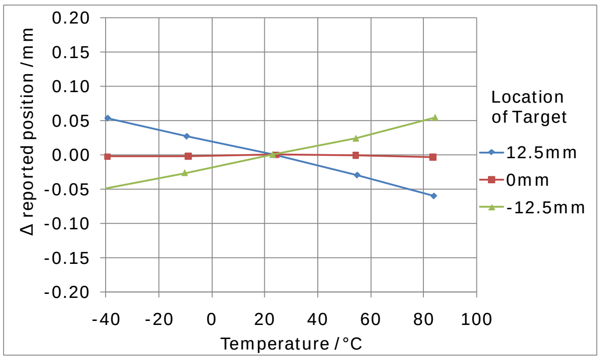

Figure 18 25mm, 1.5mm Target Gap

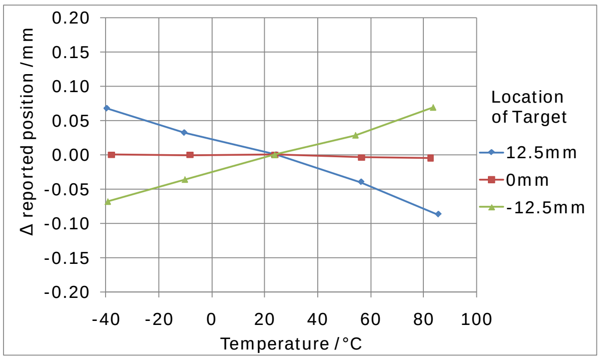

Figure 19 25mm, 3.5mm Target Gap

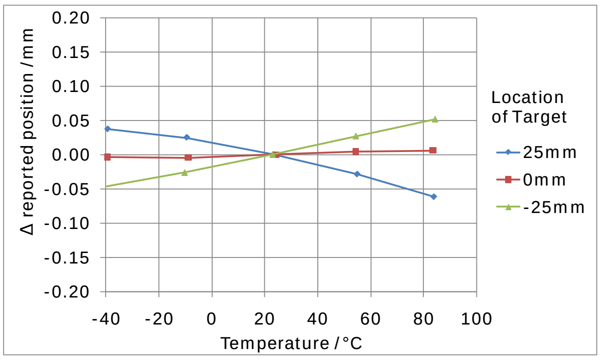

Figure 20 50mm, 1.5mm Target Gap

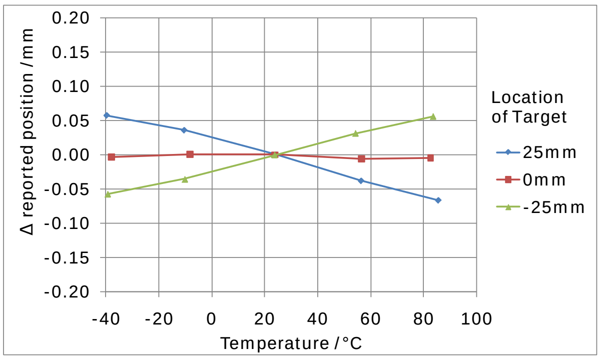

Figure 21 50mm, 3.5mm Target Gap

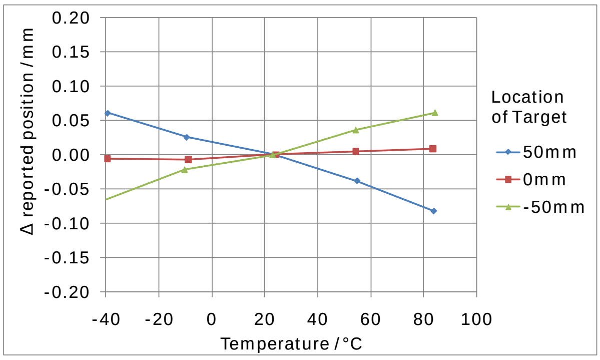

Figure 22 100mm, 1.5mm Target Gap

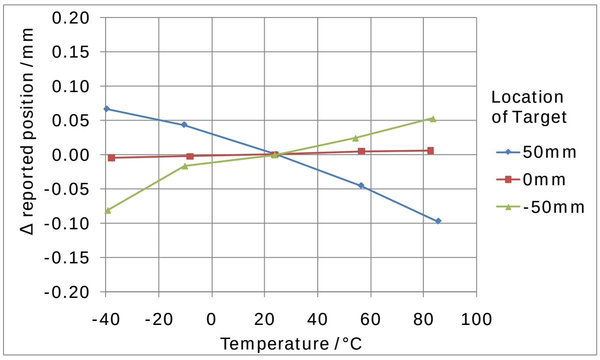

Figure 23 100mm, 3.5mm Target Gap

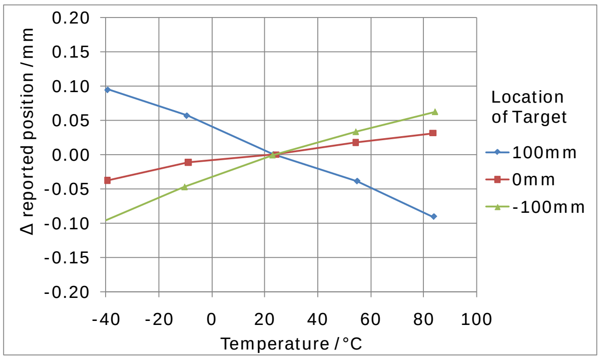

Figure 24 200mm, 1.5mm Target Gap

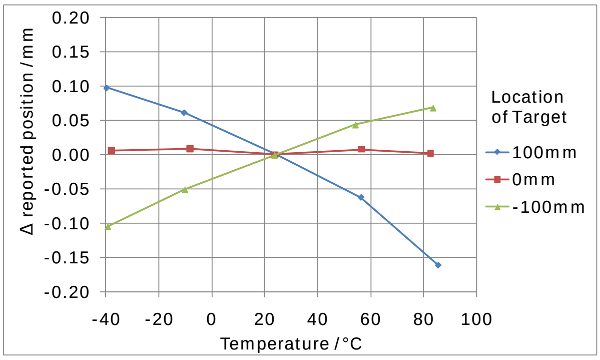

Figure 25 200mm, 3.5mm Target Gap

2.12 Amplitude

Amplitude is a measure of inductive signal coupling between the sensor and target. Higher values are preferable since they result in better resolution when the sensor is used with a CTU chip. Amplitude may be used as a coarse measure of Target Gap, and is a useful system diagnostic measurement. Figure 15 shows how Amplitude changes with Target Gap.

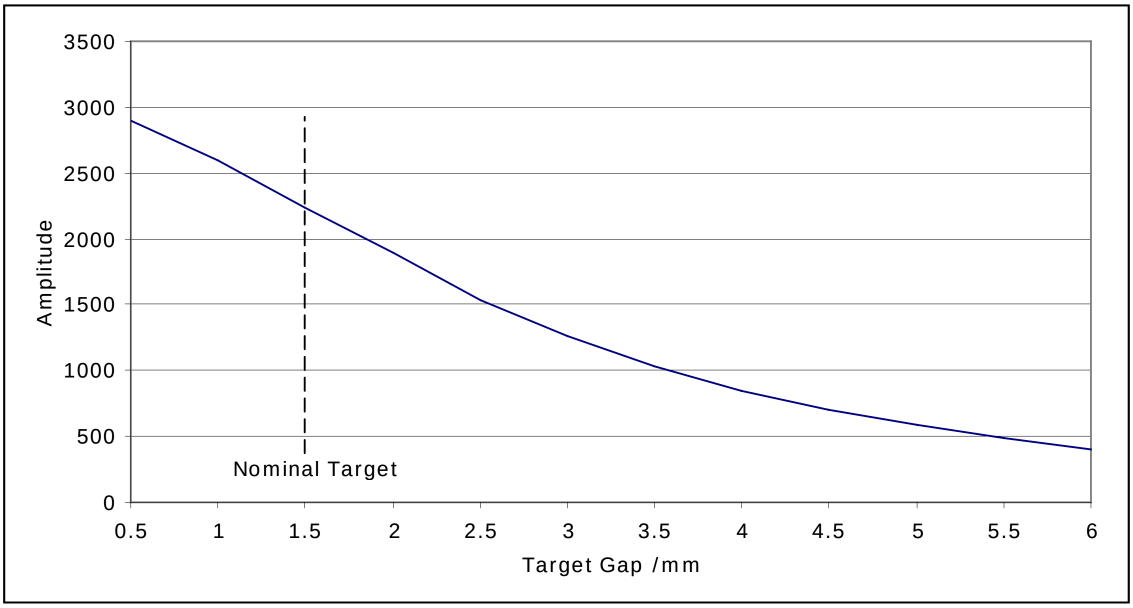

Figure 26 Amplitude reported by CTU versus Target Gap

Figure 15 is based on the minimum Amplitude across Measuring Length. The value for each gap is the minimum reading from the 25mm, 36mm, 50mm, 100mm, 150mm, 200mm and 300mm sensors at that gap.

2.13 Metal Behind Sensors

The sensors can be installed with metal behind (as drawn in Figure 16), providing there is sufficient gap to the metal (Table 4). Changes in the gap to metal should be avoided for best linearity: it is preferable for the metal to be flat and parallel to the sensor.

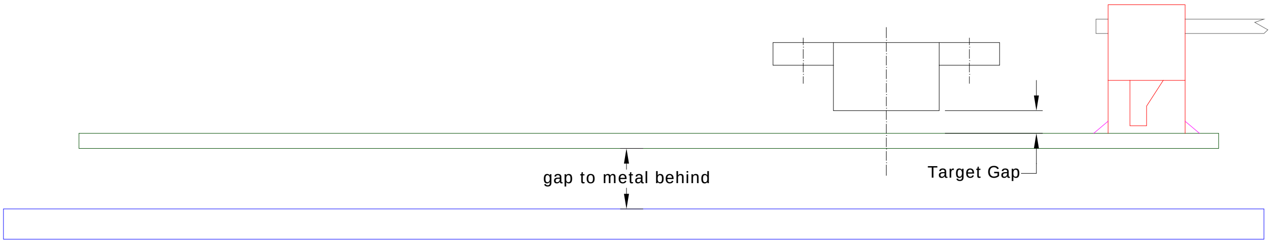

Figure 27 metal behind sensor

Table 4

Type of metal	**Gap to metal behind**	
	Absolute Minimum	**Recommended minimum**
Aluminium, copper, brass sheet (>0.1mm thick)	2mm	4mm
Stainless steel (austenitic)	3mm	5mm
Mild steel, or aluminium or copper foil (10 – 50µm)	4mm	6mm

The main effects of meal behind the sensors are to reduce Amplitude and to modify the target's resonant frequency slightly. The CTU automatically tunes to the target's frequency, so the reduction in amplitude is normally the main concern. Aluminium has the least effect on Amplitude (Figure 17). A reduction in Amplitude causes a reduction in End Valid Length (Figure 18). It also degrades resolution; see the CTU datasheet for data.

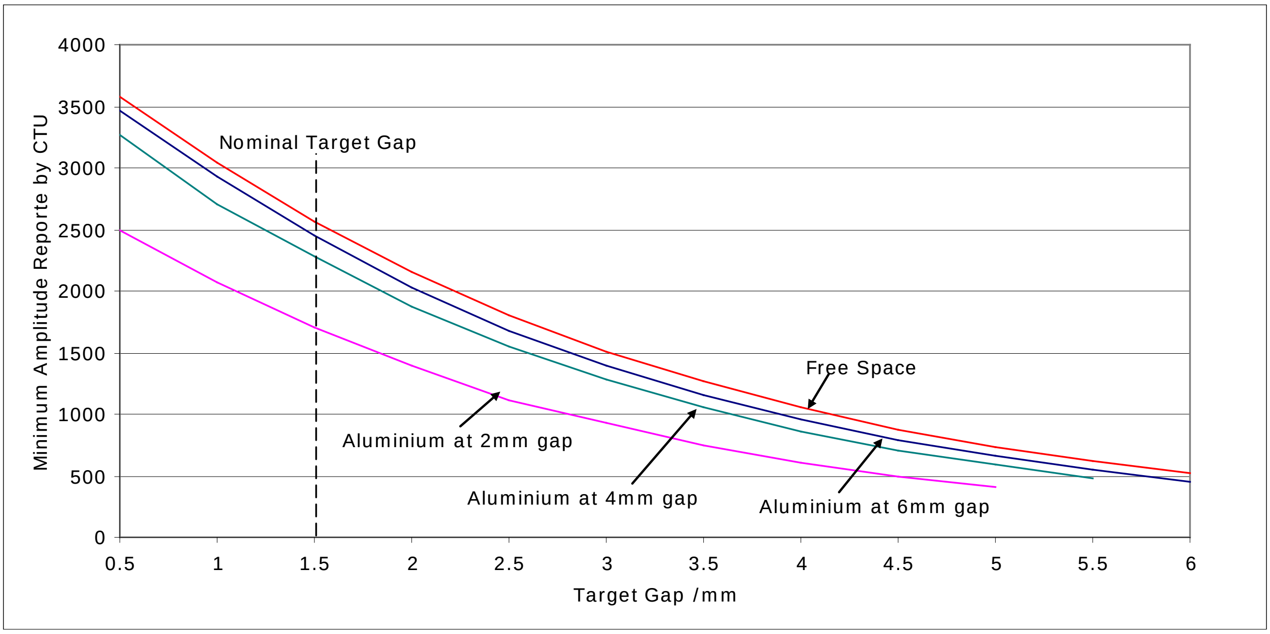

Figure 28 Reported Amplitude with an Aluminium sheet behind 50mm sensor

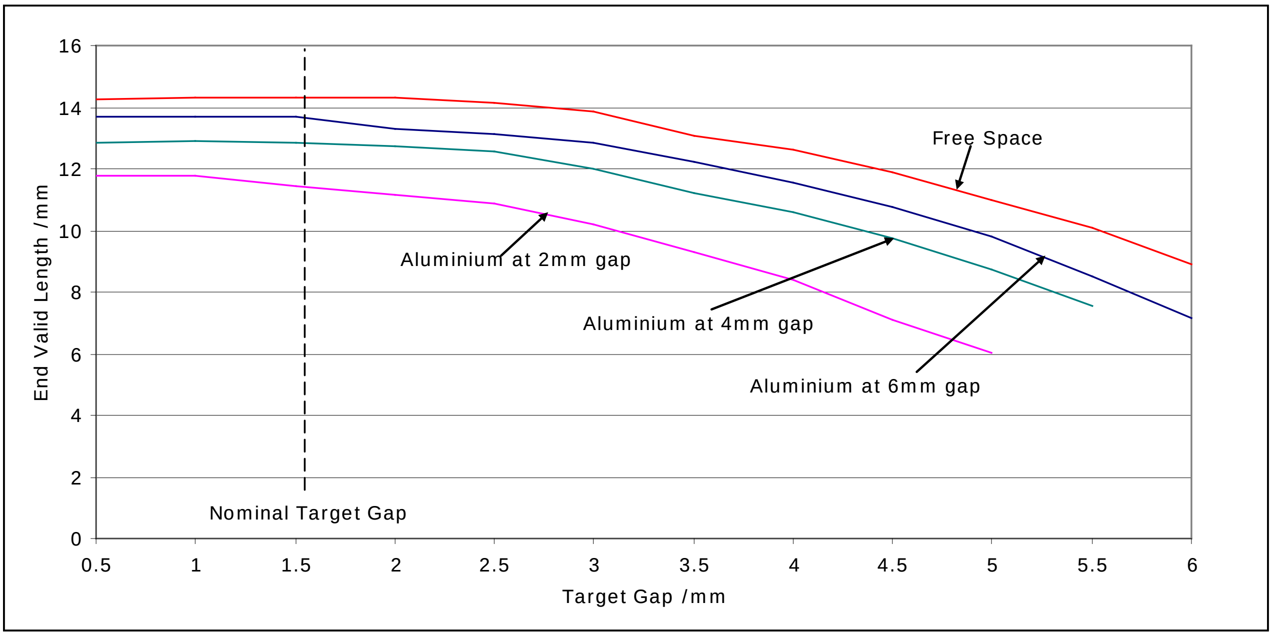

Figure 29 End Valid Length with an Aluminium sheet behind 50mm sensor

Figure 19 illustrates how Linearity Error changes with Target Gap in the presence of aluminium behind, for a 50mm sensor. There is actually a significant improvement in Linearity for larger gaps.

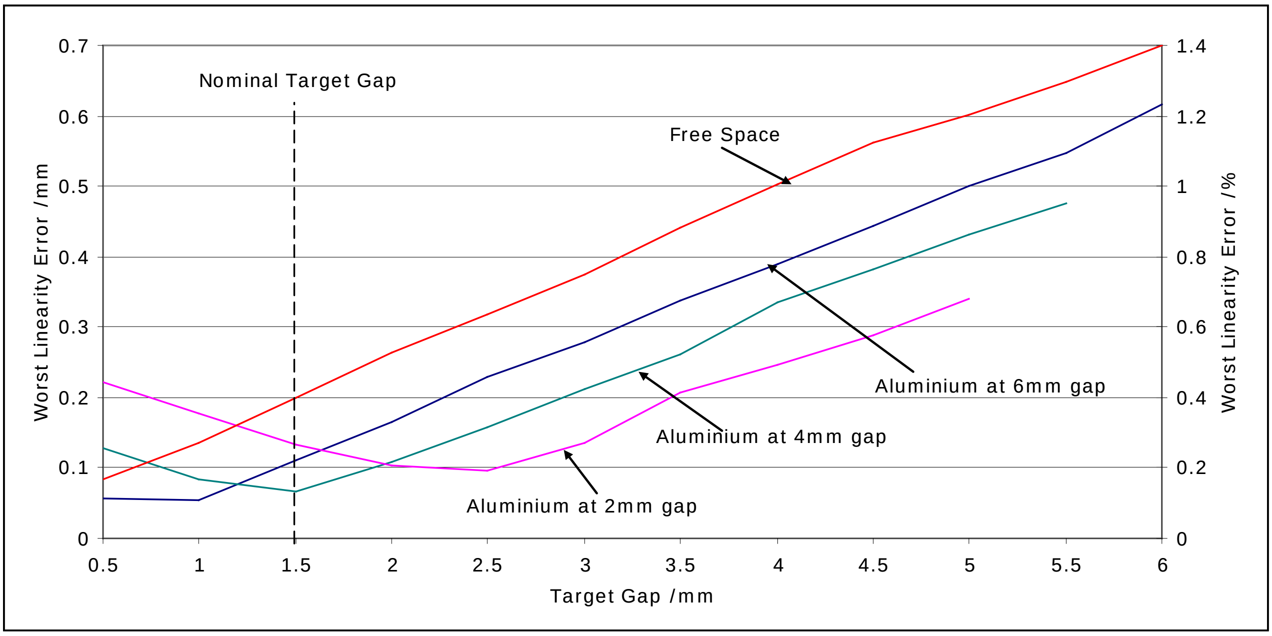

Figure 30 Linearity Error with an Aluminium sheet behind 50mm sensor

Sin Length is used to convert from CTU units to position units (Equation 1). The optimum value changes slightly with metal behind, see Figure 20 for aluminium.

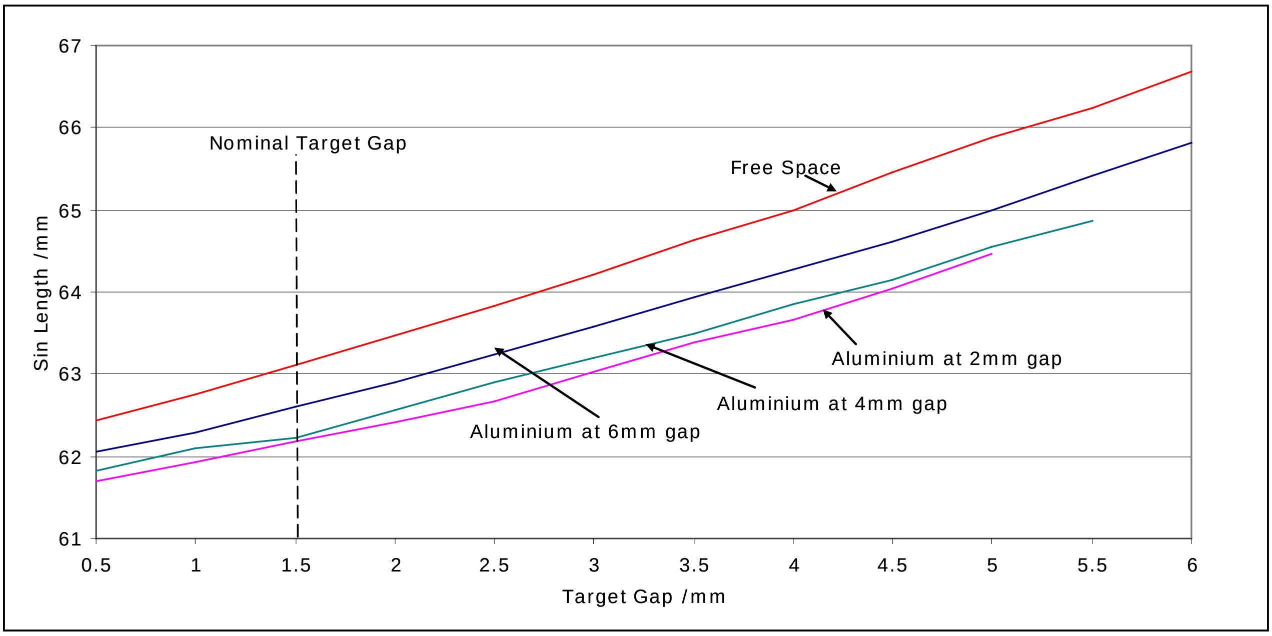

Figure 31 Sin Length with an Aluminium sheet behind 50mm sensor

2.14 Metal at Edge of Sensors

The sensors can be installed with metal at their edge (as drawn in Figure 21), providing there is sufficient gap to the metal (Table 5). As with metal behind, changes in the gap to metal should be avoided for best linearity.

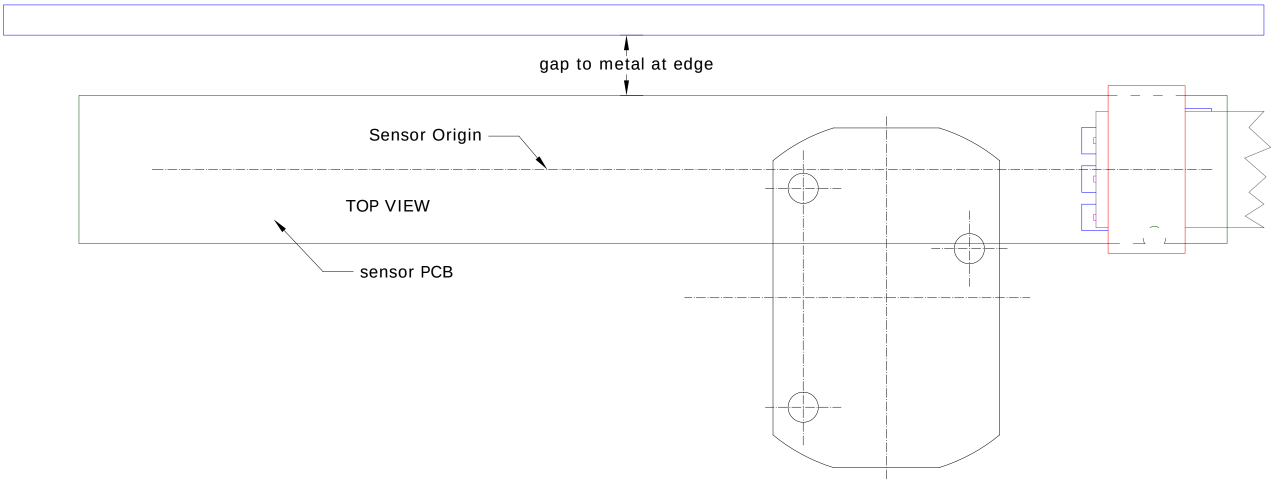

Figure 32 metal at edge of sensor

Table 5

Type of metal	**Gap to metal at edge**	
	Absolute Minimum	**Recommended minimum**
Aluminium, copper, brass sheet (>0.1mm thick)	0mm	2mm
Stainless steel (austenitic)	0mm	2mm
Mild steel, or aluminium or copper foil (10 – 50µm)	2mm	4mm

The main effects of meal to the edge of the sensors are to modify Amplitude and to modify the target's resonant frequency slightly. The CTU automatically tunes to the target's frequency, so the change in amplitude is normally the main concern. Aluminium has the least effect on Amplitude, and in fact aluminium at the edge of a sensor can increase Amplitude slightly (Figure 22). A change in Amplitude causes a change in End Valid Length (Figure 23), and resolution is also slightly changed as a result.

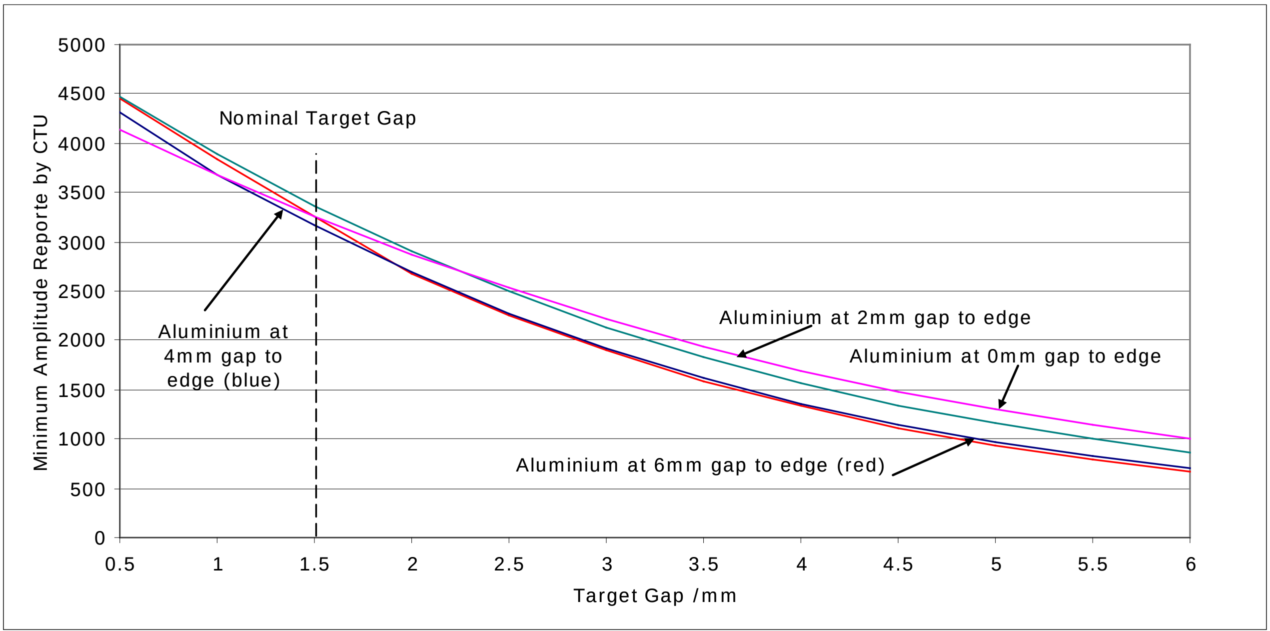

Figure 33 Reported Amplitude with an Aluminium sheet at edge of 50mm sensor

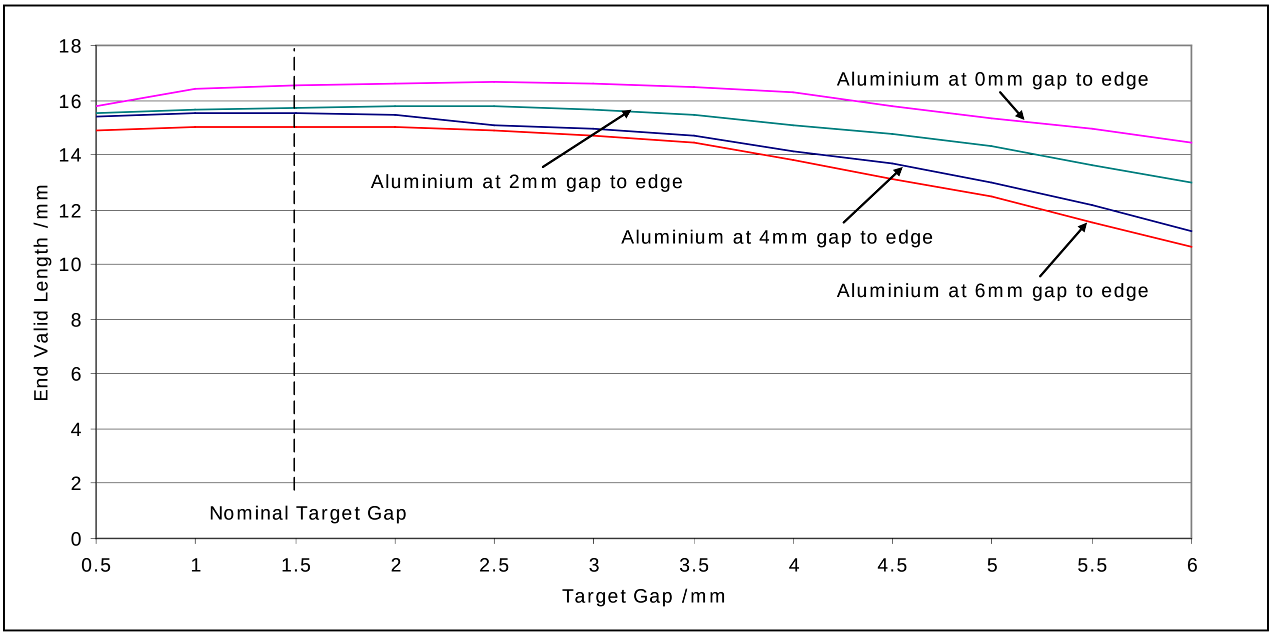

Figure 34 End Valid Length with an Aluminium sheet at edge of 50mm sensor

Aluminium at the edge of a sensor makes little difference to Worst Linearity Error (Figure 24).

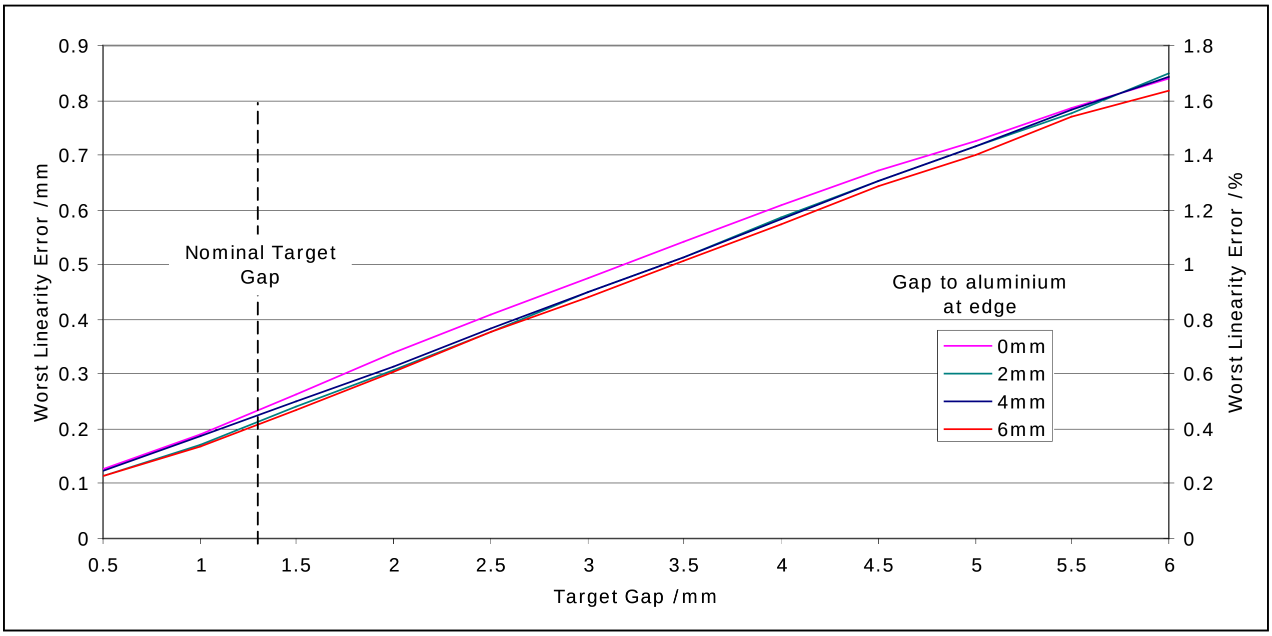

Figure 35 Linearity Error with an Aluminium sheet at edge of 50mm sensor

Sin Length is used to convert from CTU units to position units (Equation 1). The optimum value changes slightly with metal behind, see Figure 25 for aluminium.

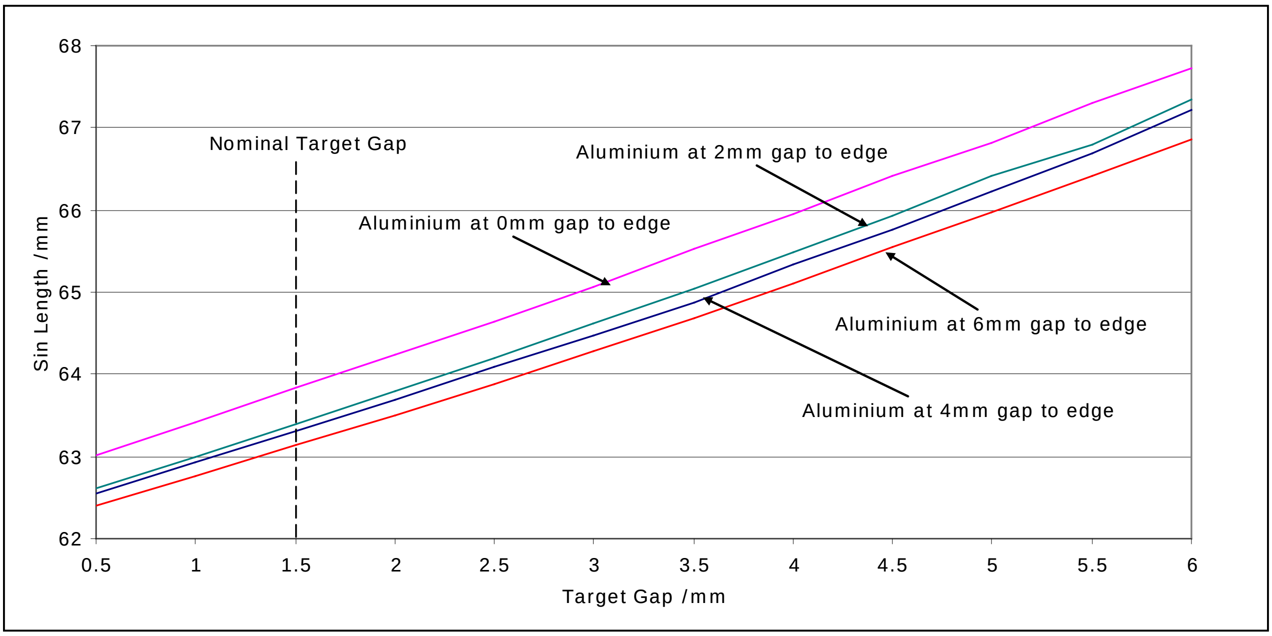

Figure 36 Sin Length with an Aluminium sheet at edge of 50mm sensor

3 Sensor Blueprints

3.1 Purpose

A sensor blueprint comprises Gerber (RS274-X) data defining the pattern of conductors required to build the sensors onto a PCB. A customer may build their own sensors for use with CambridgeIC's CTU family of processors, either as stand-alone sensors or combined with their own circuitry.

3.2 Fabrication Technology

The sensor blueprint is fabricated on a 4-layer PCB.

Table 6

Copper thickness	oz	µm
Minimum	0.8	28
Recommended	≥1	≥35
Ideal	2	70

3.3 PCB Design Parameters

Table 7

PCB Design Rules	Minimum values used	
	mm	inches
Track width	0.15	0.006
Gap between tracks	0.15	0.006
Via land outer diameter	0.64	0.025
Drill hole diameter	0.3	0.012

3.4 PCB Integration

Figure 26 illustrates the extent of the copper pattern required to build the sensor on a PCB. The Copper Length parameter is sensor specific and values are listed in Table 6. The rectangular 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.

Table 8

Sensor Blueprint Part Number	Measuring Length	Copper Length
010-0003	25mm	37.12mm
010-0047	36mm	48.12mm
010-0004	50mm	62.44mm
010-0005	100mm	112.12mm
010-0033	150mm	161.81mm
010-0006	200mm	211.8mm
010-0041	300mm	311.8mm

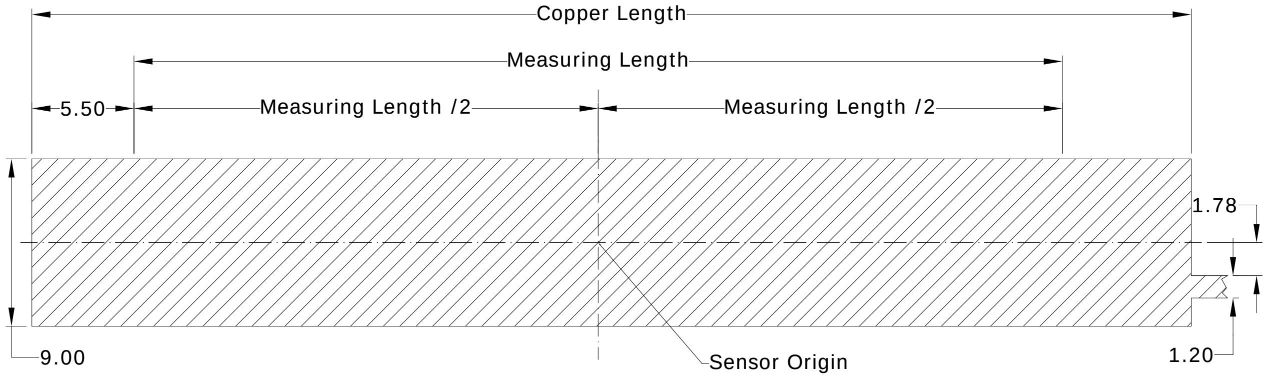

Figure 37 copper extents

3.5 Trace Connections

There are three pairs of tracks, which should be connected to the respective CTU circuit connections with the minimum practical trace lengths. The excitation pair should have minimum resistance, preferably by using traces 0.5mm wide or more.

Tracks are routed in pairs, and each member of a pair should follow the same path as the other, on different and preferably adjacent layers, to minimise errors due to unbalanced loops. VREF_SIN and VREF_COS should, where possible, be connected to the CTU circuit's VREF node as close as possible to the CTU circuit.

4 Environmental

Assembled sensors conform to the following environmental specifications:

Item	Value	Comments
Minimum operating temperature	-40°C	Limited by specification of connector
Maximum operating temperature	105°C	
Maximum operating humidity	95%	Non-condensing

Sensors built to Sensor Blueprints can operate in more extreme conditions by choice of materials and encapsulation.

5 Document History

Revision	Date	Comments
A	17 March 2009	First draft
B	1 June 2009	New sensor PCB line colours for clarity
0002	5 October 2009	Added temperature stability data
0003	10 December 2009	Revised sensor blueprint copper thickness
0004	19 January 2010	Updated title, logo and style
0005	7 June 2010	Added details of 150mm sensor
0006	14 June 2011	Swapped order of figures 7 and 8 to correct error
0007	22 September 2011	Added details of 300mm sensor
0008	13 June 2012	Added details of 36mm sensor
0009	13 February 2014	Updated legal statement

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