

Description

A precision linear resonant inductive position sensor with a measuring range of 75mm. 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 4 (Type "6.4").

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

Features

- Full absolute linear sensing
- 75mm Measuring Range
- 6-layer PCB process
- Target is sensed from FRONT or REAR of sensor
- Compact sensor coils

Performance

- Linearity Error < 0.15% at 0.5mm...2mm Gap
- Noise Free Resolution > 12 bits up to 2mm Gap
- Up to 0.5mm Y Misalignment

Applications

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

Product identification	
Part no.	Description
013-0036	Assembled sensor, 10mm wide
010-0099	Sensor Blueprint
013-1020	11mm E-Core Target

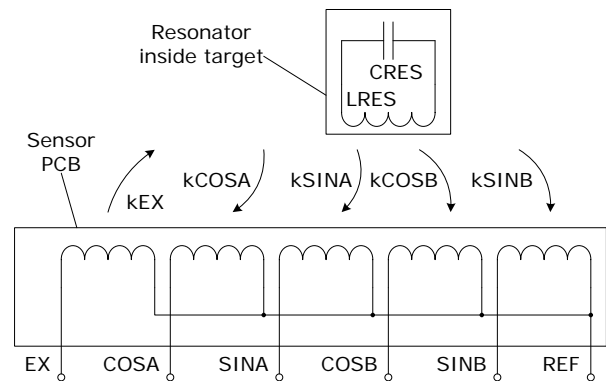


Figure 1 equivalent circuit

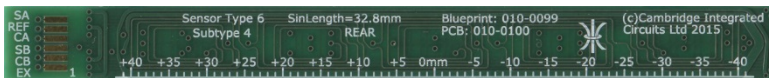


Figure 2 Sensor PCB Assembly 013-0036, REAR

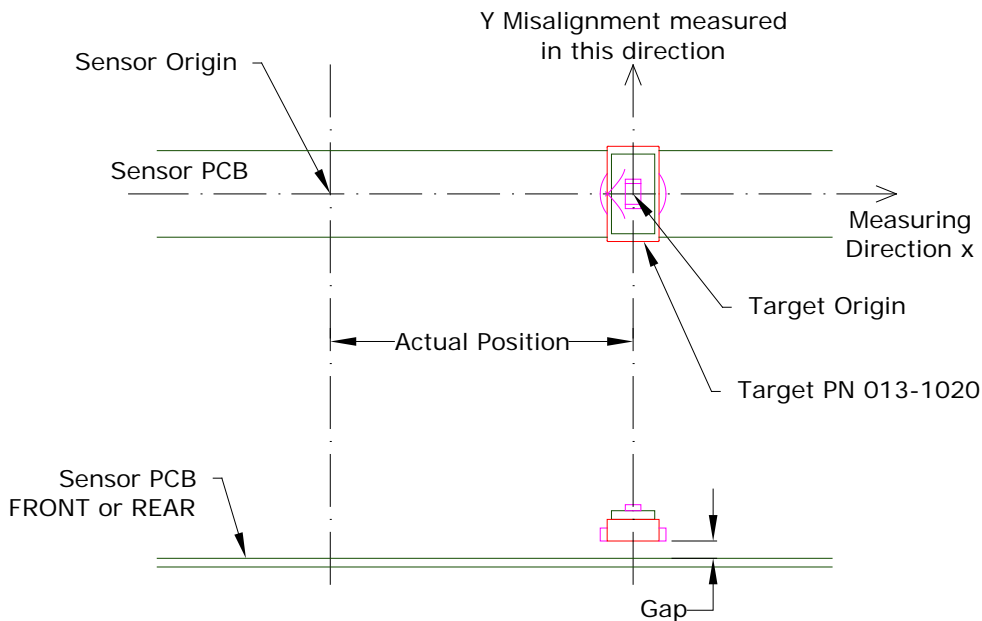


Figure 3 Alignment of sensor PCB assembly 013-0036 with target 013-1020

1 Assembled Sensor 013-0036 Mechanical Design

The 75mm Type 6.4 Linear Sensor is available as an assembled PCB including connector. Its REAR side is illustrated in Figure 2. Figure 4 is a mechanical drawing.

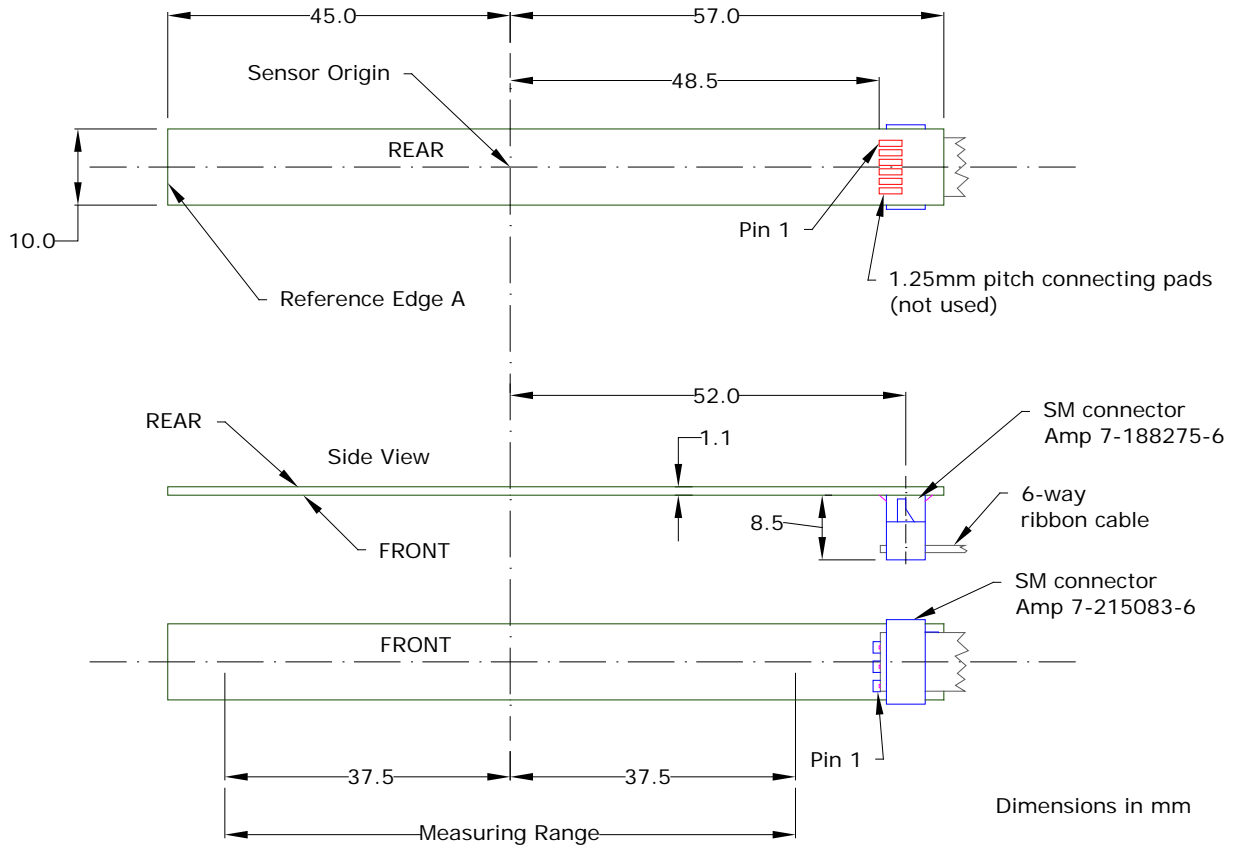


Figure 4 Mechanical drawing, sensor PCB assembly 013-0036 shown with mating connector 013-6001

The FRONT of the sensor PCB is fitted with an SM connector AMP 7-188275-6. The REAR includes a single row of 1.25mm pitch connecting pads that do not have a connector fitted. The pinout for both is shown in Table 1.

Table 1 Sensor PCB electrical connections

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

The 75mm Type 6.4 Linear Sensor assembly works with the 11mm E-Core Target, part number 013-1020. Their relative alignment is illustrated in Figure 3. The target may be adjacent either the FRONT or REAR surface of the sensor PCB.

The sensor measures Actual Position relative to the Sensor Origin. The nominal location of the Sensor Origin is 45mm to the right of Reference Edge A as illustrated in Figure 4. This edge is created with a routing process which is inherently less accurate than an alignment hole, and the resulting Offset Error is on the order of $\pm 0.3\text{mm}$ (section 3.4).

2 Principle of Operation

2.1 Electronic Interrogation

The 75mm Type 6.4 linear sensor is connected to a CambridgeIC CTU chip (e.g. the CAM204) and its associated circuitry. To take a position measurement the CTU chip first generates a few cycles of AC current in the EX coil matching the resonant frequency of the resonator. This current forces the resonator to resonate. When the excitation current is removed the resonator continues to resonate, with its “envelope” decaying exponentially as shown in Figure 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 2.2.

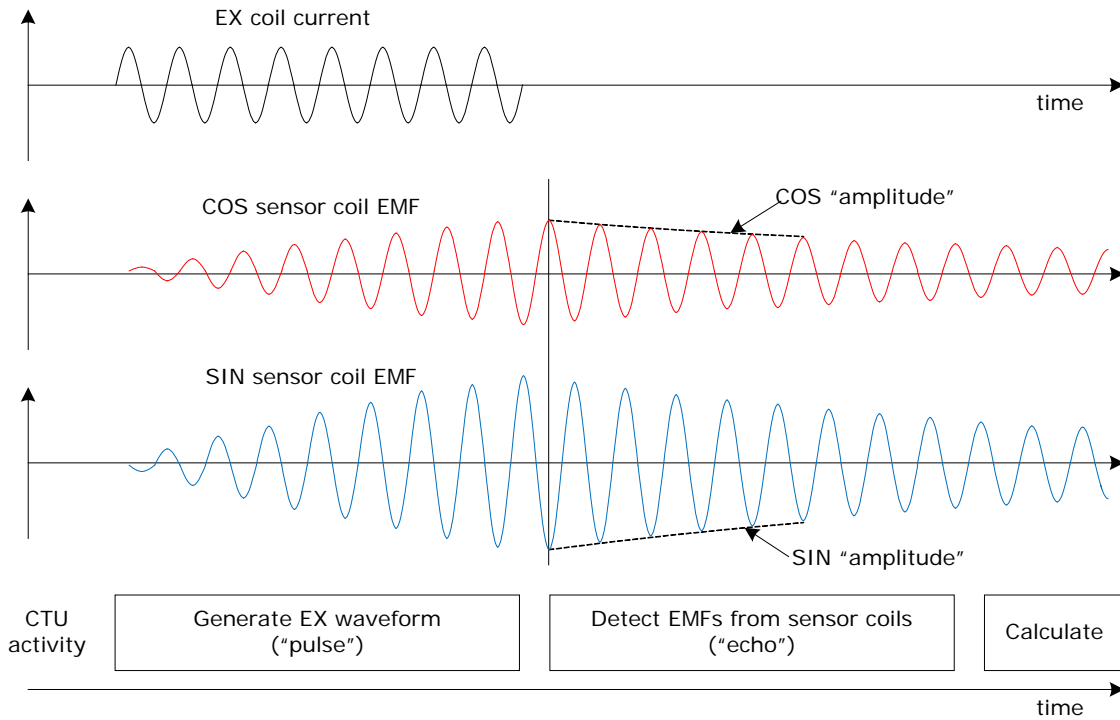


Figure 5 Electronic interrogation process

2.2 Sensor Coils and Position Calculation

Section 2.1 described how the CambridgeIC CTU chip detects the relative amplitude of the signals induced by the resonator in the sensor's 4 sensor coils. These measured amplitudes are proportional to the coupling factors between the resonator and each of the 4 sensor coils, kCOSA, kSINA, kCOSB, kSINB. This subsection describes how these coupling factors change with position, and the calculation the CTU chip performs to determine this position.

Figure 6 illustrates each of the 5 coils in the sensor individually, one above the other. In reality, they are all overlain.

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

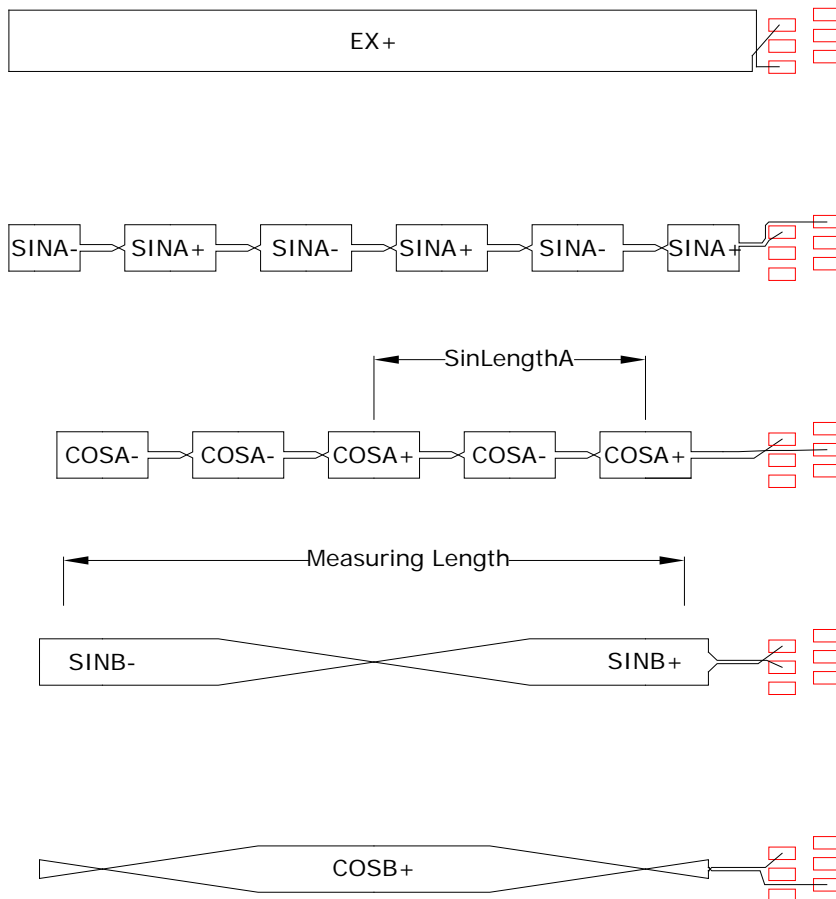


Figure 6 Coil designs, simplified for clarity

The COSA and SINA coils are fine sensor coils. The coupling factor between resonator and fine coils varies sinusoidally with position with just over 2 repeating periods along the measuring range, as illustrated in Figure 7. Their sinusoidal period is denoted SinLengthA. The kCOSA and kSINA coupling factors are in phase quadrature. The CTU chip measures these coupling factors, and performs a 4-quadrant inverse tangent calculation on them to determine *Fine Position*. This calculation is fully ratiometric, so that changes in absolute signal levels due to variations in power supply voltage, temperature and so on do not affect the measurement.

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

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

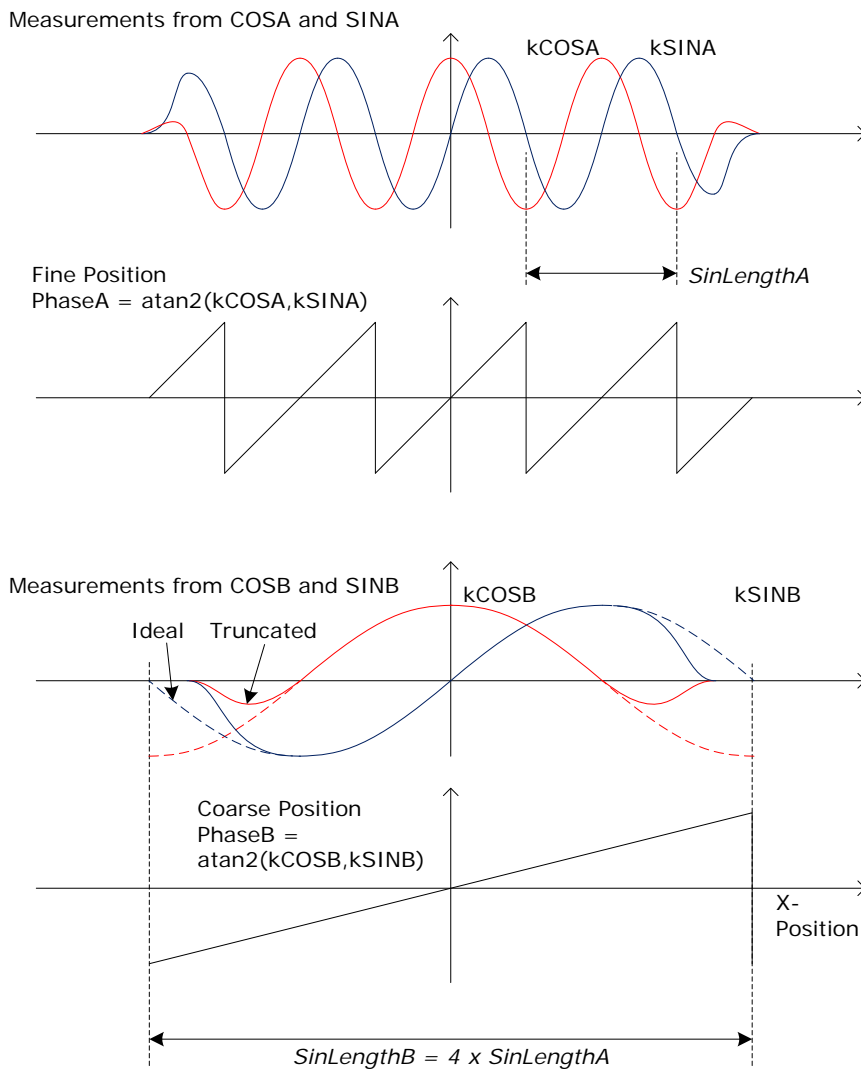


Figure 7 Sensor Coil coupling factors

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

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

The Coarse Pitch parameter $SinLengthB$ is 4 times $SinLengthA$, and the number 4 corresponds to the sensor's Subtype. Both the sensor's Type (6) and Subtype (4) must be communicated to the CTU chip for correct operation. Please refer to the datasheet for the appropriate part.

3 Definitions

3.1 Coordinate System

Figure 3 illustrates the coordinate system for the sensor, with the X-Axis running along the measuring direction and the Y-Axis perpendicular and also in the plane of the sensor PCB.

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

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

3.2 Transfer Function and Performance Metrics

The sensor is connected to a CTU chip which reports position as a 32-bit signed integer, here denoted *CtuReportedPositionI32*. The CTU chip also reports a VALID flag to indicate when the resonator is in range. These vary with Actual Position as illustrated in Figure 8.

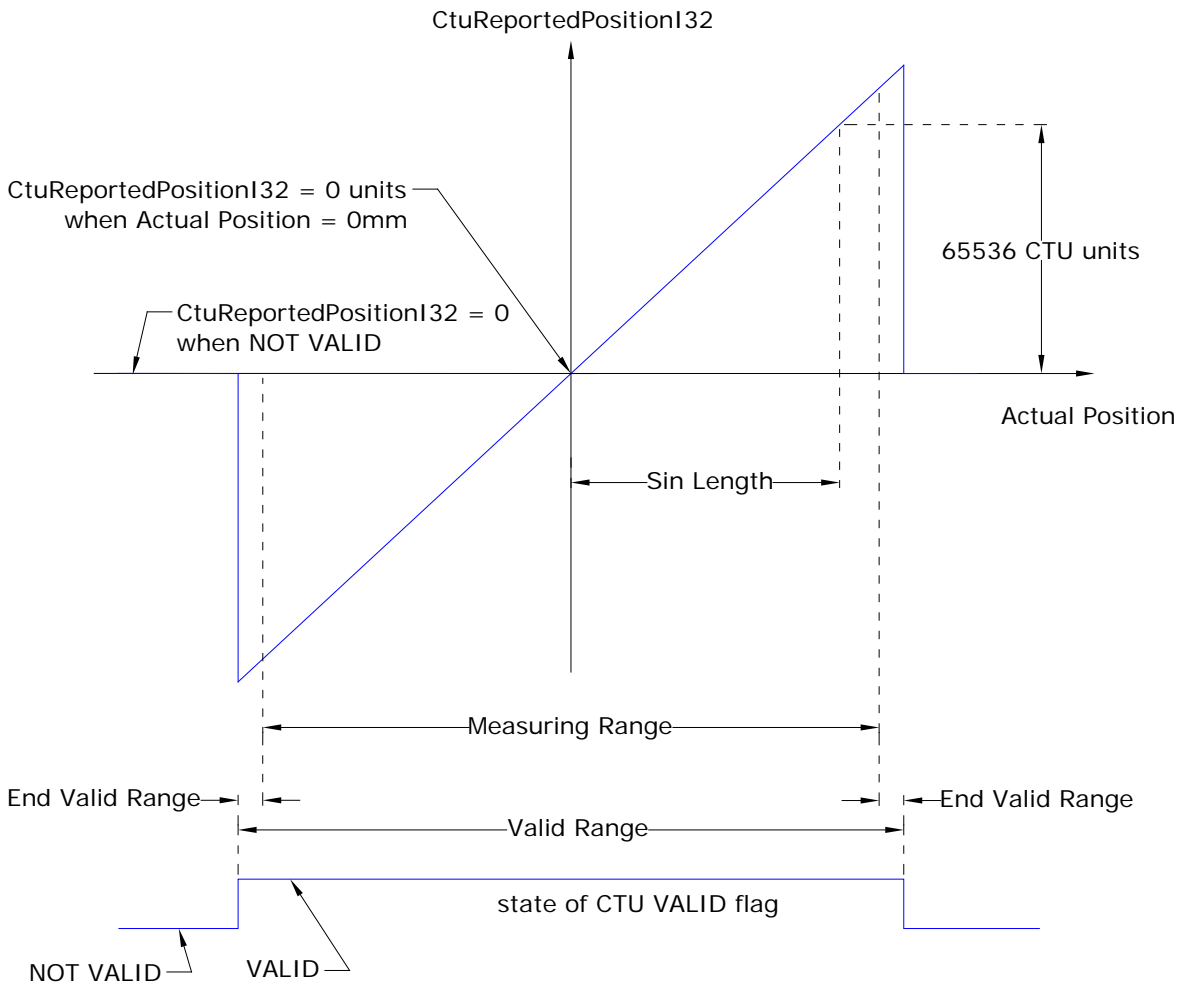


Figure 8 Transfer function

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

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

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

Equation 1

This figure is nominally equal to the Actual Position defined in section 3.1. The figures differ due to random noise, Linearity Error and Offset Error:

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

Equation 2

3.3 Random Noise and Resolution

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

$$\text{Peak to Peak Noise} = 6.6 \times \text{Standard Deviation}$$

Equation 3

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

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

Equation 4

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

The CAM502 CTU chip has an on-chip digital filter that can be configured to improve resolution at the expense of group delay. Please refer to its datasheet for the available settings and their effects.

3.4 Linearity Error and Offset Error

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

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

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

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

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

4 Performance

Figures below are representative of assembled sensor PCBs 013-0036 and sensor PCBs built to Sensor Blueprint 010-0099. Measurements are taken with a typical target PN 013-1020, and Type 6 CAM204 CTU Circuitry (see CAM204 datasheet, grade A components), at room temperature and in free space unless otherwise stated. Sensors are mounted flush against a flat surface for test purposes.

Measurements are presented as a function of Gap, which is defined in Figure 3. Unless otherwise stated, values presented below are worst case across Y misalignment of up to 0.5mm.

4.1 End Valid Range

End Valid Range is the distance each side of the Measuring Range over which the CTU chip's output remains VALID, as shown in Figure 8. It is a function of Gap as illustrated in Figure 9 below.

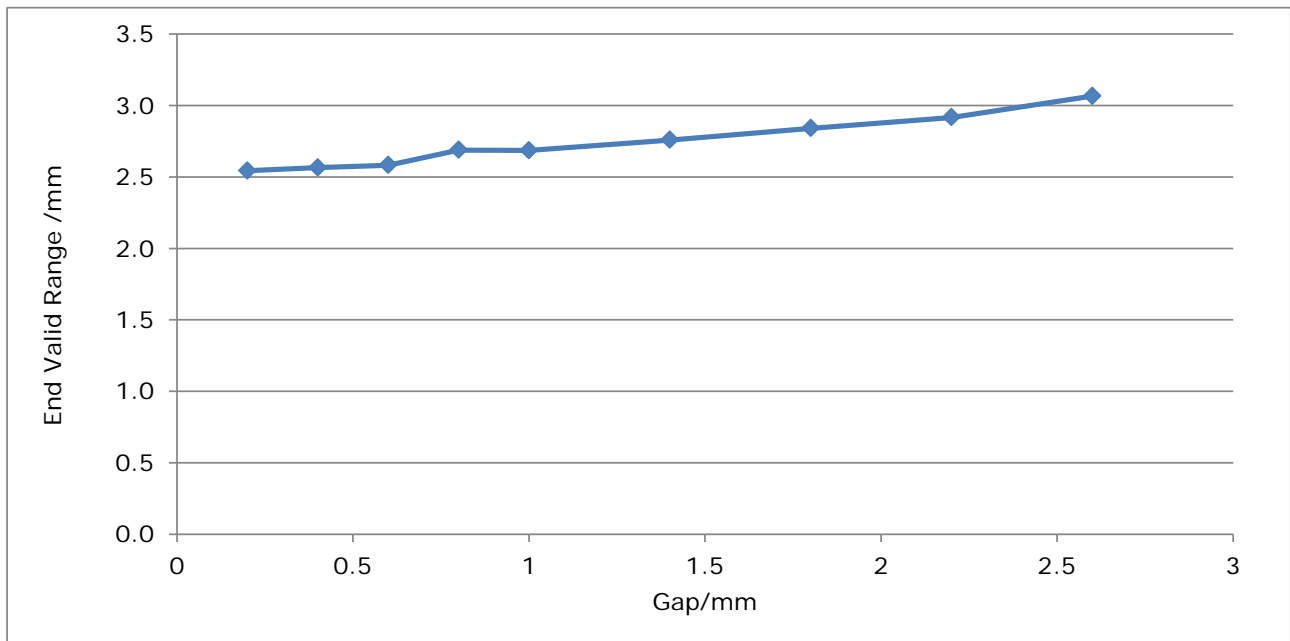


Figure 9 End Valid Range as a function of Gap

4.2 Linearity Error

Linearity Error is defined in section 3.4. Its value is also a function of Gap, as shown in Figure 10.

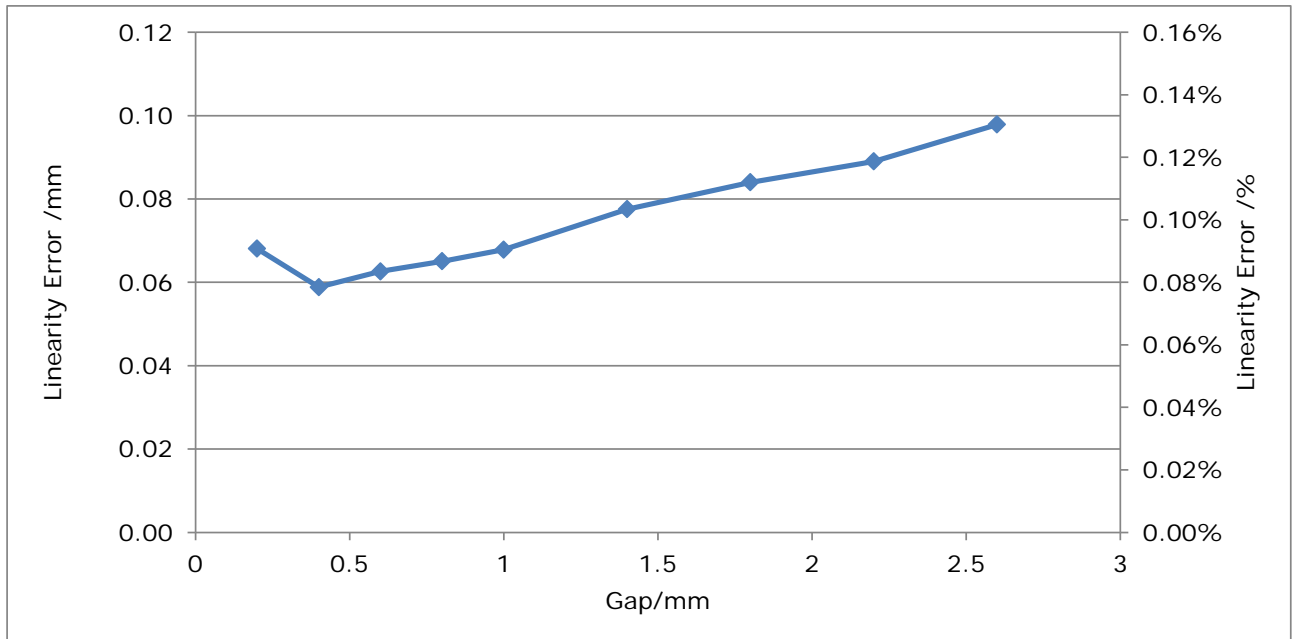


Figure 10 Linearity Error as a function of Gap

4.3 SinLength Value

The SinLength parameter is the sinusoidal pitch of the fine sensor coil coupling, SinLengthA, as illustrated in Figure 7. Its value is mainly defined by the layout of the fine sensor coils. However the exact best fit value for use in Equation 1 is also a weak function of Gap, as illustrated in Figure 11.

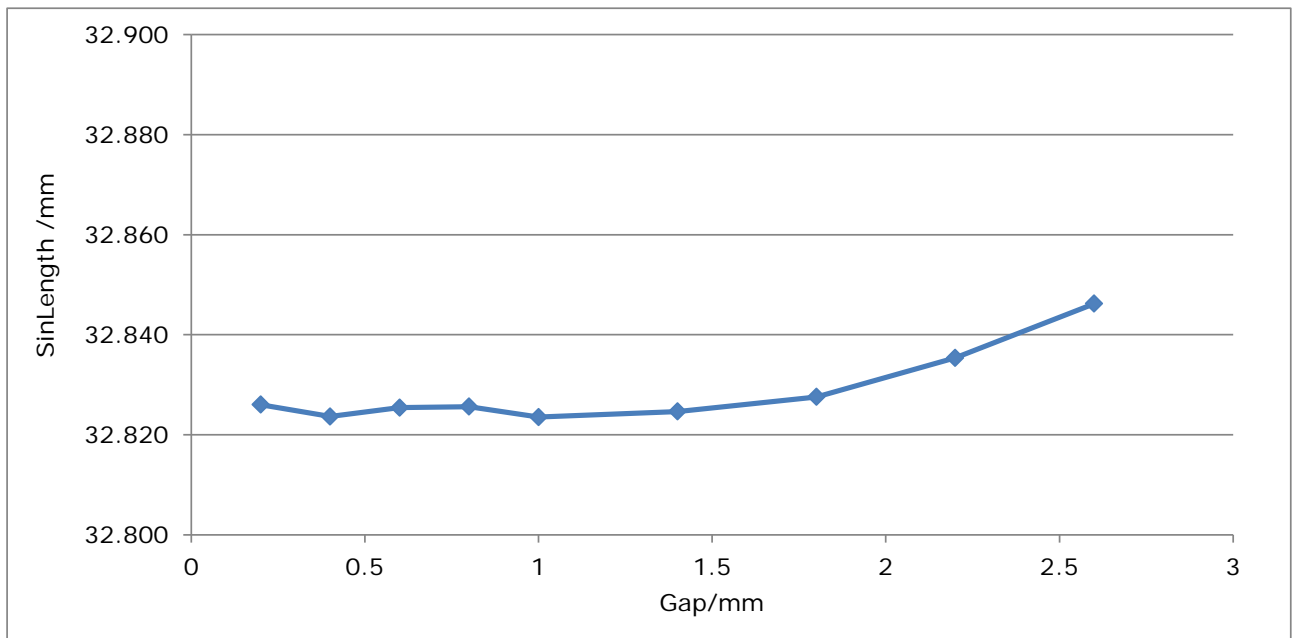


Figure 11 SinLength value as a function of Gap

The exact SinLength value is also subject to $\pm 0.1\%$ error due to stretch error in the PCB fabrication process. Thermal expansion also affects the length of the PCB and hence the SinLength value. Its magnitude is $\sim 13\text{ppm}/^\circ\text{C}$, assuming FR4 PCB material that is allowed to expand.

4.4 Amplitude

In addition to reporting position, the CTU chip also reports Amplitude. Amplitude is a useful measure of system health, and reduces with Gap as shown in Figure 12. Amplitude also reduces with the presence of nearby metal, and sensor installations should be checked to ensure any reduction is not excessive.

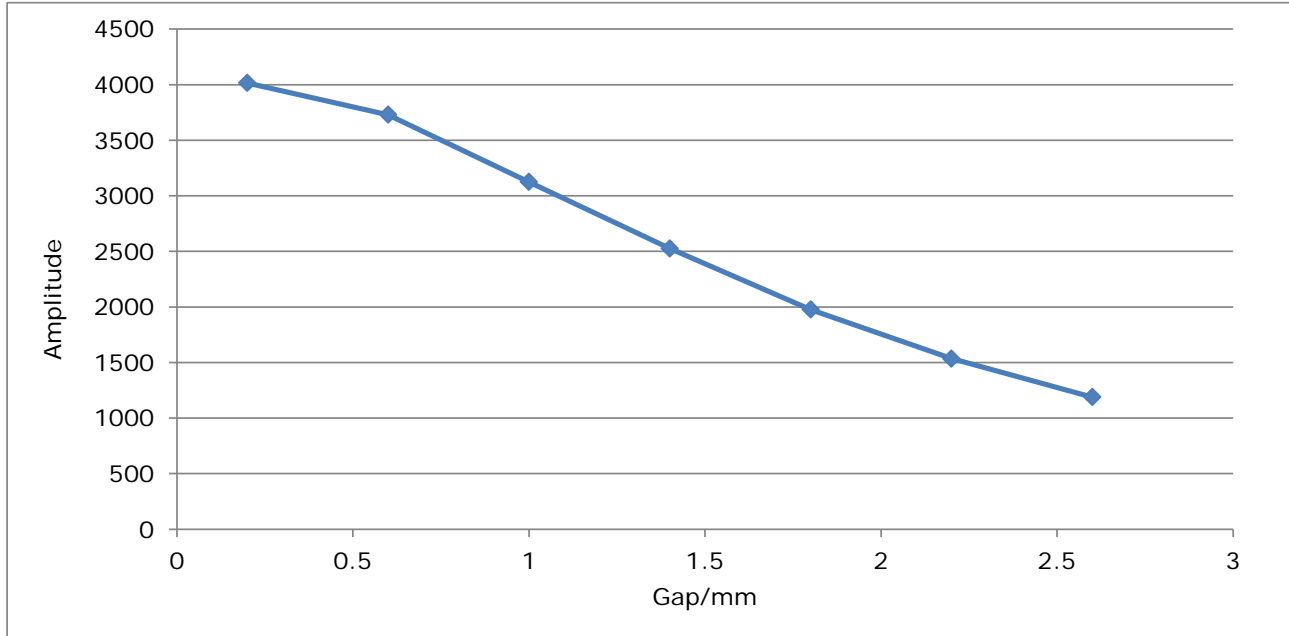


Figure 12 Minimum Reported Amplitude as a function of Gap, free space

4.5 Noise Free Resolution

Noise Free Resolution is defined in section 3.3. It is a function of the signal level detected by the CTU chip. It therefore reduces with Gap in a similar way to Reported Amplitude as illustrated in Figure 13.

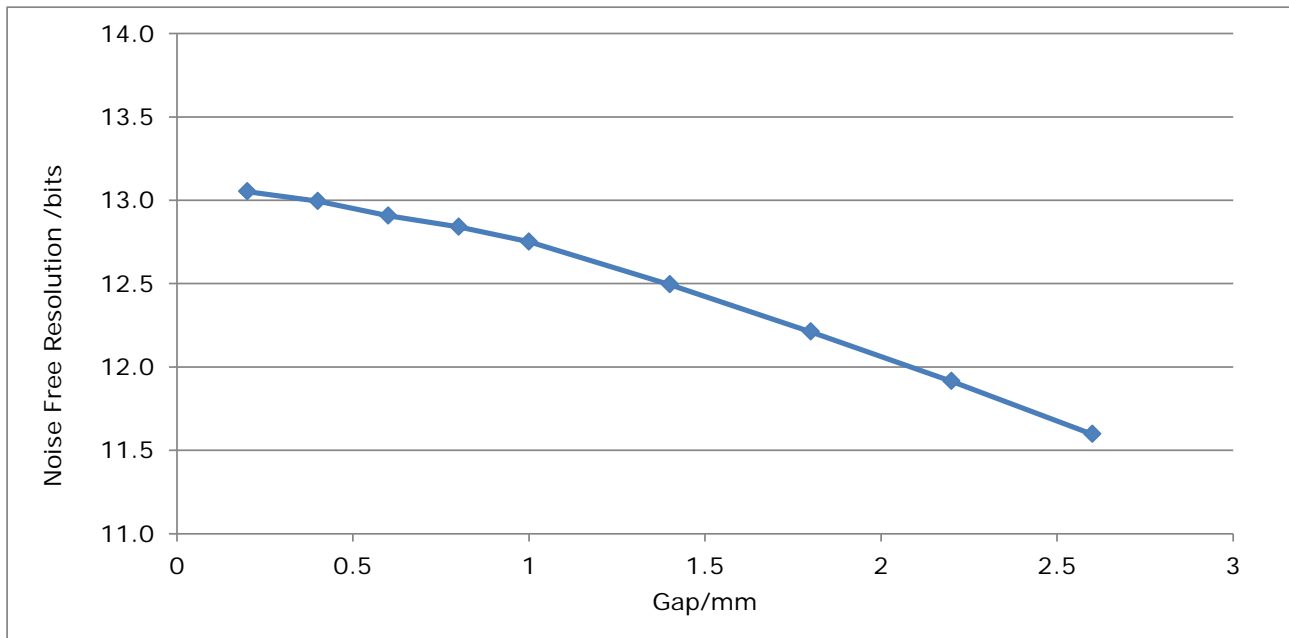


Figure 13 Noise Free Resolution as a function of Gap, CAM204 CTU chip, free space

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 Sensor Blueprint 010-0099

5.1 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 Cambridge IC's CTU chips, either as stand-alone sensors or combined with their own circuitry.

5.2 Fabrication Technology

Sensor Blueprint 010-0099 is fabricated on a 6-layer PCB. Recommended copper thickness is shown in Table 2.

Table 2

Copper thickness	oz	μm
Minimum	0.8	28
Recommended	1	35

5.3 PCB Design Parameters

Table 3

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

5.4 PCB Integration

Figure 14 illustrates the extent of the copper pattern required to build the sensor on a PCB. The shaded area is the sensor itself. The coil pattern may be rotated or flipped to fit a customer's assembly, in which case the position reported by the CTU will be transformed accordingly.

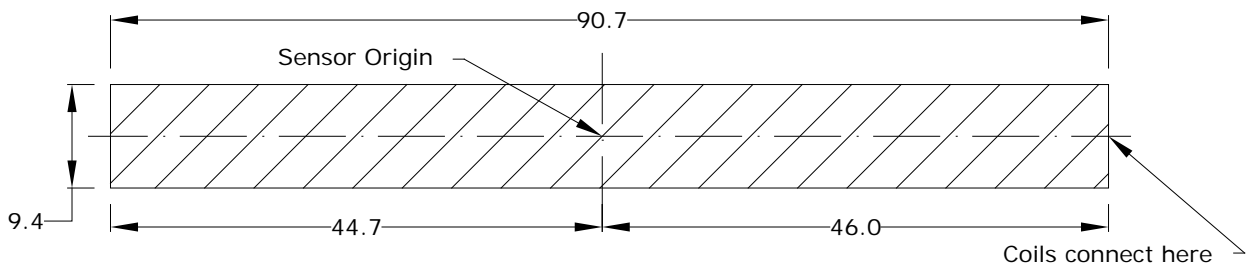


Figure 14 Copper extent, Sensor Blueprint 010-0099

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

5.5 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.

5.6 Trace Connections

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

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

6 Environmental

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

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

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

7 RoHS Compliance

CambridgeIC certifies, to the best of its knowledge and understanding that part number 013-0036 is in compliance with EU RoHS, China RoHS and Korea RoHS.

8 Document History

Revision	Date	Comments
0001	23 July 2015	First draft

9 Contact Information

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10 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.