

1 Background

This document provides suggestions and guidance for the integration of CambridgeIC's Type B linear sensors and their matching targets near metal.

1.1 Purpose

To help customers integrate CambridgeIC's linear sensing technology inside their products, where tight integration with metal parts is important.

1.2 Audience

This document is intended for a customer's design teams. In particular:

- Mechanical engineers, to help them develop appropriate mounting locations and methods, and
- Systems engineers to help them understand the performance impact of different integration approaches.

1.3 Referenced Documents

This document should be read in conjunction with the following other documents:

Part no	Title	Relevance
033-0084	Type B Sensor Reference Manual	Explains the meaning, measurement and importance of Amplitude, Q-factor and resonator frequency. Explains general effects of metal on sensor and target Screening examples (rotary only). Selection of a target's resonator capacitors depending on target inductance, which depends in turn on metal environment and any screening.
033-0098	40-100mm B6 Linear Sensors Datasheet	Sensor and target dimensions.
033-0097	200mm B12 Linear Sensor Datasheet	Performance in free space. Effect of uniform plates of aluminium behind or to the side of the sensor or target.
033-0091	CAM622 Datasheet	General context: the CAM622 processes sensor signals and communicates measurement results to a host. System level performance metrics including Amplitude and resolution only make sense in the context of this complete system. Official reference for resonator detection requirements, for example Nominal Resonator Centre Frequency and Resonator Tuning Range Relative to Nominal Resonator Centre Frequency.

2 General Considerations

2.1 Importance of Amplitude

This document refers to Amplitude throughout. Amplitude values are reported by the CAM622 IC (strictly Amplitude_A, measured from fine sensor coils), and are in arbitrary units. For this reason most Amplitude values in this document are percentages relative to the Amplitude value reported for the same physical arrangement of sensor and target measured with no metal nearby, "free space".

Amplitude should be maximised as far as possible, for two main reasons:

- Amplitude is directly related to achievable Noise Free Resolution. Roughly speaking, for every doubling of Amplitude, Noise Free Resolution will increase by 1 bit (half as much peak to peak position noise).
- A minimum Amplitude value is required for the CAM622 to detect a target, see the CAM622 datasheet for official figure. A considerable margin is advised to prevent invalid readings in all situations.

Amplitude also varies with gap between the target and sensor PCBs. For 10mm wide Type B linear sensors, it roughly halves for a 1mm increase in gap.

Unless otherwise stated measurements below are taken with 1.0mm gap, to aid comparison between integration approaches. However in practice gap should be minimised, especially if the metal environment significantly reduces Amplitude.

Please refer to the Type B Sensor Reference Manual for more detail on Amplitude and its importance.

2.2 Importance of Q-Factor

The Q-factor of the target's inductor is also important. A high Q-factor value yields high Amplitude. However Q-factor is also important in its own right, because the CAM622 needs to be able to detect and lock onto the target's resonant signal. A signal that decays too quickly (low Q-factor) is more difficult to detect.

In most cases a high Amplitude reading is an indication that Q-factor is adequate. However there may be cases where this is misleading, for example when gap between sensor and an unscreened target is very small and the target has steel very close behind. Please contact CambridgeIC for assistance if in any doubt.

For reliable operation with the CAM622, it is recommended to have a Q-factor of at least 12. As a rough indication, this corresponds to a Type B linear target with steel 3mm behind. In free space the target's Q-factor should be around 22.

Please refer to the Type B Sensor Reference Manual for a definition of Q-factor and how to measure it.

2.3 Resonant Frequency Centering

In addition to its effect on Amplitude, mounting a target adjacent to metal and/or adding a magnetic screen will change its resonant frequency.

The presence of nearby aluminium tends to decrease the target inductor's inductance value, increasing resonant frequency relative to free space. The presence of screening tends to increase the target inductor's inductance value, decreasing resonant frequency relative to free space.

The resonator capacitor values must be modified to compensate. The objective is for the target's resonant frequency to nominally match the CAM622's centre frequency (833.3kHz) when positioned in the final metal environment including any screening. The CAM622 can tune to targets across a relatively wide frequency range, but it is nevertheless important, for maximum system robustness and performance.

In some arrangements, the target's resonant frequency will change with its gap to the sensor, due to metal and/or screening behind the sensor. In this case the gap at which the target frequency is half way between maximum and minimum should be established, and capacitor values selected to suit this situation. The frequency variability due to gap change should then be included in the overall frequency tolerance budget, which must remain within the CAM622's tuning range. Please see section 4.8 for an example.

Please refer to the Type B Sensor Reference Manual for details on how to select resonator capacitors to centre the target's resonant frequency, and how to verify that frequency variability remains within budget.

3 Integration Avoiding Screening Material

3.1 Motivation

Screening material allows the sensor and target to be mounted very close to metals. However it is recommended to try designing without it, to avoid the cost of the material itself and the associated cutting, glueing and mounting processes.

Ferrite loaded polymer screening material is usually supplied with a pressure sensitive adhesive backing. This usually becomes brittle at low temperatures and soft at high temperatures, typically limiting operation to -20°C to $+85^{\circ}\text{C}$. Other adhesive techniques could be considered, but avoiding screening is the easiest way to overcome such issues.

3.2 Integration Above Metal Surfaces

Each sensor's datasheet includes a section on performance with metal nearby. This typically includes aluminium and steel. Examples are given with metal behind the sensor, behind the target and to the side of the sensor and target.

These measurements may also be used to estimate the effects of metal in multiple locations, for example behind both sensor and target, so that they are mounted between parallel metal surfaces. For example if aluminium 2mm behind the sensor reduces Amplitude to 70% of its free space value, and aluminium 3mm behind the target reduces Amplitude to 80% of its free space value, then both together will reduce Amplitude by $70\% \times 80\% = 56\%$ of its free space value. Note that in this case the distance between parallel aluminium surfaces will be 8mm (2mm aluminium gap to sensor + 1mm sensor thickness + 1mm nominal air gap + 1mm target PCB thickness + 3mm gap to aluminium). This can be reduced dramatically with screening, for example see section 4.5.

3.3 Target Integration Inside an Aluminum Pocket

It is possible to mount the target inside a pocket machined in an aluminum part, as illustrated in Figure 1.

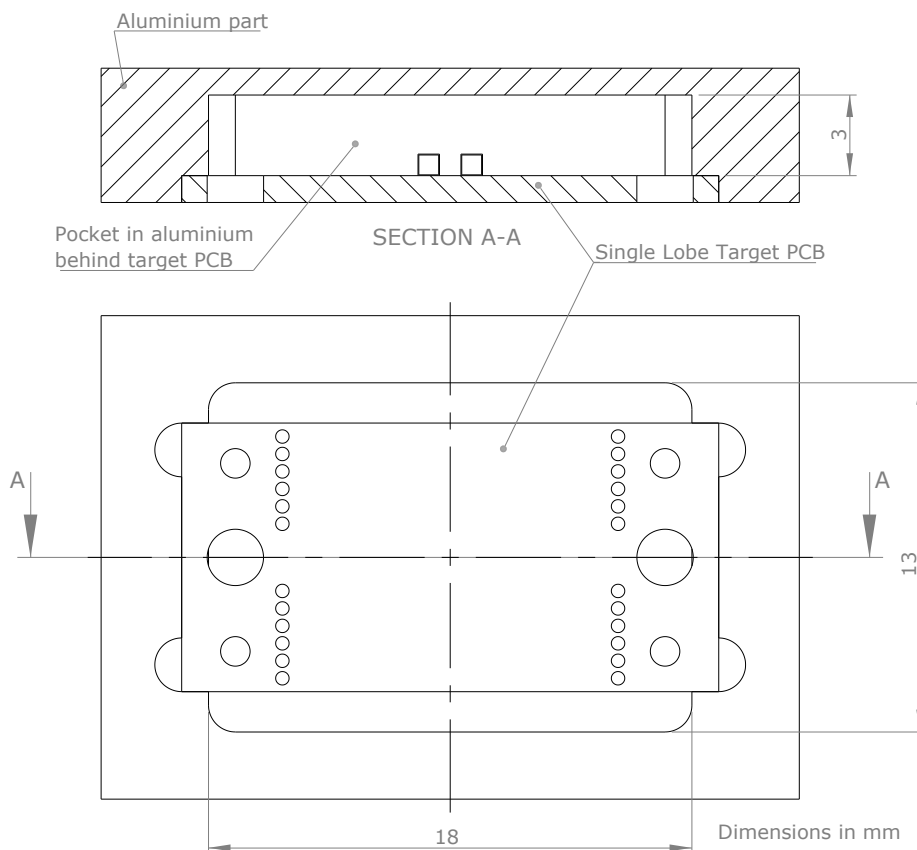


Figure 1 Single Lobe Target Integrated in a Pocket in Aluminum

Table 1 Performance measurement, Single Lobe Target Integrated in a pocket in aluminum

Test Condition	Amplitude relative to Free Space
Single Lobe Target mounted as in Figure 1 50mm B6 Sensor at 1mm gap No other metal nearby	64%

Table 1 provides a performance measurement for this arrangement. The reduction in Amplitude is relatively large. However in applications where such a pocket is possible the reduction in overall thickness may be critical.

Note that the reduction in Amplitude will be less for a deeper pocket, and for a pocket wider than 13mm. Where space permits the pocket dimensions should be maximised, to minimise the performance impact of the aluminium.

This integration method is also suitable for brass and similarly conductive materials. It is not suitable for materials with lower conductivity such as steels and titanium. In these cases an aluminium screen at least 0.1mm thick may be used between the ferrite shield and metal. Copper tape with thickness 35µm may also be used, delivering slightly worse shielding. Aluminium foil is typically 15µm thick, which is insufficient for this purpose.

4 Magnetic Screening

Magnetic screening material may be used to screen the target and/or sensor against the effects of adjacent metal, allowing much smaller separations than without.

4.1 Choice of Magnetic Screening Material

Examples in this section use Würth Elektronik's 34412 WE-FAS screening material. Please refer to Würth's datasheet for further details. This material includes a 0.2mm thick flexible ferrite layer comprising a ferrite powder loaded polymer composite. The material is supplied as a sheet laminated to pressure sensitive adhesive (PSA).

As noted in section 3.1 this material has a limited operating temperature range and adds material and manufacturing process costs. However in some cases it is essential, in order to fit a sensor or target into a tight space.

Würth Elektronik's WE-FAS screening material is available with a thinner ferrite layer: part 34411, 0.1mm. This will yield lower screening efficiency and is not recommended.

Part 34413 has thicker ferrite sheet, 0.3mm. This has greater screening efficiency but it more expensive. It is recommended for applications requiring the highest possible Amplitude and hence best resolution.

WE-FAS parts 34412 and 34413 have a relatively high permeability of 200, which is a measure of their screening efficiency. Würth Elektronik offers other older materials with lower permeability, for example 34403 with permeability of 100 and 0.3mm thick. This material and thickness is also suitable for screening, with its lower permeability offset by greater thickness. However the price of 34403 material is similar to 34412, so 34412 material is generally preferred due to lower thickness.

Metallic magnetic screening materials such as mumetal and spin melt ribbon (VITROVAC® alloys from Vacuumschmelze) are not generally preferred, since they are conductive and hence relatively lossy, yielding low Q-factor when placed near the target.

4.2 Screened Target in Aluminium Channel

This arrangement comprises a Target PCB with a rectangular piece of 34412 shielding material laminated to it. Figure 2 illustrates the shield itself. A 4mm punched hole in the middle is for the target's resonator capacitors.

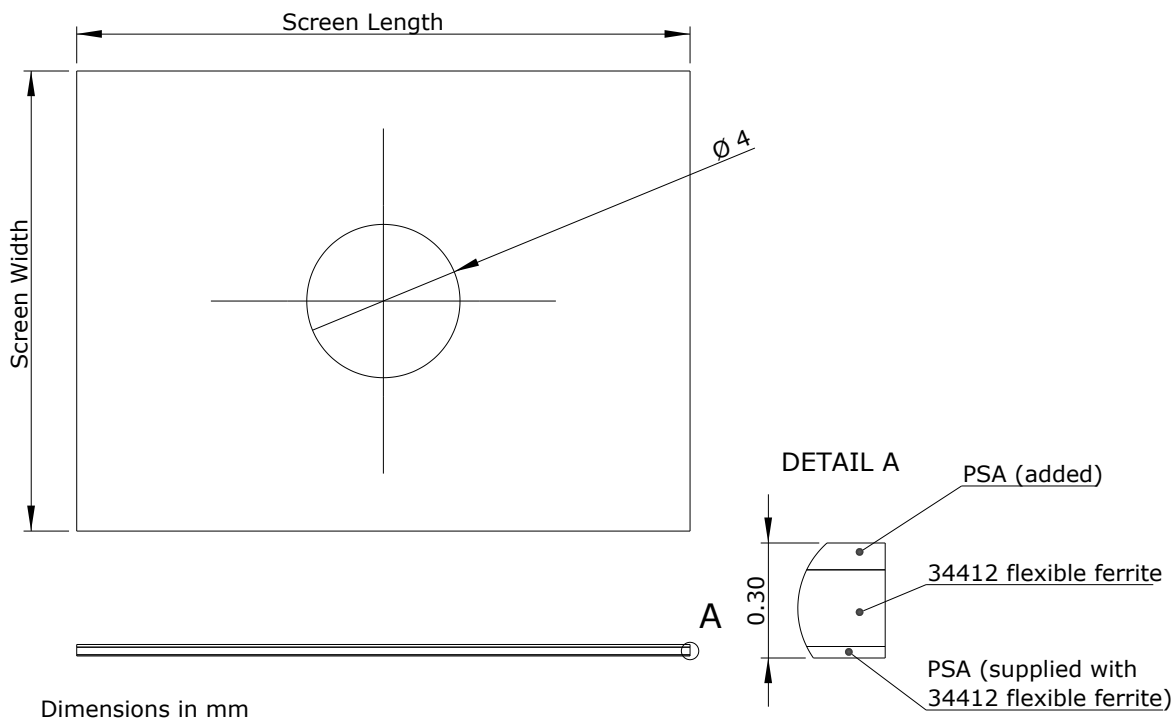


Figure 2 Magnetic shield for Single Lobe Target

The screened target sits in a 1.3mm deep channel in aluminium, as illustrated in Figure 3. The screening is 0.3mm thick and the Target PCB is 1.0mm thick, so together they fill the 1.3mm thick channel and the Target PCB ends up flush with the aluminium surface.

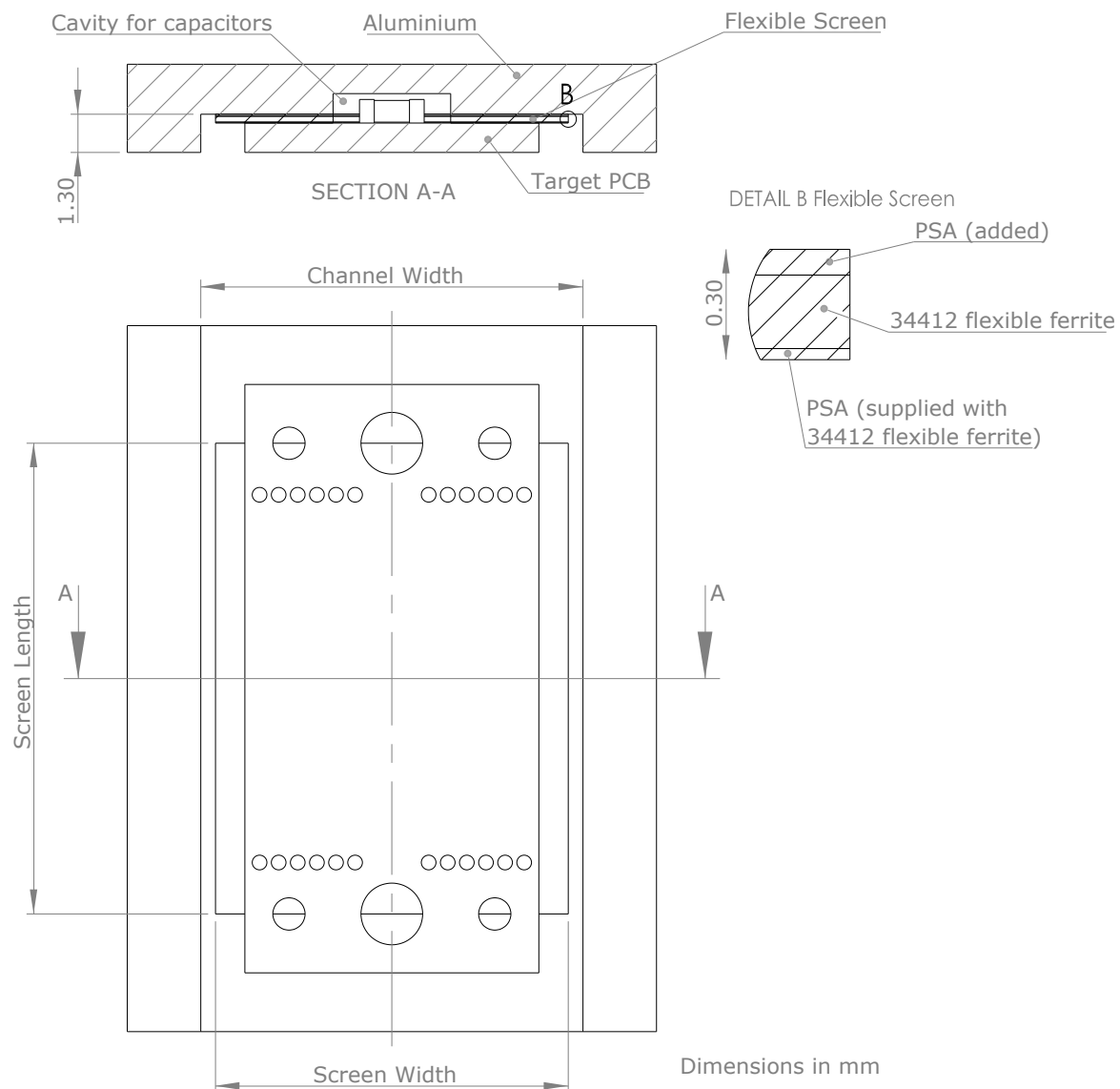


Figure 3 Screened Single Lobe Target in Aluminium Channel

Measurements were also taken with the screened target mounted flush to a flat piece of aluminium ("No channel, flat aluminium plate"). In this case the aluminium included a small hole for the capacitors.

Table 2 Performance measurements, screened Single Lobe Target in aluminium channel

Test Condition	Amplitude relative to Unscreened in Free Space		
	Screen Width 10mm Screen Length 12mm	Screen Width 10mm Screen Length 14mm	Screen Width 12mm Screen Length 12mm
Free Space, screened	95%	101%	101%
Channel Width 10mm	43%	55%	Does not fit
Channel Width 11mm	51%	64%	Does not fit
Channel Width 12mm	60%	70%	70%
Channel Width 13mm	62%	72%	73%
No channel, flat aluminium plate	66%	76%	82%

Error! Reference source not found. Table 2 provides performance measurements for this arrangement, as a function of Channel Width and screen dimensions. Measurements were taken with the 50mm B6 Sensor at 1mm gap, with no other metal nearby.

Some conclusions can be drawn from these figures, and those for metal integration provided in the sensor's datasheet:

- Screening allows the target to be mounted almost directly onto aluminium. Without it a gap of several millimeters is needed for similar performance.
- The target can be mounted in a channel, even one matching the target's width of 10mm. However larger values of Channel Width are preferred where possible.
- Increasing the Screen Width and Screen Length increases Amplitude, and larger values should be used where possible.
- Screening a target tends not to improve Amplitude significantly when there is no metal nearby.

This integration method is also suitable for brass and similarly conductive materials. It is not suitable for materials with lower conductivity such as steels and titanium. In these cases an aluminium screen at least 0.1mm thick may be used between the ferrite shield and metal. Copper tape with thickness 35µm may also be used, delivering slightly worse shielding. Aluminium foil is typically 15µm thick, which is insufficient for this purpose.

4.3 Screened Sensor in Metal Channel

The same Würth Elektronik 34412 WE-FAS screening material may be used to magnetically screen sensors, for example as in Figure 4:

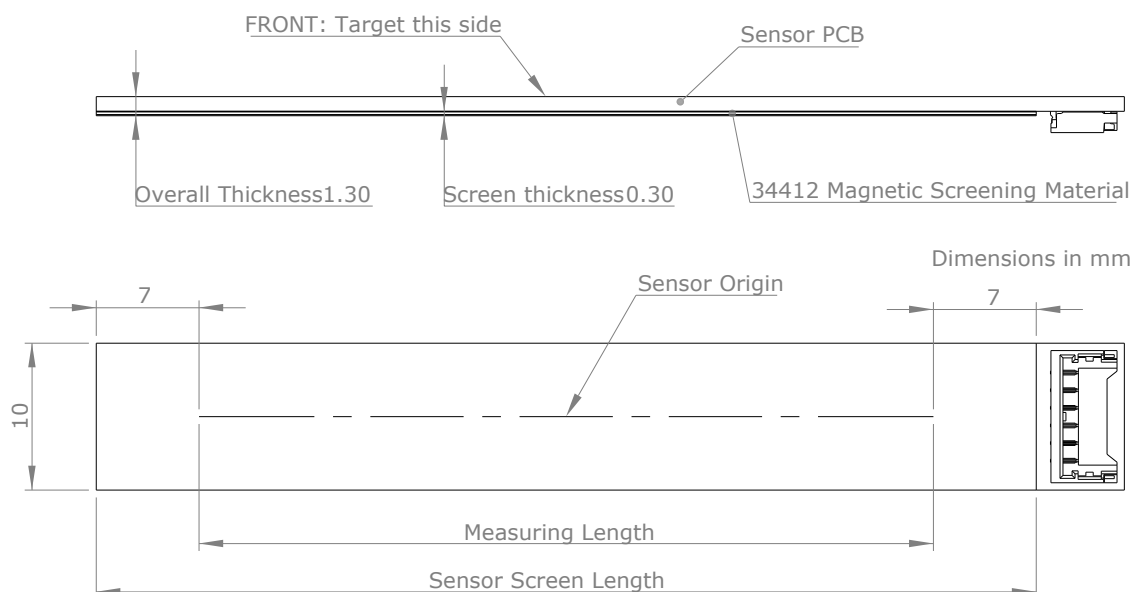


Figure 4 10mm Wide Type B Linear Sensor with Magnetic Screen

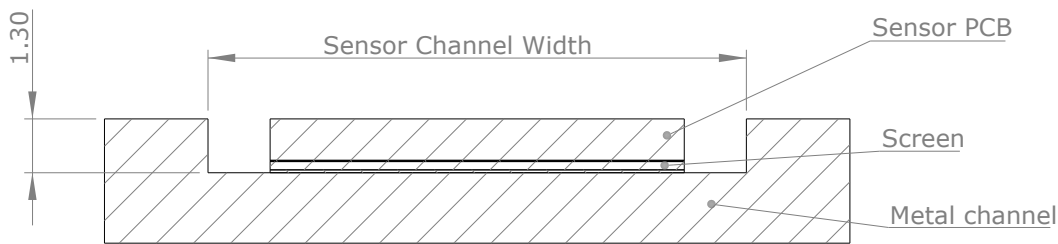


Figure 5 Screenshot Type B Linear Sensor in Metal Channel

Measurements were taken with the sensor placed in a metal channel as illustrated in Figure 5.

Figure 6 presents measured data for the arrangement of Figure 5. Relative Amplitude is plotted in the y-axis. This is the reported Amplitude divided by the reported Amplitude for an unscreened sensor and target in free space. The Sensor Channel Width is plotted on the x-axis. Two plots are shown, one for aluminium and one for steel. Both are for a gap between sensor and target PCBs of 1.0mm.

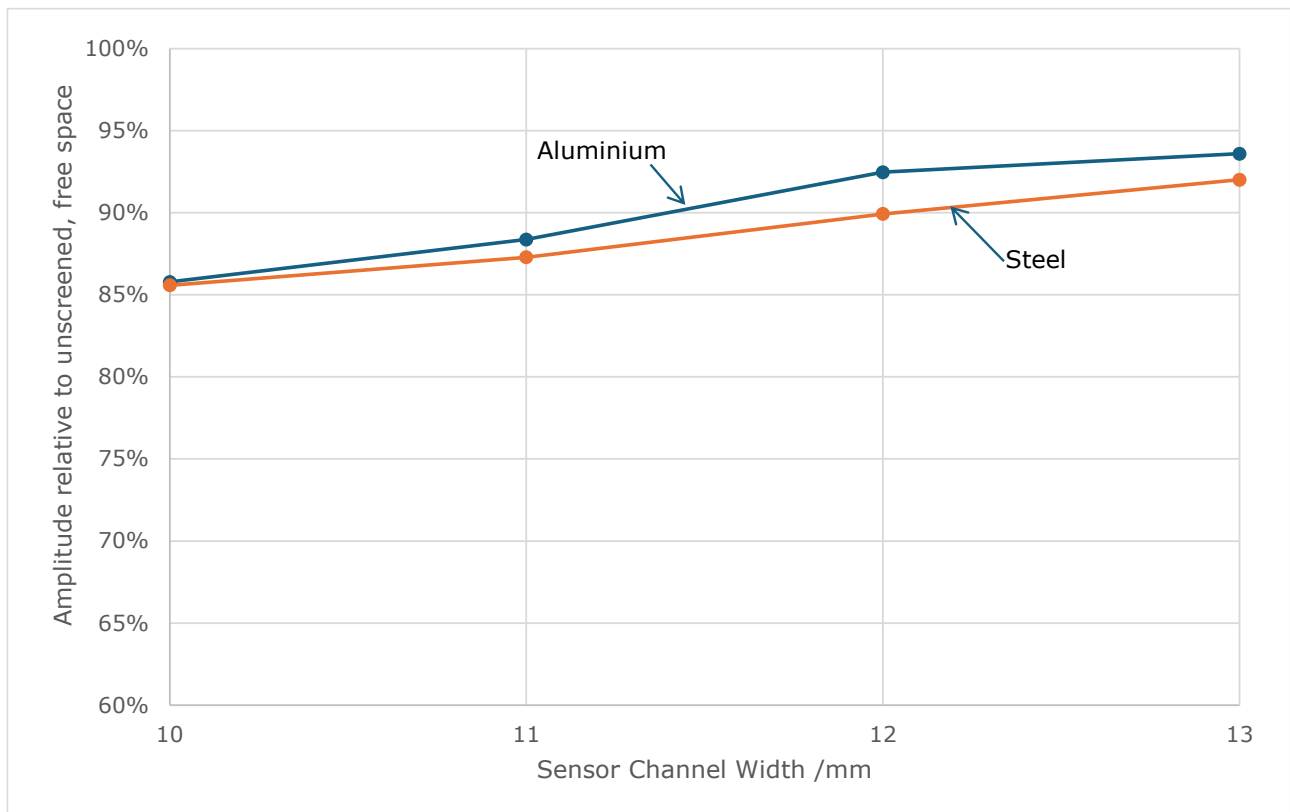


Figure 6 Relative Amplitude as a function of Sensor Channel Width and Material

Some conclusions can be drawn from these figures, those for a screened target above and from the sensor's datasheet:

- Screening allows the sensor to be mounted almost directly onto metal. Without it a gap of several millimeters is needed for similar performance.
- The Amplitude reduction relative to free space is much less than for a screened target.
- Amplitude increases slightly with Sensor Channel Width...
- ...but even a narrow channel still yields relatively high Amplitude.
- Sensor magnetic screening is effective against the influence of either aluminium or steel behind the sensor.

4.4 Screened Sensor in Aluminium Channel, Target in Aluminum Pocket

This section presents measurements taken with the screened sensor in a metal channel from section 4.3 used together with an unscreened target in a pocket in aluminium from section 3.3. The resulting assembly is shown in Figure 7.

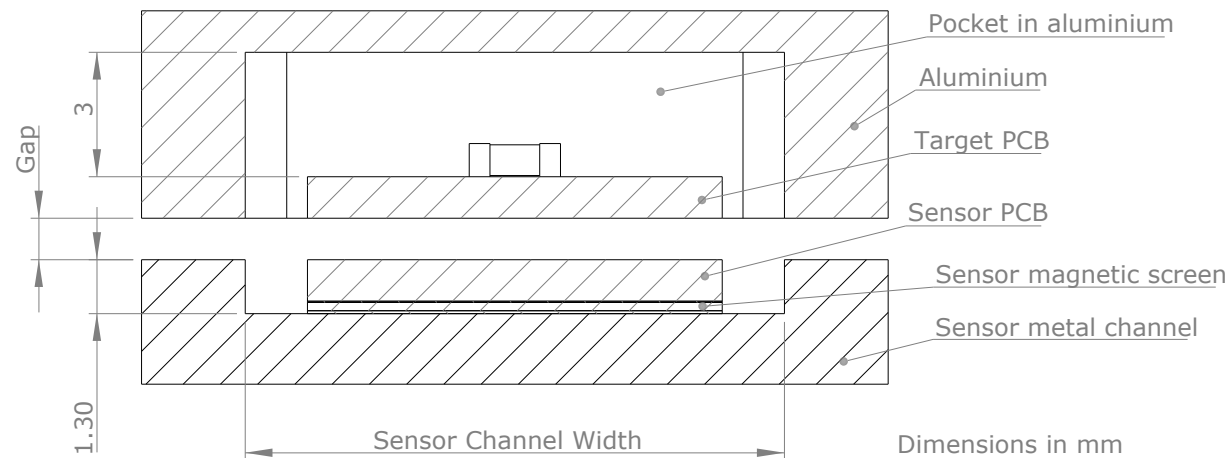


Figure 7 Screened Type B Linear Sensor in Metal Channel, Target in Aluminium Pocket

Figure 8 presents measured data for the arrangement of Figure 7. Relative Amplitude is plotted on the y-axis. This is the reported Amplitude divided by the reported Amplitude for an unscreened sensor and target in free space. The Sensor Channel Width is plotted on the x-axis. Two plots are shown, one for aluminium and one for steel. Both are for a gap between sensor and target PCBs of 1.0mm.

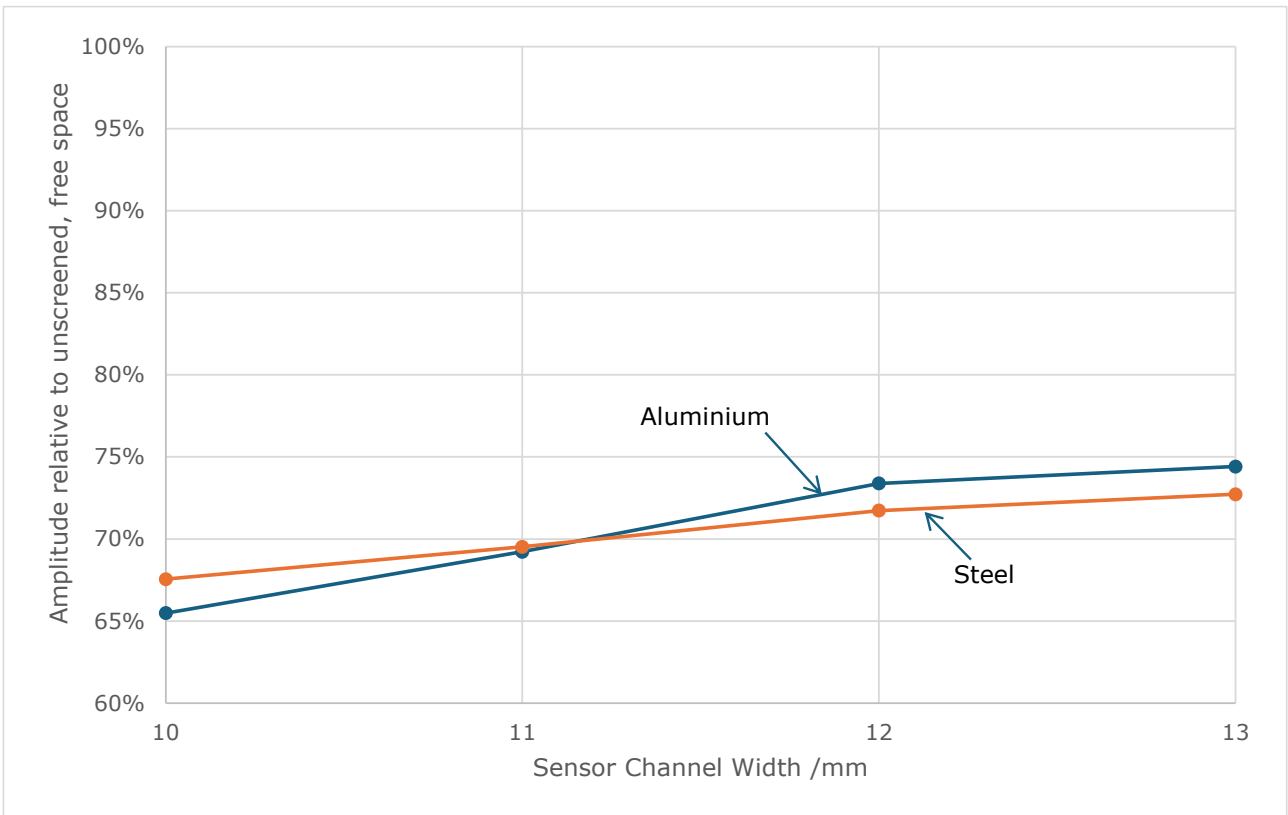


Figure 8 Relative Amplitude as a function of Sensor Channel Width and Material, Target in Pocket

Some conclusions can be drawn from these figures, and those from previous sections:

- Amplitude is significantly lower than for the screened sensor in a metal channel alone.
- Amplitude is similar to the figure for the target in an aluminium pocket alone (Table 1, 64%).
- Most of the reduction in Amplitude relative to free space is therefore caused by the aluminium surrounding the target.

4.5 Screened Sensor and Target, both in Channels

This section presents measurements taken with the screened sensor in a metal channel from section 4.3 used together with a screened target in an aluminium channel from section 4.2. The resulting assembly is shown in Figure 9.

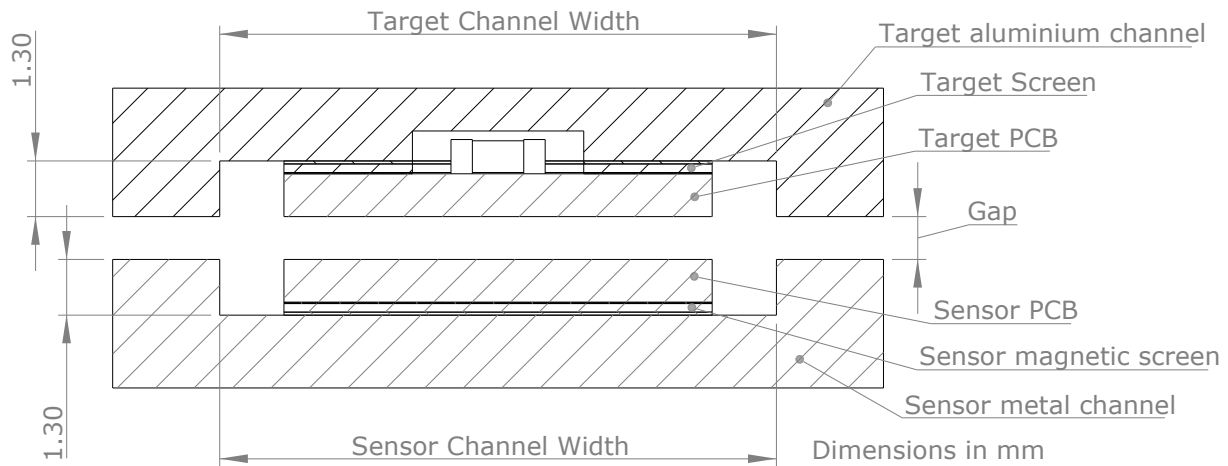


Figure 9 Screened Type B Linear Sensor and Target in Metal Channels

Figure 10 presents measured data for the arrangement of Figure 9. Relative Amplitude is plotted on the y-axis. This is the reported Amplitude divided by the reported Amplitude for an unscreened sensor and target in free space. The Sensor Channel Width is plotted on the x-axis. Two plots are shown, one for aluminum and one for steel. Both are for the following conditions:

- A gap between sensor and target PCBs of 1.0mm
- A Target Screen Width of 10mm
- A Target Screen Length of 14mm
- 50mm B6 linear sensor

Figure 11 shows how Amplitude changes with Gap, in the case of a 10mm wide aluminium sensor channel.

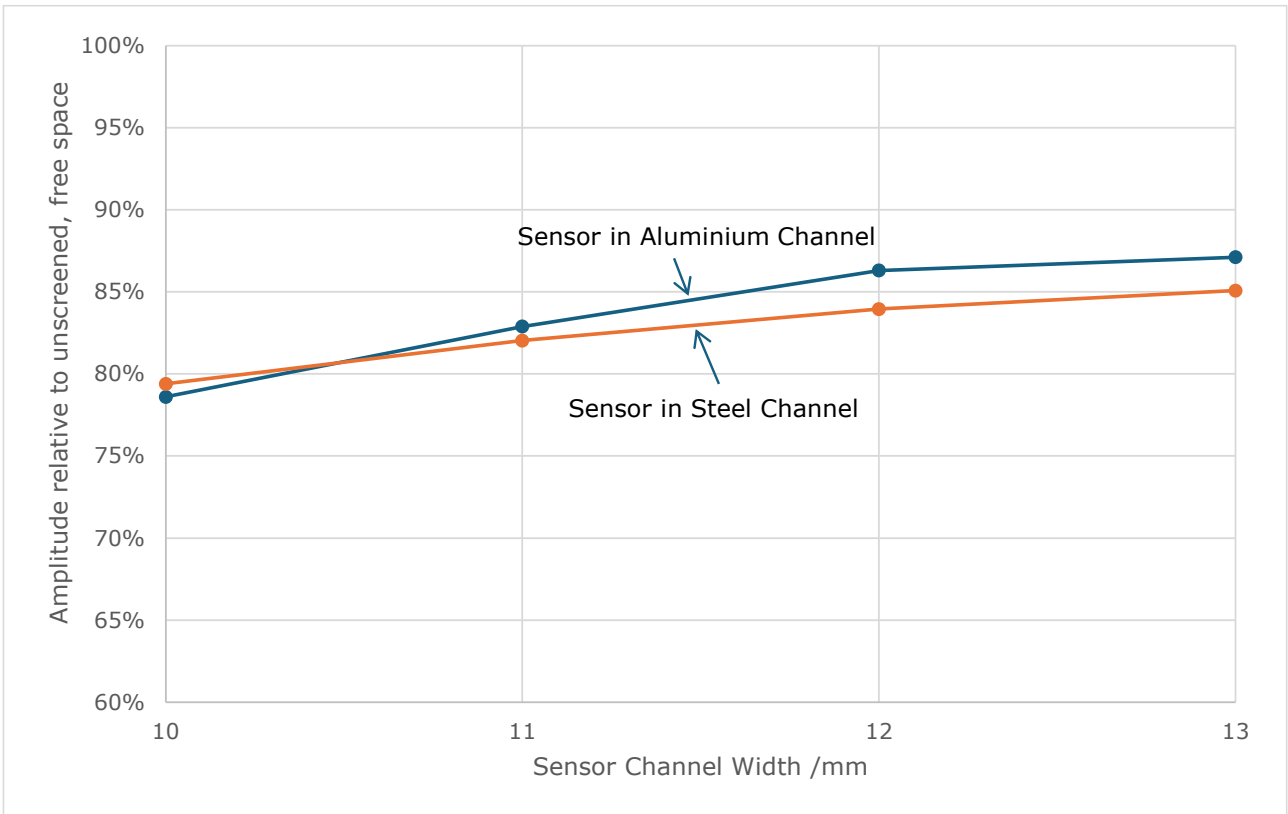


Figure 10 Rel Amplitude as a function of Sensor Channel Width and Material, Target in Aluminium Channel

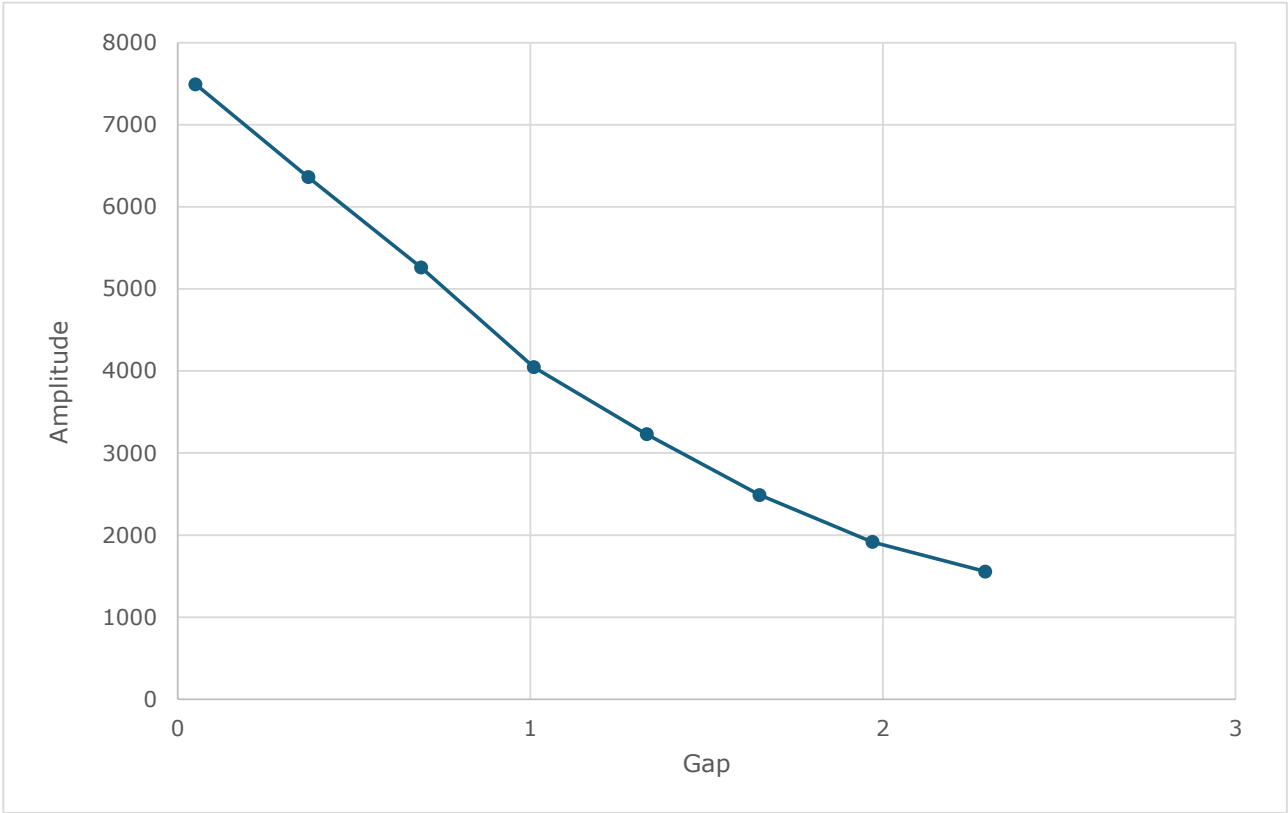


Figure 11 Amplitude as a function of Gap, Screened Sensor in 10mm aluminium channel, screened target in 12mm aluminium channel

In conclusion:

- The sensor PCB, target PCB and their screens occupy a total of only 2.6mm thickness.
- They can be installed between aluminum surfaces less than 3mm apart (plus 0.5mm for the target's capacitors).
- Screening both sensor and target makes the effect of nearby metal on Amplitude relatively small in this example.
- The relationship between Amplitude and Gap is similar to unscreened sensor and target in free space, as presented in the sensor datasheet.

4.6 Screening Double Lobe Targets

The examples given above are with single lobe targets, used for B6 linear sensors with measuring range up to 100mm. Double lobe targets are typically used for longer lengths. Double lobe target 013-1043 has coils that occupy 20mm more length than single lobe target 013-1042. Screening material for this double lobe target should therefore be 20mm longer for similar performance.

4.7 Effect of Screening on Accuracy

Sensor designs are optimised for use in free space, to yield the lowest possible linearity error. Linearity error will increase when screening is added to the sensor, due to the modified magnetic characteristics. For example a typical sensor screened as illustrated in Figure 4 had a measured linearity error of 0.065mm at 1mm gap, compared to an unscreened one with linearity error of 0.02mm.

Screening the target will have a smaller impact on accuracy.

4.8 Resonant Frequency Centering Example

As noted in section 2.3 and the Type B Sensor Reference Manual, the target's resonator capacitor should be selected to centre its resonant frequency on the CAM622's Nominal Resonator Centre Frequency (833.3kHz). In addition, any variability in frequency due to gap variation should be included in the frequency budget, when verifying that the frequency range will remain inside the CAM622's tuning range.

As an example, Figure 12 shows how the target coil's inductance LRES changes as a function of Gap for the arrangement of Figure 9, with screened sensor in an aluminum channel 10mm wide, and target screened with 14mm x 10mm magnetic screen in a 12mm wide aluminium channel.

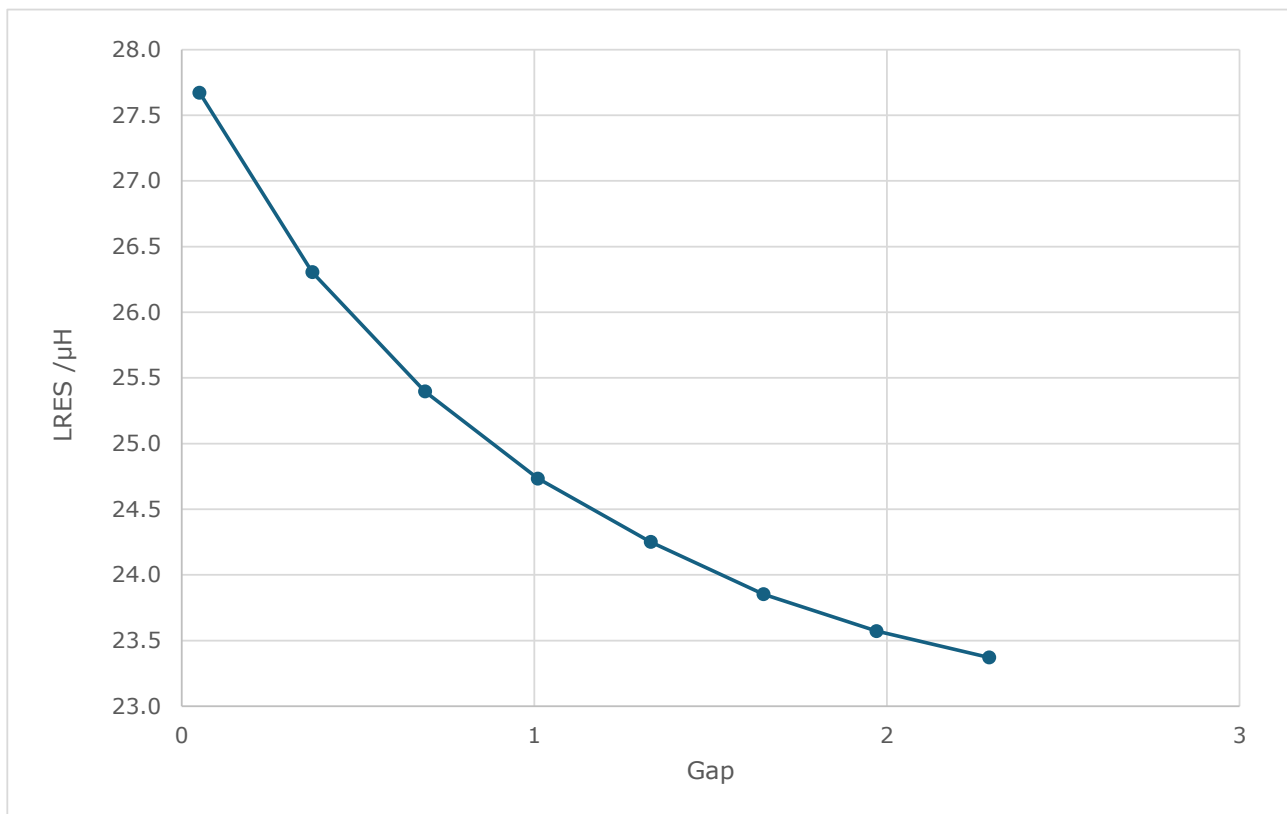


Figure 12 Target coil inductance as a function of Gap, Screened Sensor in 10mm aluminium channel, screened target in 12mm aluminium channel

If the expected gap range for the application is from 0.1mm to 1.3mm ($0.7\text{mm} \pm 0.6\text{mm}$) then the expected LRES range is from 24.2μH to 27.6μH. Choose the nominal LRES value to be half way between these two values, which is 25.9μH. Then select CRES according to Equation 1:

Equation 1

$$CRES = \frac{1}{(2\pi \times Fres)^2 \times LRES} = \frac{1}{(2\pi \times 833.3\text{kHz})^2 \times 25.9\mu\text{H}} = 1.41\text{nF}$$

This value of 1.41nF can be formed by the parallel combination $C1=1.2\text{nF}$ and $C2=220\text{pF}$, yielding 1.42nF.

The inductance variability due to gap changes is then $L_{MAX}/L_{NOM} = 27.6/25.9 = 1.06$, or 6%. Since resonant frequency depends on the square root of inductance, frequency variability due to 6% inductance change is 3%. An allowance of $\pm 3\%$ must therefore be made for frequency variability due to gap variation. This is in addition to other sources of frequency variability, including capacitor and inductance tolerances.

5 Document History

Revision	Date	Comments
0001	29 May 2025	First draft
0002	2 June 2025	Minor corrections and changes to grammar

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7 Legal

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