Renesas RL78 Family

Inductive Proximity Sensing with the RL78/G23

Introduction

This document will introduce the fundamental concepts of inductive proximity sensing and describe the application developed for the RL78/G23 based proof of concept (PoC).

Target Device

This application note is targeted at the Renesas RL78/G23 group of devices.

Contents

1. Basics of Inductive Proximity Sensing

This section will introduce the fundamental concepts of inductive proximity sensing. First an explanation of what inductive proximity sensing is followed by details of the sense methodology and circuit implementation. There will then be a description of what can be sensed with accompanying details on sense sequencing and different sense topologies. Please note that this document describes the detection of the **presence** of a conductive target through inductive proximity sensing – not the process of measuring **distance** from the conductive target.

1.1 What is Inductive Proximity Sensing?

Inductive proximity sensing is a technique where the position of a **conductive target** can be detected by measuring the effect it has on the magnetic field emitted by a coil, known as the **search coil**. The search coil (either ferrite or air-cored) configured in a simple LC parallel circuit, is excited and allowed to self-oscillate. The oscillation will cause a magnetic field to be emitted from the search coil. This magnetic field will induce eddy currents in the conductive target, and thus transfer energy out of the LC circuit, causing the self-oscillation to decay faster than that of a coil not subject to the proximal effect of a conductive object. This is referred to as “damped” oscillation. The oscillation being observed/measured in inductive proximity sensing refers to that of the voltage of the LC circuit. This system is shown in Figure 1.

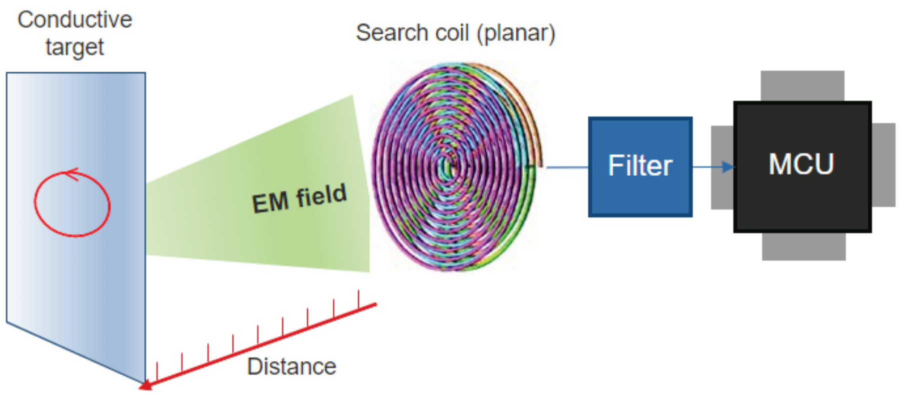

Figure 1. Inductive Sense

Detection of the target is performed by monitoring the oscillations decay. We characterise the oscillation by its ‘envelope’ which is a term used to describe the ‘general shape’ of the waveform, achieved by drawing a smooth line connecting all the peaks of the waveform as seen in Figure 2.

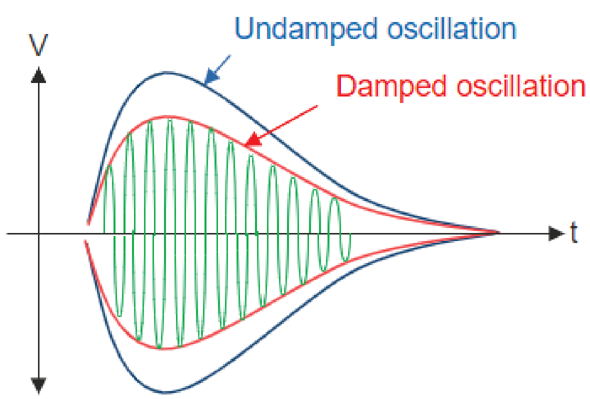

Figure 2. Oscillation envelopes

This covers the impact a conductive target has on an oscillating LC circuit and how this is both observed and characterised – next is described the methodology of the sensing, which is how a reliable & consistent judgement can be made for the proximity of a conductive target.

1.1.1 Methodology – Differential sensing technique

The sensing methodology used is known as a **differential sensing technique** where the **search coil** voltage-oscillation is compared against a similar **reference coil** voltage-oscillation. Figure 3 shows the differential sensing technique circuit.

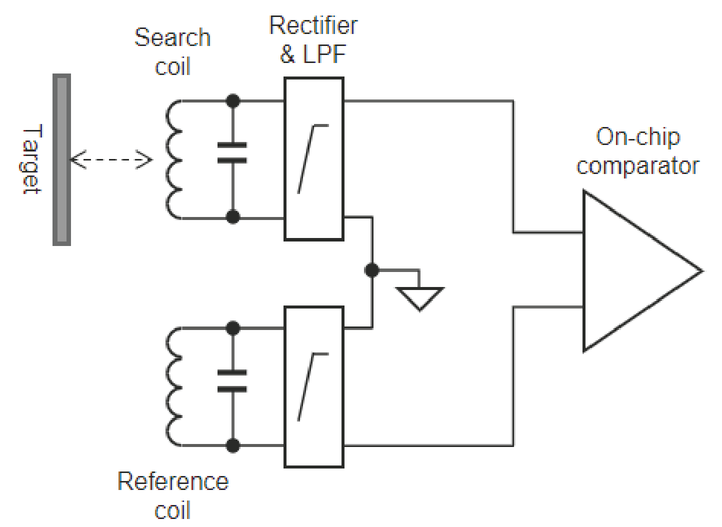

Figure 3. Circuit summary

Only the search coil is exposed to the conductive target. The oscillation of the reference coil must remain unchanged. In principle it is very much recommended to match the layouts (traces and component placement) of the reference and search coil circuits and to then ensure the reference coil is kept as far as possible from external signals/objects which could cause the reference oscillation envelope to change during operation thus causing instability in the system. Therefore, the reference coil's oscillation envelope is considered the systems constant and acts as a baseline to measure against, it does/should not vary. Figure 4 shows the oscillation envelopes of a reference coil and a search coil in a both the damped and undamped condition.

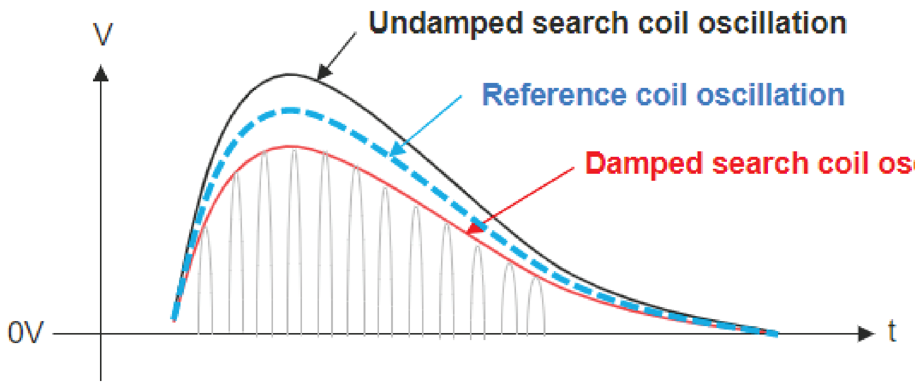

Figure 4. Oscillation post-half-wave-rectification and LPF

For binary detection, the only remaining task is to pick a point in time (w/r to the oscillation waveform envelope) at which to compare the two signals to determine whether the search coils oscillation is undamped (no target detected) or damped (target detected).

The differential measurement methodology provides a very robust measurement technique, with little effect from temperature, voltage and component ageing (due to the common-mode nature these effects have being removed inherently due to the differential method principle of the sensing technique) that can typically significantly impact commonly used absolute measurement methodologies.

Now that the differential sensing methodology has been defined – we can take a deep dive into the inductive sensing circuit/physical behaviour to better understand how and why the principles work as well as how to maximise the effectiveness of the technique.

1.1.2 Analysis – Core principles

As a conductive target enters the magnetic field generated by the inductor, eddy currents are induced. These eddy currents are the source of the energy losses in the electro-magnetic field which cause the increased damping of the LC circuits oscillation waveform, and a top-level illustration of this process can be seen in Figure 5. In this section we will describe, with help from some familiar equations, the reason eddy currents cause a dampening of the LC circuits oscillation with the hope to better understand how to maximise efficiency for detecting the conductive targets.

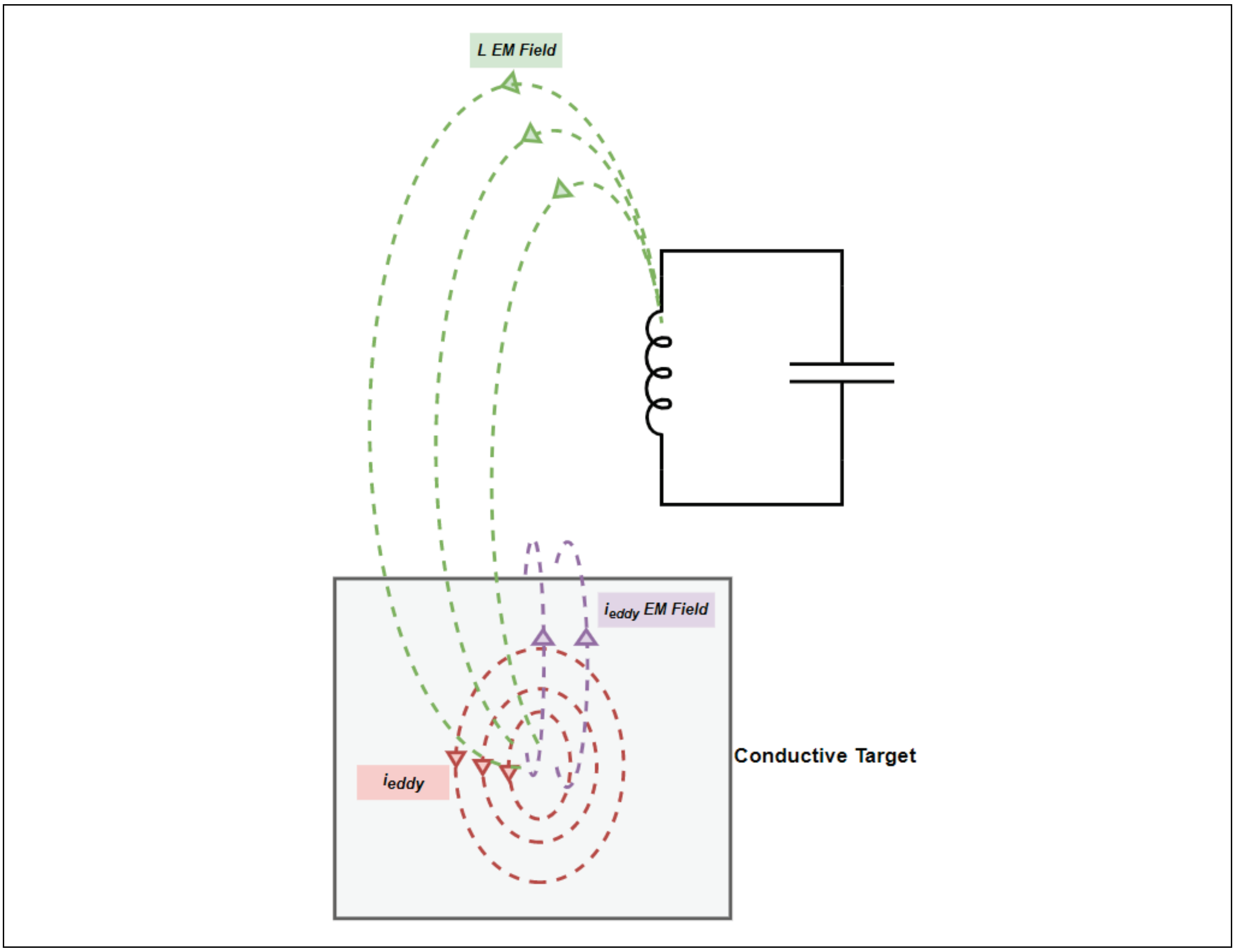

Figure 5. Electric Field Lines

Let's start with the inductor's role – first note that the inductor and capacitor form an oscillation circuit, commonly referred to as a tank, LC tank or LC oscillator. The elements of this circuit have the following properties: the inductor stores energy in the form of a magnetic field and the capacitor stores energy in the form of an electric field. The circuit operates in cycles consisting of four phases of perpetuating operation which shall be described in the following text, the initial operating conditions for the following explanation are such that the capacitor is fully charged and should be considered at positive potential, and all components/wire are ideal – shown in Figure 6.

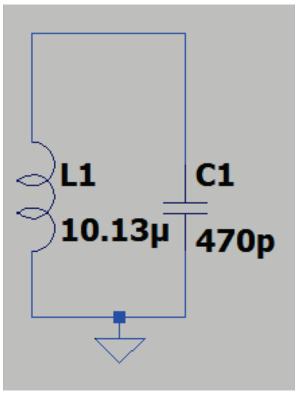

Figure 6. LC tank

First, we take the charged capacitor and connect it in parallel to the inductor. At the point of connection (t=0) the potential (voltage) of the circuit is **+V$_c$** (capacitor voltage). Current flows from the capacitor to the inductor and thus transfers energy stored in the capacitors electric field to the inductors magnetic field. During this transfer the inductors magnetic field is "**growing**" with the increasing current flow – which is described in the formulas below. Meanwhile the potential of the circuit drops with the discharging of the capacitor.

$$V = L\frac{\Delta I}{\Delta t}$$

$$V = \frac{\Delta \Phi_B}{\Delta t}$$

Second, the capacitor becomes fully discharged & the circuit is at **0V** potential with current through the inductor now at a maximum. This means the inductor is no longer being driven and its magnetic field cannot continue to grow. The inductors magnetic field therefore "**collapses**", which results in the continued drive of a (diminishing) current in the same direction, but of course, now this current is charging the capacitor. Because the magnetic field is collapsing, the voltage of the circuit (and charge of the capacitors electric field) is now negative.

Third, the inductors magnetic field has collapsed completely with no more energy to transfer and thus a zero rate of change in the magnetic field results in no current being driven by the inductor. The circuit is at a potential of **-V$_c$**. Now the capacitor discharges as it did in the first step this time with a reversed polarity and therefore reverse direction of current flow until the capacitor is fully discharged – remembering that the inductors magnetic field is again "**growing**".

Finally, the circuit potential is again at **0V** and the inductors magnetic field "**collapses**" once more. This time charging the capacitor and building the circuits potential back to the initial **+V$_c$**.

The waveform described in the steps above can be observed in Figure 7.

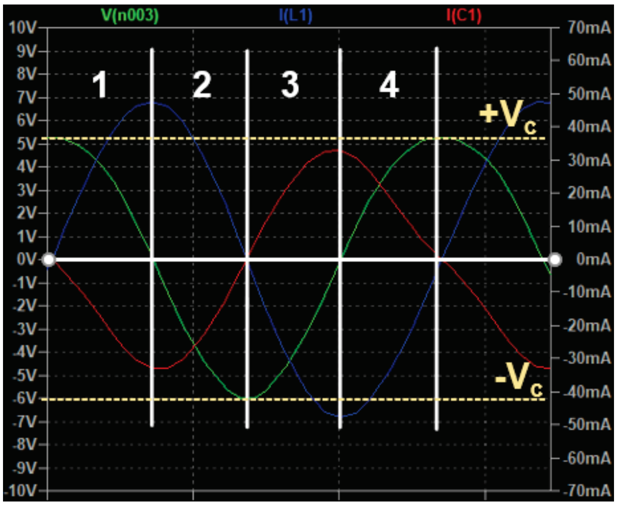

Figure 7. LC Oscillator IV

Note that sometimes in literature there is a negative sign in the equations for the voltage across an inductor. This is in reference to the self-induced voltage of an inductor described by Lenz's law in the case where the inductor can be considered a voltage source. For our analysis we focus on the potential difference of the inductor as a passive component which is best described using Kirchhoff's voltage law which removes the negative sign.

In an ideal circuit we can assume perfect energy transfer (zero-ESR components and ideal wire) – the period of an oscillation is thus given as:

$$T = \frac{2\pi}{\sqrt{\frac{1}{LC}}}$$

In a non-ideal circuit though, there are equivalent series resistances to each component as well as non-ideal wire with parasitic capacitances, inductances & resistances which means during each energy transfer half-cycle energy is inevitably lost in the form of heat and therefore the potential measured across the LC tank will decay.

Now that we have established there is a "growing" and "collapsing" magnetic field produced by the inductor during each oscillation cycle we can state there is a **changing magnetic field**. As there is a changing magnetic field present there is an opportunity to transfer energy. This is explained by faradays law of induction which states that when a conductor interacts with a changing magnetic field, a circular electric field is induced in that conductor (here we will use the example of a conductive sheet) – described in the equation below:

$$\epsilon = -N\frac{\Delta\Phi}{\Delta t}$$

This electric field drives circular currents around the conductive sheet, these currents are known as **Eddy currents**. These Eddy currents result in power dissipation, given by the following equation:

$$P = \frac{\pi^2 B_p^2 d^2 f^2}{6k\rho D}$$

Where:

- P is the power lost per unit mass (W/kg),
- B_p is the peak magnetic field (T),
- d is the thickness of the sheet or diameter of the wire (m),
- f is the frequency (Hz),
- k is a constant equal to 1 for a thin sheet and 2 for a thin wire,
- ρ is the resistivity of the material (Ω m), and
- D is the density of the material (kg/m^3)

To sum up the information the eddy currents power dissipation equation gives us specifically impacting inductive proximity sensing applications (for which the designer can control):

1. A **more conductive material** (lower resistance) will cause a **larger power loss**.
2. A **thicker material** will cause a **larger power loss**.
3. The **larger the frequency** of oscillation i.e., the smaller the value of $\sqrt{LC}$ (assuming no skin effect) the **larger the power loss**.
4. The **larger the (peak) magnetic field** the **larger the power loss**.

As for what this means for the sensing technique employed by Renesas, we want to increase the damping of the sensor circuits signal, that is, **maximise the power loss** of the eddy currents at the distance of interest. This ensures the largest difference in signal decay between a coil exposed to a conductive sheet and one which is not. This in turn makes determining the presence of a conductive target easier due to the more easily distinguishable decay profile between a circuit exposed to a conductive sheet (sensor) and one which is not (the reference).

To summarise, the damping of the oscillation envelope in the presence of a conductive target does in fact result from the eddy currents induced in the conductive target and the factors which influence that energy loss have been outlined.

An illustration of the field interactions, and subsequently the eddy currents, can be seen in Figure 8.

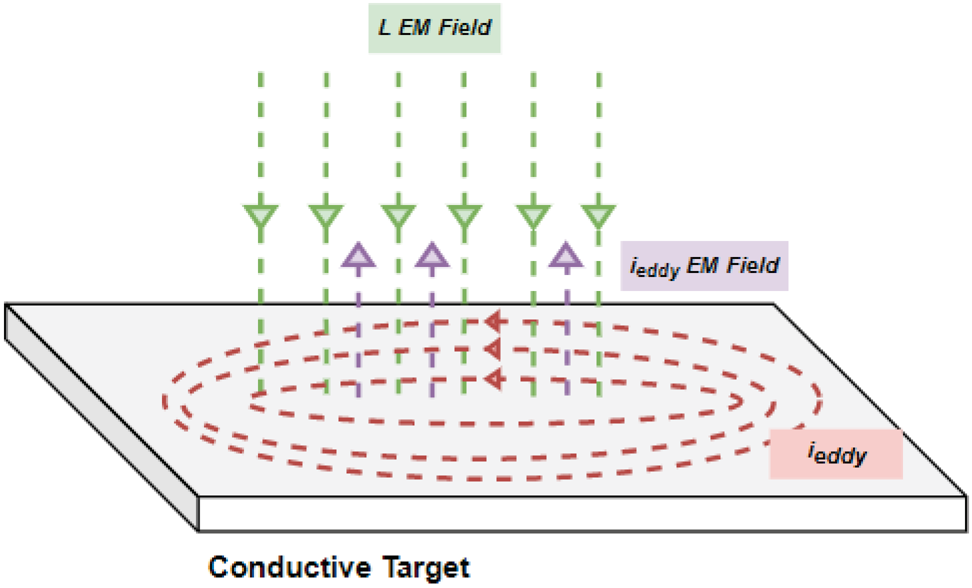

Figure 8. EM Fields

Note how in both Figure 5 & Figure 8 the conductor is interacting with the magnetic field lines where the lines are densest. This is out-of-the-side of the inductor i.e., looking down the core of the inductor – this is to ensure the conductor is interacting with the magnetic field where it is at its “strongest” i.e., the region of the field where the flux density is at its largest. This is the most efficient way of inducing a larger eddy current which will in turn increase the loading (and therefore energy transfer) from the inductors magnetic field which results in increased damping of LC voltage waveform.

So far, we have discussed the principles inductive sense from both top level and analytical points of view – the final piece of the puzzle lies in the implementation – next we describe; the circuitry required to implement the inductive sense solution, external signals required and output signal stages.

1.1.3 Circuitry – Components & constructs

We have described LC circuit oscillation so far using a model involving an initially charged capacitor – in the real world the initial charge must be applied and controlled. To trigger the LC circuit into oscillation the LC circuit must first be charged with what is named an **excitation pulse**. This is performed with a small logic-level P-channel FET. The MCU creates a narrow pulse just long enough to saturate the LC circuit. The LC circuit will then self-oscillate around 0V.

A small signal diode is then used to half-wave rectify this signal to remove the negative transition and make the signal compatible with the MCU I/O pin range. The oscillation the undergoes two stage filtering.

- The main (first) filter is used to smooth out the bulk of the oscillation and create the foundation for the output oscillation envelope.
  Note a bleed (discharge) resistor is used to ensure that the filter is discharged to match the original oscillation envelope.
- A ripple reduction (second filter) is used to remove the residual ripple to try and smoothen the envelope as much as possible without causing the output signals decay to drift from that of the original envelopes decay.

The signal is then presented to the MCU on-chip comparator input - Figure 9 shows the complete excitation and filter circuitry – in this image L2 is the sense/reference coil.

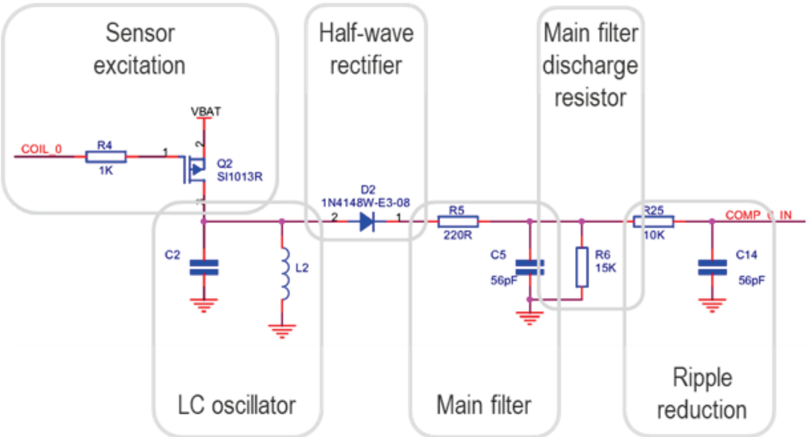

Figure 9. Excitation and filter circuit

Below in Figure 10 are presented the practical waveforms of an LC excitation and filter circuit. Remember that this circuit exists or both the reference and search coils in a simple single search coil application (Figure 3) – we will see later how to implements different sense architectures to maximise our search-coil-to-component-count ratio.

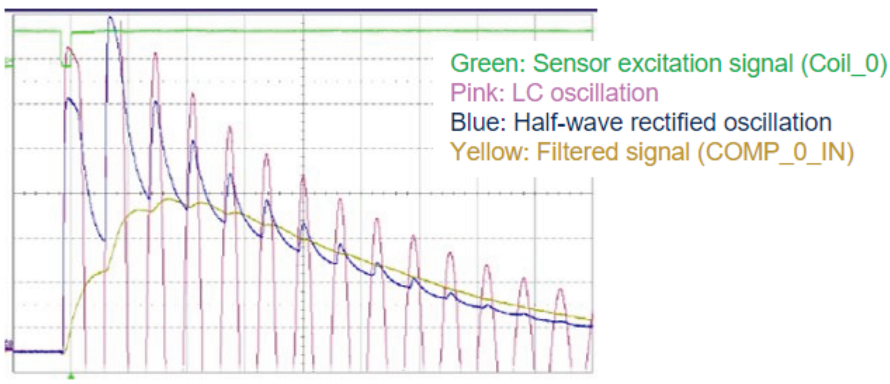

Figure 10. Practical measurements of LC circuit

After covering the “what” and “how” of inductive proximity sensing, next to be discussed is the architecture and system level design of inductive proximity sensing.

1.2 Inductive Proximity Sensing System

The following section will explore the details of constructing the inductive proximity sensing solution from coils & materials to sensor sequencing and topologies.

1.2.1 Target and Coils

The sensing target must be constructed from an electrically conductive material – the shape and size of the target is application specific but an object with larger surface area capable of intercepting more of the LC circuits electric field will dampen the oscillation of the search coil more than a target with less surface area (see Analysis – Core principle).

As for the coils (search and reference), any (matched) inductor can be used but typically inductors whose fields can be concentrated and directed are the ones desired, commonly used inductors include:

Coil Type	Positives	Negatives
Ferrite-cored Figure 11	• Established technology, typically wire-wound around a custom ferrite core. • Compact size suitable for small sensors – used commonly in threaded industrial sensors.	• Severely effected by external magnetic field and cannot be placed in proximity of each other due to cross-sensor coupling. Shielded sensors are possible but suffer with lower sensitivity. • Poor sensitivity distance and expensive BoM item
Air-cored Planar Figure 12	• Established technology, typically fabricated from a multi-layer PCB trace. • DC Magnetic field immune and can be closely co-located without cross-over coupling. • High sensitivity – coil diameter directly determines the sensitivity distance.	• Mid to high-end PCB fabrication technology required to reliably manufacture the coil. • Spiral pattern considered difficult to design, but there are on-line design tools available that create layout patterns.

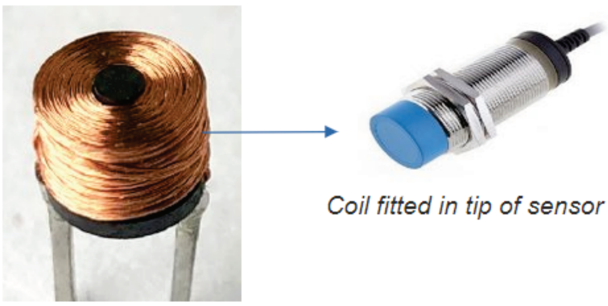

Figure 11. Ferrite-cored inductor

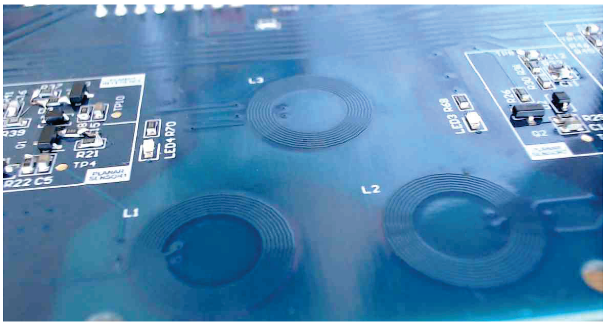

Figure 12. Air-cored Planar Inductor

1.2.2 Single and Multi-Sense Architectures

There exist two sensor topologies; single and multiple – the following section describes these topologies in detail. It is worth noting that when referring to the number of sensors, actually being referred to are the number of search coils required, as the number of references can change depending on the topology, but the number of search coils is a function of application requirements.

As shown in Figure 9 the circuitry for **each search and reference coil** there exists 3 portions of circuitry.

- Excitation (PFET, inductor & capacitor)
- Rectification (Diode)
- Filter (3x Resistors & 2x Capacitors)

When a single sensor is required, the architecture is illustrated in Figure 3 where there exists a single search and reference coil each consisting of all three stages required, excitation, rectification & filtering.

When two or more sensors are to be sampled there becomes two choices architecturally speaking. These choices are driven by the requirements on the sequencing of the sampling, which will be covered in detail in the next section. But it is worth briefly mentioning that there exist two multi-sensor sequencing options, and these are **sequential** and **simultaneous** sampling. And depending on the architectural requirements search coils may share filtering circuits and/or reference coils which impacts the total circuit components required & number of comparators required in the system.

Both architectures are illustrated in the Figure 13 & Figure 14.

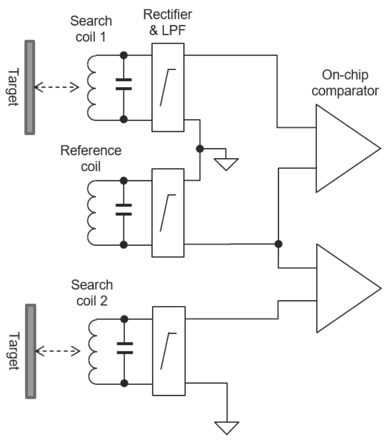

Figure 13. Simultaneous Sensing

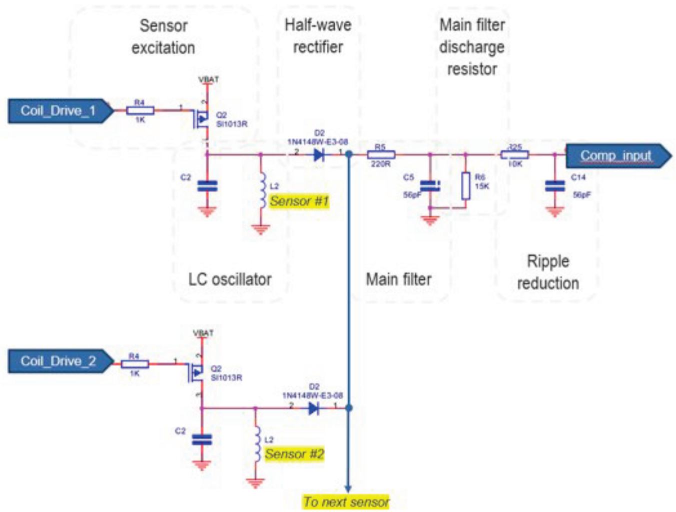

Figure 14. Sequential Sensing (search coil - OR diode)

The table below summarises the minimum possible circuit component requirements for each architecture, grouped into stages as follows.

- Number of excitation circuits (search & reference)
- Number of search filter circuits (search & reference)
- Number of search rectification diodes (search & reference)
- Number of comparators

Architecture	Search			Reference			Comparators
	Excitation circuit	Filter circuit	Rectifier diode	Excitation circuit	Filter circuit	Rectifier diode	
Single Sensor	1	1	1	1	1	1	1
N x Multi-sensor (sequential)	N	1	N	1	1	1	1
N x Multi-sensor (simultaneous)	N	N	N	1	1	1	N

The table above indicates that a single reference is needed for any number of sensors – there exists an exception to this rule. In a system where there is a requirement for more than a single coil type – that is there are both ferrite cored coils & air cored coils required, perhaps for mechanical reasons – or variations in the LC circuit is required, i.e. varying L values between search coils which will affect sense distance – a reference coil must exist to match each of these configurations.

1.2.3 Sensor Sequencing

In the previous section sensor sequencing was introduced. This section will describe the sensors sequencing mechanisms which exist. The sequences which exist are **Single**, **Multiple Sequential** & **Multiple Simultaneous**.

Single sensor sampling can be used to detect independent proximity events i.e., button press, actuator end position, event counting etc – for this architecture a single sense coil circuit & single matched reference coil circuit are both required with a single comparator.

Multiple sequential sensor sampling is a technique whereby multiple sensors are arranged such that a non-time-critical linked proximity event can be sensed. Here the sensors are scanned, one after another – examples of this would be in multiple key-press detection, multi-point actuator positioning (Figure 15) and rotary switch position detection.

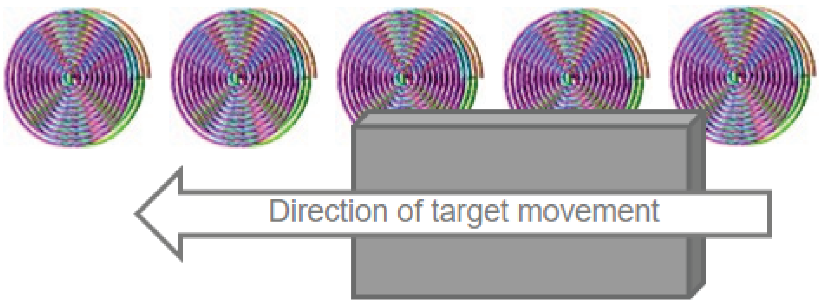

Figure 15. Linear actuator with multiple sensors

Multiple simultaneous sensor sampling is a technique whereby multiple sensors are arranged such that the sensors are sampled simultaneously – this is useful in application where simultaneous proximity events are critical – an example of this is rotational shaft speed sensors with direction detection (Figure 16).

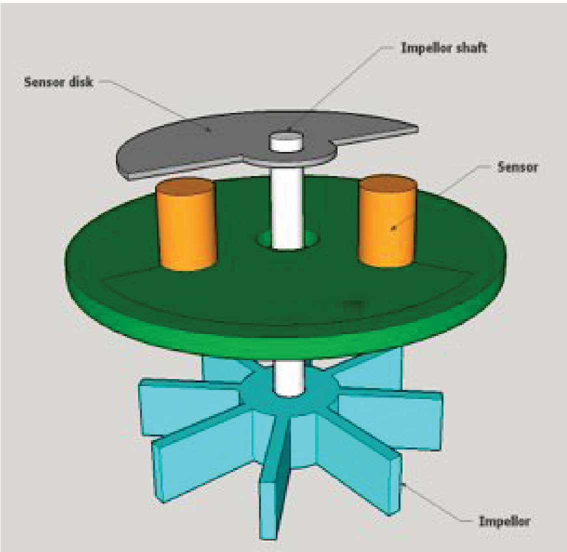

Figure 16. Rotational liquid flow sense with multiple sensors

2. RL78/G23 PoC Architecture

The following section outlines the RL78/G23 inductive sense proof of concept architecture – covering the peripheral resources consumed, memory footprint, scan times & hardware blocks.

2.1 Architectural Diagram

The diagram shown in Figure 17 outlines the hardware and peripheral blocks used in constructing the solution.

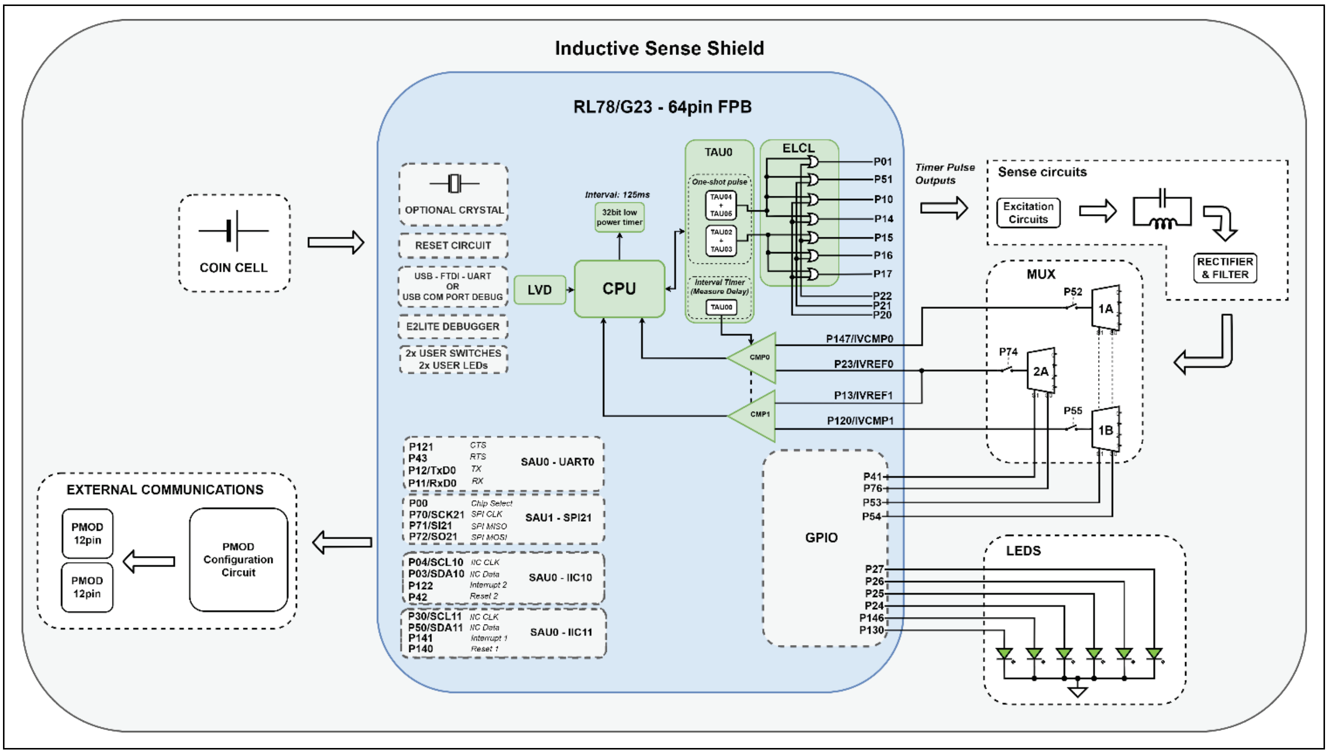

Figure 17. System architecture visual aid

2.2 Peripheral and Software Resource Consumption

For a detailed breakdown of the peripheral & software resource consumption please see R12UZ0106EG0100.

3. RL78/G23 Inductive Sense PoC

The RL78/G23 Inductive Sense Shield PoC encompasses the Inductive Sense Shield hardware and the software, both binary and source, written for the RL78/G23 64pin FPB.

The combination of these units demonstrates the RL78/G23's capabilities in performing Inductive Proximity Sensing using the novel differential technique (1.1.1). The PoC in full performs conductive target proximity sensing on; ferrite cored inductors, PCB planar inductors (printed coils) & rotational direction sensing on PCB planar inductors. The following section explains the implementation details of the technology from a systems design perspective – that is the tuning of the sensitivity and sensing thresholds of these coils and the specifics of the power consumption and the effect that the inductive sense scan has on a systems power consumption.

3.1 Tuning

The differential sensing technique employed with the Renesas Inductive Sense Shield solution alleviates the need for run time calibration or offset compensation but does require, at the time of solution development, tuning. The tuning is performed by manipulating the individual pulse width timings for the reference and search coils, and the pulse delays relative to each coil. We typically describe the timings of the search coil relative to that of the reference coil i.e., the search coil pulse is lagging/in-phase/leading the reference coil. The final parameter involved with the tuning process is the measurement time, which is the delay between the start of the one-shot timers for both coils and the point at which a measurement/comparison of the coils decaying output waveforms is performed.

To summarise these parameters:

- **Reference Coil Pulse Width** – The "on-time" of the FET used to charge the LC tank for the reference coil.
- **Search Coil Pulse Width** – The "on-time" of the FET used to charge the LC tank for the search coil.
- **Search Coil Delay** – The start time of the search coils pulse relative to the reference coils pulse.
- **Measurement Time** – The time between starting both the search and reference coils one-shot pulse timers and when to perform the measurement/comparison of their decaying waveforms.

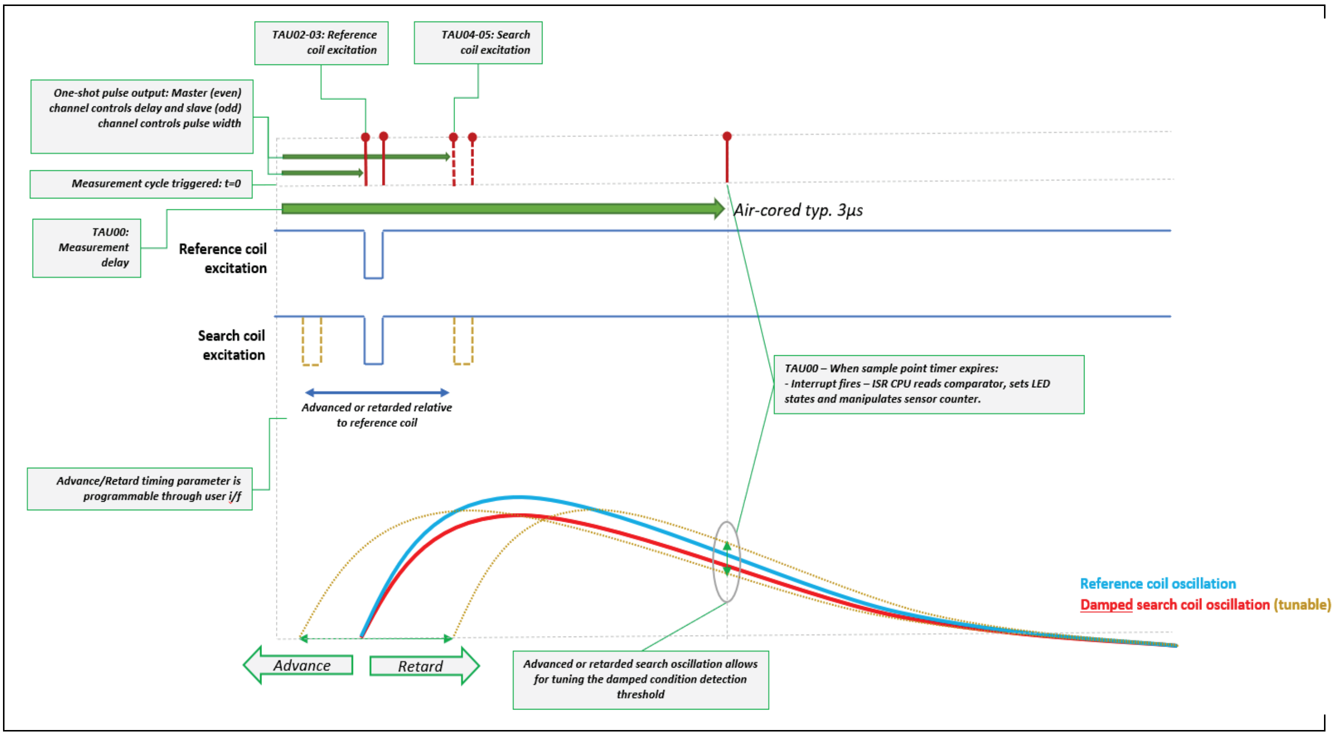

Figure 18. Timing diagram of tuneable parameters

The most influential factor in tuning this system is the search coil delay. Figure 18 shows the affect this parameter has on the damped envelope at the point of measurement. By advancing or retarding the search coils excitation relative to the reference coil we can finely tune the detection threshold for determining the presence of a conductive target.

3.2 Power Consumption

Inductive proximity sensing is a low power technology and can be used in battery powered applications. The following section will dissect the power consumption from a systems perspective – enabling a designer to determine the impact implementing Inductive proximity sensing has on their systems power supply.

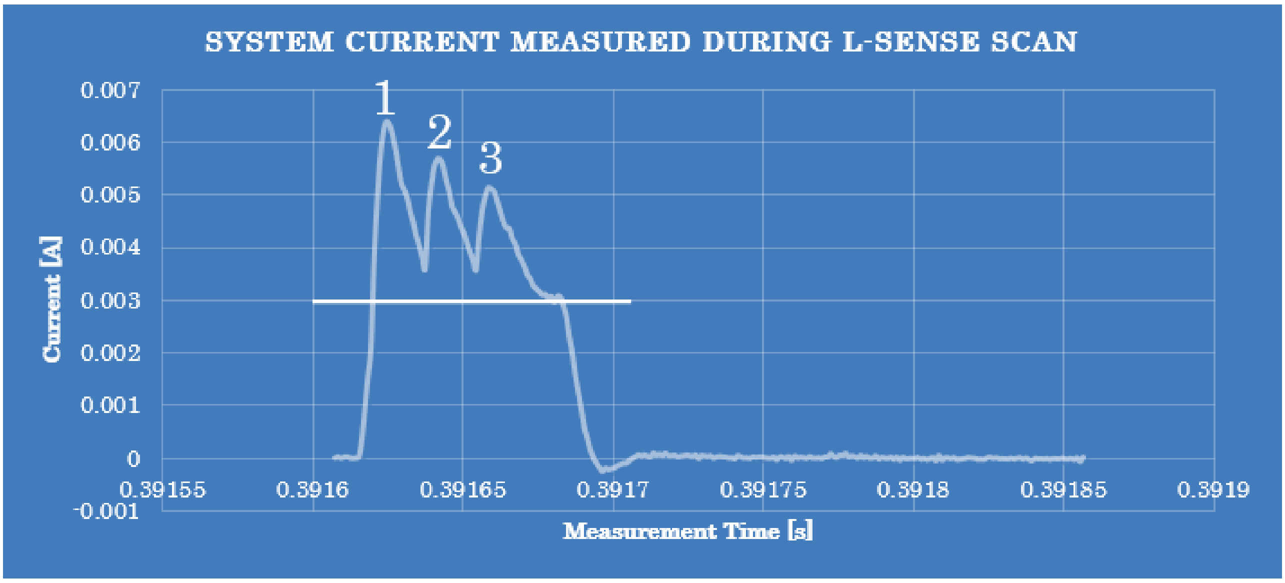

Figure 19. Current Consumption During Scan

The data presented in Figure 19 has been manipulated to remove static currents on the inductive sense shield and RL78/G23 FPB. Namely the FTDI USB-UART circuitry & the de-multiplexers inputting to the on-board comparator used to select which coil group to measure.

When analysing the data in Figure 19 two observations are apparent.

1. There are 3 current spikes, labelled 1, 2 & 3. Each of these three spikes represent the group of coils as they are being scanned.
2. The basal running current of the RL78/G23 is approx. 3mA. As seen by the inflection at the end of the 3rd peak before returning to the low power STOP mode.
   This has been cross referenced with internal device settings and the hardware user manual.

From this information we can now infer the current requirements for energising the LC tank circuits of each coil within each group. Note that the system voltage is 3.3V.

Using the basal operating current of the RL78/G23 & the data contained in the graph in Figure 19, the table below is populated to describe the individual current consumptions associated with each **individual** coil circuit. To compute the peak current & average per coil, the following formulas were applied to the data in the graphs respectively.

Peak			Average		
Rotation (Planar)	Planar	Ferrite	Rotation (Planar)	Planar	Ferrite
1.122 mA	0.895 mA	0.714 mA	0.634 mA	0.581 mA	0.454 mA

Finally combing all the information above the total average current of a full scan (every coil in every group) is observed to be 1.476 mA.

3.2.1 Observations

The currents presented in this document are the measured system currents, which is the currents into VDD of the board during operation – not those directly into the LC circuits as they would be best described as in-rush currents. The reason these current peaks have such a noticeable gradient is that the system has a substantial capacitance as observed from the power-supply which includes the VDD decoupling capacitors, and the parasitic capacitances associated with the board – this ensures the current demand on the power-supply is not too aggressive in that the peaks are smoothed due to the capacitance providing the current/energy used to energise the LC circuits.

As such a worthy design note is to use low-ESR decoupling capacitors in this system to ensure energy transfer from the capacitors into the demanding LC circuits can be sustained without loading the power supply or any on board regulators too much.

4. Conclusion

The differential inductive proximity sensing technique described in this application note is targeted at the binary distinction between the presence or lack of a conductive target. The lack of mechanical parts paired with the differential nature of the technology makes this a robust & reliable design choice. Enabling this technology with the RL78/G23 brings the optimum combination of low power, high performance & built-in peripheral features to make this a true low cost & low power solution for markets including, but not limited to:

- White goods (buttons and rotary dials)
- Industrial/factory automation (Item detection and end-stop)
- HMI (buttons and rotary dials)
- Rotation counting (Water meters and impeller speed/direction detection)
- Medical (buttons and rotary dials)

This application note describes the fundamental principles of the inductive sensing and how the Renesas RL78/G23 PoC enables this technology. For information on making modifications/customisations or extensions on the implementation of the PoC, please see the related documentation for the relevant hardware, linked in the next page.

Website and Support

Visit the following URLs to learn about the kit and the RL78 family of microcontrollers, download tools and documentation, and get support.

Y-DKPROX-SENSOR-SHIELD-RL78G23	RL78/G23 Inductive Proximity Sensor Shield
Sensor Shield Schematic	RL78/G23 Inductive Proximity Sensor Shield Schematic
Sensor Shield Quick Start Guide	R12QS0054EG0100
Sensor Shield User Manual	R12UZ0106EG0100
RL78/G23 64p FPB Resources	RL78/G23-64p Fast Prototyping Board | Renesas
RL78 Product Information	RL78 Low Power 8 & 16-bit MCUs | Renesas
RL78 Product Support Forum	RenesasRulz
RL78 Videos	RL78 Family Software & Tool Course | Renesas
Renesas Support	renesas.com/support

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Mar.05.24	—	First release document

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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