Application Report
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Method to Select the Value of LC Sensor for MSP430™ Extended Scan Interface (ESI)

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ABSTRACT

This document describes a method that can be used to select an LC sensor for use with the MSP430™ Extended Scan Interface (ESI).

1 LC Sensor Selection

For a sampling rate of Fs and an excitation time of Δt, the average current consumption of LC sensor is as follows:

For a capacitor, C = Q/V, which gives the average current I = Fs × Q = Fs × CV

For an inductor, V = L × ΔI / Δt, which gives the average current I = Fs × (ΔI × Δt / 2) = Fs × (V × Δt^2 / 2L)

Total average current = Fs × V × (C + Δt^2 / 2L)

Total average power = V × average current = Fs × V^2 × (C + Δt^2 / 2L)

The copper resistance of the inductor consumes some power. However, it is negligibly small, as the current is in the range of microamps. The power of the resistor is I^2R, which is very small.

Figure 1 shows the current consumption of an LC sensor with a sampling rate of 500 Hz, excitation time of 1 µs, and a V of $V_{CC}/2$ (1.5 V).

Current of LC (uA)

C (pf) \ L (uH)	1	2.2	4.7	10	22	47	100	220	470	1000
47	375	170	80	38	17	8	3.79	1.74	0.83	0.41
100	375	171	80	38	17	8	3.83	1.78	0.87	0.45
220	375	171	80	38	17	8	3.92	1.87	0.96	0.54
470	375	171	80	38	17	8	4.10	2.06	1.15	0.73
1000	376	171	81	38	18	9	4.50	2.45	1.55	1.13
2200	377	172	81	39	19	10	5	3.35	2.45	2.03
4700	379	174	83	41	21	12	7	5	4.32	3.90
10000	383	178	87	45	25	15	11	9	8	8
22000	392	187	96	54	34	24	20	18	17	17
47000	410	206	115	73	52	43	39	37	36	36
100000	450	245	155	113	92	83	79	77	76	75

Figure 1. Current Consumption of LC Sensor

From Figure 1, the current consumed becomes smaller when both the inductor value and the capacitor are smaller. Compared to the ESI standby current of a few microamps, the LC current consumption should be selected to be within 1 µA.

As the inductor value increases, the copper resistance also increases. A higher resistance leads to a fast damping of LC oscillation signal. Therefore, a smaller copper resistance is preferred.

The physical size of the capacitor is small. However, the inductor is much bigger. This is one of the limitations when choosing an inductor of higher value. The casing for the sensor might not provide enough space for two or three sensors.

In addition, the detection distance is related to the area of the metal portion of a rotor plate covered with the magnetic field generated from the inductor and the concentration of magnetic field. If the rotor plate is too small or the physical size of the inductor is too large, the effective covering area can be reduced, which reduces the magnetic energy absorption rate of inductor through the eddy current on the metal portion of the rotor plate.

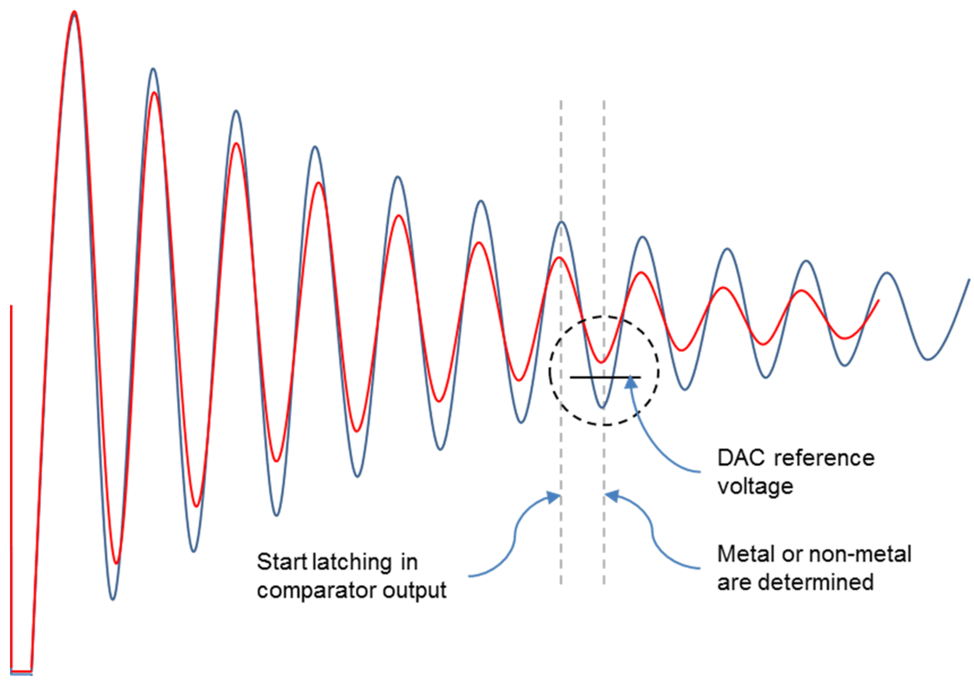

Figure 2. LC Oscillation Signals And Latch-In Timing

From Figure 2, the lower range of LC signal is used to determine the metal and non-metal portions of the rotor plate. The optimal timing to latch in the comparator output is at the time between the two lower peaks. The internal oscillator of the ESI can be used to tune the timing to reach this position.

However, there is a drift of the internal oscillator by 0.35%/°C and by 2%/V. A drifting margin should be provided to avoid too many recalibrations of the oscillator. If setting the margin to be ± 0.5 µs and to set the latch in timing when the LC signal is above its mid-level, the minimum period of the LC signal should be larger than 2 µs (500 kHz).

Figure 3 shows the oscillation frequency of an LC sensor. The data near 500 kHz are marked in gray for easy reading. In combination with Figure 1, the number of values for the inductor and capacitor are limited to a the area highlighted in light blue in Figure 3.

Freq of LC (KHz)

C \ L	1	2.2	4.7	10	22	47	100	220	470	1000 (uH)
47	23,215	15,652	10,708	7,341	4,949	3,386	2,322	1,565	1,071	734
100	15,915	10,730	7,341	5,033	3,393	2,322	1,592	1,073	734	503
220	10,730	7,234	4,949	3,393	2,288	1,565	1,073	723	495	339
470	7,341	4,949	3,386	2,322	1,565	1,071	734	495	339	232
1000	5,033	3,393	2,322	1,592	1,073	734	503	339	232	159
2200	3,393	2,288	1,565	1,073	723	495	339	229	157	107
4700	2,322	1,565	1,071	734	495	339	232	157	107	73
10000	1,592	1,073	734	503	339	232	159	107	73	50
22000	1,073	723	495	339	229	157	107	72	49	34
47000	734	495	339	232	157	107	73	49	34	23
100000	503	339	232	159	107	73	50	34	23	16
(pf)										

Figure 3. Oscillation Frequency of LC Sensor

An additional precaution to the selection of inductor and capacitor is to consider the variation of LC oscillation frequency due to temperature change and aging.

For LC signal period $T = 2\pi \times \sqrt{LC}$

Then, $\Delta T / \Delta L = T / 2L$

Which implies, $\Delta T / T = \Delta L / 2L$

Similarly, $\Delta T / T = \Delta C / 2C$

A 10% change in either L or C leads to a 5% change for the time period of the LC signal.

By experiment, using 220 pF and 470 µH on the sensor board, a total of 1 µs is increased for a 40 periods of signal when the temperature is increased above 80°C.