Inductive Position Sensor

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

Bruce Chao / MSLD-SME

September 22nd, 2022

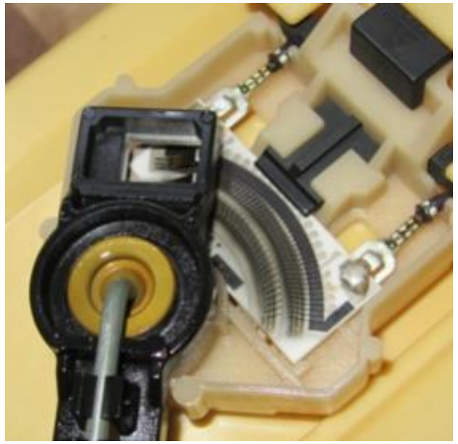
SMART | CONNECTED | SECURE

Agenda

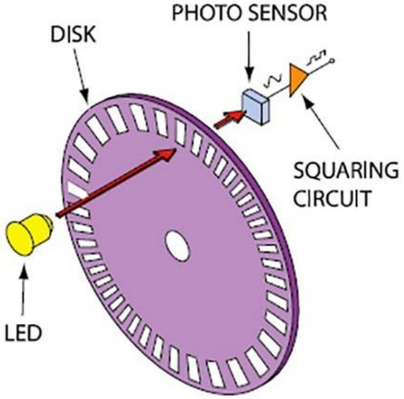
- **Position Sensor Technologies**
- **Understanding what is the inductive position sensor**
- **Microchip Inductive Position Sensor**
- **Applying the Technology**

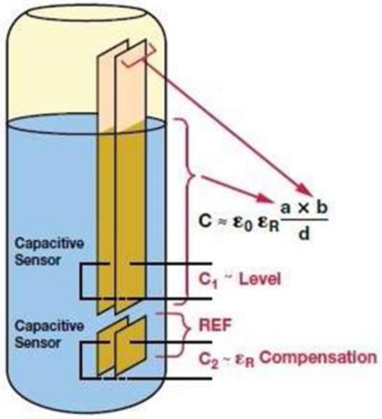
Position Sensor Technologies

- **Contact**
  - Potentiometer

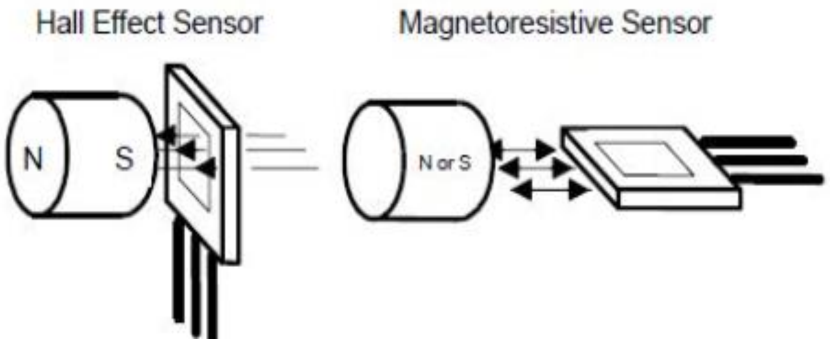


- **Non-Contact**
  - Optical – Encoders
  - Laser
  - Capacitive
  - MagnetoResistive (MR, AMR, GMR, TMR)
  - Hall Effect Sensor
  - Inductive Position Sensor
    - Wire wound (LVDT/RVDT,etc)
    - PCB/Flex BD



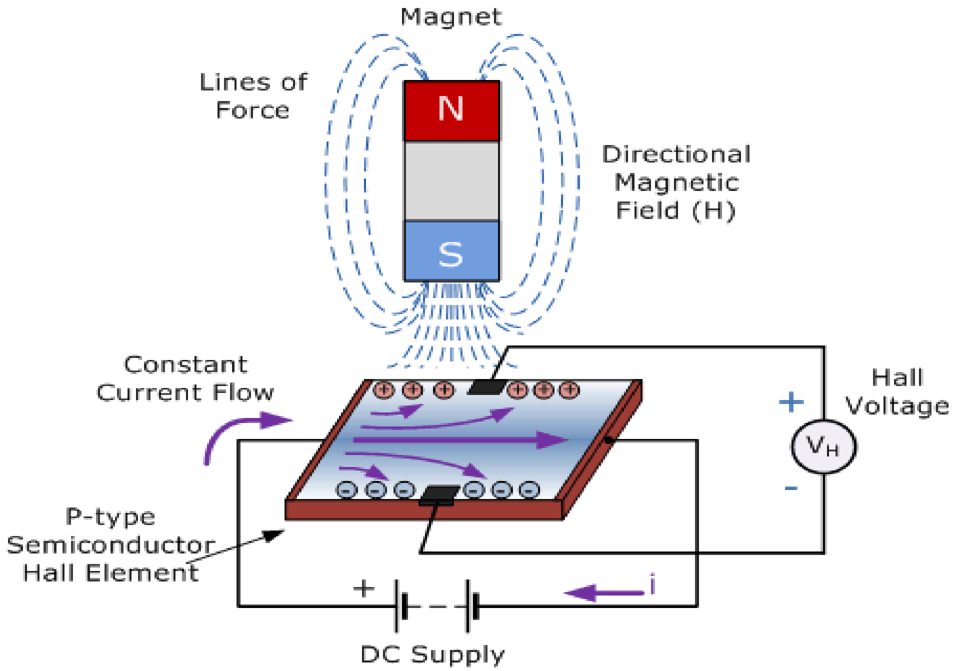


Capacitive Level Sensing



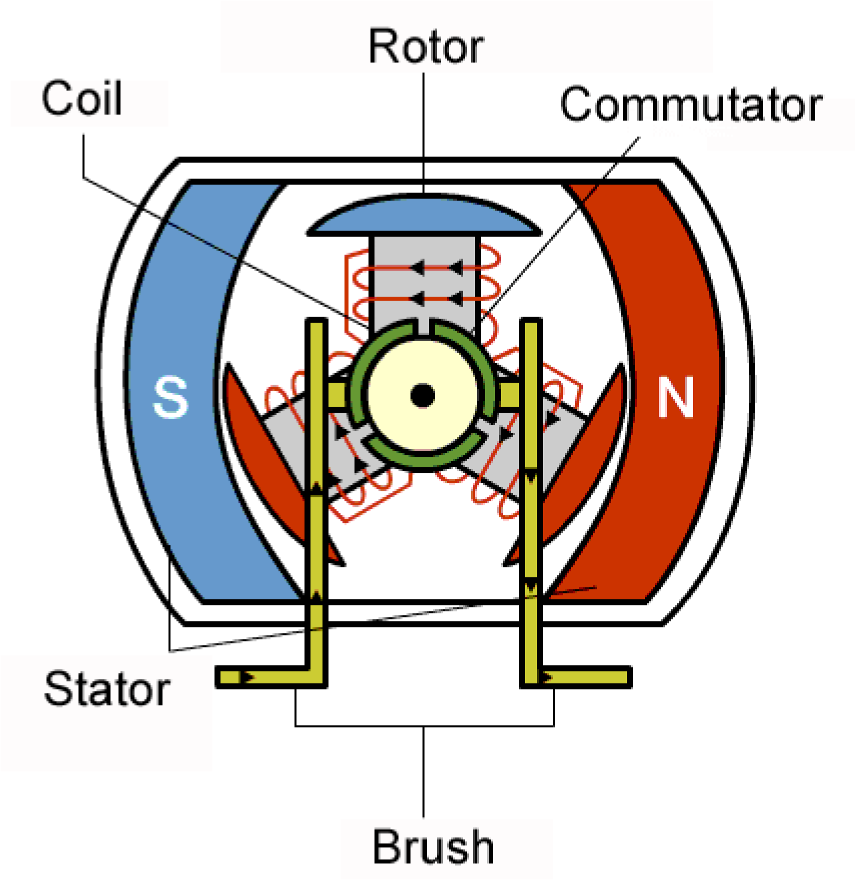
Hall Effect Sensor (Magnet)

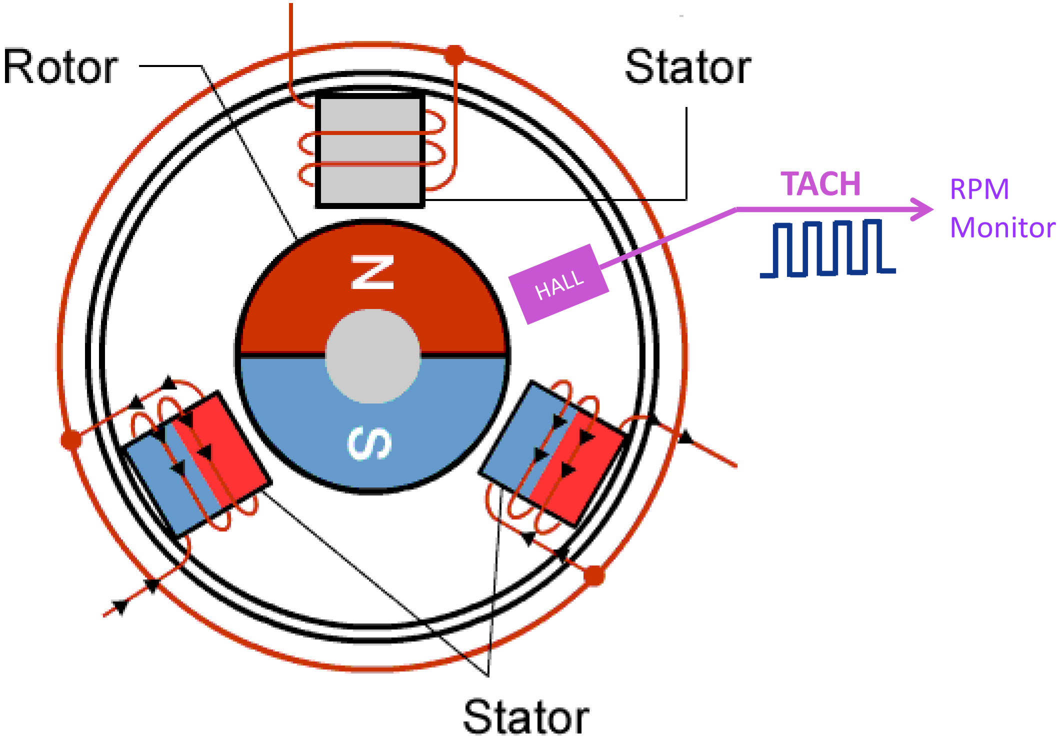
- **The Hall effect was discovered by Dr. Edwin Hall in 1879**
- **Measure Hall voltage (V_H)**



- **Disadvantages**
  - Magnet Target Required
  - High Temperature influence (Hall & Magnet)
  - Influenced by External Magnetic field
  - Limited measurement Range
- **Advantages**
  - No or less PCB Space
  - Understood by Market
  - Simple in concept

Brushed DC Motor vs. Brushless DC Electric Motor (BLDC)





Source : Internet web

Tachometer – Motor Speed Monitor

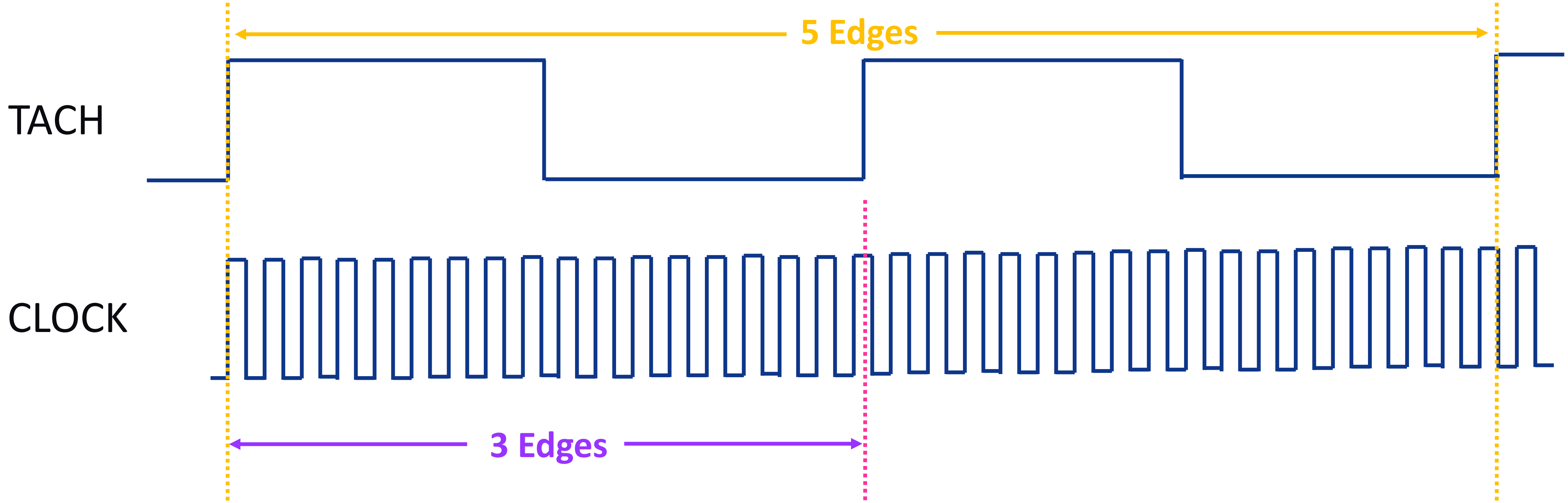
- Usually, the DC motor using Hall effect sensors for the speed monitor. Hall effect sensors detect the rotor position and drive the motor. The driving technique is pulse-width-modulation (PWM) wave.
- The magnets lining the rotor each have their own north and south end, with just one of those ends facing and interacting with the stator. There are an equal number of north and south magnets facing out from the rotor, and each set of N and S magnets is referred to as a 'pole pair'. For each pole pair in the motor there are two poles, so if the motor has 4 poles / magnets, there are 2 pole pairs.
- Hall effect sensors is sensitive to the magnetic field. The output voltage will change when the magnetic field (N or S) is close to the Hall sensor during the motor rotation

EDGESX[1:0]		MINIMUM TACH EDGES	NUMBER OF FAN POLES	EFFECTIVE TACH MULTIPLIER (BASED ON 2 POLE FANS)
1	0			
0	0	3	1 pole	0.5
0	1	5	2 poles (default)	1
1	0	7	3 poles	1.5
1	1	9	4 poles	2

Minimum Edges for Motor rotation

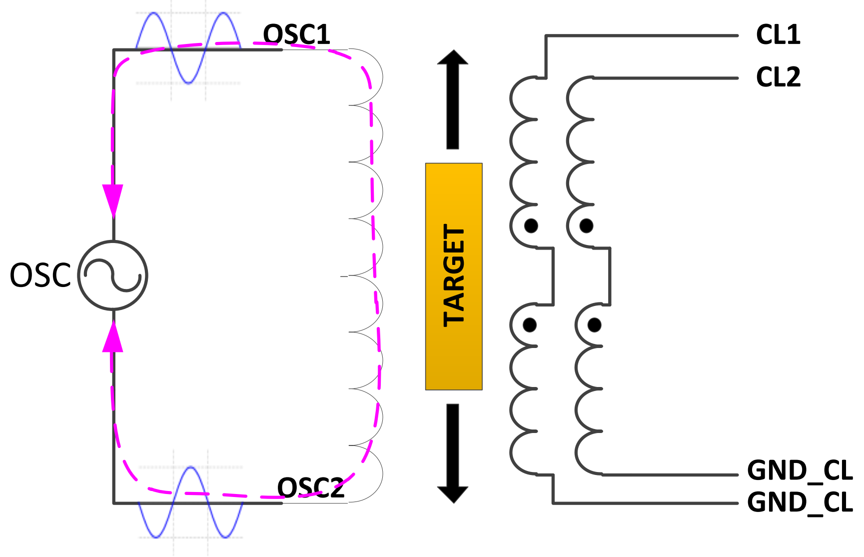
Motor Speed Detection by 32.768KHz Clock

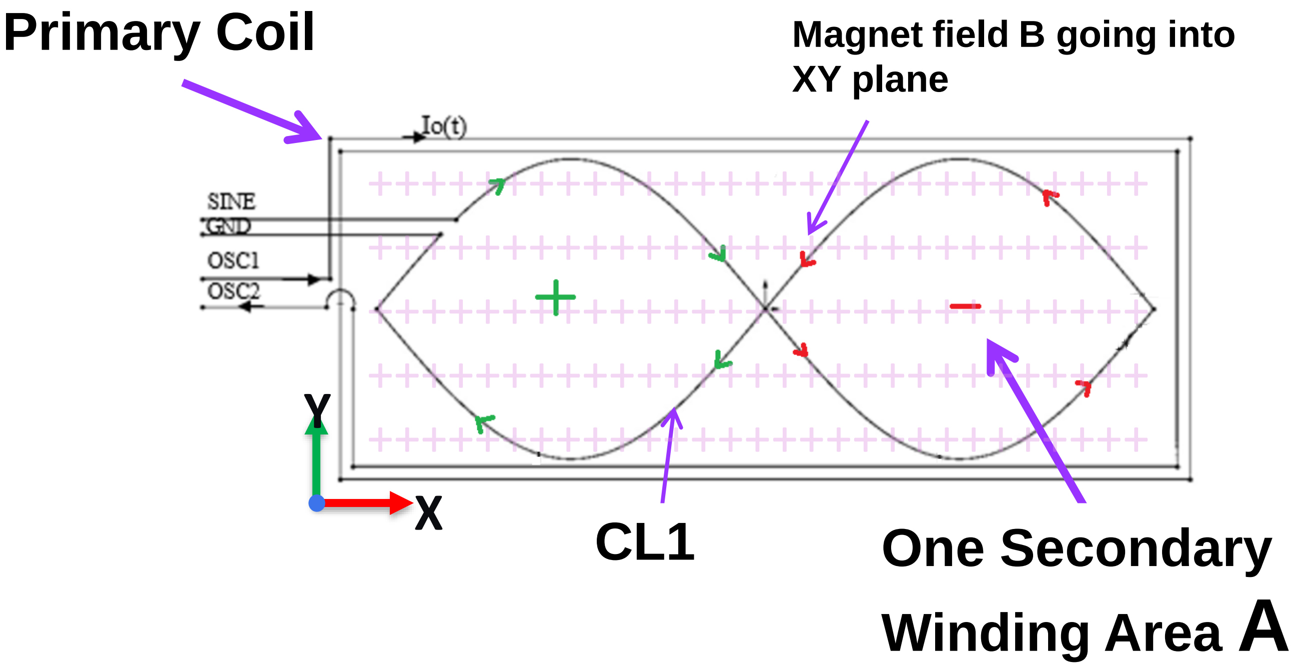
- The 32.768KHz clock is reference signal for the motor speed monitor.
- The “TACH Reading Registers” contents describe the current tachometer reading for each of the fans. By default, the data represents the fan speed as the number of 32.768kHz clock periods that occur for a single revolution of the motor.

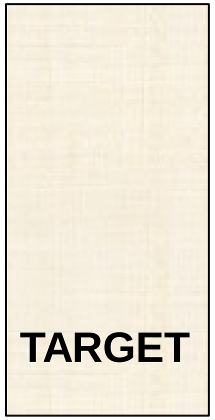


Inducing Secondary Voltage without Target

- Assume Magnetic Field is Uniform
- Output Voltage is zero (no target)







Faraday's Law

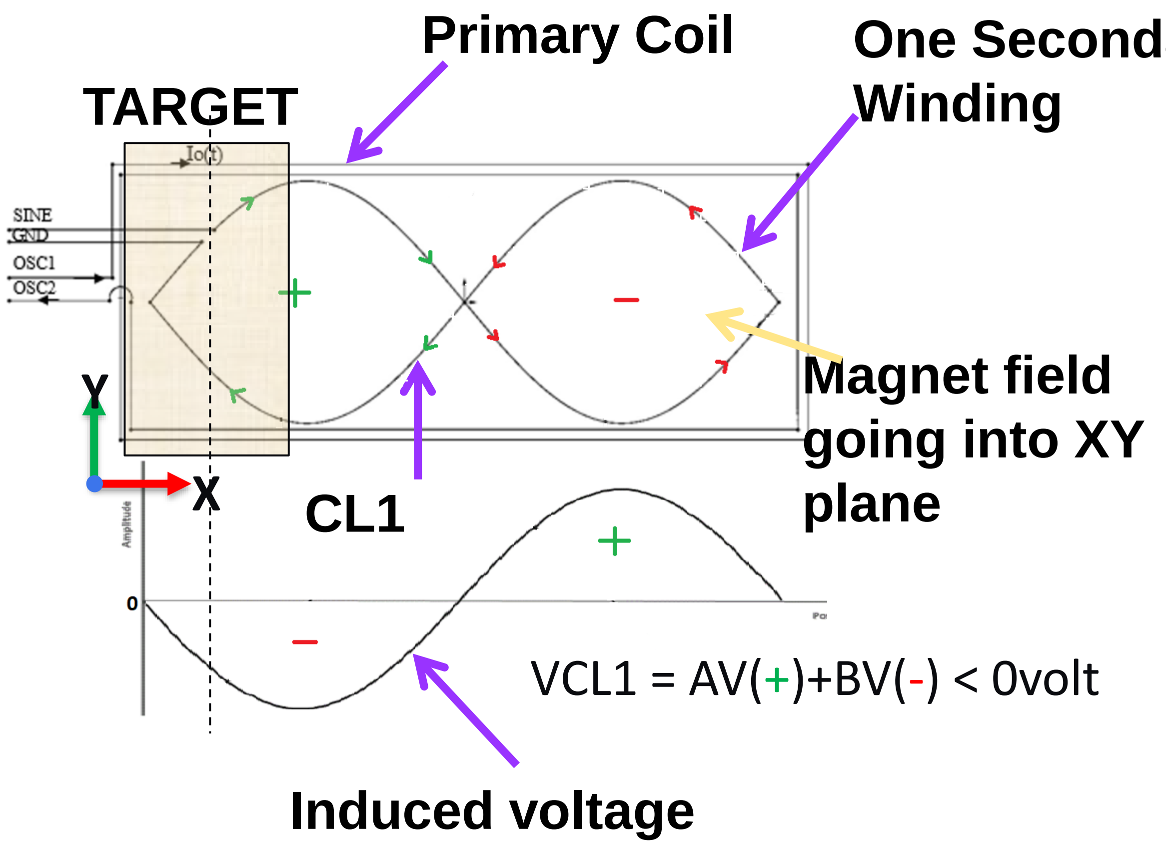
$$V(+) = -\frac{dBA}{dt}$$

$$V(-) = \frac{dBA}{dt}$$

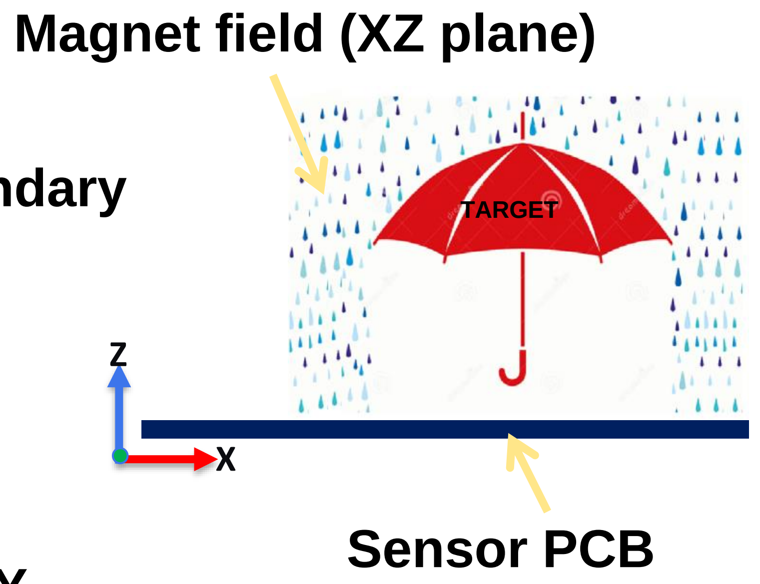
$$V_{CL1} = V(+) + V(-) = 0 \text{ volt}$$

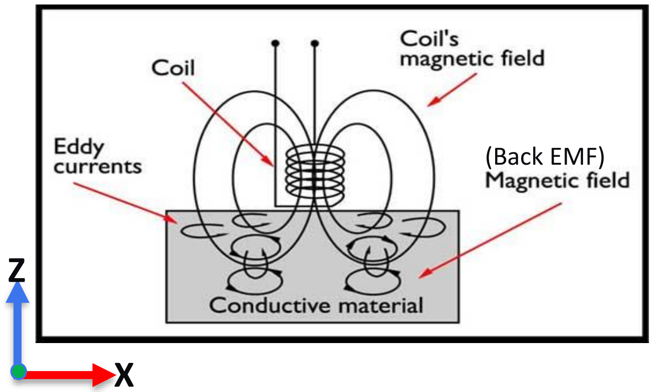
Inducing Secondary Voltages with Target

- Target disturbs Magnetic Field
- Output Voltage is Non-Zero



VCL1 = AV(+)+BV(-) < 0volt



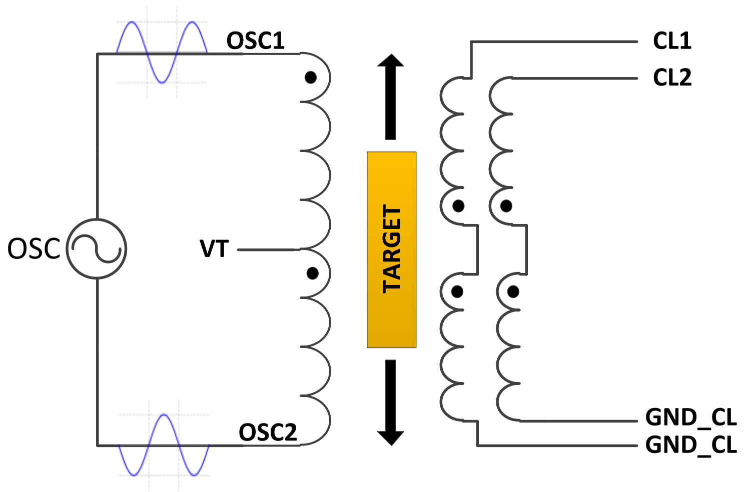


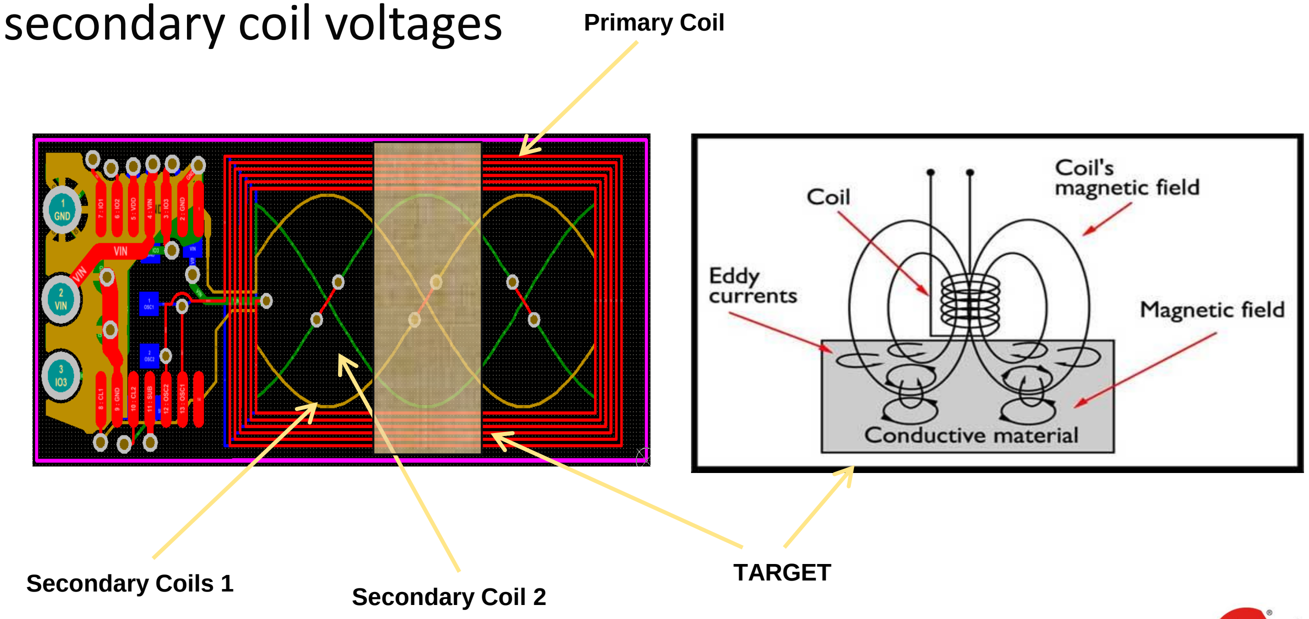
Inductive Sensors Basics

How the Inductor Sensor Works

1. **No magnet** Needed. Instead we use a **primary coil** to generates an AC magnetic field
2. The magnetic fields couples onto two secondary coils generating a voltage
3. A metal target **disturbs** the generated magnetic field
4. The secondary coils receive **different** voltages vs target **position**
5. **Position** is determined by the **ratio** of secondary coil voltages

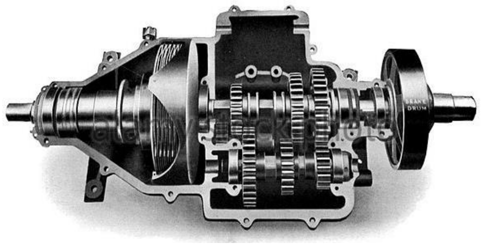
Basic Transformer Model





Microchip Inductive Sensor Advantage (vs. Hall Sensors)

Higher Accuracy	• Very low temperature drift
Better Noise Immunity	• Active rejection of stray magnetic fields
Lower Cost	• No magnet needed
Reference Solutions	• Compete Sensor PCB layout



Microchip Inductive Sensing IC Portfolio

Choose Grade 0 or Grade 1

Choose the Output Interface

Choose the Application

Features	LX3301A	LX3302A	LX34050	LX34070
Calibration segments	6	8	Any	Any
Sensor Offset Adjust	Yes	Yes	N/A	Yes
Gain Adjust (bits)	Yes	Yes	N/A	Yes
Output interfaces	**Analog, PWM**	**Analog, PWM, SENT, PSI5**	**Sin/Cos**	**Differential Sin/Cos**
Output Resolution (bits)	12	12	Analog	Analog
Redundant IC Support	Yes	Yes	Yes	Yes
Sample Rate (samples/sec)	2KHz	2KHz	Any	Any
Dynamic Airgap Calibration	Yes	Yes	N/A	N/A
MCU	Internal	Internal	External	External
Temperature*	–40 °C to 125 °C	–40 °C to 150 °C	–40 °C to 150 °C	–40 °C to 150 °C
AEC-Q100	**Grade 1**	**Grade 0**	**Grade 0**	**Grade 0**
ISO26262 Support	ASIL B	ASIL B	ASIL B	ASIL C
Calibration Programming Options	VIN	VIN, GPIO	VIN, GPIO	VIN, GPIO
Key Applications	**Actuators, Pedals, Levers**	**Actuators, Pedals, Levers**	**Motor Control**	**Motor Control**

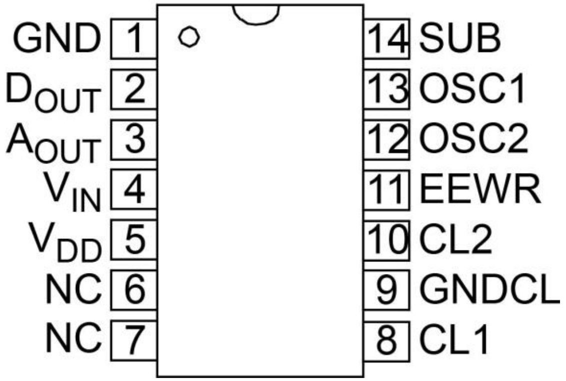
MICROCHIP

LX3301A

- **Built-in oscillator for driving primary coil**
- **Two independent analog channels with demodulation**
- **Selection of SINC/FIR digital filter**
- **Two 13-bit ADCs**
- **One 12-bit DACs**
- **One 16-bit PWM**
- **Fault detection and protection**
- **Digital Calibration with EEPROM**
- **TD, PWM with PP/OD output**
- **AEC-Q100 certification**
- **ISO26262 ASIL B support**

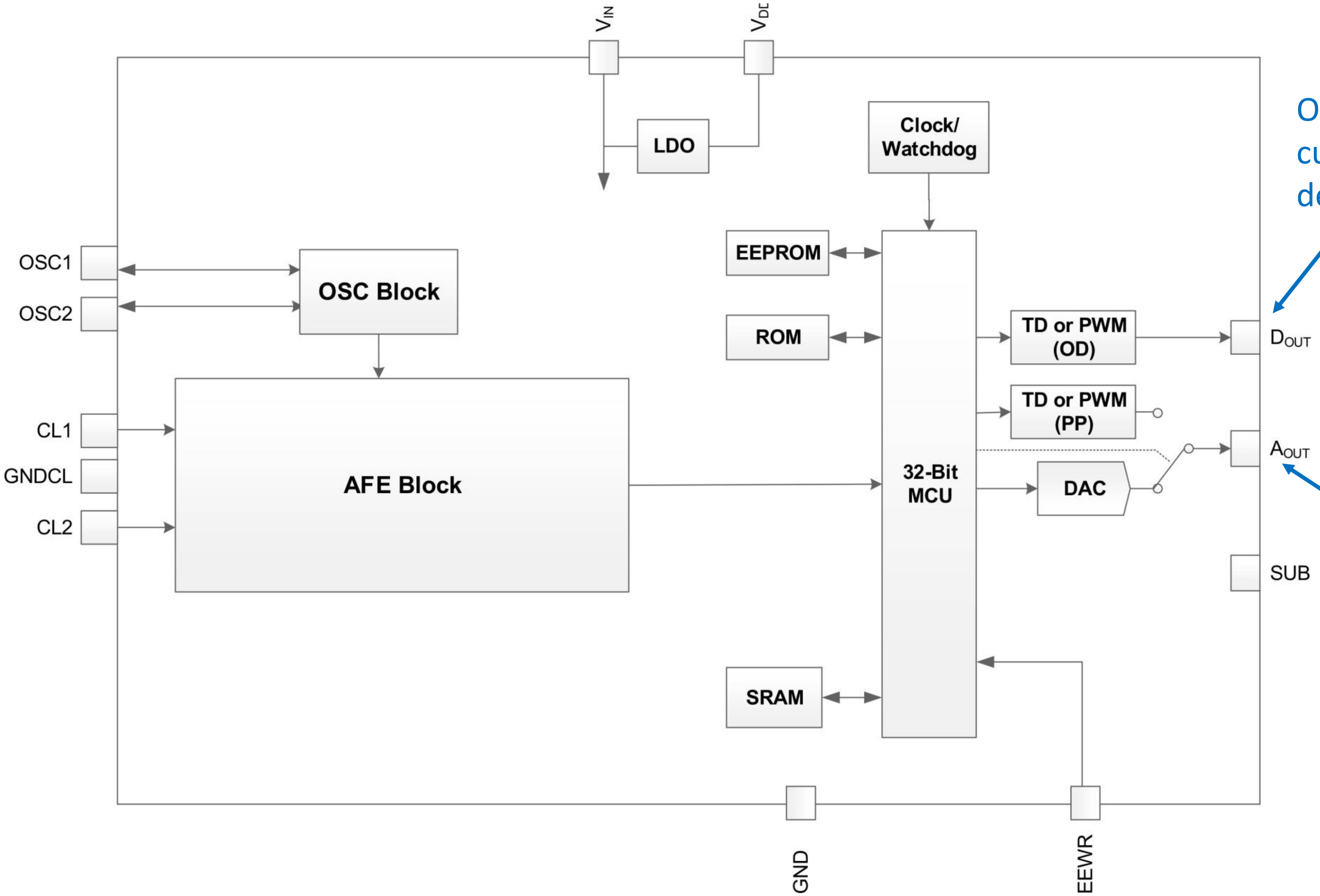
- **Application**
  - Automotive control
  - Medical Equipment
  - ATE Equipment
  - Industrial process control
  - Smart energy saving control

14-Pin TSSOP
(Top View)



MICROCHIP

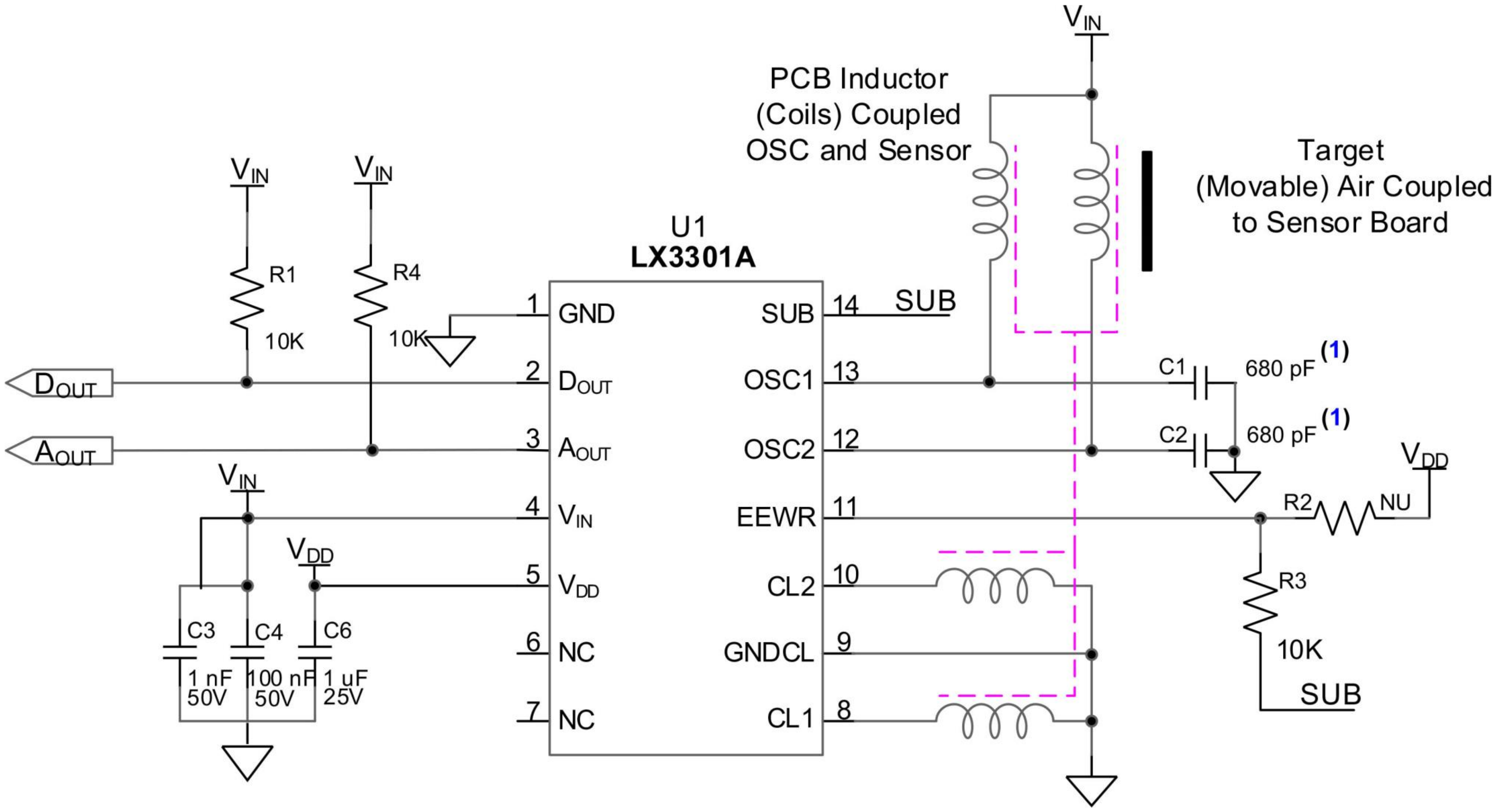
LX3301A – Block Diagram



Open-Drain PWM with the current limit or the threshold detector(TD)output

Analog output.
It can be programmed to provide an analog-output. threshold detector, or PWM (PP) output.

LX3301A – Reference Schematic

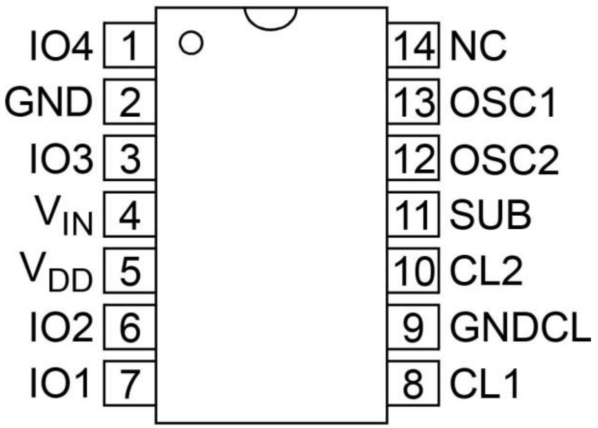


LX3302A

- **Built-in oscillator for driving primary coil**
- **Two independent analog channels with demodulation**
- **Two 13-bit ADCs**
- **One 12-bit DACs**
- **One 16-bit PWM**
- **Fault detection and protection**
- **Digital Calibration with EEPROM**
- **Wide range supply voltage (4.0~11.0V)**
- **SENT/PSI5 output (Digital)**
- **PWM/DAC/PGA output (Analog)**
- **AEC-Q100 certification**
- **ISO26262 ASIL B support**

- **Application**
  - Automotive control
  - ATE Equipment
  - Industrial process control
  - Smart energy saving control

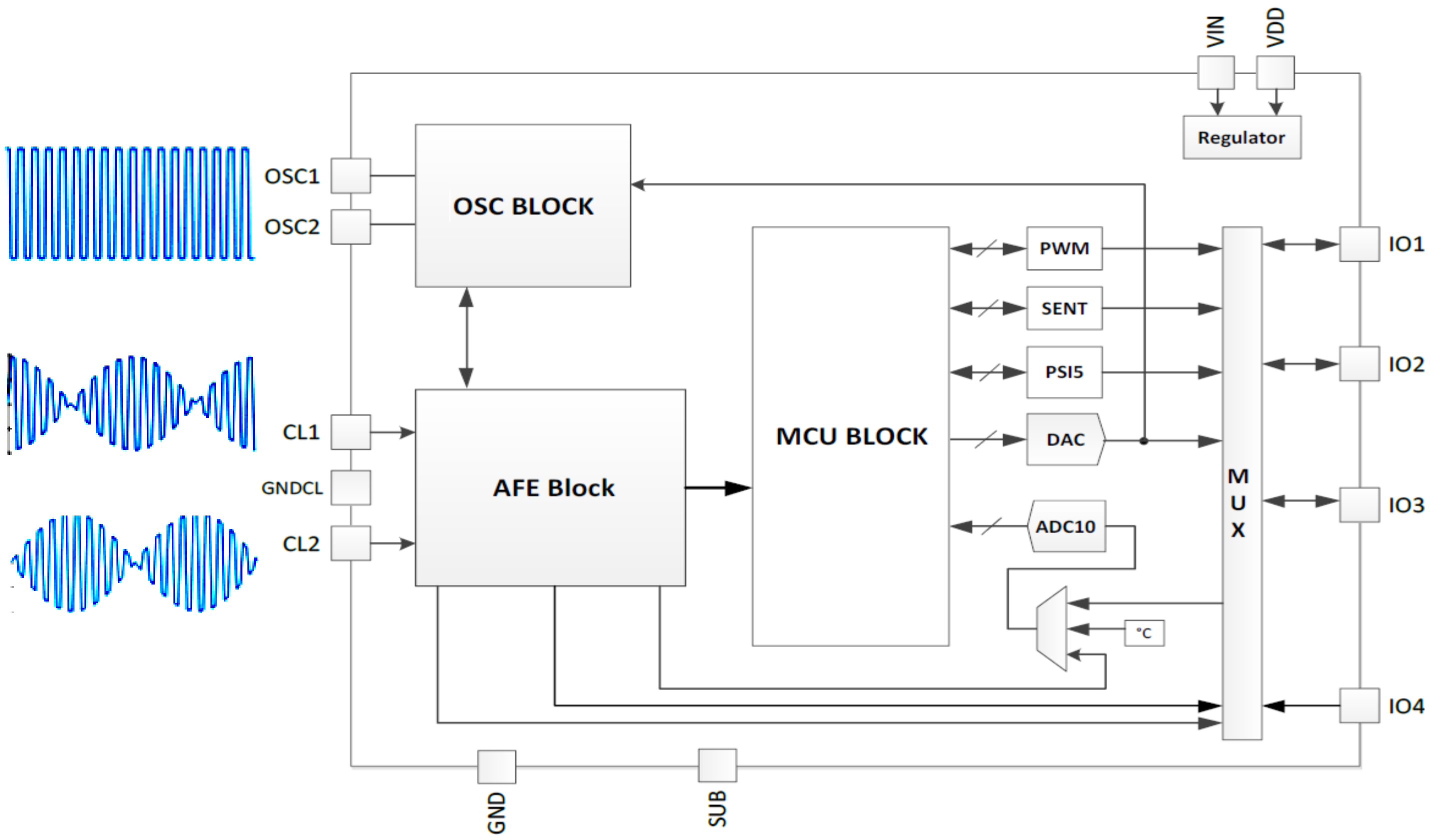
14-Pin TSSOP
(Top View)



MICROCHIP

LX3302A Block Diagram

- OSC1,2 Generates Magnetic Field
- CL1, CL2 detects voltage
- ADC read Demodulated signal
- uP Calculates Position
- PWM/SENT/PSI5/DAC/PGA outputs Signal

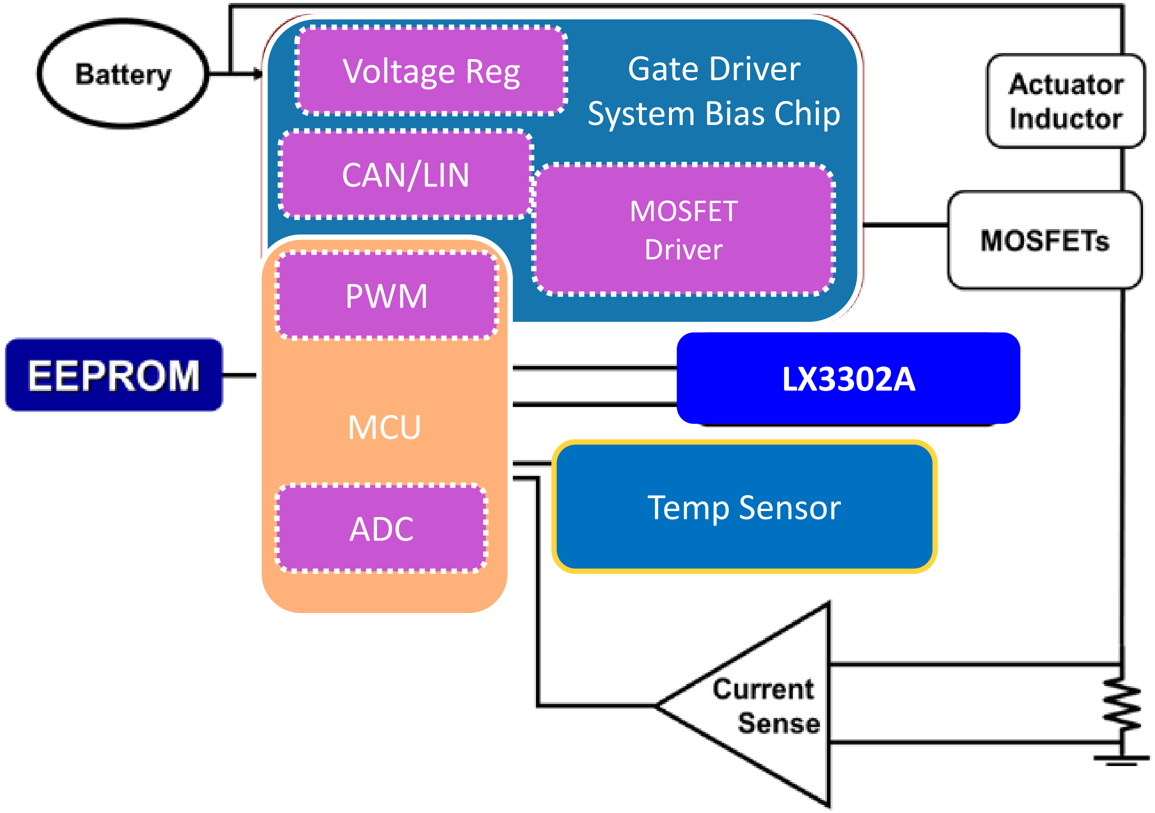


MICROCHIP

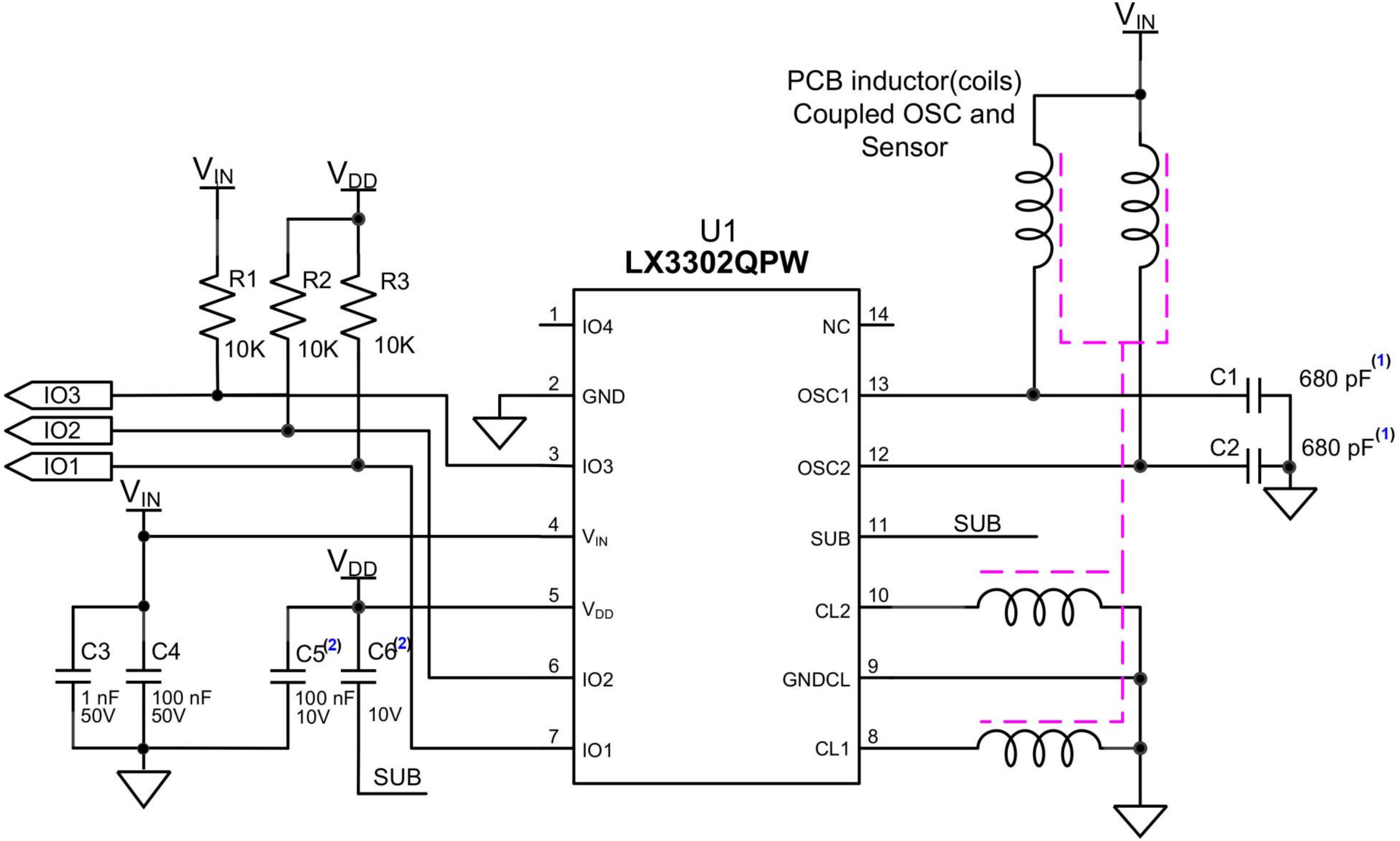
Output Flexible for system

- **Analog Output**
  - 12 DAC
- **PWM**
  - 2kHz, 1kHz, 500Hz, 250Hz Frequency
- **SENT**
  - Three Wire sensor specific digital output
- **PSI5**
  - Two wire sensor specific current modulated solution

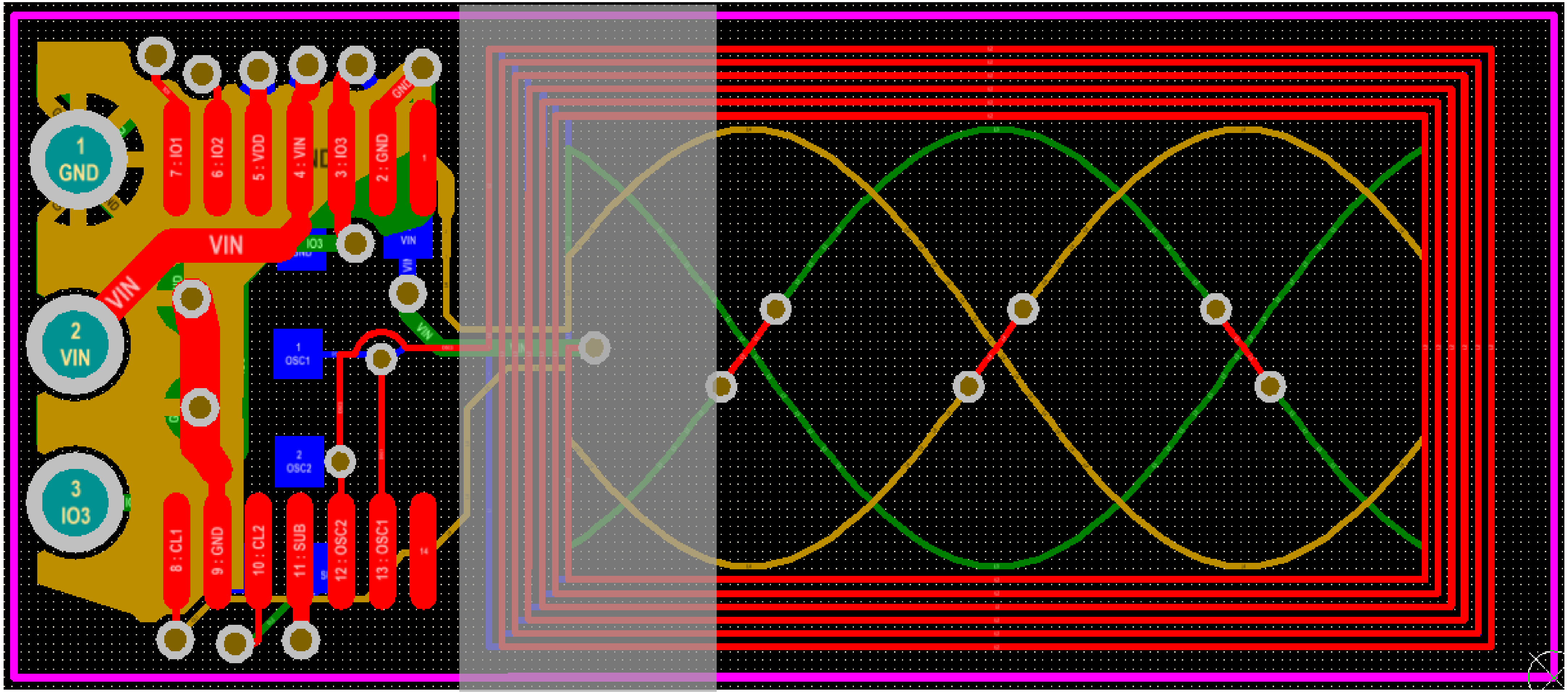
Turbo/Throttle body/EGR Control



LX3302A – Reference Schematic

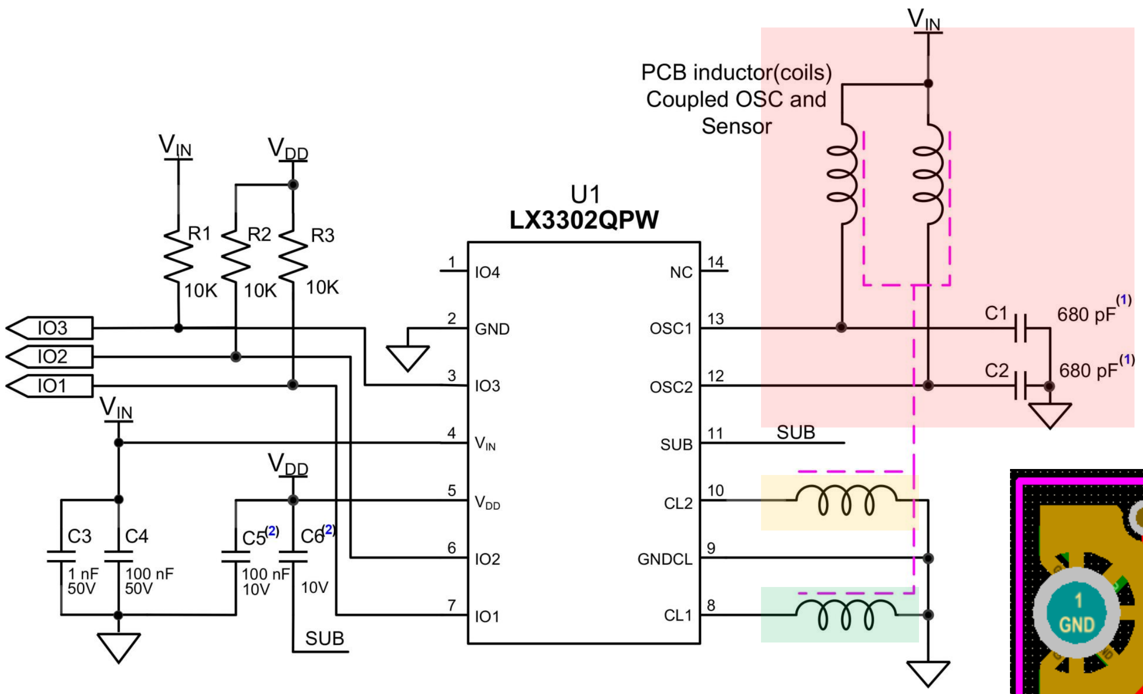


LX3302A – Layout with the Reference Board



MICROCHIP

LX3302A – Reference Schematic

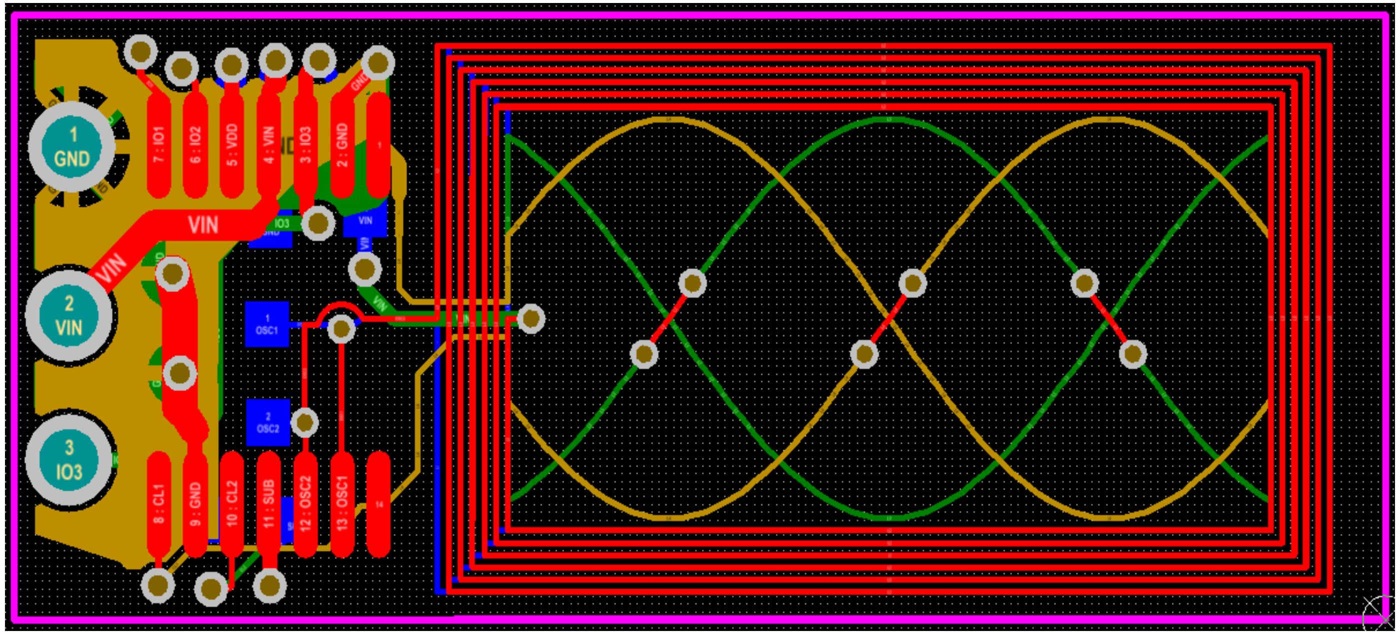


Primary Coils

LC oscillator

$Freq = 1 / (2 * \pi * \sqrt{LC})$

Frequency Range : 1 to 6 MHz



Secondary Coils (SIN)

Secondary Coils (COS)

LX3302A – REFRESH Rate

- This parameter sets the value of the refresh rate of the ADC update. If the PWM output is selected, then the PWM frequency is always equal to the ADC update rate. Also, WDSCALE should be selected. Refer to SENTCLK for Refresh mode and the WDSCALE selection for SENT mode.

Bit Value	ADC1 and ADC2 Sampling Clock	PWM Frequency	WDSCALE
011	$F_{CLK}/8$	2 kHz	001
100	$F_{CLK}/16$	1 kHz	001
101	$F_{CLK}/32$	500 Hz	010
110	$F_{CLK}/64$	250 Hz	011

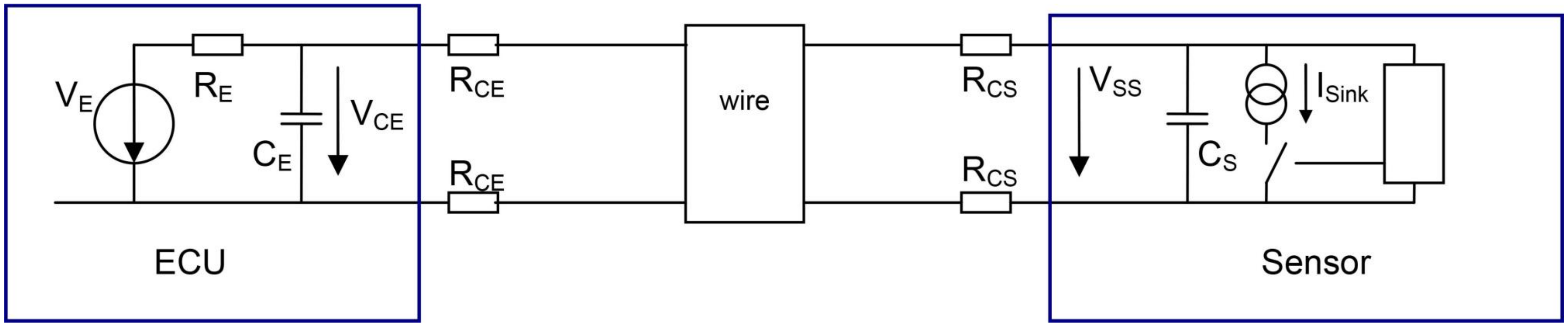
REFRESH configuration
(PWM output)

Bit Value	Tick Clock (µs)	Refresh	WDSCALE
00	3	1 kHz	1
01	6	500 Hz	2
10	12	250 Hz	3
11	24	250 Hz	4

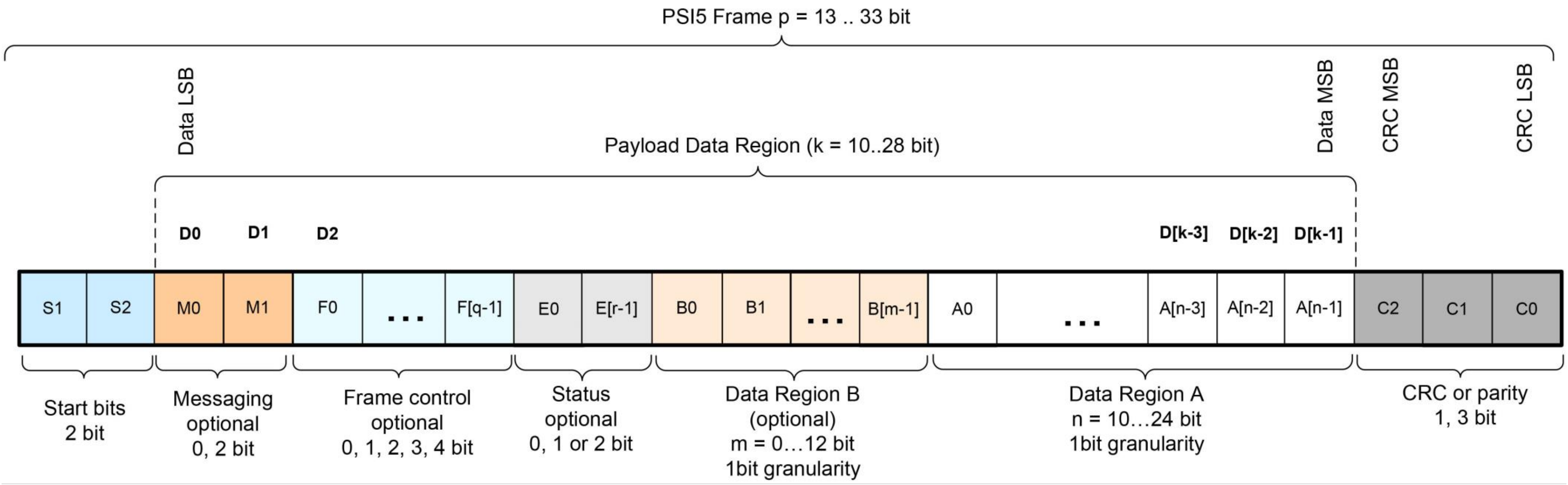
SENTCLK configuration
(SENT output)

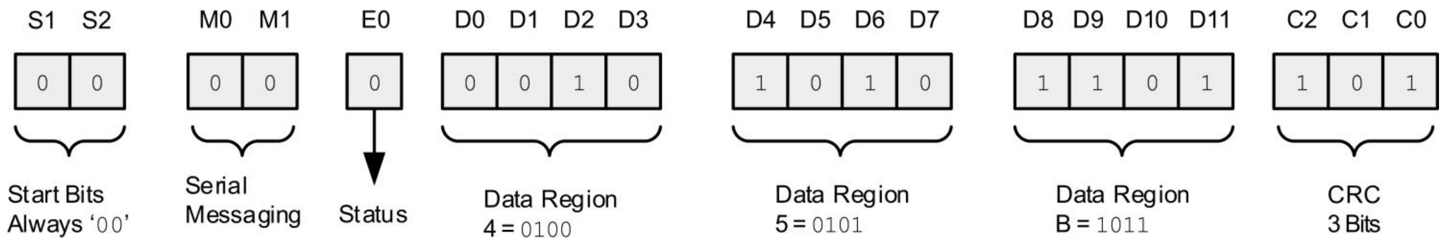
PSI5 - Peripheral Sensor Interface 5

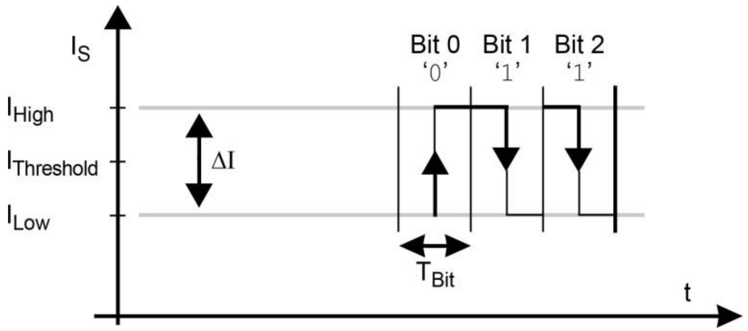
- The PSI5 is an open standard interface for bidirectional digital sensor data communication in vehicles.
- PSI5 uses two wires for both power supply to the sensors and data transmission. The ECU provides a pre-regulated voltage to the sensor. Data transmission from the sensor to the ECU is done by current modulation on the power supply lines. Current oscillations are damped by the ECU.



PSI5 Frame



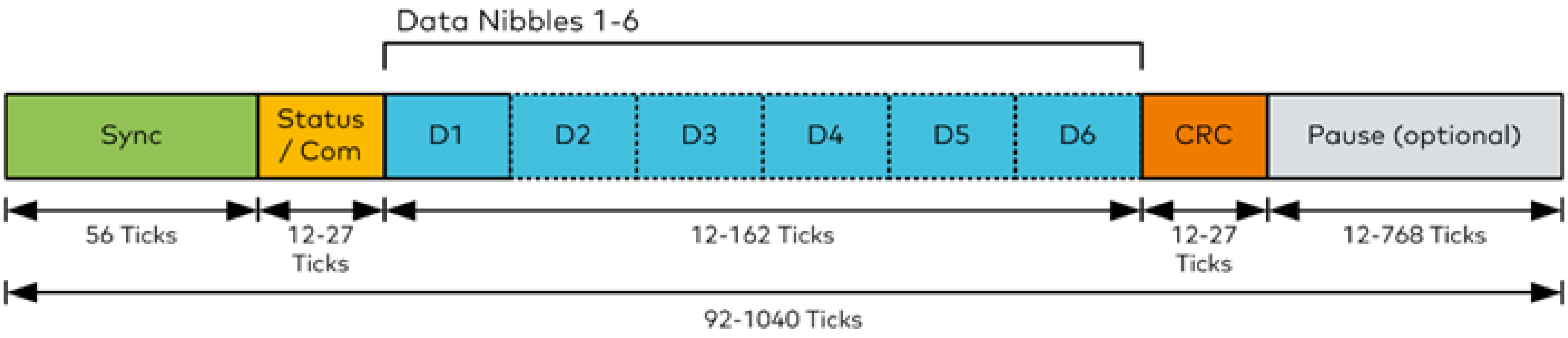




LX3302A - Encoded PSI5 Format for 0xB54

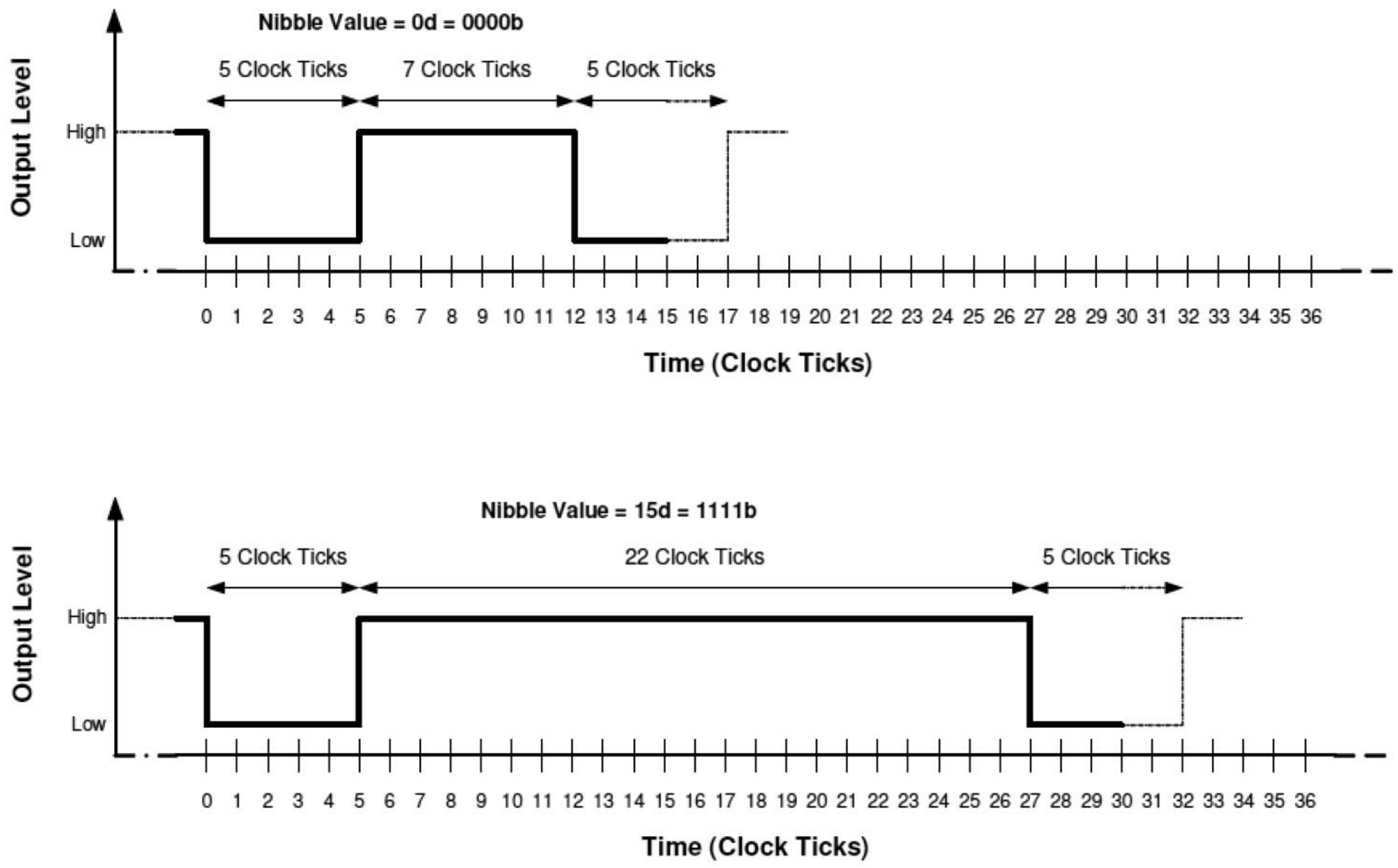
SENT – Single Edge Nibble Transmission

- The SENT (SAE J2716) protocol is a point-to-point scheme for transmitting signal values from a sensor to a controller
- The basic unit of time in SENT is called a tick, where a tick can be between 3 - 90 µs, at the sender's option. Each message is preceded by a calibration pulse with a high period of 56 ticks for framing and calibration of tick length.



SENT – Timing Diagram

- SENT consists of transmitting eight nibbles (one nibble equals four bits) in sequence. Each nibble is coded using a PWM output referenced to the falling edge. The series of transmitted pulses are measured from falling edge to falling edge (clock tick) with a programmable time granularity of 3 µs, 6 µs, 12 µs and 24 µs.



SENT – Decode Example

Code : (Nibble[us] – Ticks[us] *7) / Ticks[us]

First

Waveform Segment	Unit	Value
Sync_Logic-L (5 Tick)	us	14.34
Sync_Logic-H (51 Tick)	us	147.28
5 Clock Ticks	us	14.32
Status & Comm Nibble	us	20.32
Data Nibble 1	us	20.32
Data Nibble 2	us	31.86
Data Nibble 3	us	20.34
Data Nibble 4	us	20.32
Data Nibble 5	us	20.30
Data Nibble 6	us	20.34
CRC Nibble	us	40.52

Item	Unit	Length	Diff
Clock Ticks	us	2.886	0.022
Verified the Clock Ticks	us	2.864	

Segment	DEC (raw)	DEC (round)	HEX	BIN
Status & Comm Nibble	0.04	0	0	0000
Data Nibble 1	0.04	0	0	0000
Data Nibble 2	4.04	4	4	0100
Data Nibble 3	0.05	0	0	0000
Data Nibble 4	0.04	0	0	0000
Data Nibble 5	0.03	0	0	0000
Data Nibble 6	0.05	0	0	0000
CRC Nibble	7.04	7	7	0111

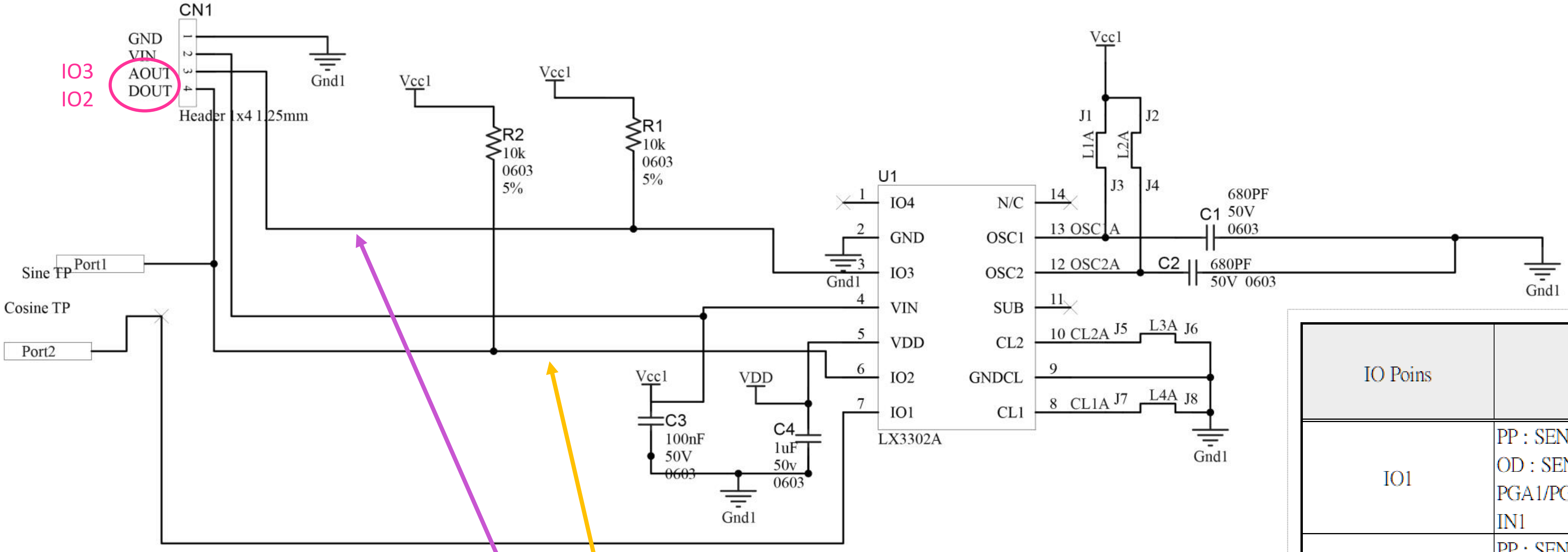
Second

Waveform Segment	Unit	Value
Sync_Logic-L (5 Tick)	us	14.42
Sync_Logic-H (51 Tick)	us	147.14
5 Clock Ticks	us	14.42
Status & Comm Nibble	us	20.16
Data Nibble 1	us	20.20
Data Nibble 2	us	31.76
Data Nibble 3	us	20.22
Data Nibble 4	us	20.20
Data Nibble 5	us	20.20
Data Nibble 6	us	20.20
CRC Nibble	us	40.40

Item	Unit	Length	Diff
Clock Ticks	us	2.885	0.001
Verified the Clock Ticks	us	2.884	

Segment	DEC (raw)	DEC (round)	HEX	BIN
Status Nibble	-0.01	0	0	0000
Data Nibble 1	0.00	0	0	0000
Data Nibble 2	4.01	4	4	0100
Data Nibble 3	0.01	0	0	0000
Data Nibble 4	0.00	0	0	0000
Data Nibble 5	0.00	0	0	0000
Data Nibble 6	0.00	0	0	0000
CRC Nibble	7.00	7	7	0111

Example Schematic – EVB of LXE3302ARD001



IO2 (DOUT) : SENT, PWM, PGA1/2

IO3 (AOUT) : SENT, PWM, PSI5, DAC

IO1 : SENT, PWM, PGA1/2

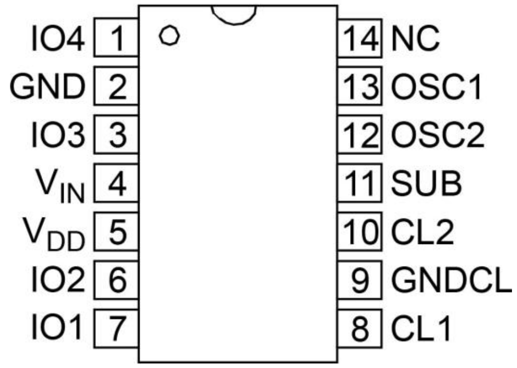
IO Poins	Support Function
IO1	PP : SENT, PWMB, PWM, GPIO1 OD : SENTB, PWMB, GPIO2 PGA1/PGA2 IN1
IO2	PP : SENT, PWMB, PWM, GPIO1 OD : SENTB, PWMB, GPIO2 PGA1/PGA2 IN2
IO3	PP : SENT, PWMB, PWM, GPIO1 OD : PWM, PWMB, SENT, SENTB, GPIO3 PSI5, GPIO3 with a threshold DAC_OUT IN3 with a threshold
IO4	IN4

LX34050

- **Built-in oscillator for driving primary coil**
- **Two independent analog channels with demodulation**
- **User-programmable EEPROM for storing calibration and configuration parameters**
- **Analog output**
- **Fault detection and protection**
- **Low-temperature Drift**
- **-40ºC to +150ºC operation**
- **Excellent long-term stability**
- **AEC-Q100 certification**
- **ISO26262 ASIL B support**

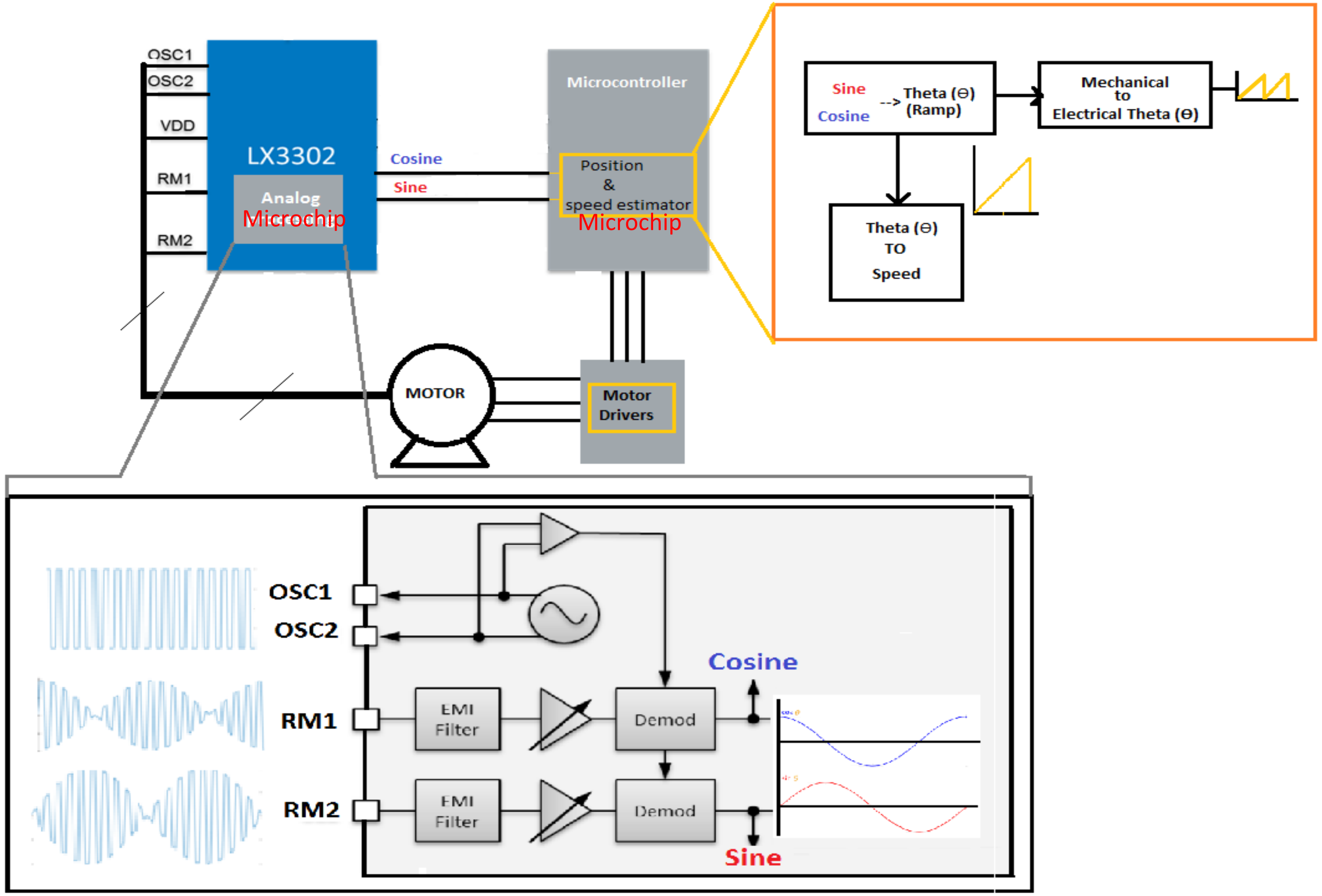
- **Application**
  - Automotive HS Position Sensor
  - Absolution Position for Motor Rotor Position
  - Magnetic Resolver Transformer Replacement
  - LDVT Transformer replacement
  - Motor Control
  - Factory Automation

14-Pin TSSOP
(Top View)

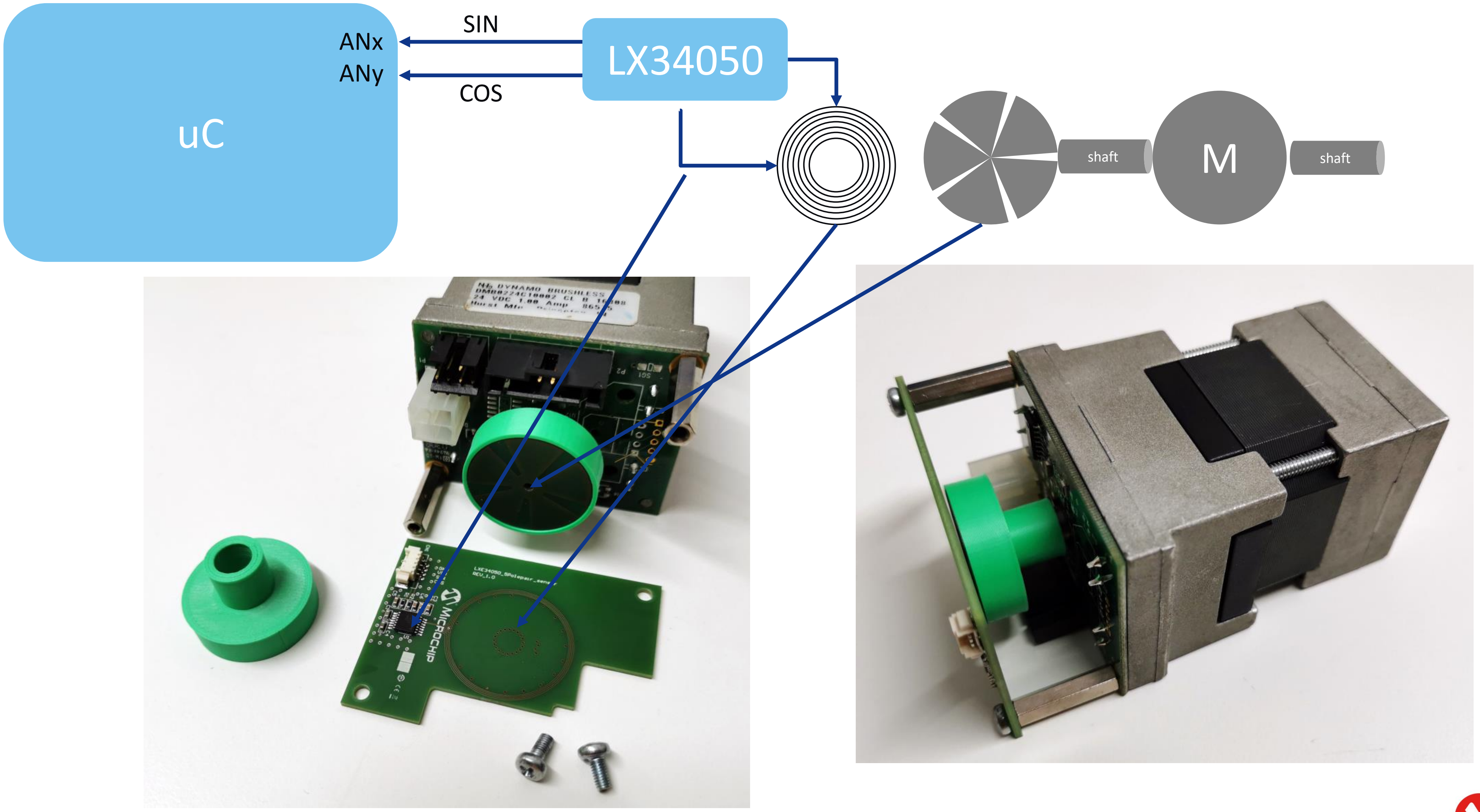


LX34050 + uC for High-Speed Motor Control

- The LX34050A outputs analog output signals (sin and cos) to represent position.
- Optimized for high-speed motor applications (50k rpm).
- 100kHz Bandwidth in LX34050A



Block Diagram

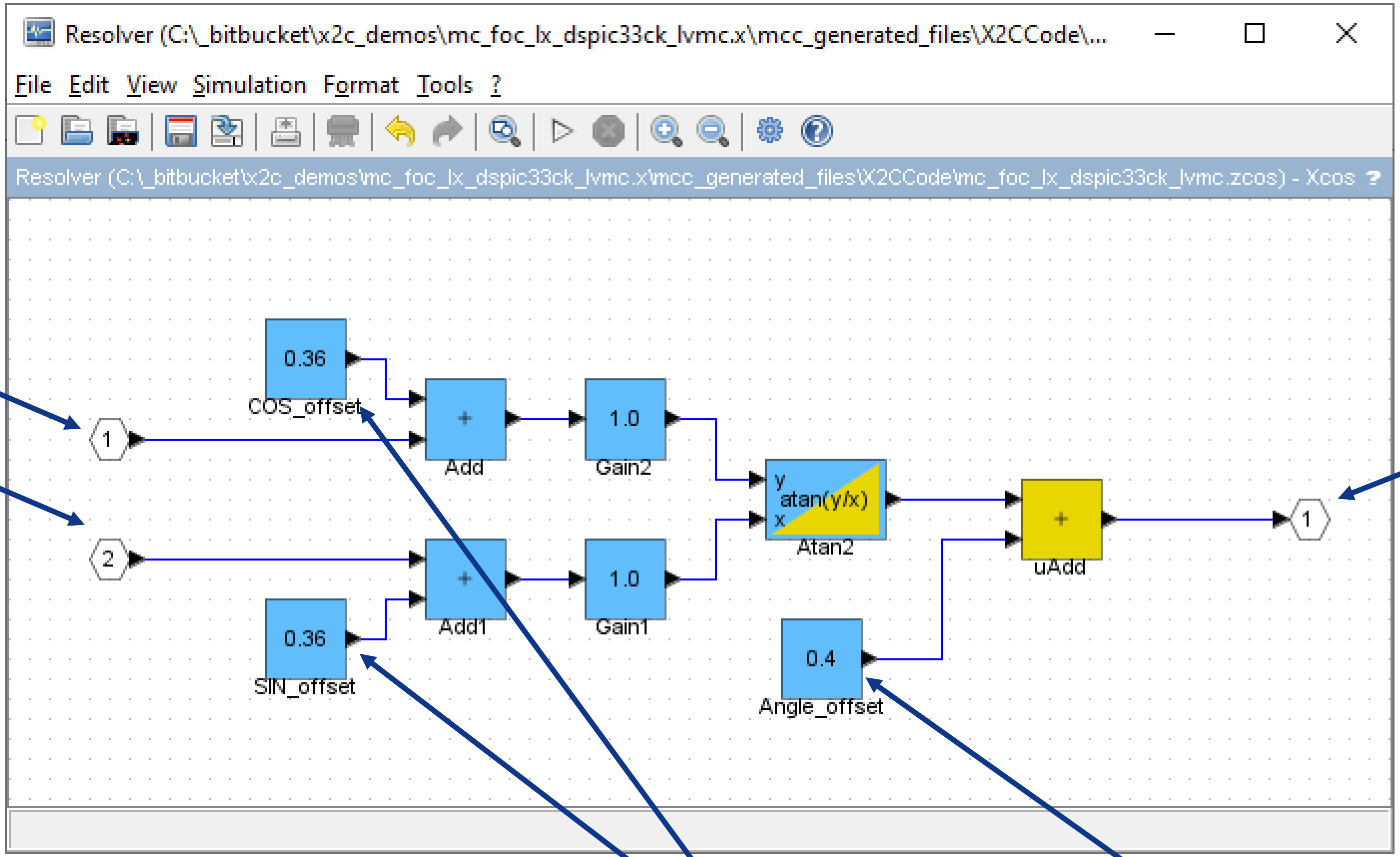


Signal Process by the Micro-Controller

LX34050

SIN

COS



Absolute

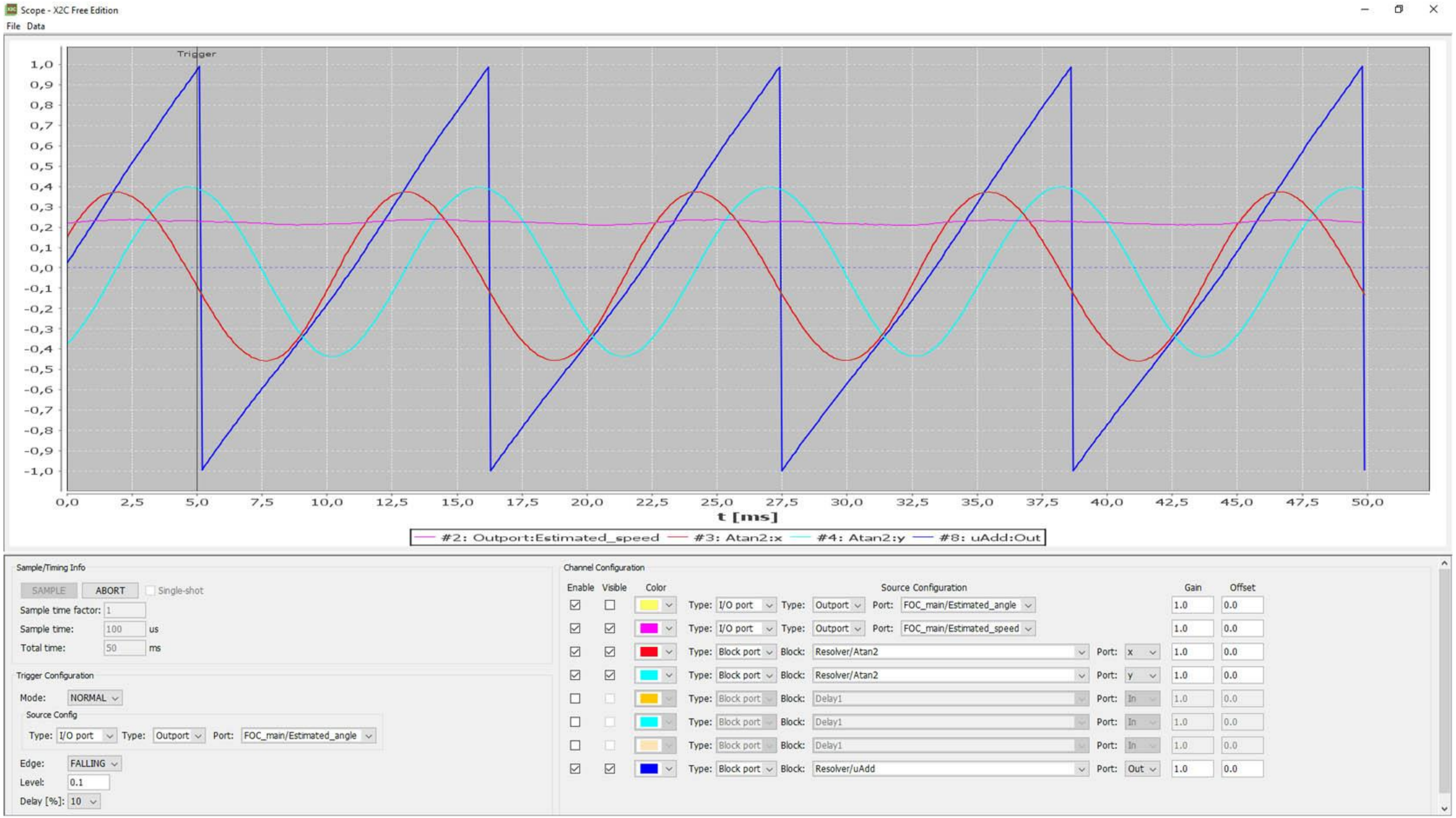
Rotor

Position

Angle offset for 0 alignment

Analog signal offset

Signal Measurement and Calculation

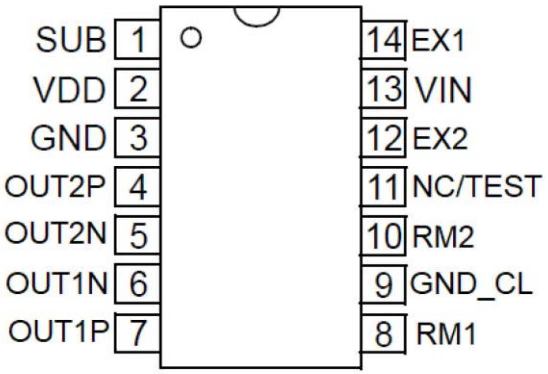


LX34070

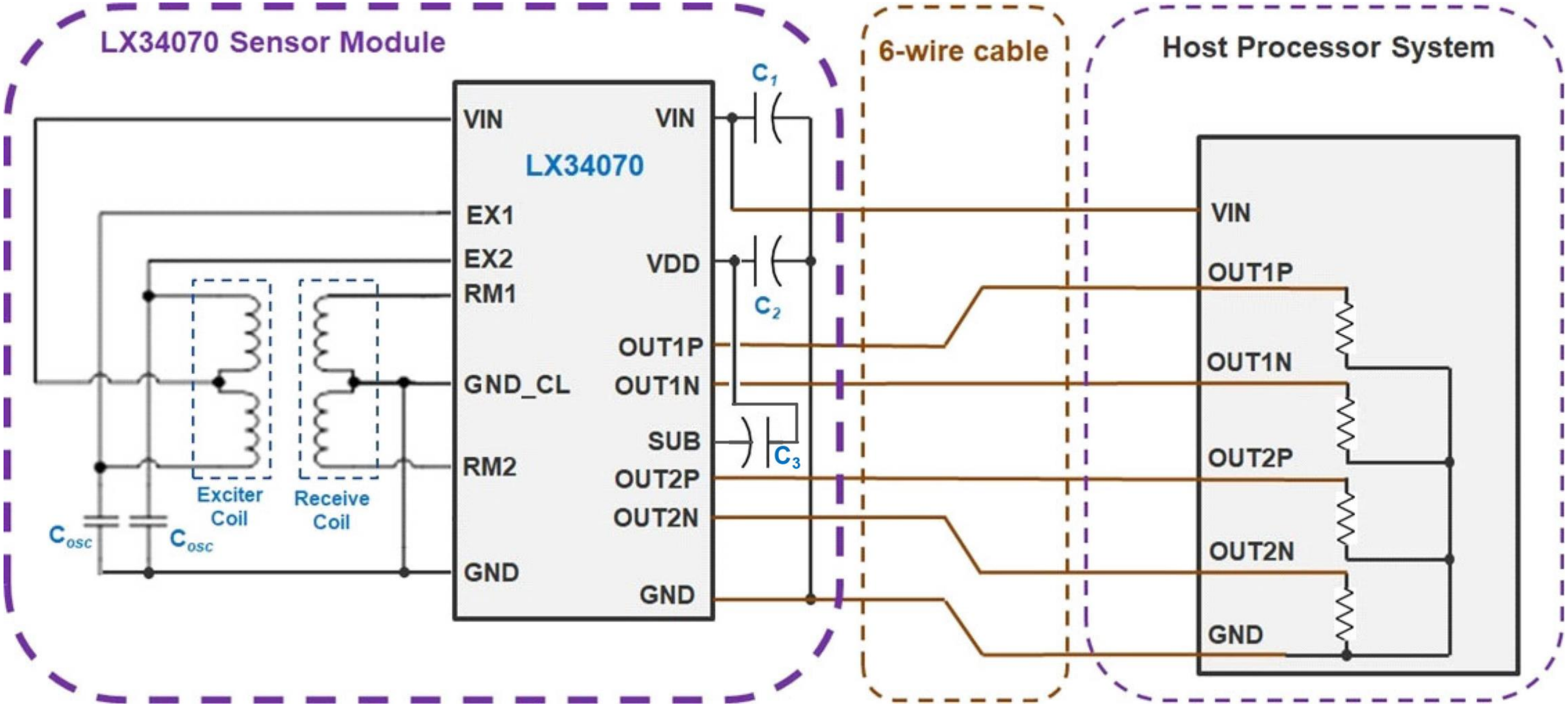
- **Built-in oscillator for driving primary coil**
- **Two independent analog channels with filtering and amplitude demodulation**
- **Differential output buffers with accurate common-mode level and protection**
- **User-programmable EEPROM for storing calibration and configuration parameters**
- **Fault detection and protection**
- **Low-temperature Drift**
- **-40ºC to +150ºC operation**
- **Excellent long-term stability**
- **AEC-Q100 certification**
- **ISO26262 ASIL C support**

- **Application**
  - Automotive HS Position Sensor
  - Automotive Control
  - Medical Equipment
  - ATE Equipment
  - Industrial Process Control
  - Smart Energy Saving Control

14-Pin TSSOP
(Top View)



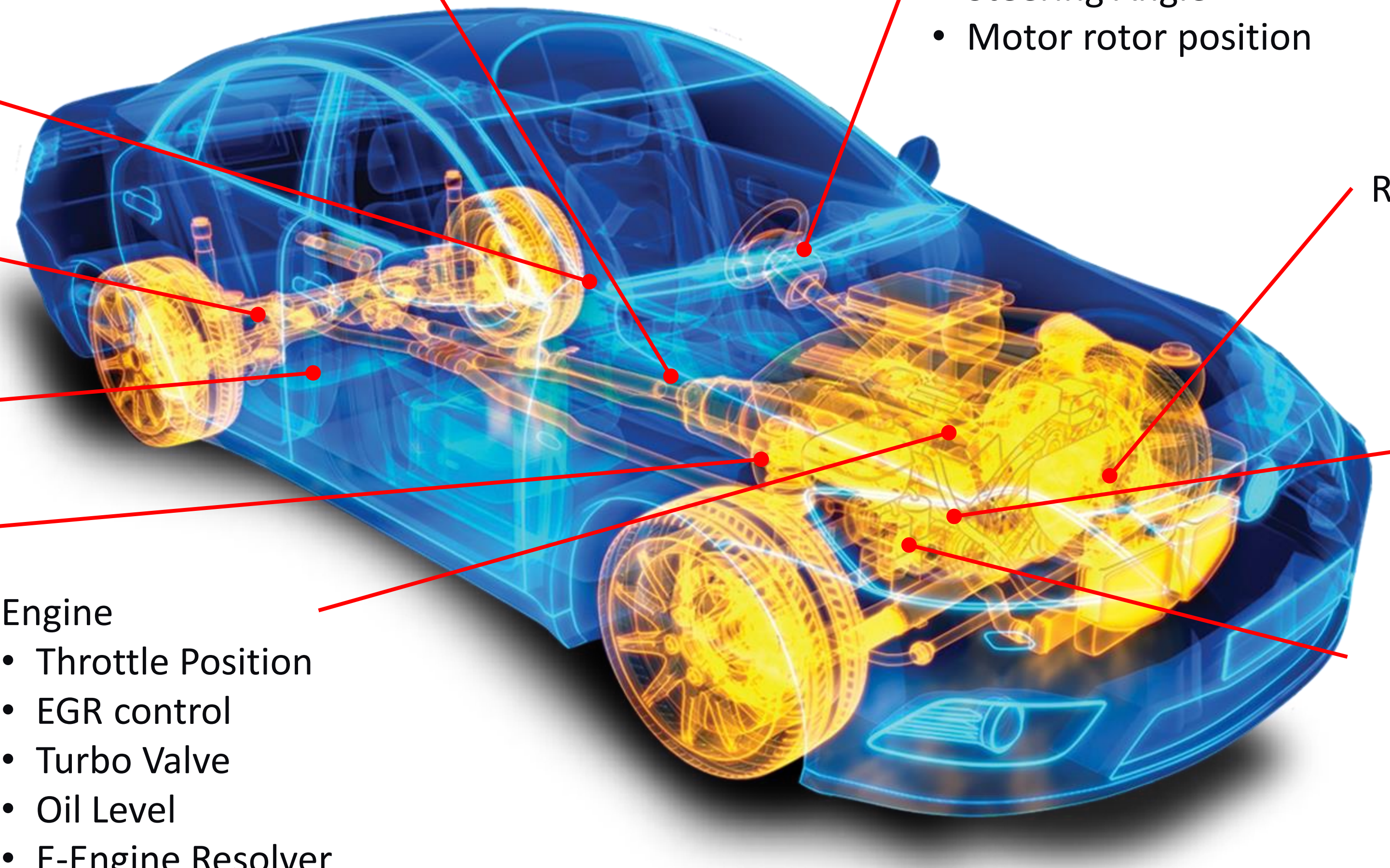
LX34070 – Application Block



MICROCHIP

Applying The Technology

Applications for Inductive Sensor Position ICs

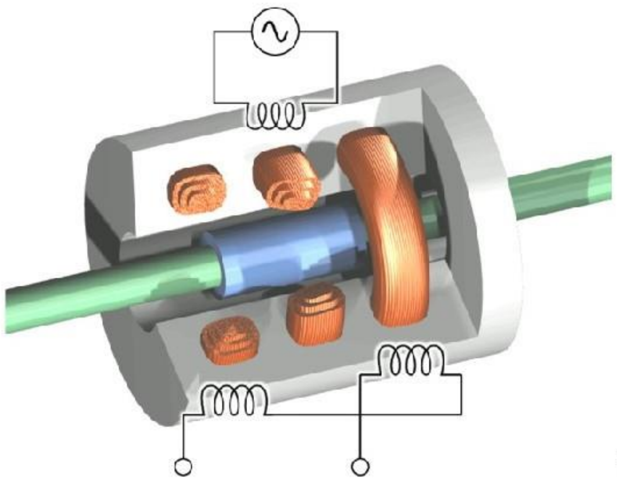


MICROCHIP

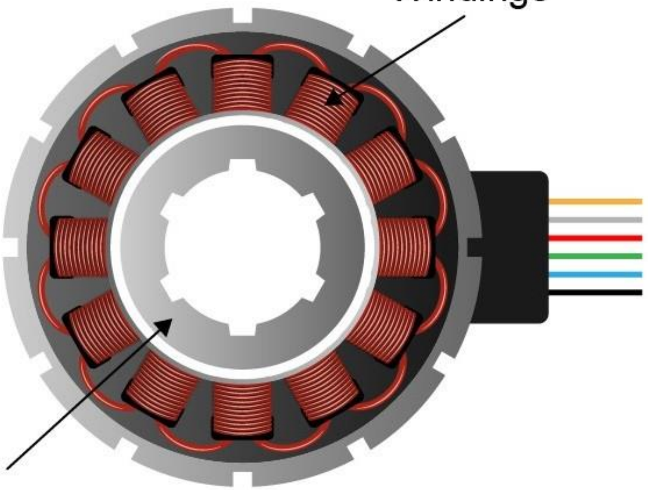
Microchip Inductive Sensors Improve older Technology

LOWER WEIGHT, SMALLER SIZE, LOWER COST

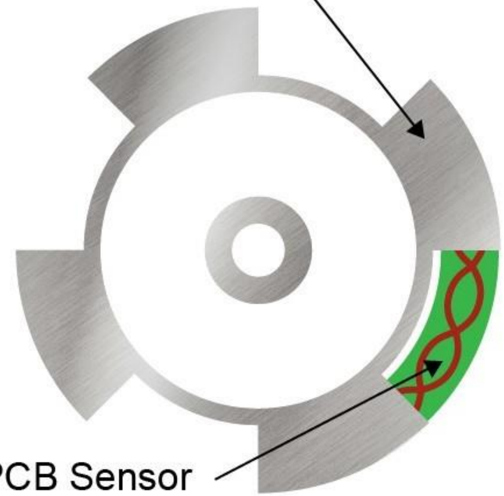
Linear Variable Differential Transducer (LVDT)



Magnetic Resolver

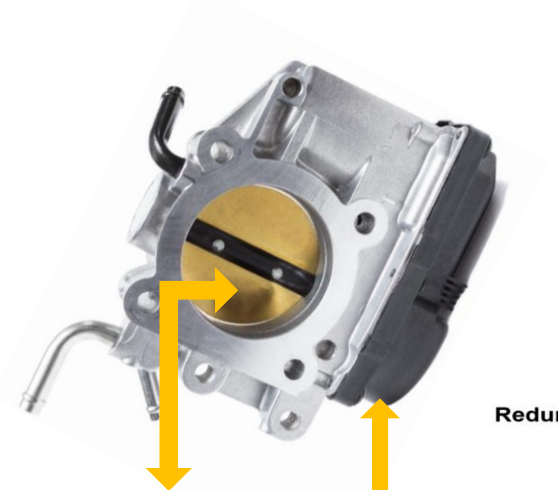


Inductive Position Sensor



Inductive Sensors Replace Hall Effect Devices and Magnets

Rotary Sensor

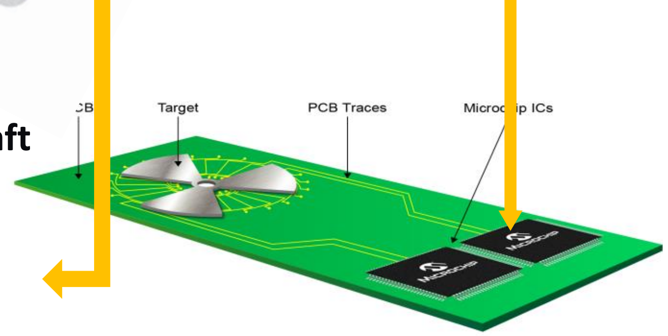


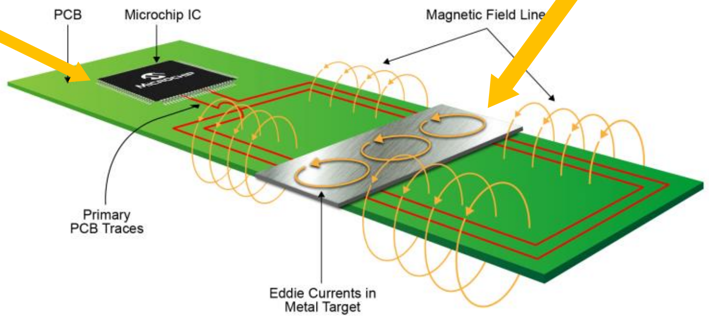
Linear Example

Microchip IC

Metal Target

Redundancy Sensors



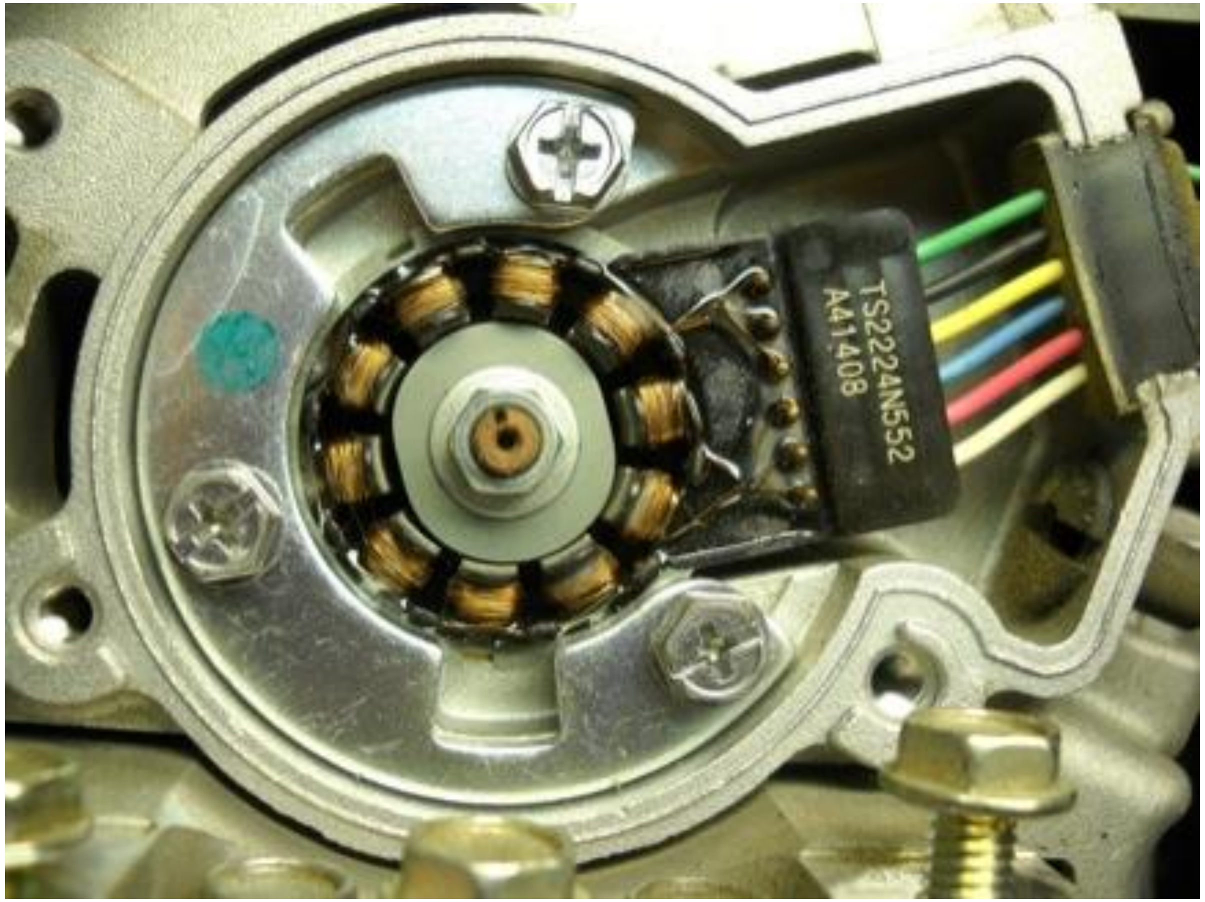


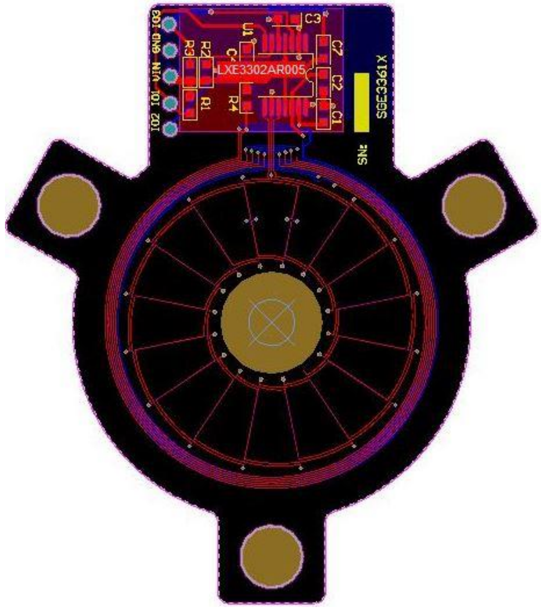
Metal Target
at the end of Shaft

Housing
Hold Sensor PCB

HIGHER ACCURACY,   BETTER NOISE IMMUNITY, LOW COST

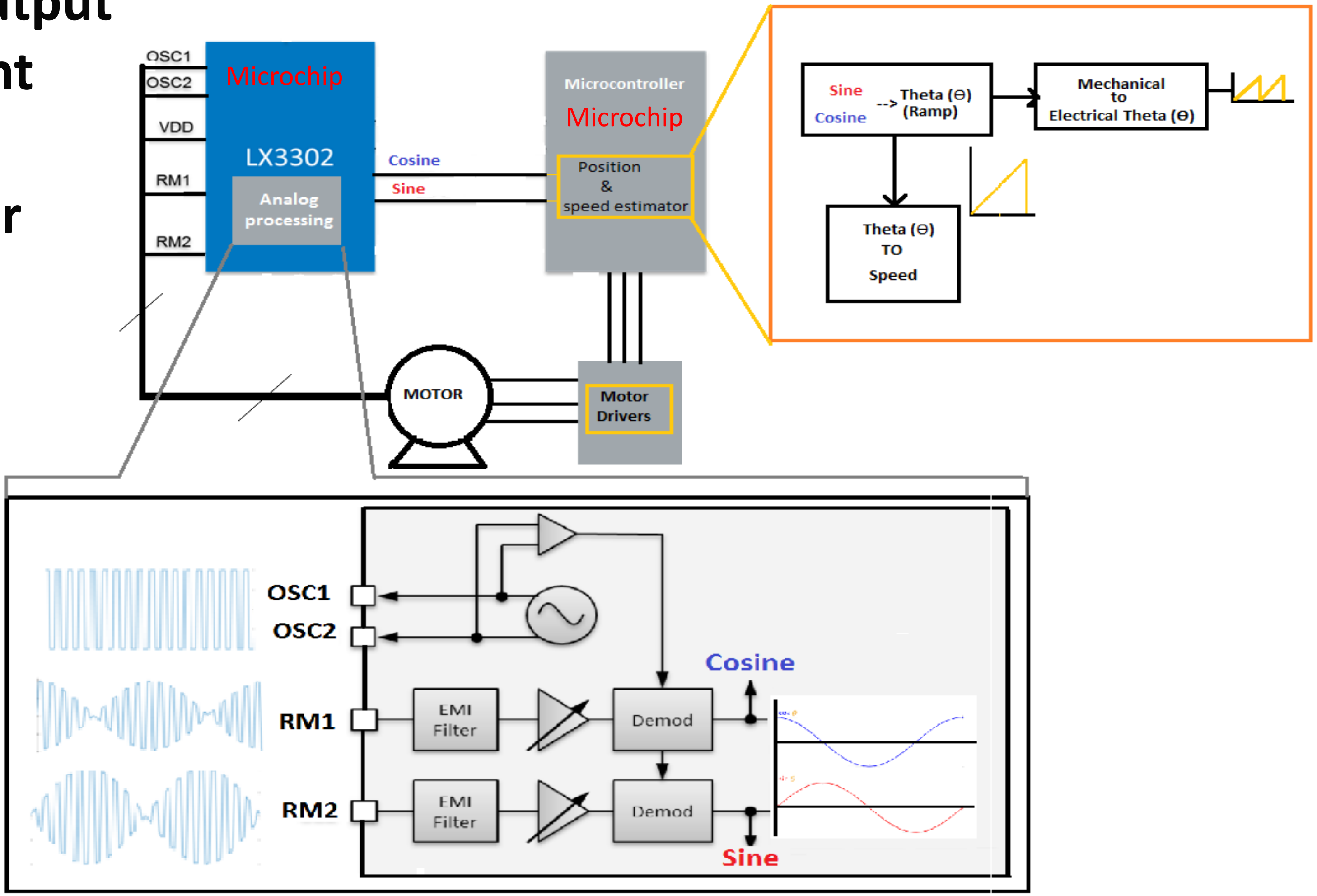
Demodulator enables high resolver replacement



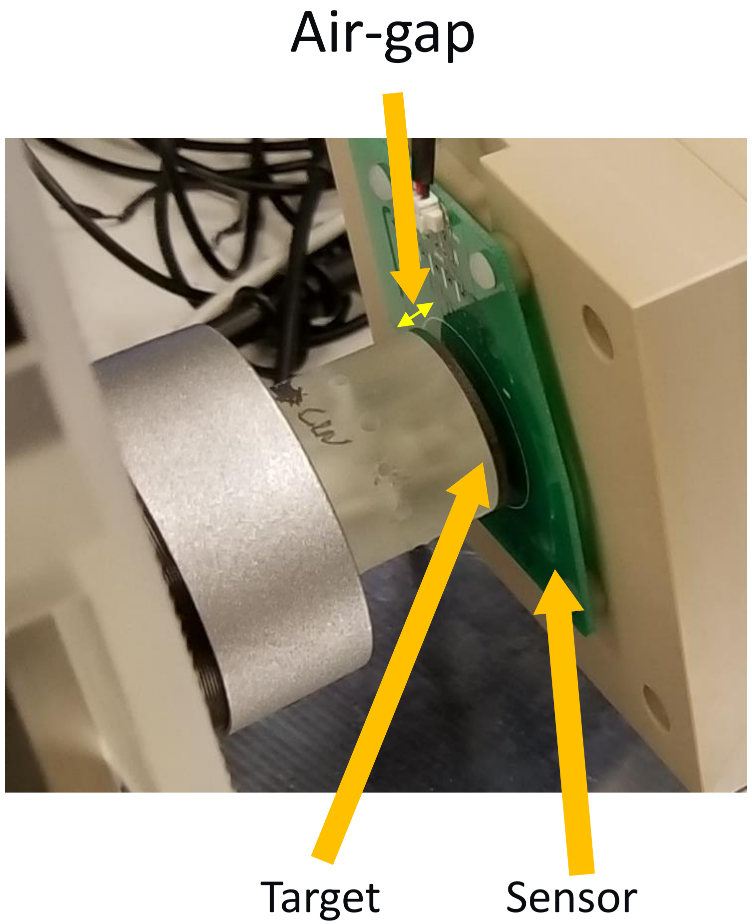


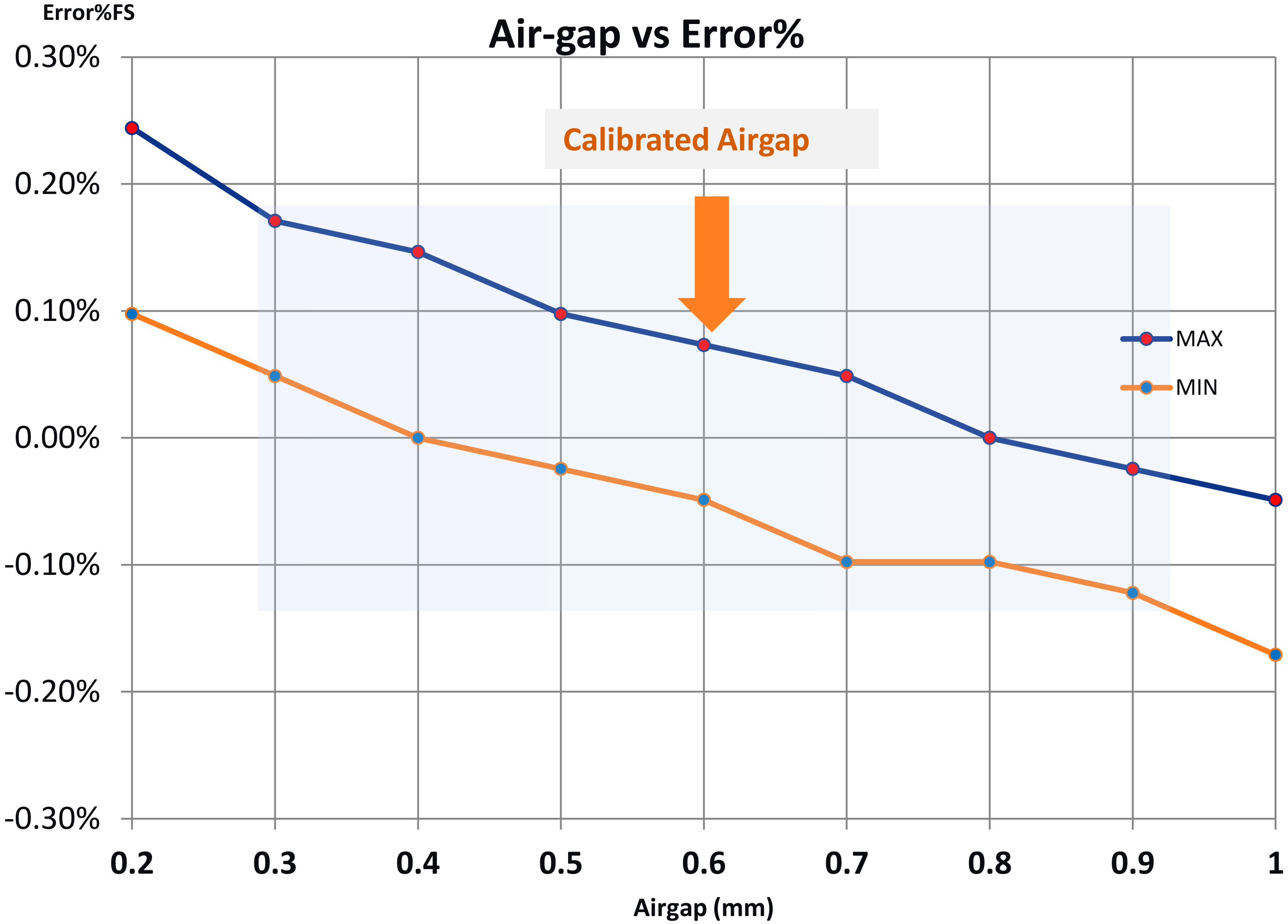
LX3302A + uC for High-Speed Motor Control

- The LX3302A outputs analog output signals (sin and cos) to represent position.
- Optimized for high-speed motor applications (50k rpm).
- 100kHz Bandwidth in LX3302A



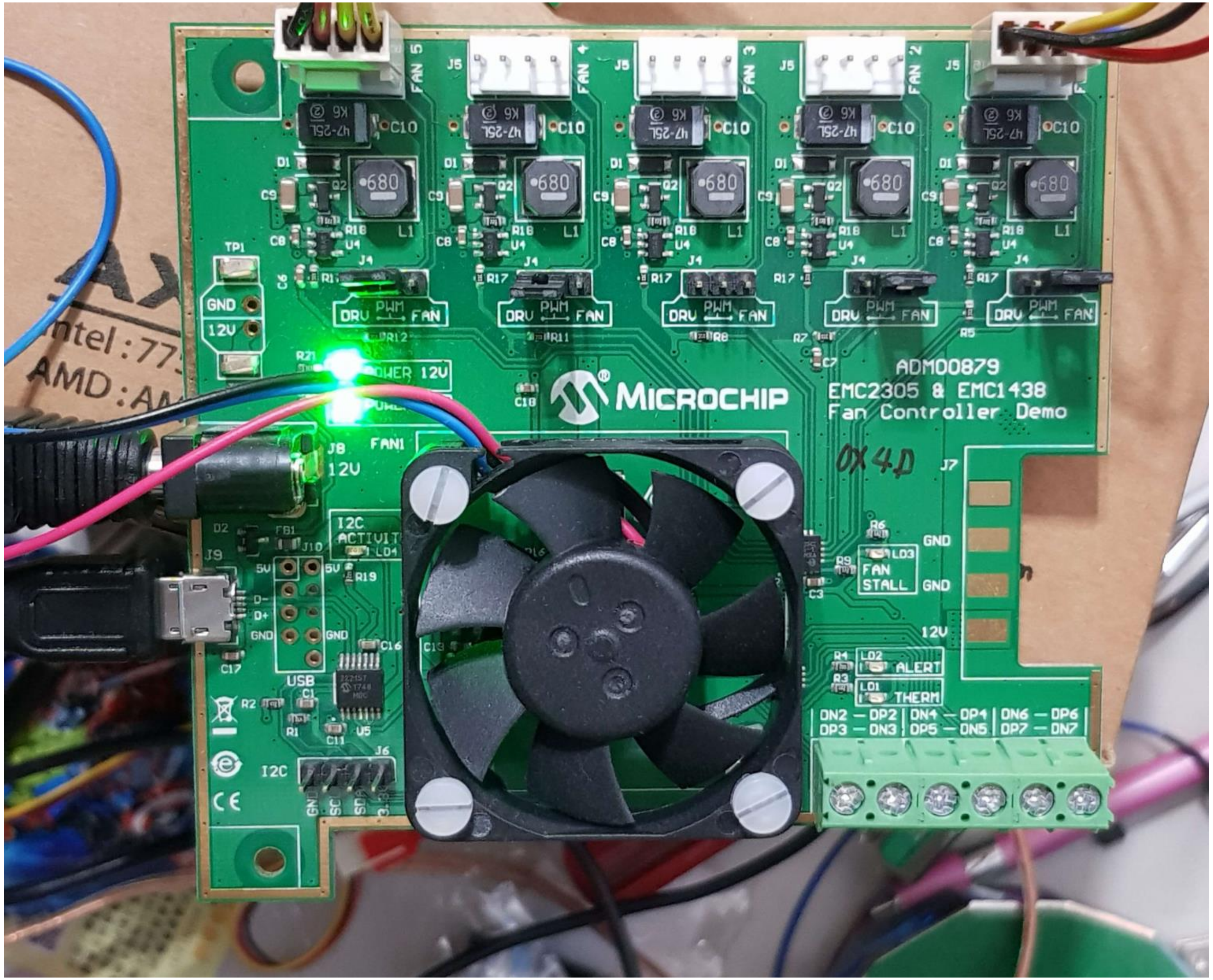
Higher Accuracy



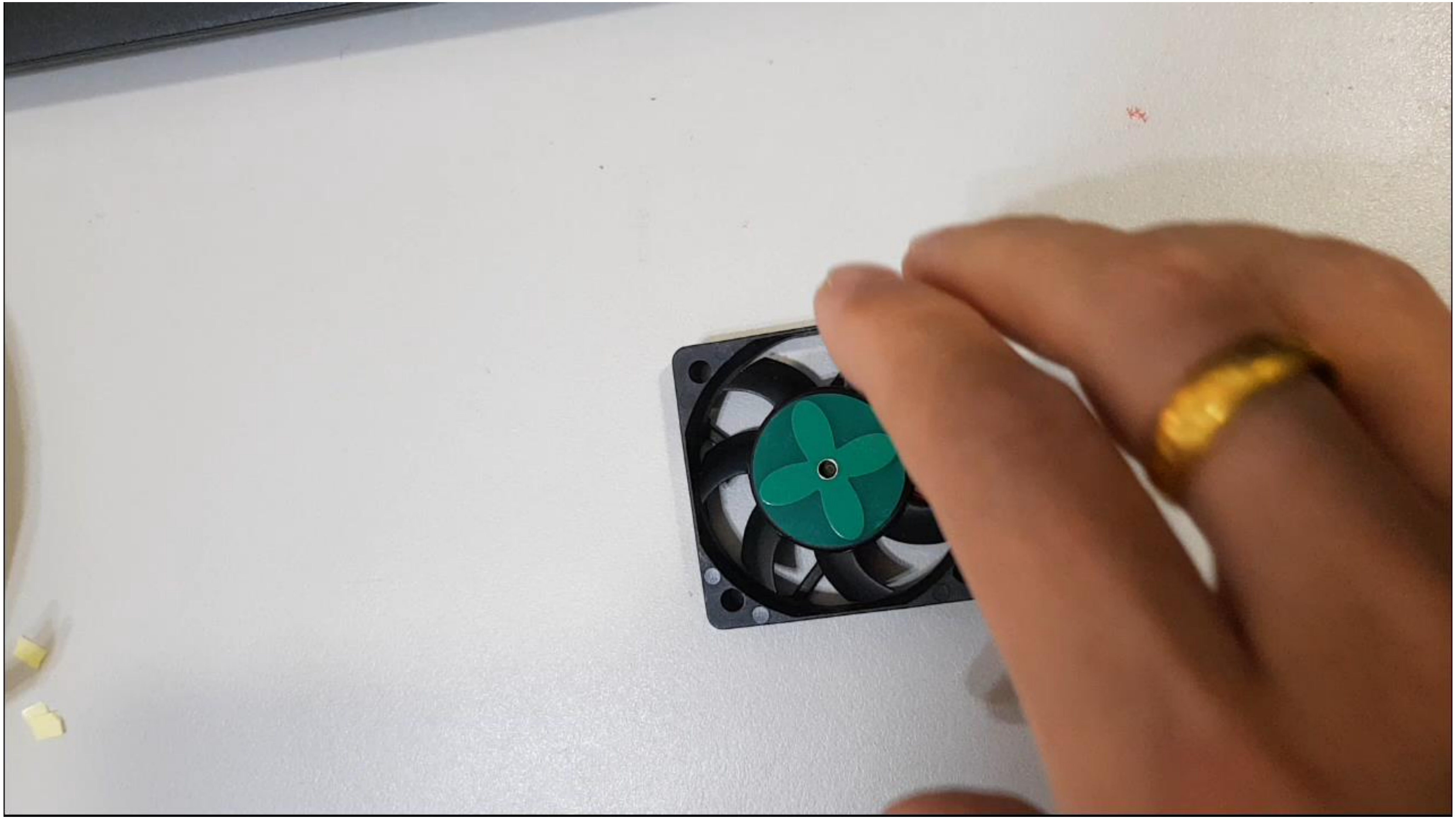


MICROCHIP

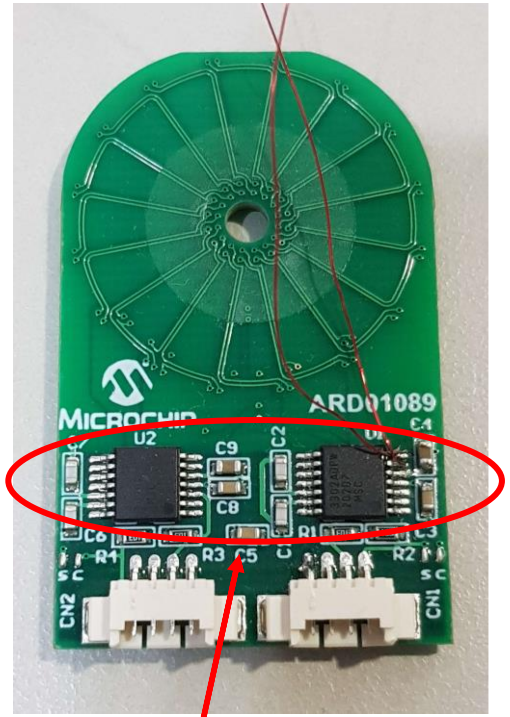
ADM00879 – EVB with EMC2305 & EMC1438



Double Check the Center Point and Balance of the Target

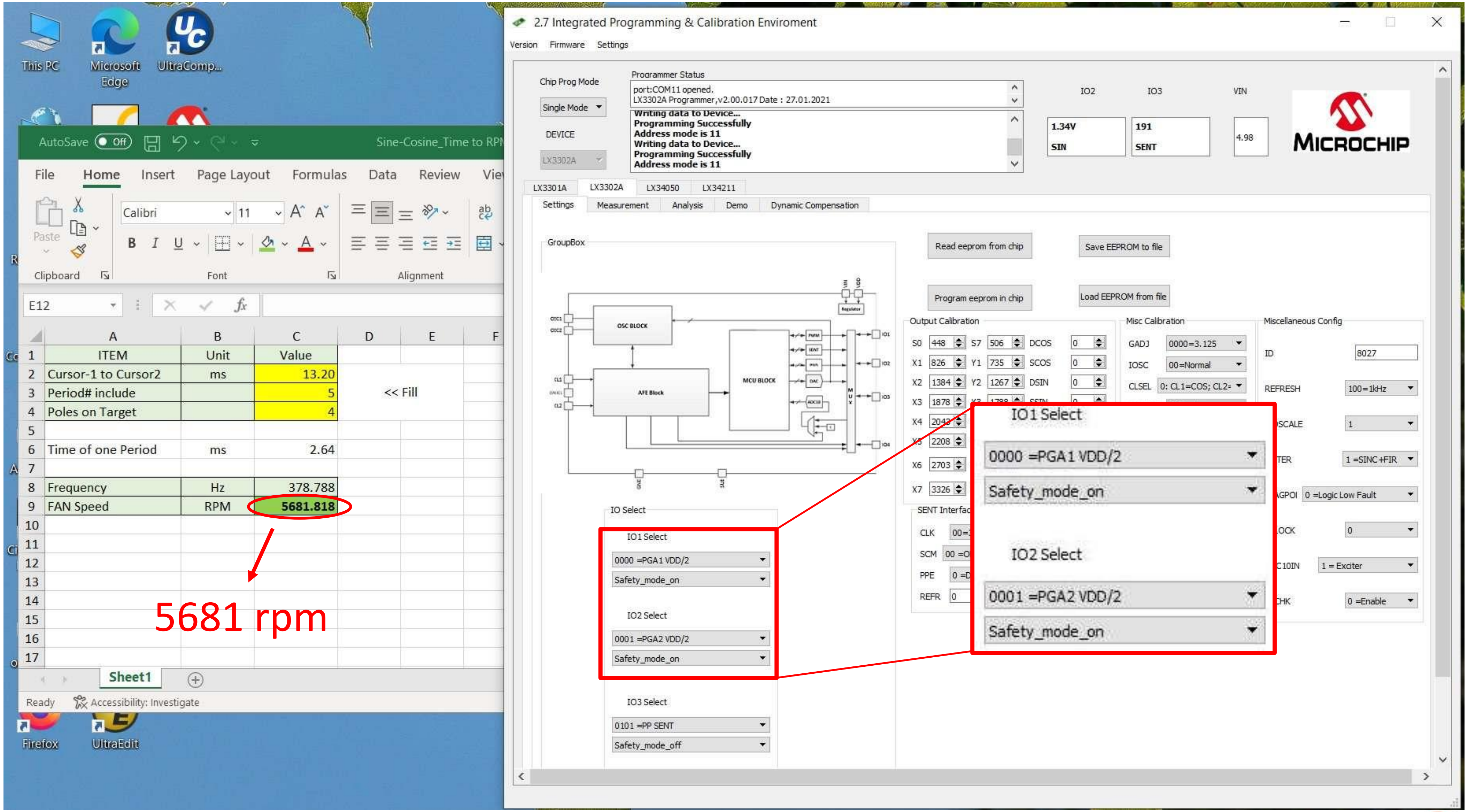


Paste the Inductive Position Sensor close to the Target

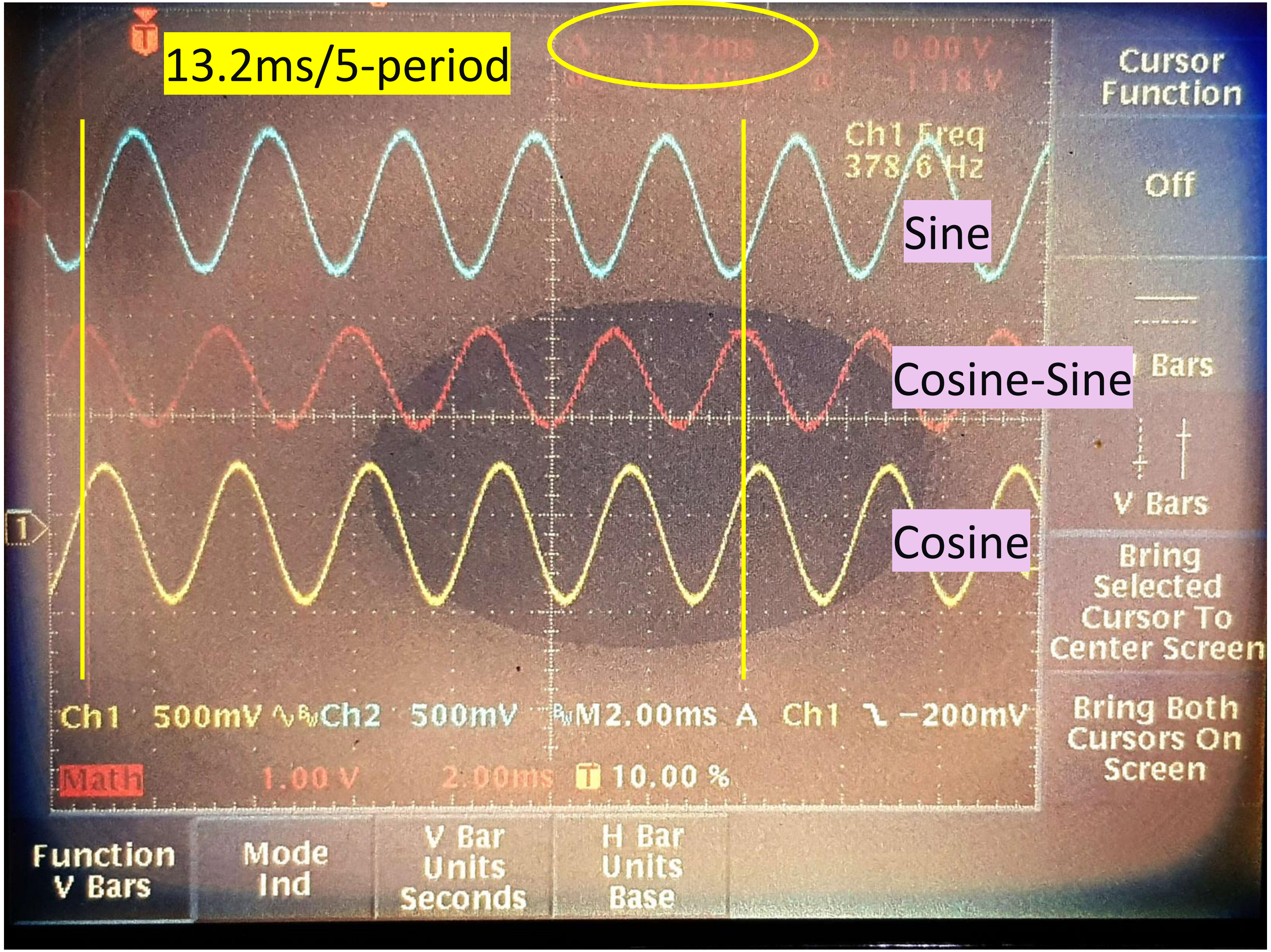


MICROCHIP

Configurate the output of IO1/IO2 to PGA1/PGA2 by IPCE

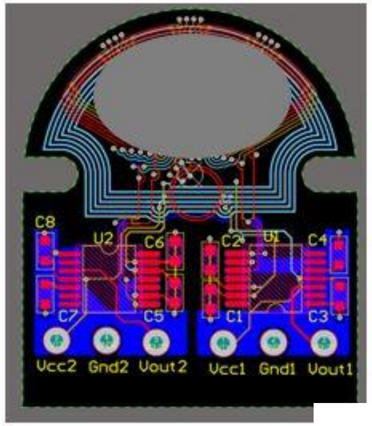


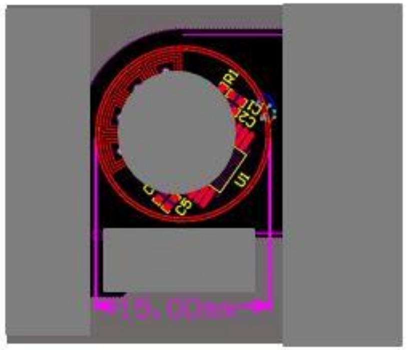
The Waveform from PGA1 (Cosine) & PGA2 (Sine)

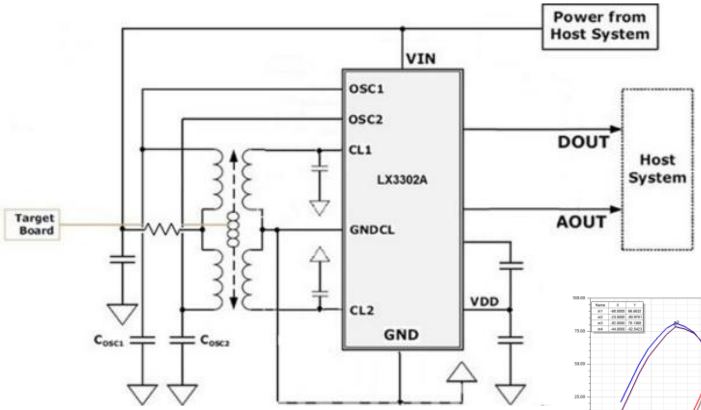


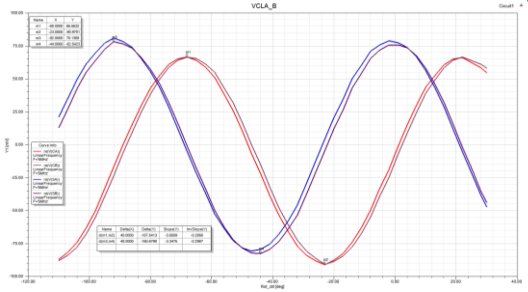
Microchip helps design an Inductive Sensor

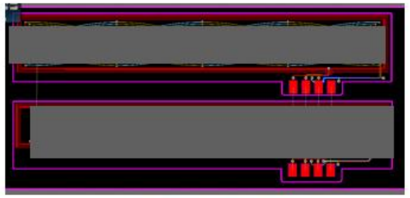
- **Customer requirements from questionnaire**
  - PCB space, Air gap to target, Accuracy, Output interface
- **Microchip Creates PCB designs in Altium**
- **Microchip simulates accuracy**
- **Microchip/Samples Tools to verify results**

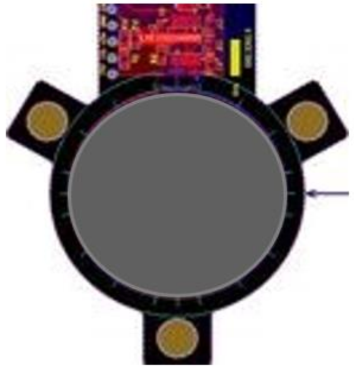


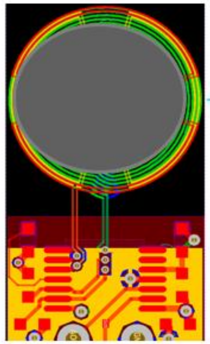












MICROCHIP

Four Steps to a Sensor Design

Value Identified: High Accuracy, Robust, Lower Costs

Identify Sensor Requirement

Microchip Designs PCB Sensor with Sims:

Customer Tests and Validates Sensor

MICROCHIP

Key Specifications Steps

- **Output Interface**
- **Measurement Range**
  - Stroke and Clamp Range Values
- **Nonlinearity Error**
- **Airgap between Sensor and Air Gap**
  - 1-4mm is typical. More requires study.
- **Number of PCB Board layers (2,4)**
- **Metal of the Target**
  - Aluminum , Copper, Non-Magnetic Steel

Inductive Position Sensor Application Information

Customer	
Application	
Customer Project Name	
Sensor IC Part No.	☐ LX3302A ☐ LX3301A ☐ Other: ____________ ☐ Want MCHP to recommend
Requester	
Requester Contact Info	

1. Basic Sensor Information (*fill this out as much as you can*)

Item	Specification	Comments
Type of Sensor (see **Figure 1** for sensor type)	☐Linear ☐ Rotary ☐ Arc	
Output Interface (up to three/two can be used simultaneously for LX3302A/LX3301A. See datasheet to details)	☐ Analog ☐ PWM ☐ NPWM ☐ SENT ☐ PSI5 ☐ SIN/COS	
Measurement Range (mm/deg) (See Figure 2 for definition)		
Airgap Range (mm + +/-mm): (Typical + tolerance)	(____mm) +/- (___ mm)	
Nonlinearity Error (%) (See Figure 3 for error % definition)		
PCB Layers (2/4/6)		
PCB Thickness (mm)		
PCB Dimensions (mm x mm) (Including sensor IC, sensor, connector, mounting holes)		
Target facing PCB layer (IC is soldered to top layer)	☐Top layer ☐ Bottom layer	
Redundancy Design (ASIL-C and ASIL-D applications often require redundant sensors)	☐Yes ☐ No	

Microchip Inductive Sensing IC Portfolio

Choose Grade 0 or Grade 1

Choose the Output Interface

Choose the Application

Features	LX3301A	LX3302A	LX34050	LX34070
Calibration segments	6	8	Any	Any
Sensor Offset Adjust	Yes	Yes	N/A	Yes
Gain Adjust (bits)	Yes	Yes	N/A	Yes
Output interfaces	**Analog, PWM**	**Analog, PWM, SENT, PSI5**	**Sin/Cos**	**Differential Sin/Cos**
Output Resolution (bits)	12	12	Analog	Analog
Redundant IC Support	Yes	Yes	Yes	Yes
Sample Rate (samples/sec)	2KHz	2KHz	Any	Any
Dynamic Airgap Calibration	Yes	Yes	N/A	N/A
MCU	Internal	Internal	External	External
Temperature*	–40 °C to 125 °C	–40 °C to 150 °C	–40 °C to 150 °C	–40 °C to 150 °C
AEC-Q100	**Grade 1**	**Grade 0**	**Grade 0**	**Grade 0**
ISO26262 Support	ASIL B	ASIL B	ASIL B	ASIL C
Calibration Programming Options	VIN	VIN, GPIO	VIN, GPIO	VIN, GPIO
Key Applications	**Actuators, Pedals, Levers**	**Actuators, Pedals, Levers**	**Motor Control**	**Motor Control**

Q & A