TLE4929x Crankshaft Sensor - TLE4959x Transmission Sensor

Fully programmable sensor

TLE4929C/TLE4959x

This user manual is intended to provide system know-how and practical guidance beyond the information found in the datasheet. It shows a variety of features available in the TLE4929C/TLE4959C/TLE4959-5U already implemented for your application. For details on the exhaustive feature set, see the datasheet and the EEPROM programming manual. This document focuses on system integration and a variety of tools for evaluation purposes.

Table 1 User-manual is valid for all types of TLE4929C/TLE4959x

Type	Description
TLE4929C-XAN-M28	locked EEPROM, temperature-compensated for Neodymium back-bias magnet / toothed wheel application, Vdd-capacitor = 220nF, tin-plating on the leads
TLE4929C-XAF-M28	unlocked EEPROM, temperature-compensated for Ferrite pole-wheel / magnetic encoder wheel application (pre-programmed), Vdd-capacitor = 220nF, tin-plating on the leads
TLE4929C-XHA-M18N	unlocked EEPROM, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 100nF, nickel plating on the leads
TLE4929C-XHA-M38N	unlocked EEPROM, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 470nF, nickel plating on the leads
TLE4929C-XVA-M18AA	unlocked EEPROM, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 100nF, tin-plating on the leads
TLE4929C-XVA-M38AA	unlocked EEPROM, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 470nF, tin-plating on the leads
TLE4929C-XVA-M18NA	unlocked EEPROM, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 100nF, nickel-plating on the leads
TLE4929C-XVA-M38NA	unlocked EEPROM, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 470nF, nickel-plating on the leads
TLE4929C-X2A-M38N	preprogrammed crankshaft sensor for 2-wheeler application, temperature-compensated for -825ppm magnetic material, Vdd-capacitor = 470nF, nickel plating on the leads
TLE4959C	locked EEPROM, temperature compensated for -600ppm magnetic material, Vdd-capacitor = 220nF, tin-plating on the leads
TLE4959C-FX	unlocked EEPROM, temperature compensated for -600ppm magnetic material, Vdd-capacitor = 220nF, tin-plating on the leads
TLE4959-5U	locked EEPROM, temperature compensated for -800ppm magnetic material, 4 pin package PG-SSO-4-1, tin-plating on the leads
TLE4959-5U-FX	unlocked EEPROM, temperature compensated for -800ppm magnetic material, 4 pin package PG-SSO-4-1, tin-plating on the leads

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1 Introduction to speed sensing

The TLE4929C/TLE4959x was designed to sense speed and position of a toothed wheel or of a magnetic encoder wheel. Earlier sensor used to be limited to either crankshaft speed sensing (TLE4929C) or transmission shaft sensing (TLE4959C). Due to the implementation of EEPROM the TLE4929C allows several further application to be accessed.

A typical speed-sensor configuration is illustrated in ***Figure 1***. It contains a toothed wheel on a rotating shaft, the speed-sensor itself where connecting cables are attached and the backbias-magnet which generates a static field on the position of the sensing elements (Hall probes). The movement of the toothed wheel modulates the flux-lines of the back bias field. This modulation is measured as speed-signal and direction-signal. Out of these signals, the TLE4929C generates pulse-width modulated output-pulses on the open drain output to indicate a certain direction. The Falling edge of the output-signal indicates either the middle of the tooth or the middle of the notch when configured with hidden hysteresis. The length of the output-pulse is either rotational direction clock-wise (CW) or counter-clock-wise (CCW).

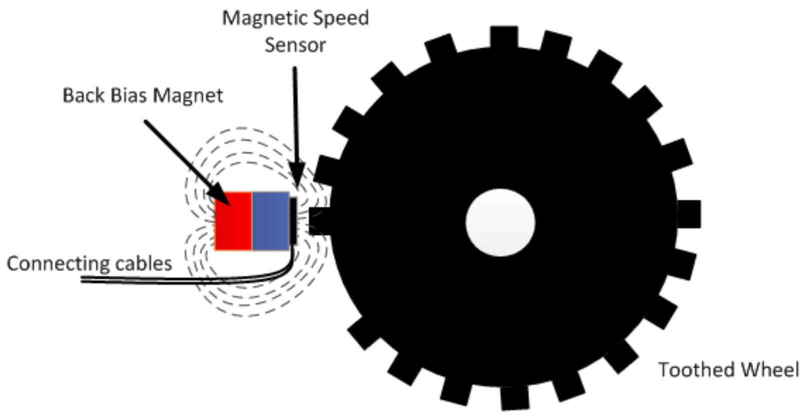

Figure 1 Typical speed sensor configuration

1.1 Introduction to magnet circuit design

The magnetic field of a permanent magnet exits from the north pole and enters the south pole. If a north pole is attached to the backside of the TLE4929C, the field at the sensor position is positive, as shown in ***Figure 2***. For the purpose of low jitter, only one polarity of back-bias-field is allowed: Either the north-pole of the back-bias magnet is attached to the back-side or the south-pole is attached to the front-side of TLE4929C.

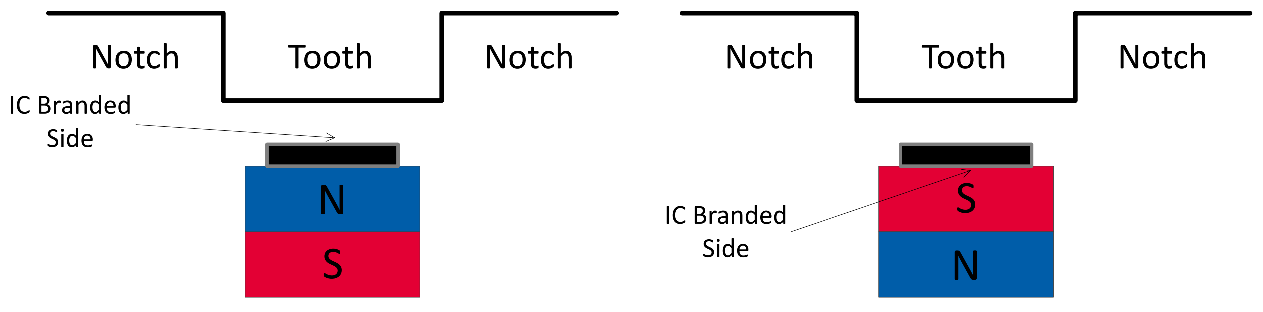

Figure 2 Definition of the Positive Magnetic Field Direction

For good position accuracy in the application, the center of the sensing elements has to be aligned with the center of the back-bias magnet (normal magnetized).

2 Application

In this section, application relevant information based on specific parameters is given. Key parameters for speed sensing with focus on crankshaft applications are explained.

2.1 Magnetic encoder wheel

In seldom cases the toothed wheel is replaced by a magnetic encoder wheel. The used space can be reduced in the application for the disadvantage of increased cost of the wheel. The weight and mass of the module for sensing the wheel can be reduced as well as the back-bias magnet is not necessary any more.

In the application with a magnetic encoder wheel the flux-lines are send out from the wheel itself as illustrated in ***Figure 3***. The magnetic sensing elements are directly sensing the flux-lines of the wheel. In using strong wheels very large air gaps up to 15mm can be achieved due to the big size of the poles on the surface of the wheel.

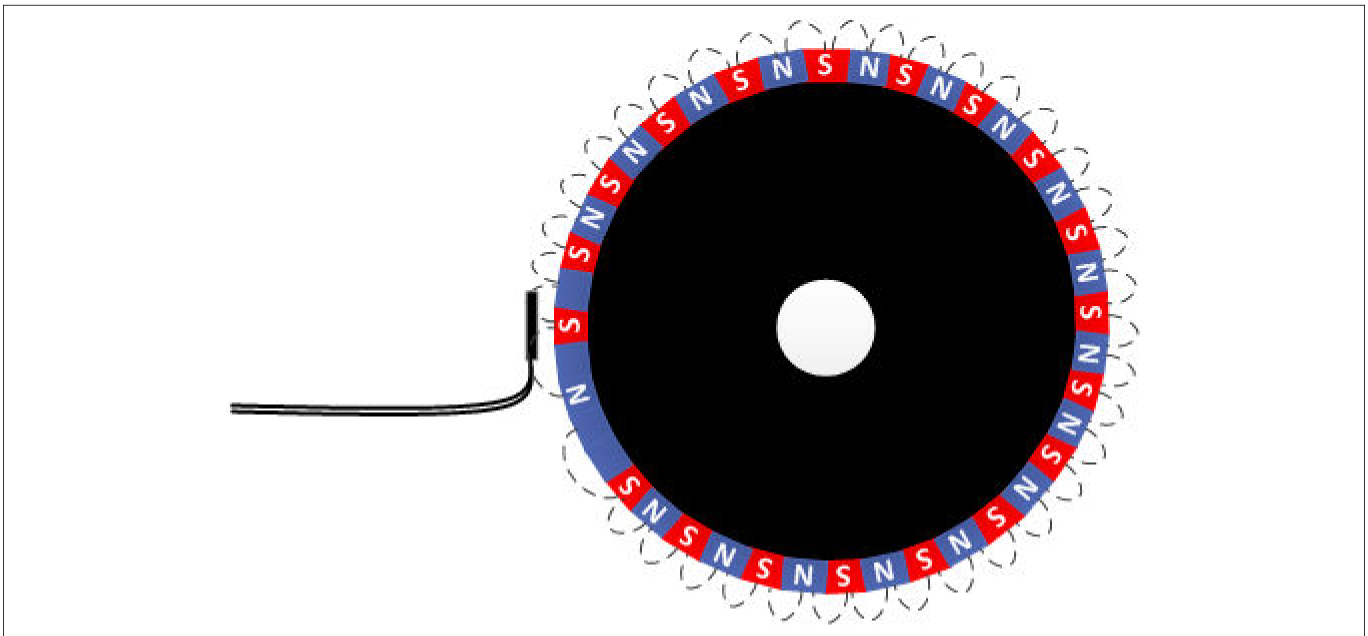

Figure 3 Application setup for magnetic encoder wheel

2.2 Air gap

As indicated in ***Figure 4*** the air gap is the distance from the surface of the wheel to the surface of the module (OEM-view) or from the surface of the wheel to the surface of the sensor (Tier2-view). Typical material thickness between the surface of the sensor and the surface of the module is 0.5mm to 1.0mm.

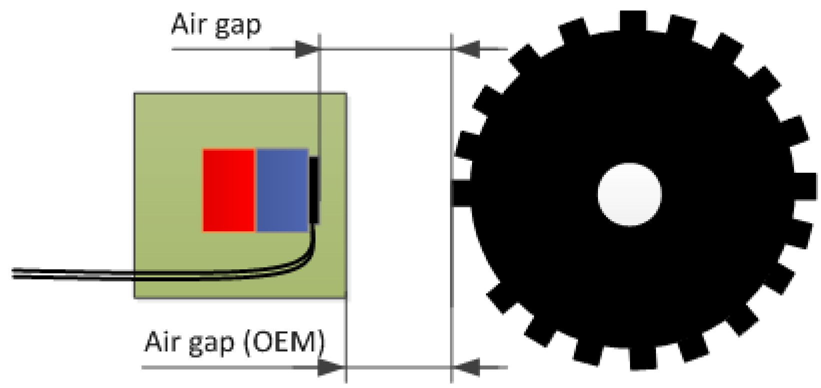

Figure 4 **Definition of air gap in the application "toothed wheel"**

Due to mounting tolerance of typical +/-1mm of worldwide OEMs an active sensor has to operate at an air gap starting at 0.7mm going up to 3.2mm. This is a standard-value for modern combustion engines in 4-wheel vehicles.

In India, for 2-wheelers using a VR-sensor, the OEMs went for an air gap of 0.7mm with a tolerance of +/-0.1mm. So they have sufficient signal down to 150rpm when ECU starts firing the pistons.

2.3 Frequency-range

The common maximum frequency in crankshaft-applications is 8kHz for the magnetic signal frequency. This number can directly be taken from 8000rpm as the toothed wheel (trigger wheel) has 60 teeth in a period-width of 6°. Typically 3° for tooth and 3° for notch. To be accurate the typical crankshaft-wheel has a geometry which is called 60-2 as two consecutive teeth are omitted for this application.

As some OEMs are requesting a maximum frequency of 10kHz the TLE4929C has two specifications:

1. 0Hz .. 8kHz: optimized for good repeatability, as noise in the signal path is reduced by a low-pass-filter.
2. 0Hz .. 10kHz: optimized for maximum frequency knowing there is already reduced air gap-performance and increased jitter in the range from 8kHz to 10kHz.

The theoretical frequency-limit of forward-pulses with a length of 45µsec is around 20kHz taking into account the falling and rising edge of the 45µsec-pulse as well. In the reverse direction with a pulse-length of 90µsec the theoretical limit is slightly above 10kHz. According to different pulse-lengths this theoretical frequency-limit will change as there is only a limited time until the following pulse has to appear at the output. Using an oscilloscope this upper limit can be seen very well.

The lower-limit of frequency-range is 0Hz which is needed for the stop-start-application in crankshaft. Please see ***Chapter 2.9***.

2.4 Phase accuracy

Phase accuracy is based on the parameter "Hard Edge Offset" (HEO). HEO is the difference from the edge of the toothed wheel to the switching event as described in ***Figure 5***

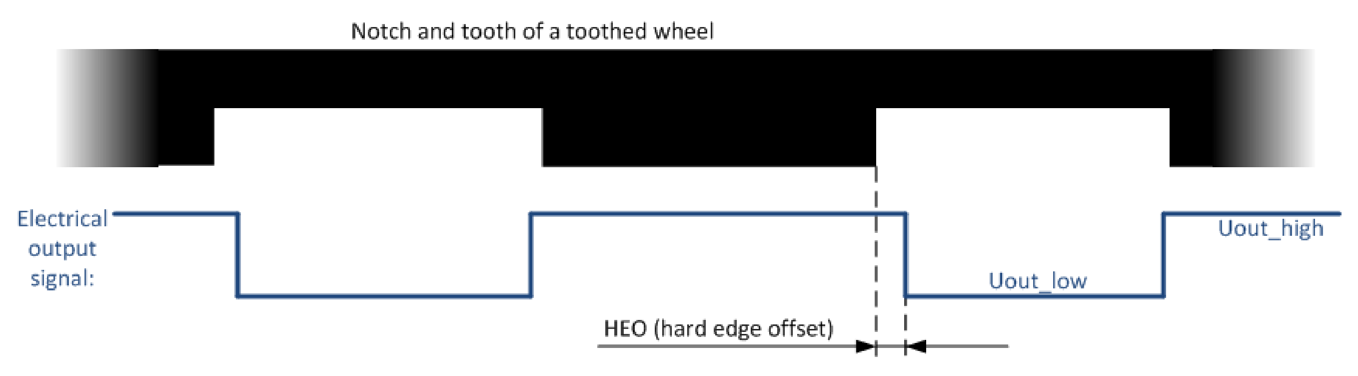

Figure 5 **Definition of Hard Edge Offset (HEO)**

The programming of the ECU (Engine control Unit) is compensating the HEO based on application-characterization-measurements which results in a certain angle-value. As the programming of the ECU is based on the characterization of a relevant number of sensors there will be a residual angular-error left depending on variation in module-position (tilting, twisting or shifting in respect to the toothed wheel) or magnet-position inside the module or other influences like tolerances of the sensor or the back bias magnet. The possible failure due to these influences is called phase accuracy.

TLE4929C has a typical phase accuracy of 0.1°crank. Larger values correspond to factors mentioned above or even a badly manufactured wheel. A tooth-to-tooth-runout will not allow the sensor to do perfect calibration.

For the high-end engines worldwide an accuracy of maximum 0.3°crank on the complete system is needed. For this reason the smallest seen diameter is about 95mm and the number of teeth is 60-2 (60 teeth where 2 consecutive teeth are missing). With a differential Hall-sensing principle the middle of the tooth and the middle of the notch is sensed. There is no dependency on the air gap since the magnetically middle of the tooth is equal to the mechanical middle of the tooth. This is opposite to mono-cell Hall sensors which sense the edge of the tooth: The magnet edge of the tooth is changing with air gap and therefore gives an inherent phase error over air gap.

2.5 Jitter / Repeatability

Phase accuracy should not be mixed up with jitter! Phase jitter is the deviation of an output-signal corresponding with a certain tooth from one round to the other round. This small deviations mainly results from mechanic vibration or magnetic / electrical noise in the system.

The output jitter of magnetic speed sensors based on Hall technology is mainly dominated by the electrical noise of the Hall sensor element. 1/f noise can be reduced using chopping and spinning techniques but white noise cannot be avoided.

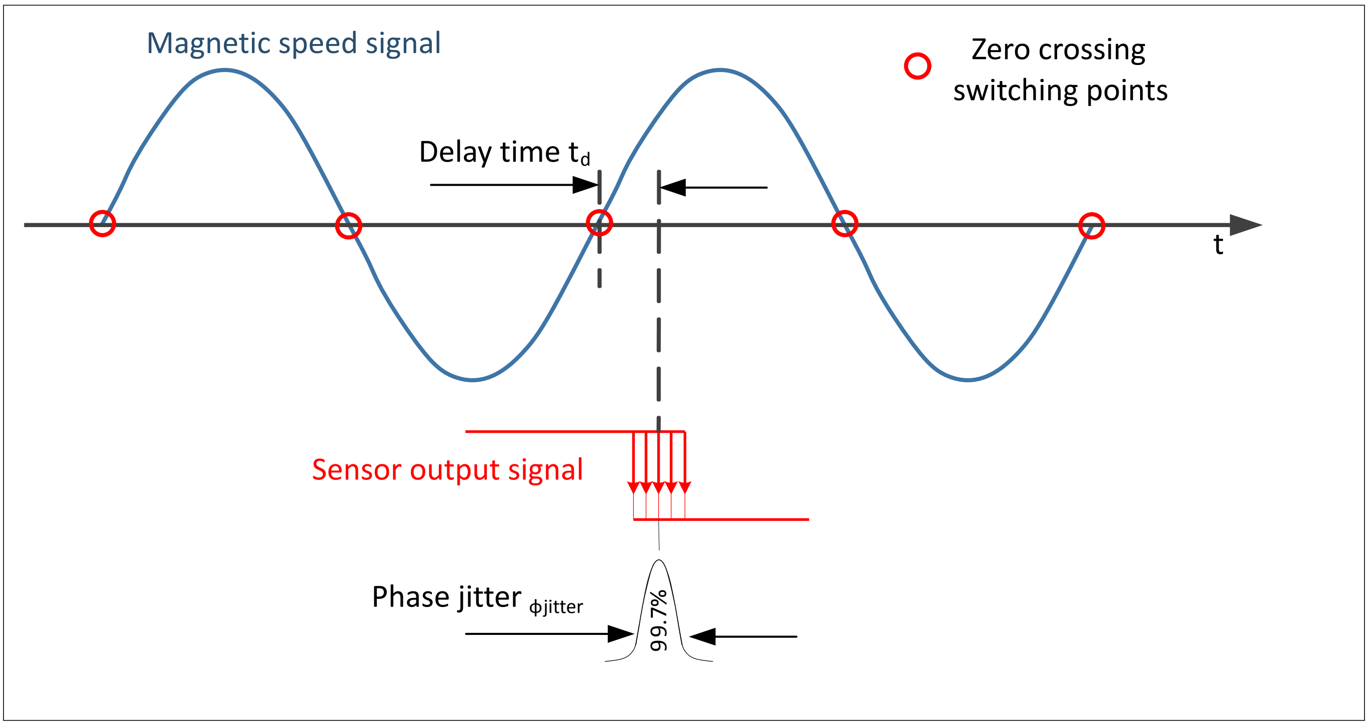

Figure 6 **Definition of Jitter and Delay Time**

TLE4929C has excellent jitter-behavior taking into account power-consumption and is on the edge of achievable performance possible with Hall-technology.

2.6 Delay-time

One of the most important parameters in phase accuracy is the delay time. It is the time the sensor needs to capture the magnetic signal until it is transmitted to the electrical output.

This delay time is the “dynamic” part of the phase accuracy and can be compensated by the ECU: The procedure is to calculate the rotational frequency of the shaft and use this frequency to calculate the delay time into an additional angle of the shaft. The higher the frequency of the shaft the higher the rotational angle that passed during delay-time. ECU has to add this value to the calculated position in order to get the actual position of the shaft in the moment of the calculation.

State of the art speed sensors have a small value between maximum and minimum delay time.

The reason of this importance is called "speed effect" and means the delay calculated add accounted for by the ECU is the typical value of the delay-time. At low rpm the discrepancy is small but it increases linearly with rpm.

2.7 Rotational vibration of the shaft (Crankshaft applicaiton)

Rotational vibration is a traditional topic in transmission applications when shifting gears. In transmission applications there is the possibility of air-gap vibration and rotational vibration of the shaft.

Since the stop-start-application was introduced to combustion-engines the rotational vibration was introduced in crankshaft as well. Hybridization increased the duration of vibration, as the combustion engine can be stopped while the car is driving on electric drive. During the stop-phase of the combustion engine the crankshaft-sensor (TLE4929C) typically stays powered and the crankshaft itself is free to vibrate as the car is driving along rough streets.

According to some OEM-profiles the rotational vibration of the crankshaft is in the range of 0.1° up to 18°. Depending on the stop-position everything inbetween can be observed by the TLE4929C:

- Stopping somewhere with almost no vibration: TLE4929C will see no sufficient signal to do any new calibration.
- Stopping in the middle between two switching points with little vibration: TLE4929C will see no sufficient signal to do any new calibration.
- Stopping at a switching point with little vibration: TLE4929C will see sufficient signal to do new calibration on a smaller amplitude. Alternating pulses in forward- and backward-direction will be submitted to ECU. This results in no wrong / no additional pulses but will have slight deviation in phase accuracy.
- Stopping somewhere with vibration to cause calibration on the new position: TLE4929C will adapt its offset and calibrate the new switching-point and the new amplitude. No wrong / no additional / no missing pulses. In case of a restart of the combustion engine the sensor will have bad phase accuracy for a limited number of teeth. (Please see "Case 2" in following figure.)
- Stopping at the tooth or notch or the signature region with vibration to cause calibration on the new position: TLE4929C will adapt its offset and calibrate the new switching-point and the new amplitude. No wrong / no additional / no missing pulses. In case of a restart of the combustion engine the sensor will have bad phase accuracy for a limited number of teeth. This wrong calibration might even result in missing teeth for a limited number of teeth. In next chapter there is a describtion of several watchdog mechanism that can prevent or reduce the number of missing pulses. (Please see "Case 3" in following figure.)

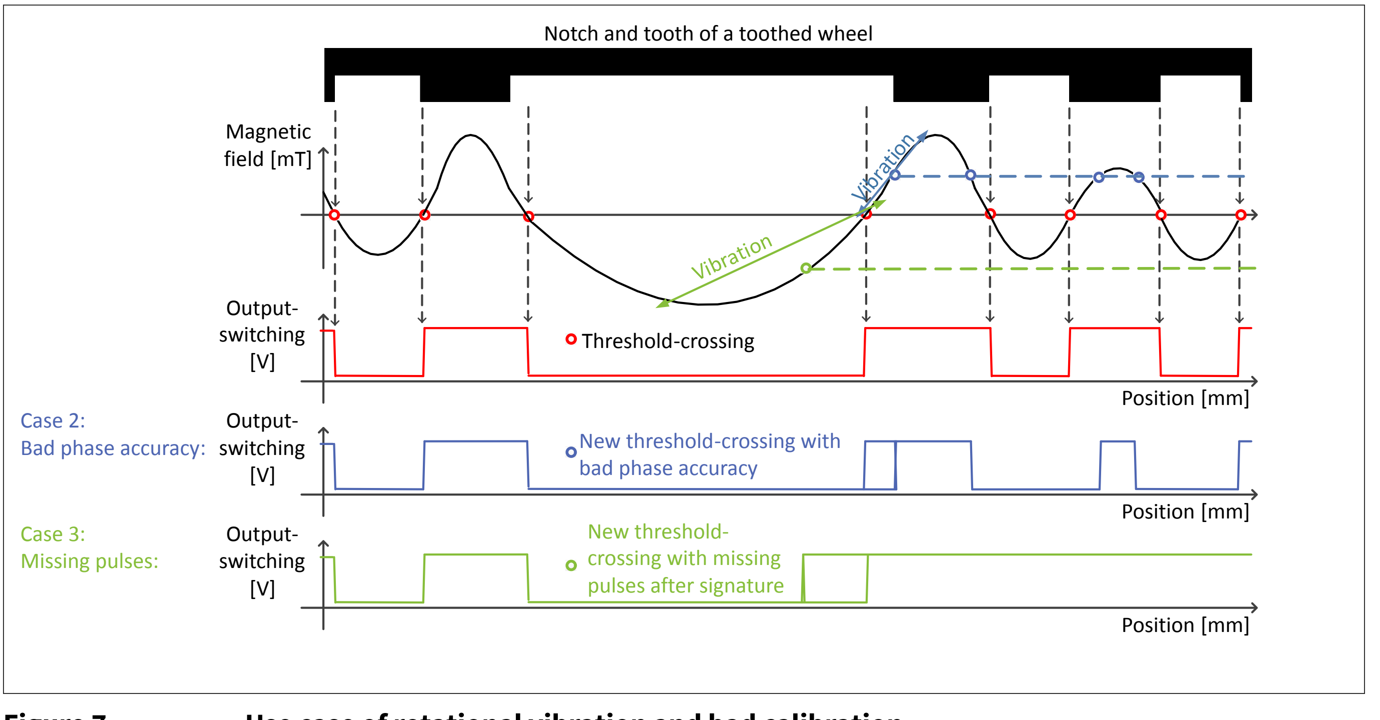

Figure 7 **Use case of rotational vibration and bad calibration**

The red line in ***Figure 7*** indicates normal behavior of TLE4929C. Stopping at the first blue point and applying vibration will cause a new offset after a defined number of detected new minimum and maximum-values. As a result the switching threshold is updated and in normal rotation there will be bad phase accuracy for a defined number of output-edges.

2.8 Watchdog to handle non standard application situation

Magnetic speed-sensors faced various problems in the last decades. Therefore different mechanisms were invented to face application-specific problems. Some of these mechanisms (watchdogs) prevent the lose of output-pulses, like the Stop-Start-Watchdog or the Time-Watchdog. An other mechanisms recover a “stuck” sensor from a dead end in the application, like the System-Watchdog. The following chapters explain the application influences and the functionality of these mechanisms.

2.8.1 System-Watchdog

In the use case of an application in a rough mechanical environment, like magnetic particles on top of the sensor-module, or sudden mechanical movements of the module in respect to the trigger-wheel (air-gap-jump / shift of the module / twist of the module / tilt of the module) the switching-threshold might be suddenly wrong due to the new magnetic condition.

The system-watchdog monitors regularly the detection of magnetic minimum and magnetic maximum. In normal operation between each extreme a switching edge (protocol without direction detection) or between each pair of extremes a certain pulse-length (protocol with direction detection) appears at the output. As soon there is no regular output-switching at the output the system-watchdog searches for the new switching threshold and applies it to the TLE4929C.

Typically the transmission application takes advantage of this mechanism and brings back the TE4929C to normal operation within a certain number of pulses.

2.8.2 Stop-Start-Watchdog (Crankshaft application)

The use case for this mechanism is the hybrid engine that stops and restarts the crankshaft of the combustion engine. When the combustion engine is stopped the speed sensor has to stay in calibrated mode and is needed to follow the movement of the crankshaft in case of rotation or vibration. When the ECU restarts the combustion engine the crankshaft is accelerated and all forward and backward-pulses have to be issued accordingly. The difficulty in this application is to not loose pulses during temperature drift.

Temperature drift influences the switching threshold in various ways:

- The magnetic material has a certain temperature coefficient which reduces/increases its field-strength. As a position-tolerance between the middle of sensing elements of TLE4929C and magnetically middle of the back-biasing magnet, a switching-offset-drift will occur and influence the accuracy of the output-pulse. In worst case the magnetic offset has a large drift which exceeds actual calibration.
- The mechanical setup of the trigger-wheel, air gap, sensing module and housing of the engine cause a mechanical displacement of module and trigger-wheel. A similar effect on the switching-threshold can occur.

To avoid a drifting switching-threshold out of the switching-range the Stop-Start-Watchdog is implemented. It follows the thermal drift and keeps the switching-threshold in the middle between minimum peak and maximum peak of the speed-signal. No pulses will be lost. No wrong direction will be issued.

2.8.3 Time-Watchdog

For the case a hybrid car is powered up electrically and driving first on electric drive the crankshaft can see vibration and wrong calibration. A wrong calibration can lead to missing pulses during start-up of the combustion engine.

The Time-Watchdog resets the switching-threshold after a certain time. This helps the application to reset part of the calibration as soon the combustion engine is in standstill. No deadlock will occur. Maximum one missing pulse or one additional pulse can occur.

2.9 Stop-Start capability (Crankshaft application)

During stopping the combustion engine and waiting for a certain time, and restart of the engine, the electronic control unit (ECU) has to know precisely the position of the crankshaft and therefore the camshaft. The TLE4929C family has multiple advanced features to support this feature, as best crankshaft sensor available.

In the following scheme the different phases of a typical stop-start cycle are illustrated.

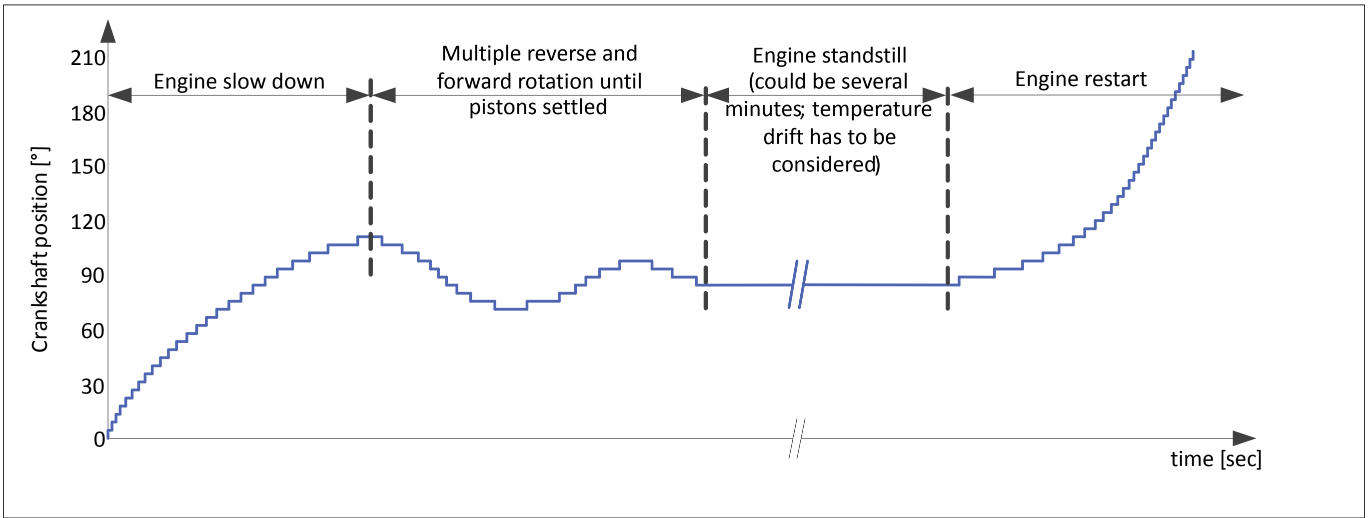

Figure 8 Scheme of the crankshaft position before, during and after stop-start

Shutting down the engine starts with not firing the piston any more. In the first phase the crankshaft decreases its rotational speed due to friction of the system. Typically a toothed wheel indicating the crankshaft position has 60 - 2 teeth positioned every 6° around the wheel. The missing 2 teeth indicate a reference zone where the ECU synchronizes its absolute angle. So in steps of 6° the absolute position of the crankshaft is reported to the ECU. The delay between the different position changes is getting larger and larger.

When reaching the point when the mass of the system can not compress the actual piston, with the gasoline inside, the crankshaft turns in reverse direction. Due to mass of system and pressure in the cylinders this happens several times back and forth. The sensor as well as the ECU have to recognize and count speed pulses in direction forward as well as in direction backward. This feature can be covered by most of the bidirectional crankshaft sensors without loosing any pulses while indicating the correct direction.

During engine standstill there is the most critical phase of the stop-start feature. The temperature drift influences the internal signals in the sensor.

For the final phase it is important for the sensor to be in calibrated mode, to be as accurate as possible during startup.

2.9.1 Dedicated design in the TLE4929C family (Crankshaft application)

Several features are implemented in the TLE4929C family to have outstanding performance in stop-start functionality.

a.) There is no random offset drift, due to the special chopping technique of the Hall-elements

b.) There is compensated residual electrical offset-drift trimmed for each single sample in factory based on two point temperature measurement

c.) There is compensation of loss of signal amplitude due to the external magnet circuit. Our customer has the possibility to choose the magnetic material that has to be compensated.

d.) In case a stand-still is observed due to no signal-change for a certain time a special algorithm takes over responsibility to have full accuracy latest at the second output-pulse after restart of the engine.

2.9.2 Temperature compensation of magnetic material

Magnetic encoder wheels as well as the back bias magnet in a toothed wheel application are made of a certain magnetic material. The most cost-effective is ferrite (Fe). The material that allows the strongest fields is Neodymium (NdFeB). The best in terms of temperature-degradation is Samarium-Cobalt (SmCo). All of these commonly used materials have a negative temperature-coefficient (TC) in the range of -300ppm up to -1900ppm. So every application suffers a smaller maximum air-gap at high temperature.

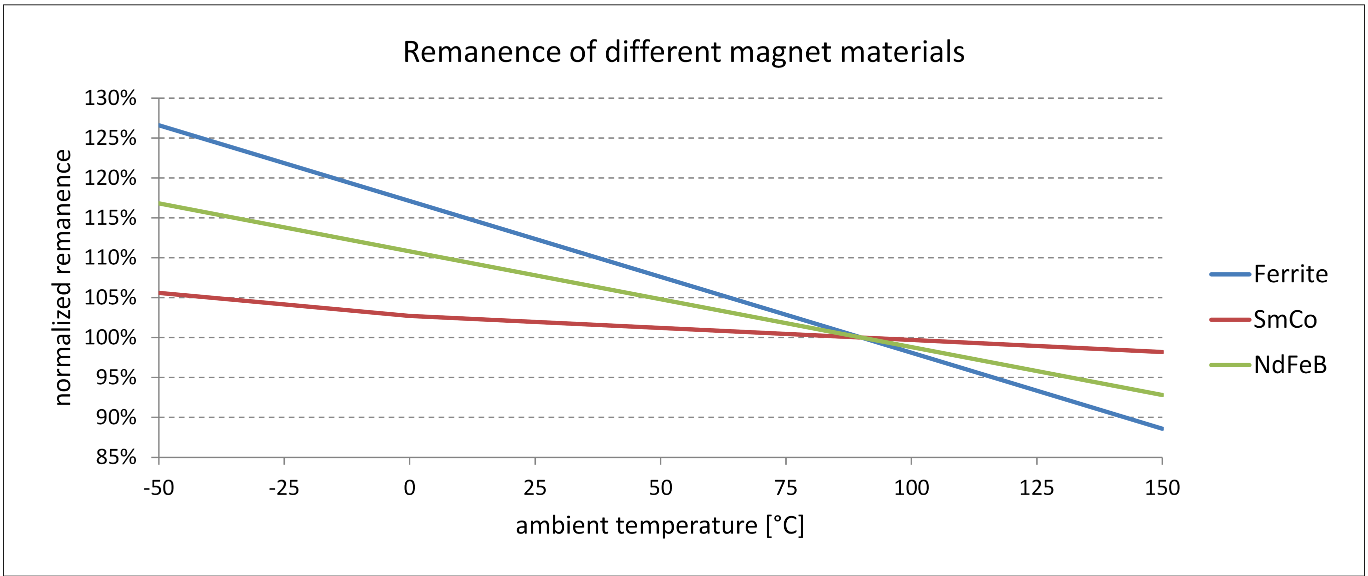

Figure 9 **Remanence of magnetic materials versus temperature**

As a natural consequence of changing back bias field during the stop-phase, the sensor has to recognize a different signal amplitude. When the engine is stopped at a temperature of 90°Celsius and 5 minutes later restarted again at 130°C (heating after driving up a hill) the loss of signal amplitude is about 10% in a ferrite magnetic circuit. TLE4929C family does a constant temperature-measurement of the sensor itself and compensates the difference in the amplitude already in the analog signal path. Therefore the main-comparator as well as the digital core always see the same amplitude of the signal, independent from temperature of the magnet circuit.

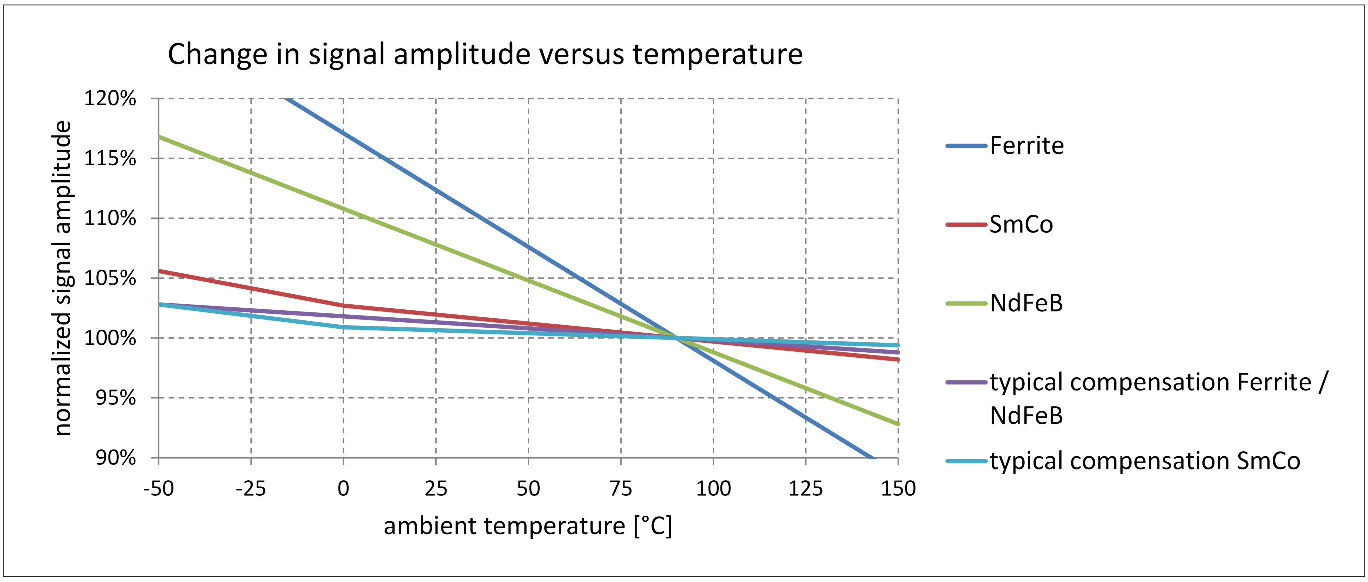

Figure 10 Signal amplitude after analogue signal path with / without temperature compensation

As can seen in ***Figure 10*** the amplitude of the speed-signal decreases with temperature. Ferrite-material has the temperature-coefficient of -1900ppm. TLE4929C family compensates the degradation of signal amplitude and keeps the whole system fully calibrated.

2.9.3 Measurement on system-test bench (Crankshaft application)

Verification of the stop-start feature is done with a specialized system test bench in four phases:

CALIBRATION:

First phase is powering up and calibrating the TLE4929C. The sensor is placed at the target air gap and the target temperature while the crank wheel is doing at least three rotations. This ensures the sensor is always in the same condition before entering the real stop-start measurement.

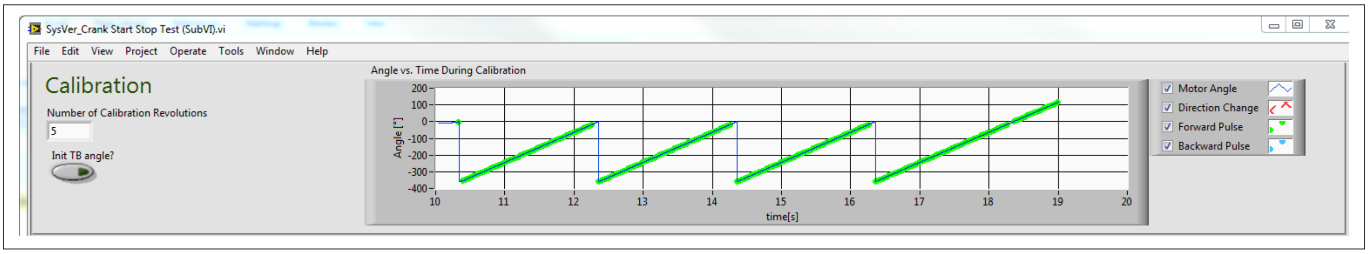

Figure 11 Graphical user interface on system test bench “stop-start”: phase CALIBRATION

ENGINE-STOP:

The second phase stops the wheel at a well defined position of the crankshaft target wheel. Therefore a typical use case of the application is simulated. The wheel rotates a few teeth more as the chosen final stop position. Like in the engine where the pressure between the pistons is balanced the test bench rotates the wheel forward and backward for exactly defined angles.

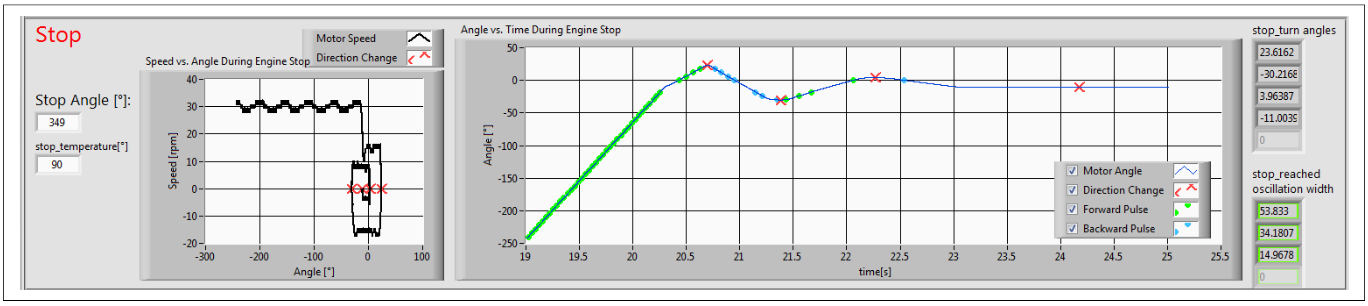

Figure 12 **Graphical user interface on system test bench “stop-start”: phase ENGINE-STOP**

TEMPERATURE-DRIFT:

The third phase changes temperature of the whole system. A high precision encoder monitors the smallest movement in the system to know the exact system-position through all 4 phases.

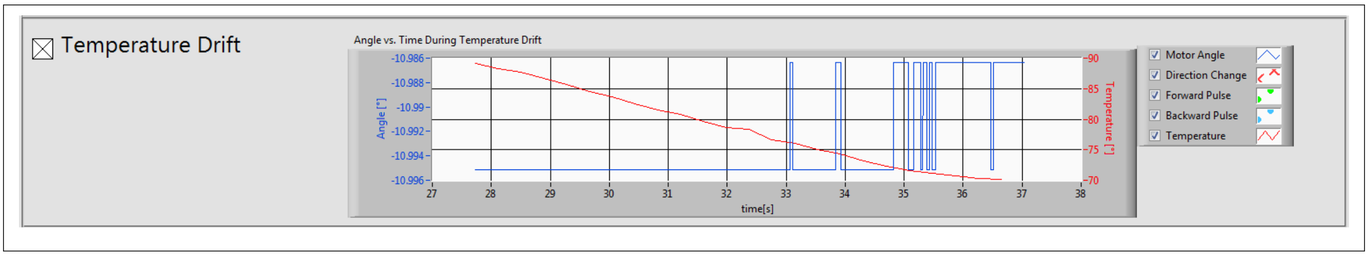

Figure 13 **Graphical user interface on system test bench “stop-start”: phase TEMPERATURE-DRIFT**

ENGINE-START:

The fourth phase starts the engine again with simulated movement backward for some degrees and then simulated firing of the piston. The transmitted pulses of TLE4929C are counted by the system test bench as the ECU would do. Due to parallel usage of the high precision encoder every output edge can be compared with the system. Additionally the system counts forward- and backward-pulses until the reference-zone. The test is passed when the transmitted position of all teeth is exactly at the physical position of all teeth of the encoder-wheel.

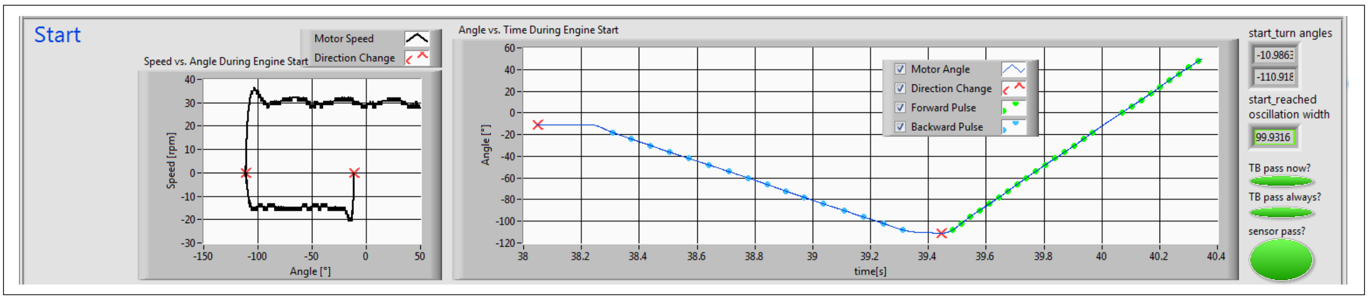

Figure 14 **Graphical user interface on system test bench “stop-start”: phase ENGINE-START**

The described measurement is done on 12 stop-positions along a standard 6°crank tooth as well as on 12 stop-positions during the 18°crank reference-zone. Several air gaps were measured as well as several temperature-drifts. A typical result of TLE4929C performaqnce is no lost edges/pulses.

2.10 Types of output-protocol

During evolution of engine controlling several protocols at the voltage-output have been used.

It started with passive VR-sensors that gave a voltage-peak with its height dependent on speed of the shaft and air-gap of the sensing module.

Adding electronics to the sensor-module the voltage-output was following the profile of the toothed wheel independent from air gap or rotational speed of the trigger wheel.

The stop-start application promoted a protocol sending the information of rotational direction.

The so far last step is the crankshaft-protocol invented by VW in 2017, combining the advantage of double edges in rotational direction forward (one rising and one falling edge for a pair of tooth and notch) and providing backward-information in rotational direction backward (one defined pulse-width for a pair of tooth and notch).

2.10.1 Crankshaft-protocol without direction detection

As shown in ***Figure 5*** the voltage-output follows the teeth and notches of the toothed wheel. For easier explanation the switching-point "edge of the tooth" is illustrated.

Differential Hall-Sensors like the TLE4929C have the switching-point in the middle of the tooth and in the middle of the notch. Through EEPROM the user can choose to have the falling edge in middle of tooth or to have the falling edge in middle of the notch assuming a rotational direction forward.

Turning the trigger-wheel in the reverse direction will change the falling edge of the output into a rising edge. Like shown in ***Figure 5*** either from left side of the chart to the right side, or going from the right side to the left side of the chart.

2.10.2 Crankshaft-protocol with direction detection

To indicate rotational direction forward or reverse to the ECU a pulse-width-modulated protocol was invented:

The falling edge is still at the same position as it is in the crankshaft protocol without direction, but the rising edge is now used to modulate the pulse-length. In standard crankshaft application a pulse-width of 45µs indicates rotational direction "forward" and a pulse-width of 90µs indicates rotational direction "reverse". Some OEMs have different pulse-length, for rotational direction indication.

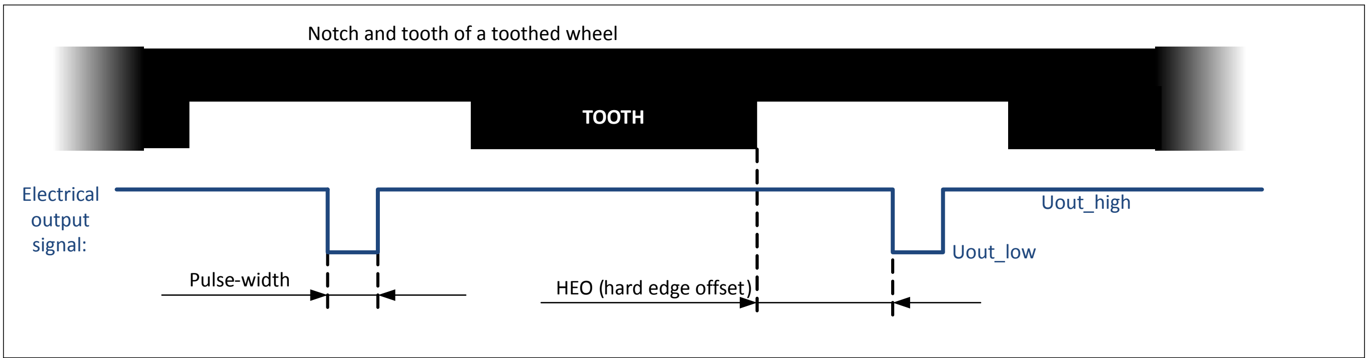

Figure 15 Crankshaft-protocol with direction detection

In both rotational direction, the falling edge of the electrical output signal is at the same mechanical position of the wheel. So the ECU is able to count the steps of 6° correctly and is always in phase with the trigger-wheel.

2.10.3 Double accuracy protocol

The advantage of the protocol without direction detection is 116 edges for position detection during each revolution. (double accuracy)

The advantage of the protocol with direction detection is correct angular position when the engine is stopped after normal operation. At restart of the engine the ignition can immediately fire the actually loaded piston and the engine is much faster at restart compared to a complete new "cold-start" when the starter-motor has to turn the crankshaft for several revolution, before firing of pistons begins.

The "double accuracy protocol" takes the best of both protocols: In forward-direction the engine receives 116 edges of rising or falling edges. So the engine has double resolution of crankshaft as compared to competition.

In reverse rotational direction this new protocol issues 60µsec-pulses to indicate the reverse-information to the ECU. In case of direction-change there is one dedicated pulse to indicate forward-direction to the ECU. When the crankshaft is now turning in forward direction the TLE4929C-XVA goes to the mode of 2 edges per tooth.

The ECU has to detect the dedicated pulse-width and count these pulse-width with 6° crankshaft in the correct direction on a standard tooth. In the case of edges the ECU counts 3° in forward-direction every standard-tooth.

The usage of this protocol is protected.

3 Integration into system

By the definition “system” in respect to a crankshaft-sensor the design of the module is understood. In the module there is a connector, a lead frame, a sensor and a back-bias magnet. The module typically is placed in front of the toothed wheel (Z-axis). This chapter will stick to the drawing illustrated in ***Figure 16*** but various other configuration are allowed as well as long as magnetic flux-lines are passing through the sensing elements and are modulated by teeth of a toothed wheel.

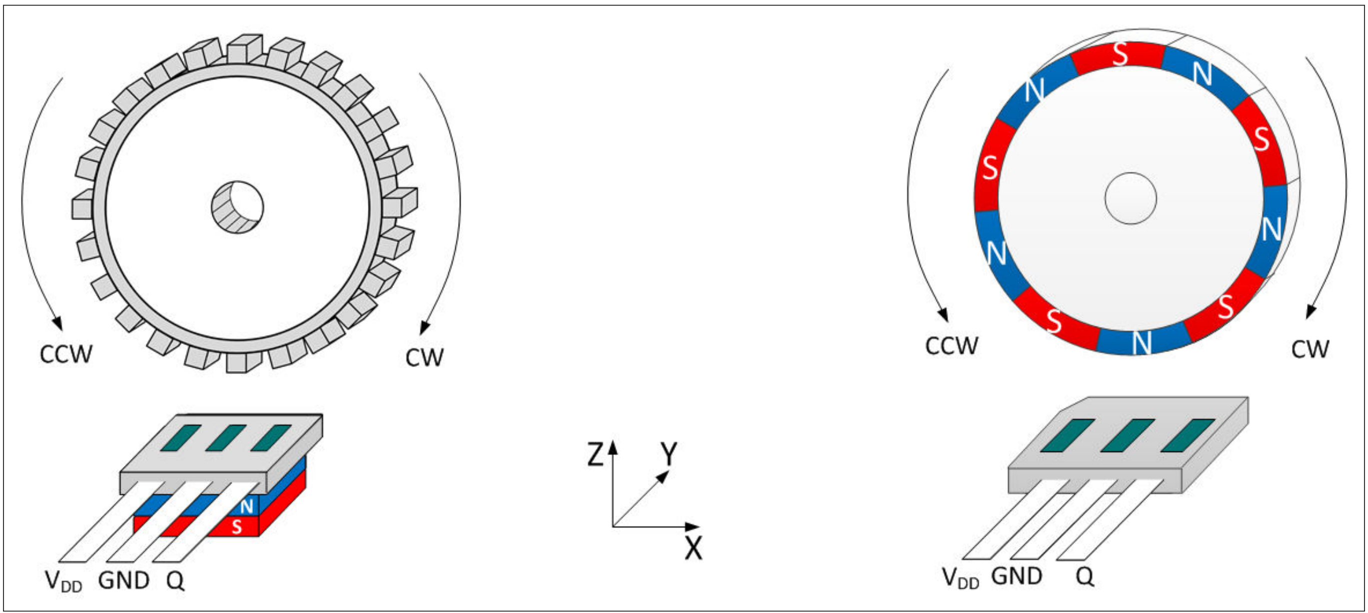

Figure 16 Definition of the Positive Magnetic Field Direction

For the case of an magnetic encoder wheel instead of a toothed wheel no back bias magnet is needed. The modulation of the flux lines is similar, when the magnetic poles move in front of the TLE4929C/TLE4959x.

3.1 Back-Bias-Magnet

The back bias magnet is only needed in toothed wheel applications. No special geometry or additional pole piece is needed. A simple block magnet or a simple cylindric magnet is sufficient. It is necessary to create a constant back-bias magnet field. Bypassing teeth of the toothed wheel concentrates the flux over the sense elements. From sensing element point of view in front of a tooth the magnetic field-vector Bz is longer than in air/notch. This behavior is called modulation of back-bias field. The algorithm of TLE4929C/TLE4959x is able to follow this modulation, to find local maximum field strength and local minimum field strength, to calculate the mean value and to create output edges or output-pulses on this mean value.

The strength of the backbias magnet determines the key-parameters “jitter” and “maximum air gap”. A weak magnet is cheap but due to the smaller amplitude in field modulation it leads to less maximum air gap performance. Further the jitter-value will increase as the slope of the magnetic signal is longer near switching-threshold. The signal to noise ratio (SNR) is smaller.

A stronger backbias magnet will allow larger air gap and excellent jitter performance. As all magnetic differential sensors, the backbias field has to be compensated by internal circuitry. Most of the sensors in the market have a limit of 500mT, which is not allowed to exceed at the position of the sensing element. Detailed information regarding strength an polarity of the magnet as well as position of the sensing element please find in data sheet of TLE4929C/TLE4959x.

Magnetic parameters in the data sheet are specified to support the proper design of the back-bias magnet.

3.2 Magnetic parameter

In this section the magnetic parameters mentioned in the data sheet are briefly explained.

3.2.1 Frequency range

As Hall elements intrinsically generate additional Hall-noise in the frequency-range from 0Hz to 10kHz, it is important to limit the bandwidth of the signal-path of TLE4929C/TLE4959x. This 8kHz limitation enables a good jitter-performance. The choice between full frequency range and 8kHz-range is a trade-off between low jitter-value on one side and large air gap-range over a 10kHz frequency range on the other side.

To a certain degree a strong backbias magnet can be used to be good in both parameters.

3.2.2 Dynamic range of the magnetic field of the differential speed channel

As the speed-channel of TLE4929C/TLE4959x is based on a differential principle the delta between left and right Hall element (outer sensing elements) is calculated. One single Hall element is allowed to sense a signal of -60mT up to +60mT. Adding both and assuming an ideal match of the toothed wheel (pitch = 5.0mm/ tooth is about 2.2mm) the differential signal can go up to +/-120mT. Exceeding this signal-range will result in signal-clipping and typically reduced phase accuracy.

3.2.3 Dynamic range of the magnetic field of the direction channel

The mechanism described in ***Chapter 3.2.2*** is also valid for the middle sensing element used to determine rotational direction. Clipping the middle sensing element does not affect jitter or phase accuracy immediately. Exceeding by more than 50% will influence sampling-points of speed-channel and is not recommended.

3.2.4 Static range of the magnetic field of the outer Hall probes in back-bias configuration

This parameter is the range of homogenous magnetic back bias field which can be compensated by the TLE4929C/TLE4959x. Typically the sensing elements of Infineon Hall-Sensors in PG-SSO-3-x and PG-SSO-4-1 package are 0.7mm above the surface of the backbias magnet. Further taking a minimum air gap of 1.0mm from surface to TLE4929C/TLE4959x to toothed wheel into account a backbias magnet with core-remanence of 1000mT will not violate the requirement for backbias magnet-compensation.

3.2.5 Static range of the magnetic field of the outer Hall probes in encoder configuration

The mechanism described in ***Chapter 3.2.4*** is also valid for configuration to magnetic encoder wheel. Since magnetic encoder wheel only have an offset due to imperfections a much smaller range will be compensated.

3.2.6 Static range of the magnetic field of the center Hall probe

The center Hall element has only one setting to fit both applications: Toothed wheel as well as magnetic encoder wheel, the specified range is a compromise between both.

3.2.7 Allowed static difference between outer probes

Due to position tolerances between sensing elements, backbias magnet and toothed wheel the outer sensing elements are not be perfectly centered in the application. The specified value in the data sheet gives the range where TLE4929C/TLE4959x can compensate a delta between the outer sensing elements. The range is designed to operate magnets without a pole piece.

3.2.8 Magnetic differential field amplitude for full performance on stop-start

For the reason of residual offset in the sensing elements, in the signal-path and in the backbias magnet, the TLE4929C/TLE4959x might issue an output-pulse during temperature related drifts. For this reason a field amplitude is specified for the speed signal. Considering a worst case signal/offset drift for each 20K temperature change a certain signal amplitude has to be in place and calibrated by TLE4929C/TLE4959x. Following this specified values no false pulses will be issued during temperature drift.

3.2.9 Magnetic temperature compensation of gain in analog signal path

The used material for backbias magnets in crankshaft application is either NdFeB or SmCo. These magnets have an average loss of 20% of magnetic field strength when moving from -40°C up to 150°C. In other words this is a loss of signal amplitude by 20% over the temperature range.

Applying this signal loss on the stop start application there is a loss of calibration during temperature drift. To avoid wrong calibration after stop period the TLE4929C/TLE4959x has a build in temperature-compensation of the gain in the analog speed path. In most of the derivates of the TLE4929C/TLE4959x this value is in the region of +825ppm to compensate an average loss of magnetic field which is assumed for -825ppm. In detail SmCo has less loss and NdFeB has more losses.

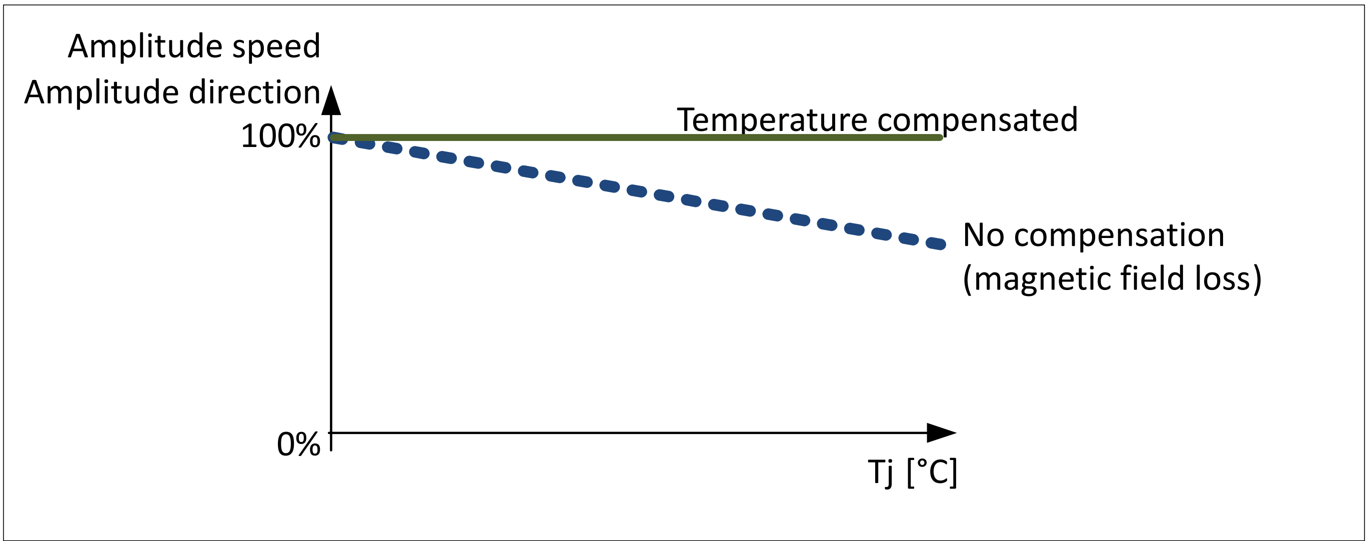

Figure 17 Compensation of gain versus temperature

3.2.10 Compensation of switching threshold over temperature in analog signal path

Switching threshold in speed-channel is affected by temperature change as well. Hall technology (independent from manufacturer) has random offset over temperature. TLE4929C/TLE4959x has a compensated switching threshold over temperature by performing an individual trimming process. So for the module-designer the switching threshold can be considered as absolutely flat over temperature.

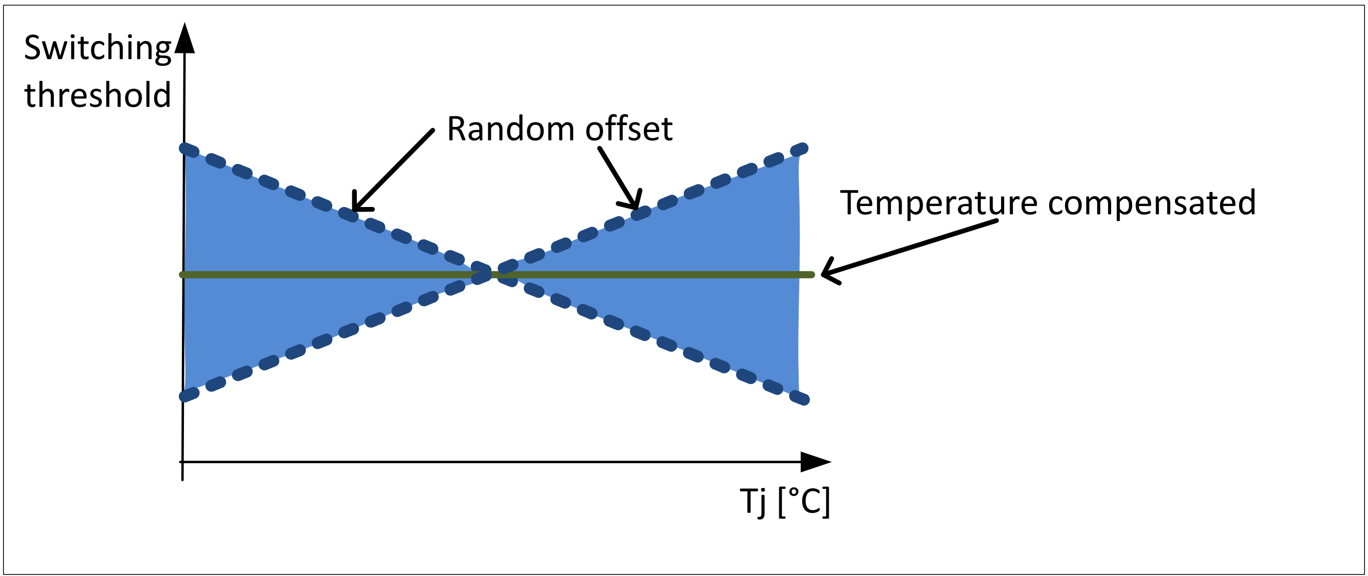

Figure 18 **Compensation of switching threshold versus temprature**

3.2.11 Not compensated air gap drift

One important influence on the air gap drift over temperature is the mechanical component of the engine itself.

As the engine-block is made from iron as well as the triggerwheel these parts will increase their size slightly with temperature as these have the same temperature coefficient. Taking into account a sensor module made out of PAx or PPS with a long finger with a different mechanical temperature coefficient an air gap change is possible. A mechanical change of air gap by 0.6mm can result in either half or double of the amplitude of the signal.

A short module design is in advantage compared to a very long module design.

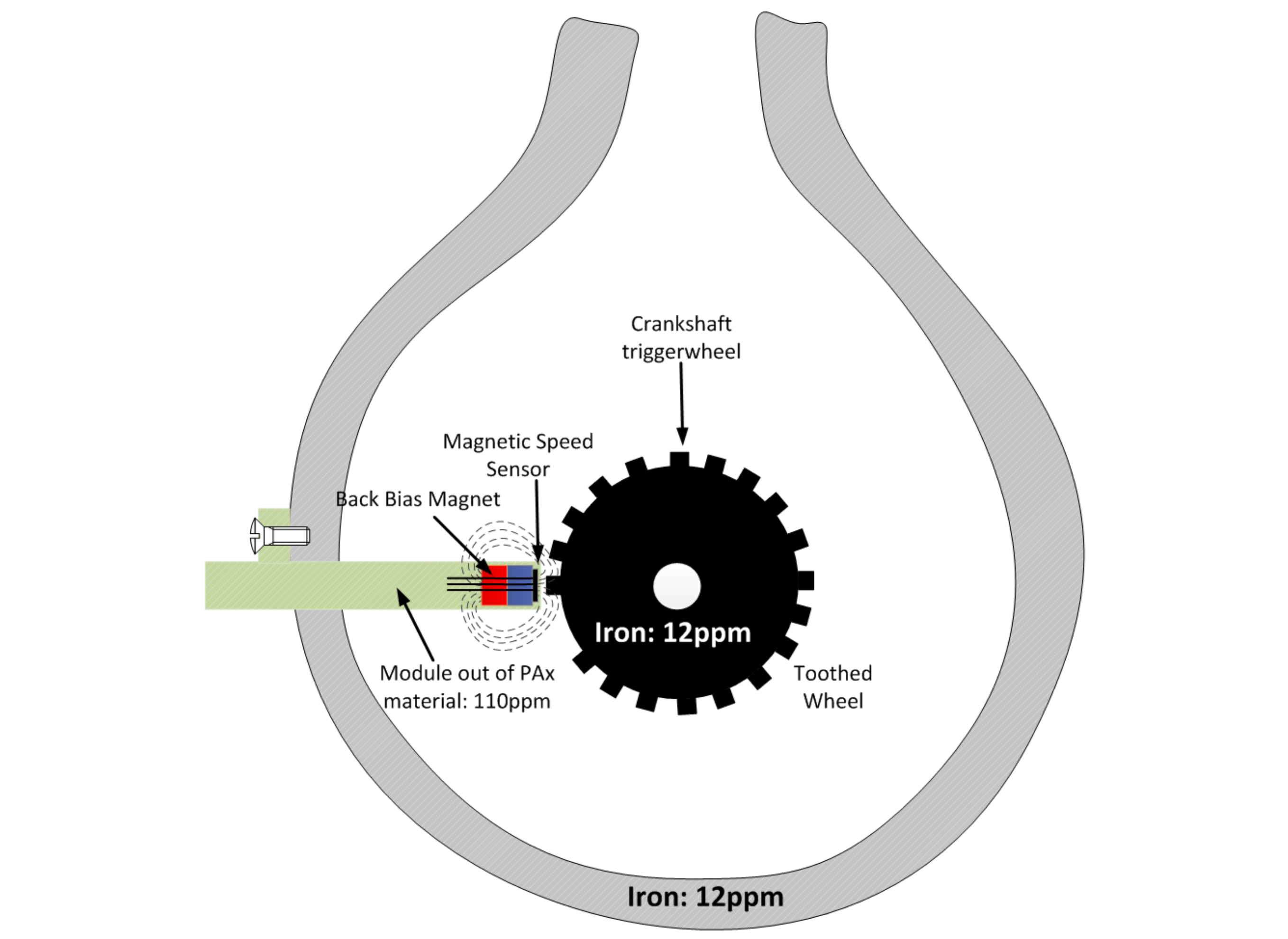

Figure 19 **Mechanical influence on air gap of crankshaft module**

3.3 Displacement

Displacement is a severe topic in the application since all production steps follow some tolerance. To gain a good phase accuracy (HEO) it is mandatory to keep displacement as small as possible. The alternative is trimming end of line, but is too expensive and takes too much time.

Displacement happens to all 3 axis and additionally tilting and twisting on all 3 axis increases the effect. Following the coordinate-system in ***Figure 16*** the displacement in Z-axis is air gap between module and toothed wheel.

As the TLE4929C/TLE4959x is a Hall-speed-sensor there is only one magnetic sensing direction: Bz - field vector passing perpendicular the package.

3.3.1 Module displaced towards toothed wheel

Module displacement results primarily in decreased phase accuracy. The X-axis is parallel to the circumference of the wheel. Every 100µm is directly added to the phase accuracy considering the circumference as 360° of the crankshaft.

Shift on Y-axis, tilt on X-Axis as well as twisting on Z-axis will not affect the phase accuracy but will degrade the maximum possible air gap. As estimation tilting and twisting of up to 3° can be neglected. Shifting is dependent on thickness of the toothed wheel. Thick wheels are more robust against Y-shifting.

Tilt on Y-axis will influence phase accuracy and maximum air gap.

Shift on Z-axis is the air gap.

General recommendation is to evaluate the worst case position, worst case tilting and worst case twisting in the application test bench and assess the performance.

3.3.2 Magnet displaced towards sensing elements

Also inside the module displacement occurs. But there is less effect on the application. The basic requirement is to apply the same field-strength Bz on left and right sensing element. The possibilities of shifting and tilting create a difference in the two outer positions of the Hall elements. As described in ***Chapter 3.2.7*** this miss-alignment can be compensated by TLE4929C/TLE4959x.

Important for phase accuracy is the position of the sensing elements with respect to the toothed wheel. Attention should be paid for a good alignment of the sensing elements. Backbias-magnet and module are considered as support. Position of sensing element is the reference and therefore most important.

Deviations in tilting and shifting of the magnet typically have a slightly reduced air gap performance.

3.4 Adjust the proper k-factor

The crankshaft sensor is sensing the crankshaft position which is used to calculate the ignition timing. A precise crankshaft position will enable precise ignition timing. Today state of the art is a crankshaft sensor mounted together with a magnet in a module. As all components have their own magnetic and mechanical tolerances an overall tolerance of something like +/-0.3°crank is the accuracy of the sensed crankshaft position. With the introduction of adjustable switching threshold (k-factor) the accuracy of each module can be increased to +/-0.1°crank.

This is the mechanism, how tolerance is bad due to positioning:

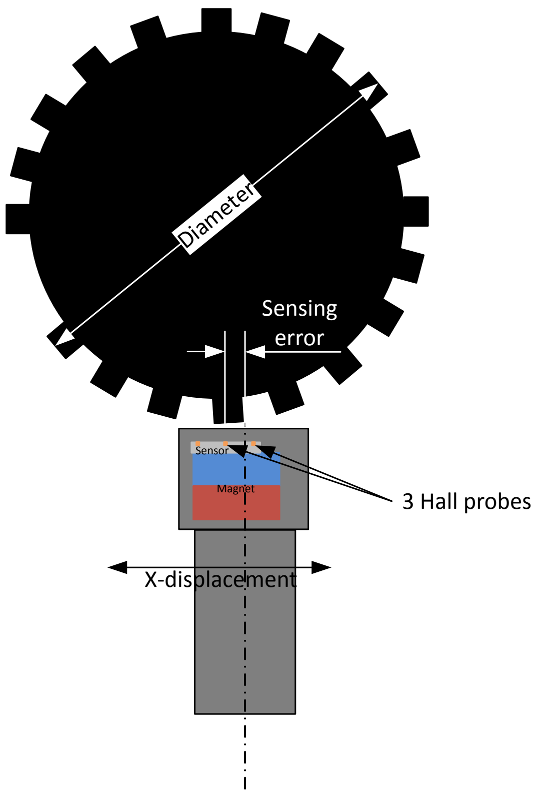

Figure 20 Mechanical tolerances on the crankshaft sensor module causee wrongly position

When the sensor middle Hall probe is in front of the middle of the tooth an output switching generated indicating: “This is the middle of the tooth.”

Due to position tolerances of the sensor and of the magnet (X – displacement) the middle of the sensor is not always the middle of the module. And even if the sensor and the module would have the mechanical middle and the magnet is displaced there would be a deviation of the magnetic middle to the module middle. These tolerances cause a wrong crankshaft position sensed and calculated in the engine control unit.

Translated to magnetic parameters the teeth are modulating the back bias magnet field lines. The sensor detects the modulation of these field lines. Out of the detected maximum and minimum signal the switching threshold is calculated at the 50% level as explained in the TLE4929C-Xxx datasheet. Only when the mounting tolerances are 0µm the +/-0.1°crank can be achieved as pictured in ***Figure 21***.

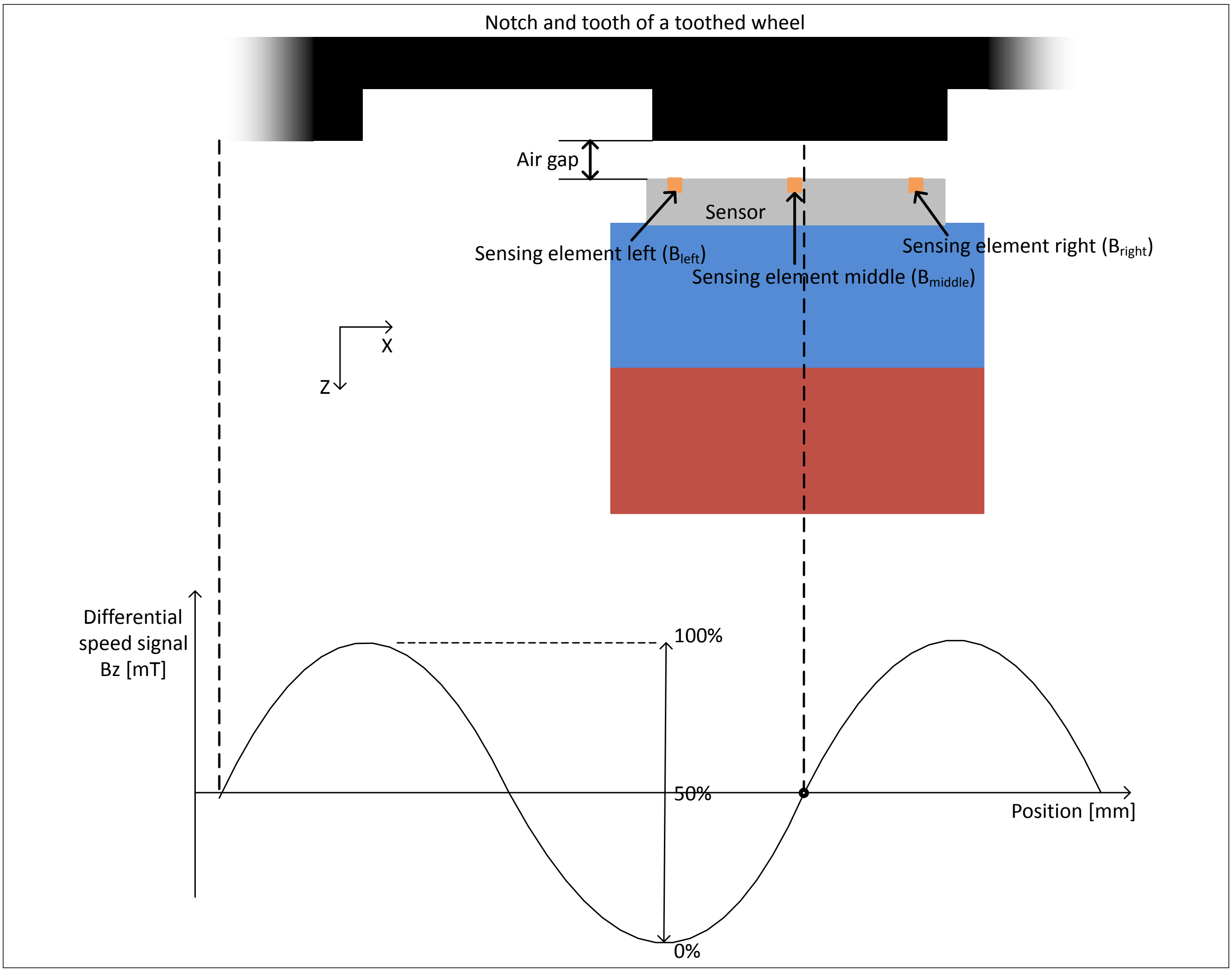

Figure 21 Perfect aligned module and 50% switching threshold fits perfectly

As described in ***Figure 22*** the sensor is misaligned compared to the magnet. For this reason the 50% level is crossed too early as indicated by the solid line. A zero crossing is issued too early to the engine control unit. Following the line till the 60% level where the red dot is placed we find the good position indicating the middle of the tooth again.

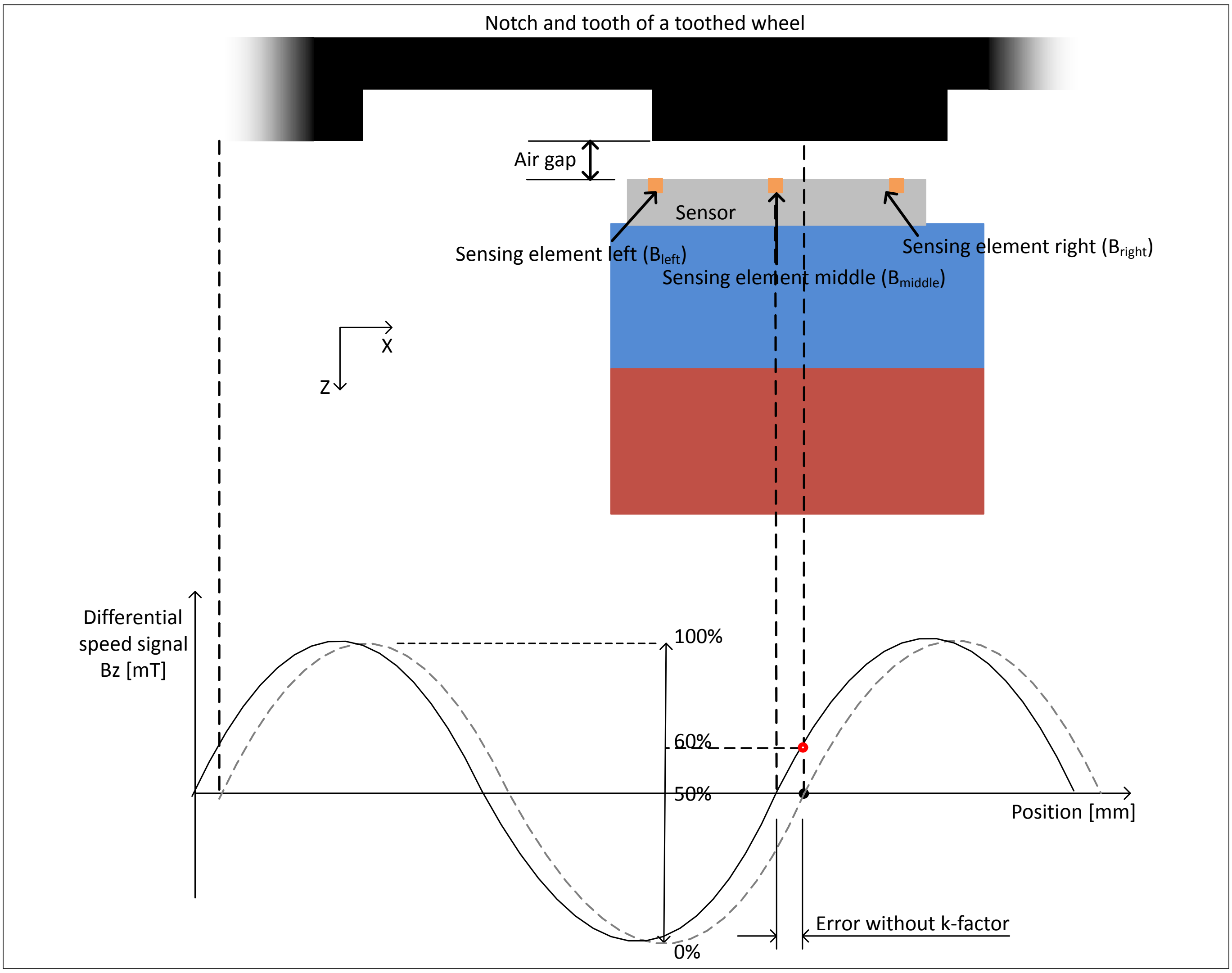

Figure 22 **Perfect aligned module and 60% switching threshold fits perfectly**

There are two strategies to increase the accuracy of the system:

1. The TIER11 does an end of line calibration: The TIER1 measures the difference between the magnetic zero-crossing and the real mechanical middle of the tooth. An correction of +/-10% can be programmed into the EEPROM through the option "k-factor". For two additional steps (measuring and programming) the TIER1 can upgrade its modules to 0.1°crank accuracy.
2. Nevertheless the OEM will have additional mounting tolerances of the module at the engine block. These additional mounting tolerances will result in approximately 0.3°crank accuracy again. To overcome this the OEM can redo the same programming as the TIER1 again on the complete engine block. This is probably a little more costly but gives again a 0.1°crank accuracy on the complete engine.

3.5 Adjust the proper offset update algorithm

The new market for misfire detection is identified in 2-wheeler application. The important key parameter for misfire detection is jitter performance. A typical requirement from the OEM´s is 0.015°crank as a 3 sigma value. To achieve these small numbers in Hall technology the offset switching threshold has to be adjusted to the trigger wheel.

Whereas in 4 wheeler application 58 teeth (60 – 2 configuration) is the worldwide standard the 2-wheeler still have to find their final wheel design. So far a 36-2 configuration is identified. In the TLE4929C-X2A the 34 teeth algorithm is already implemented and pre-programmed.

Why is it important to adjust the offset update algorithm to the used trigger wheel?

Every system has mechanical manufacturing tolerances in the trigger wheel and mechanical mounting tolerances of the trigger wheel. One slightly smaller tooth or a bent tooth or a runout of the trigger wheel will cause irregularities in the magnetic signal measured by the crankshaft sensor TLE4929C. For this reason the switching threshold strategy is to update the switching threshold only once per rotation at exactly the same position every time. The calculation for the update of the switching threshold will always be the same and for this reason the threshold will be the same as in the revolution before. This is the key to get superior jitter performance at the output of the crankshaft sensor TLE4929C.

In the ***Figure 23*** and ***Figure 24*** there is an example on a 7 teeth wheel:

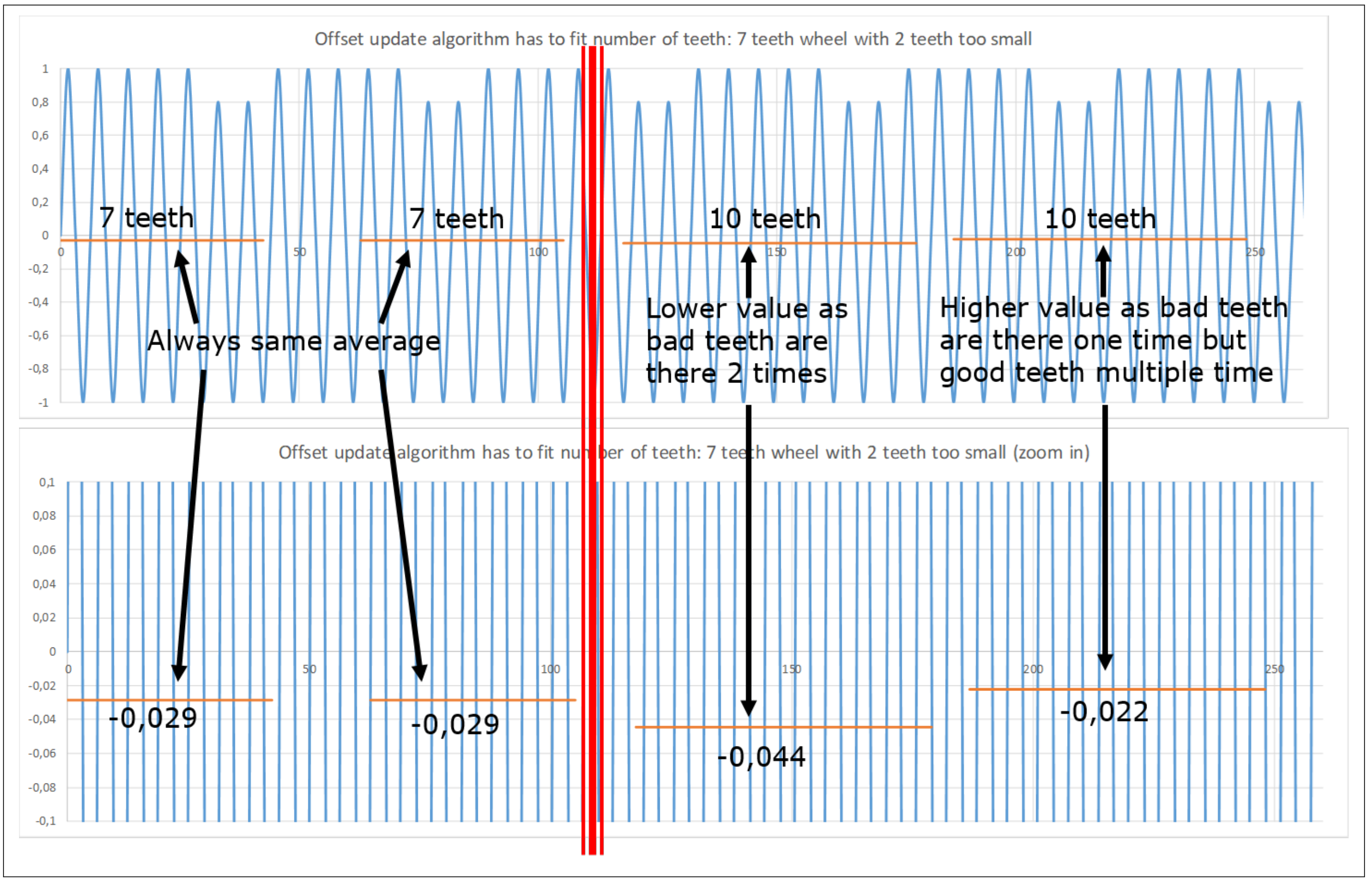

Figure 23 7 tooth average matches / 10 tooth average is different

Two teeth of the 7 teeth wheel are slightly bent and the maximum positive sine wave in the magnetic signal is slightly decreased. Calculating the average value over the entire revolution gives the same value. Independent of its starting point it is always the same value. Comparing the same 7 teeth wheel with calculation of a 10 teeth average different results will be achieved. Dependent on the point the averaging starts there will be the small tooth twice or only once counted. So there will be different values in the averaging.

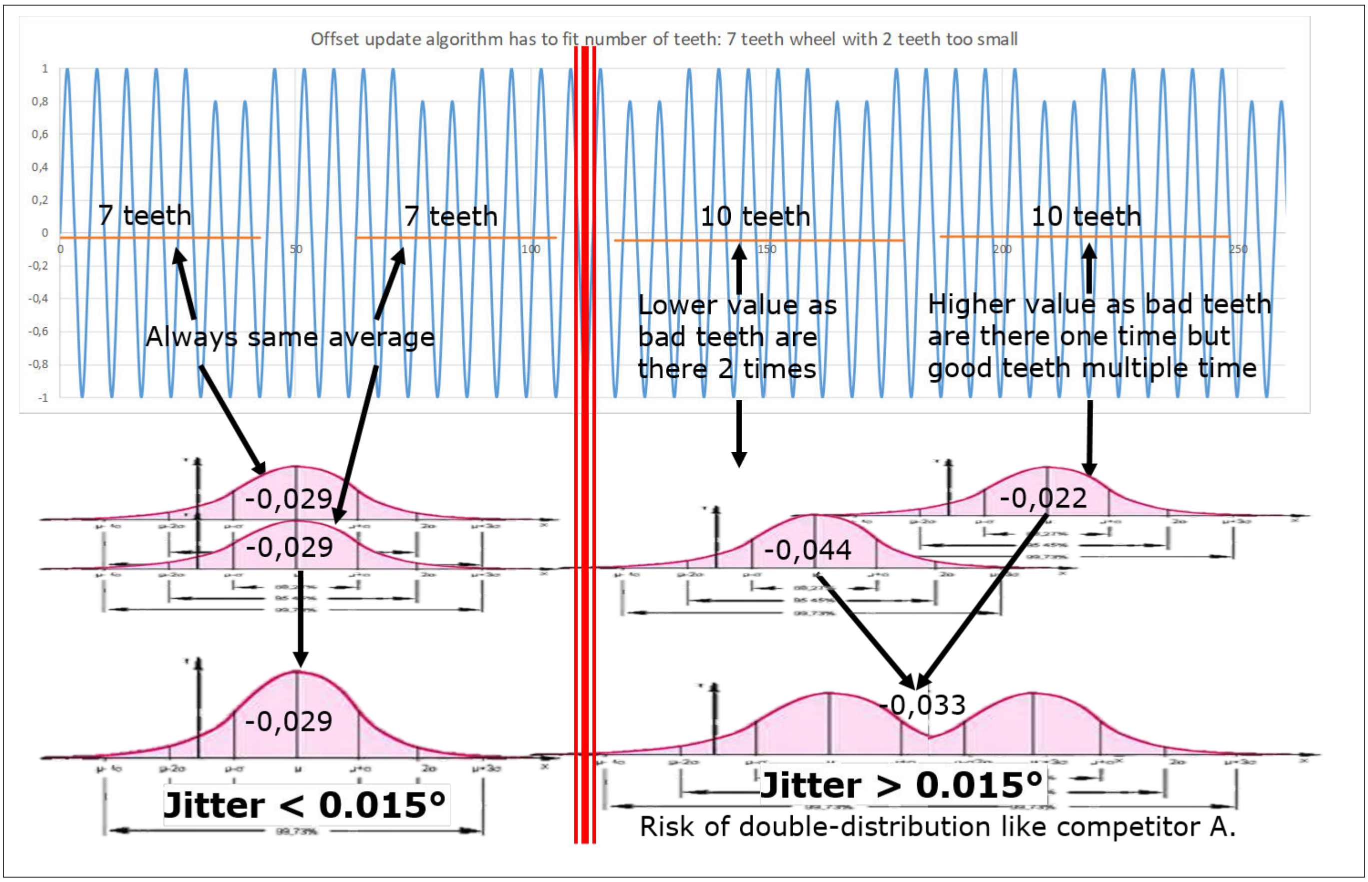

Figure 24 **Summed up distribution on different algorithm**

Summing up the same distribution will have the same sigma for the matched use case. For the not matched use case the distribution will spread dramatically. This large spread is very bad and will be the killing point for the system feature misfire detection.

As a consequence the proper number of teeth has to be programmed into the TLE4929C-X2A which is in this case 34 teeth for the 2-wheeler application.

3.6 When to enable the HYBRID watchdog

Modern cars carry out a range of self-diagnostic checks as soon as the driver's door is opened. This reduces the amount of time it takes for a warning lamp to light up. A lot of other things can happen, however, from the moment the car door is opened to the time the car pulls away. The car can be loaded, for example, or children have to be buckled into their seats. As such, it is completely normal for the car to rock slightly while stationary. These slight movements travel through the drive wheels, transmission and clutch and cause the crankshaft trigger wheel to turn. In some unfortunate situations, this can result in the crankshaft sensor picking up a valid magnetic signal.

To overcome this issue, an algorithm has been implemented in the sensor to delete calibration data generated before the engine is switched on.

If we take just a brief look at the wide range of hybrid architectures, it quickly becomes clear that this add-on function will help car manufacturers to identify and ignore any inaccurate calibration data.

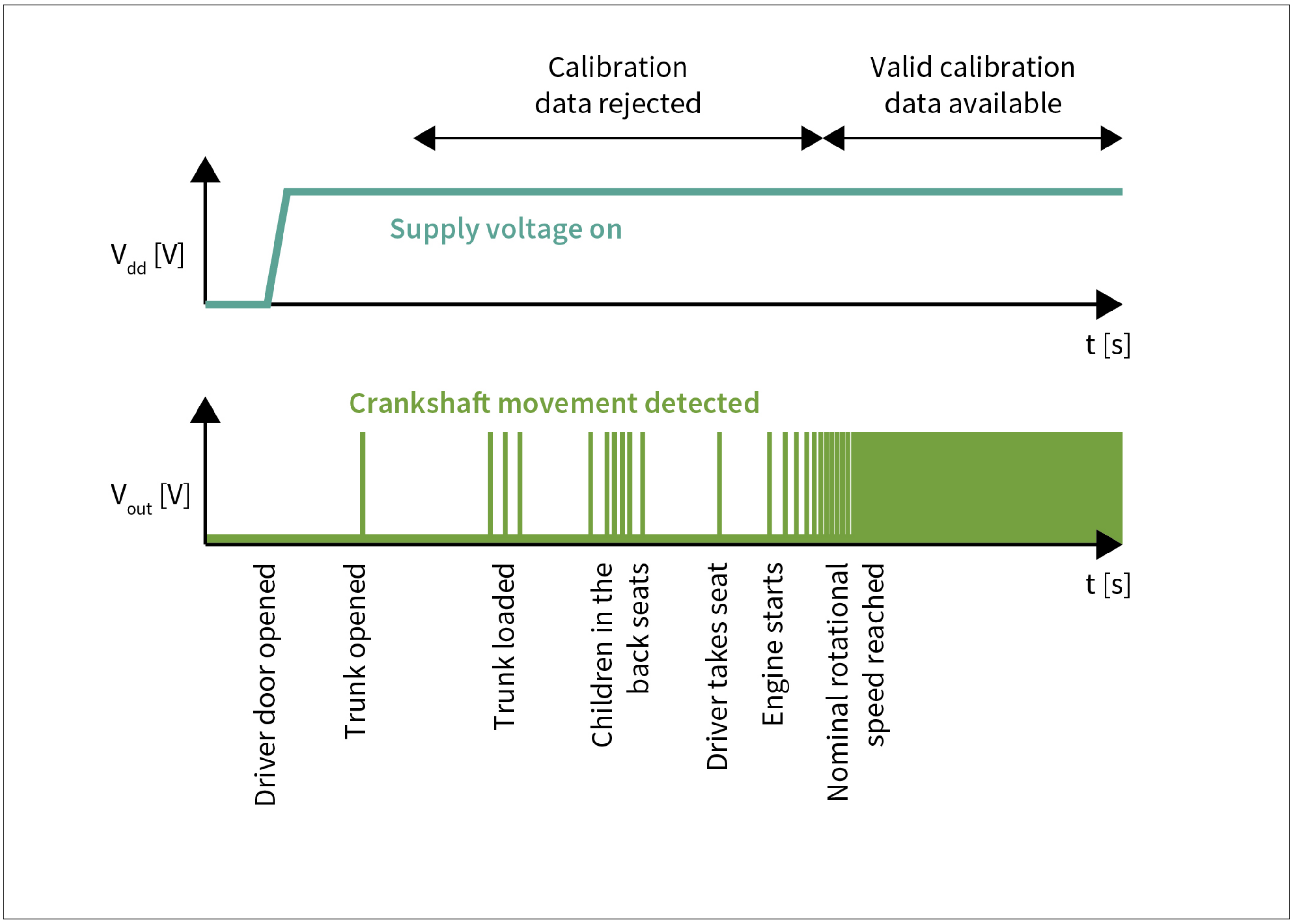

Figure 25 **How the TIMEOUT algorithm works**

A new function is required for a “big” plug-in hybrid solution. To correctly identify the position of the crankshaft trigger wheel, an algorithm has been implemented in the sensor that detects slower, sub-nominal crankshaft rotation and, in conjunction with other monitoring functions, prevents incorrect calibrations. New calibration data is only accepted when the system is operating normally.

Collectively, the algorithms named here enable the movements of the crankshaft trigger wheel to be accurately observed and tracked. Based on the crankshaft angle the engine control unit knows at all times which stroke each piston is on and how much time is left until the next ignition.

As the crankshaft sensor always provides reliable information, the sizing of components required to restart the combustion engine can be reduced.

With an advanced crankshaft sensor, the fuel can be injected and ignited in just half a rotation. Starting the engine in this way requires only a fraction of the battery energy needed for a cold start.

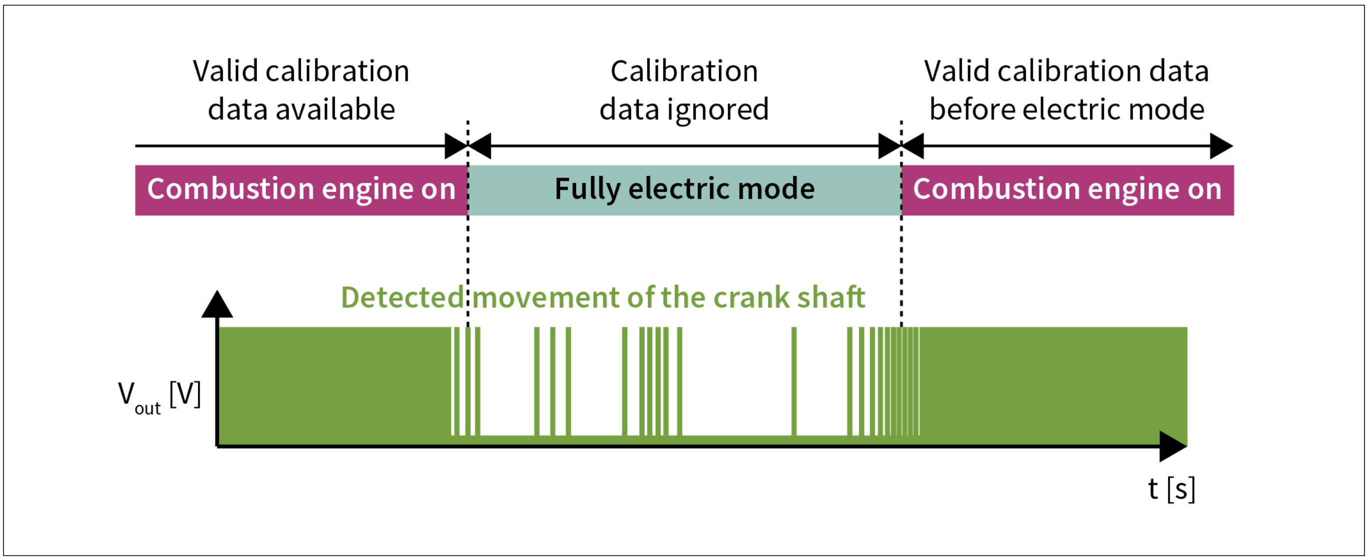

Figure 26 **How the HYBRID watchdog works**

Figure 26 explains in detail how this new HYBRID algorithm is working in the system:

In the left side of the chart the combustion engine is running in normal operation and the output pulses are present all the time as they are intended to do.

In the middle of the chart the integrated combustion engine (ICE) is switched off as the hybrid vehicle is going to operate on electric power. During this fully electric mode some bumps in the road or some shaky roads can move, rotate or vibrate the crankshaft. Some forward and backward pulses will be issued as the teeth move in front of the sensor. In this mode it is very important to not calibrate on these sporadic signal. For this reason the TLE4929C-XHA implemented the HYBRID watchdog which detects a lower crankshaft rotation speed of 100rpm and disables all calibration features. As soon the rpm will increase above 100rpm the calibration is enabled again.

So in the right part of this figure the ICE will use the former calibration parameters and will operate properly.

There will be no missing pulses, no additional pulses and no wrong pulses at the output of the sensor.

The hybrid algorithm is available only in the TLE4929C-XHA, the latest derivative of the TLE4929C-family.

4 Evaluation tool

The tool to evaluate TLE4929C/TLE4959x in the application is the well known PGSISI2. It is used since more than 10 years for the different kind of magnetic speed sensors in wheelspeed-, transmission-, camshaft- and crankshaft-applications. The PGSISI2-box is always the same hardware but the firmware is flashed when a new PC-software is connected to it using the USB-cable.

Additionally there is a specific daughter-board which customizes the PGSISI2-box to the TLE4929C/TLE4959x. Again there was some reuse of existing hardware. In this case the daughter board of TLE4986C, which shares the same interface.

Figure 27 **Picture of PGSISI2 and the corresponding daughter board to interface TLE4929C/ TLE4959x**

4.1 PGSISI2 and TLE4929C/TLE4959x-daughter-board

As pictured in ***Figure 27*** the PGSISI2 is a robust box which acts as a serial interface (USB_to_serial) to the computer. The harware inside provides programmable voltages from 0 to 21V to the two used pins of TLE4929C/ TLE4959x: “Vdd” and “Q”. Further there is a digital input for the read back-channel to decode the answer of TLE4929C/TLE4959x.

The daughter board is used to customize the PGSISI2-box to a Infineon-sensor. There are BNC on the board which can be used as synchronization-signal to external hardware like a customer test bench.

The complete evaluation-kit is named “**TLE4986C PROGRAMMERKIT**” and can be ordered at Infineon using the ordering-number “**SP001012368**”.

For customers already owning a PGSISI2 the daughter-board can be ordered at a much lower price. The name is “**TLE4986C EVALBOARD**” and can be ordered by ordering-number “**SP001012364**”.

Please do not worry when Infineon-stock is zero and delivery-time is 1 to 3 weeks. The boards are assembled in the laboratory already and will be shipped as soon an order arrives.

4.2 Digital diagnosis interface

TLE4929C/TLE4959x has a digital core with a 4-wire-interface implemented based on the SPI-standard. As there are only 3 pins available which all have dedicated functionality Infineon used a modulation on Vdd to send commands into TLE4929C/TLE4959x.

For doing the readout of internal registers the existing output “Q” is used but with enhanced in output-speed. As a third function the EEPROM-programming-voltage is provided on this pin as well.

Commands from GUI (passing through PGSISI2 and daughter board) are send to the TLE4929C/TLE4959x in using a special modulation of Vdd. As described in ***Figure 28*** the TLE4929C can demodulate the signals “serial clock”, “serial data in” and “chip enable”.

To not enter digital diagnosis interface by accident a password has to be send right at the beginning. There is only a short time-window after power on when TLE4929C accepts Vdd-modulation as digital data stream. Once the correct password is received TLE4929C/TLE4959x will accept further data. No further time limit is implemented. The digital diagnosis interface mode is terminated in either violating interface-timing or in performing a reset.

The interface of TLE4929C/TLE4959x is designed for laboratory usage and for end of line calibration in production environment. Internal registers as well the content of the EEPROM can be read or written.

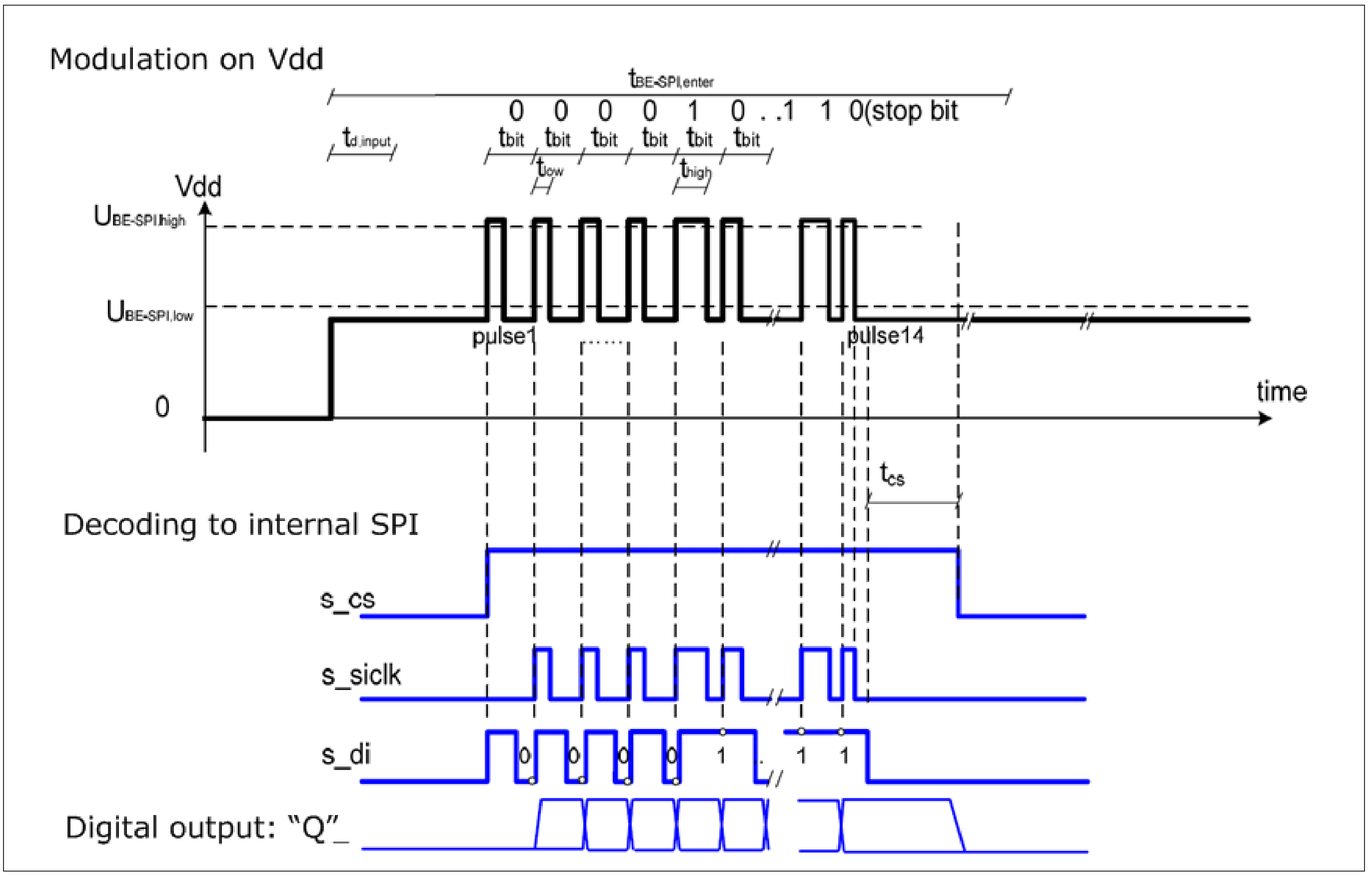

Figure 28 **Vdd-modulation to interface TLE4929C**

In reading-mode the answer is transferred on the Q-pin using the synchronization-information from Vdd-pin. Therefore it is a synchronous serial interface.

During design in activities at the customer, the following signals are typically read from TLE4929C/TLE4959x:

1.) EEPROM-content (read/write) to parametrize TLE4929C/TLE4959x to customer flavor

2.) Speed-signal (read) to assess phase accuracy, minimum airgap and maximum airgap

3.) Direction-signal (read) to assess quality of direction detection in signature region of toothed wheel 60-2.

4.3 GUI (Graphical User Interface)

At the local field application engineer the GUI of before mentioned EVAL-Kit can be ordered. The latest version will be distributed. This section is referring to GUI version 1.4.0. This section describes some basic steps how to operate TLE4929C/TLE4959x in digital diagnosis interface mode.

4.4 Establish contact with TLE4929C/TLE4959x

First make sure PGSISI2 and daughter-board is attached.

After starting the GUI it will search for connected PGSISI2-boxes and ask to choose one as pictured in ***Figure 29***

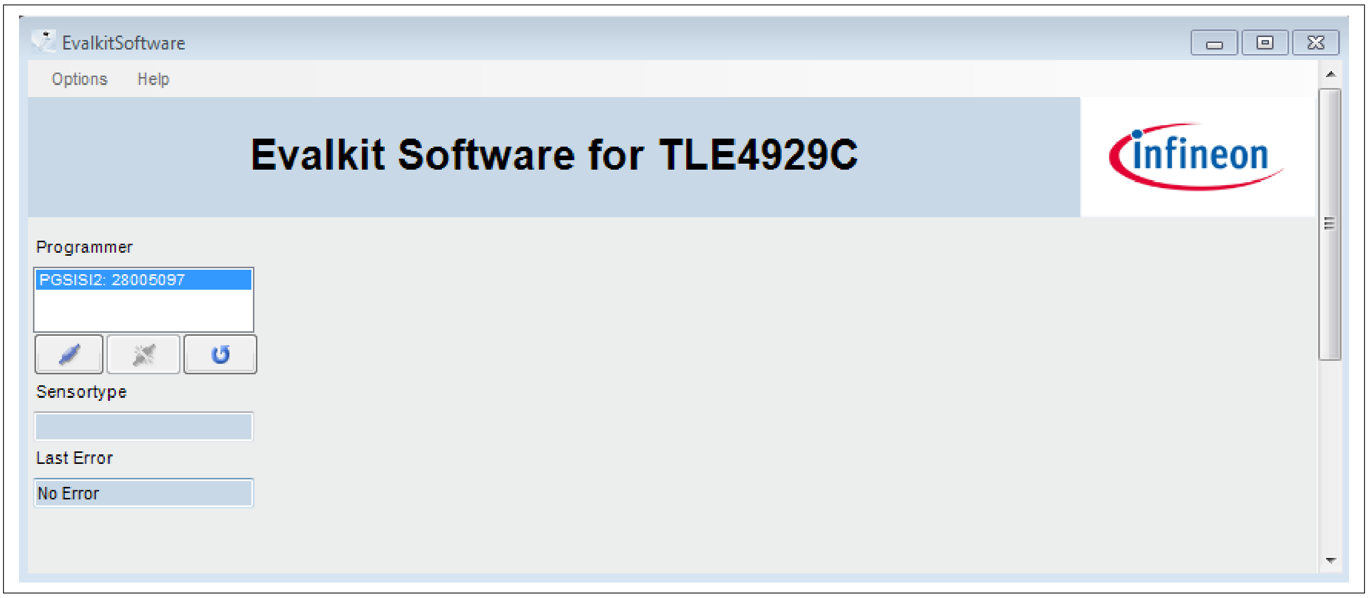

Figure 29 Evalkit: choose PGSISI2-box

After establishing the connection to the PGSISI2-box the GUI asks for the attached sensor.

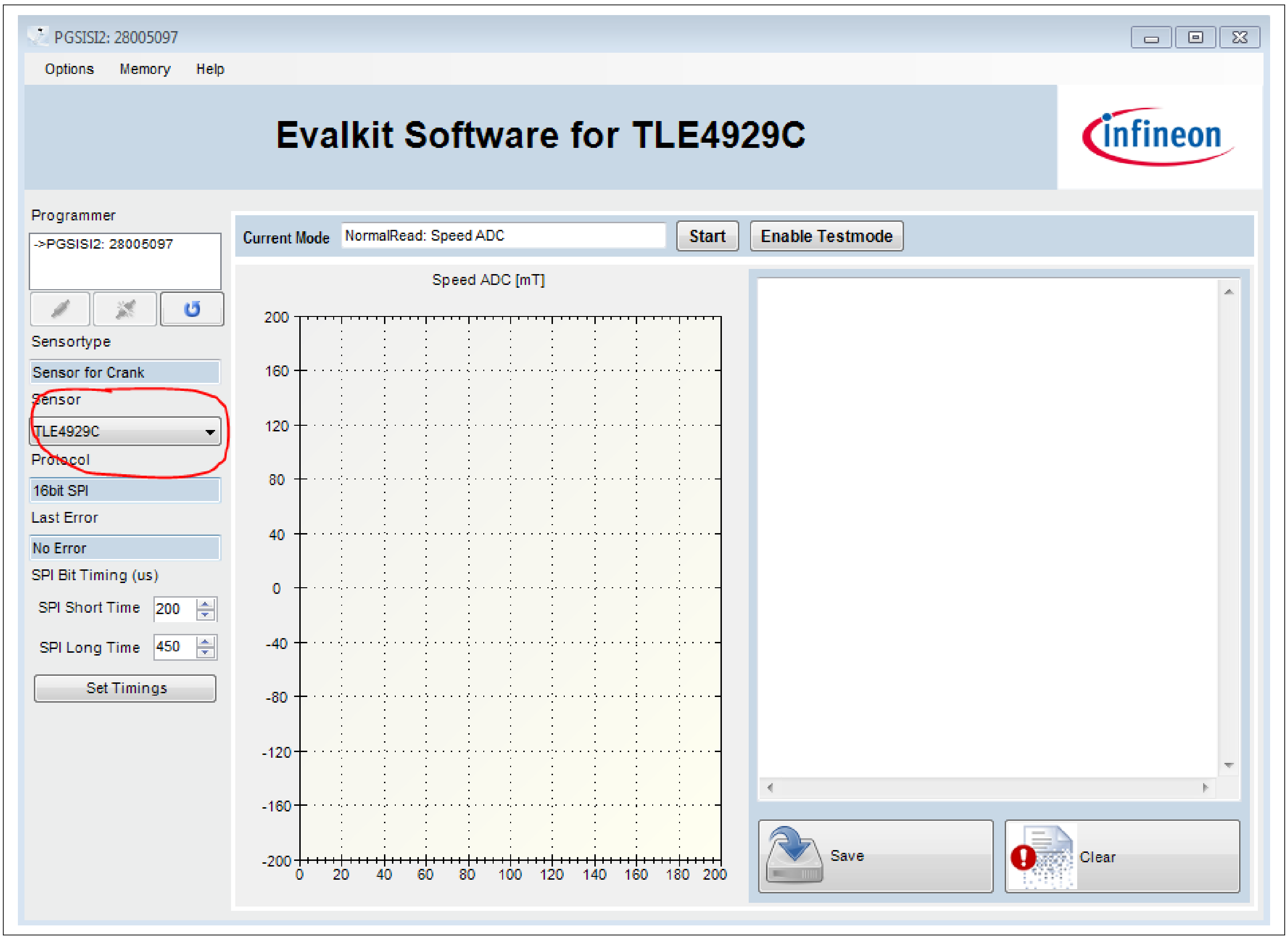

Figure 30 **Evalkit: choose TLE4929C as attached sensor**

After choosing the correct device the PGSISI2-box will be parametrized to the interface-parameters.

4.4.1 Read and write EEPROM

As described in the EEPROM programming guide the TLE4929C/TLE4959x comes with 32 Bits of user-EEPROM allowing the customers to adjust several application parameter.

The EEPROM can be read and written by the GUI in choosing the Submenu “EEPROM Values” from the pull down menu “Memory” in the very first line of the Evalkit Software.

As shown in *Figure 31* the available options are named in the left area of the new window. Here the option to be changed can be selected and afterwards in the upper right corner modification can be done to this particular setting. The area in the middle of this window contains the overview of all options.

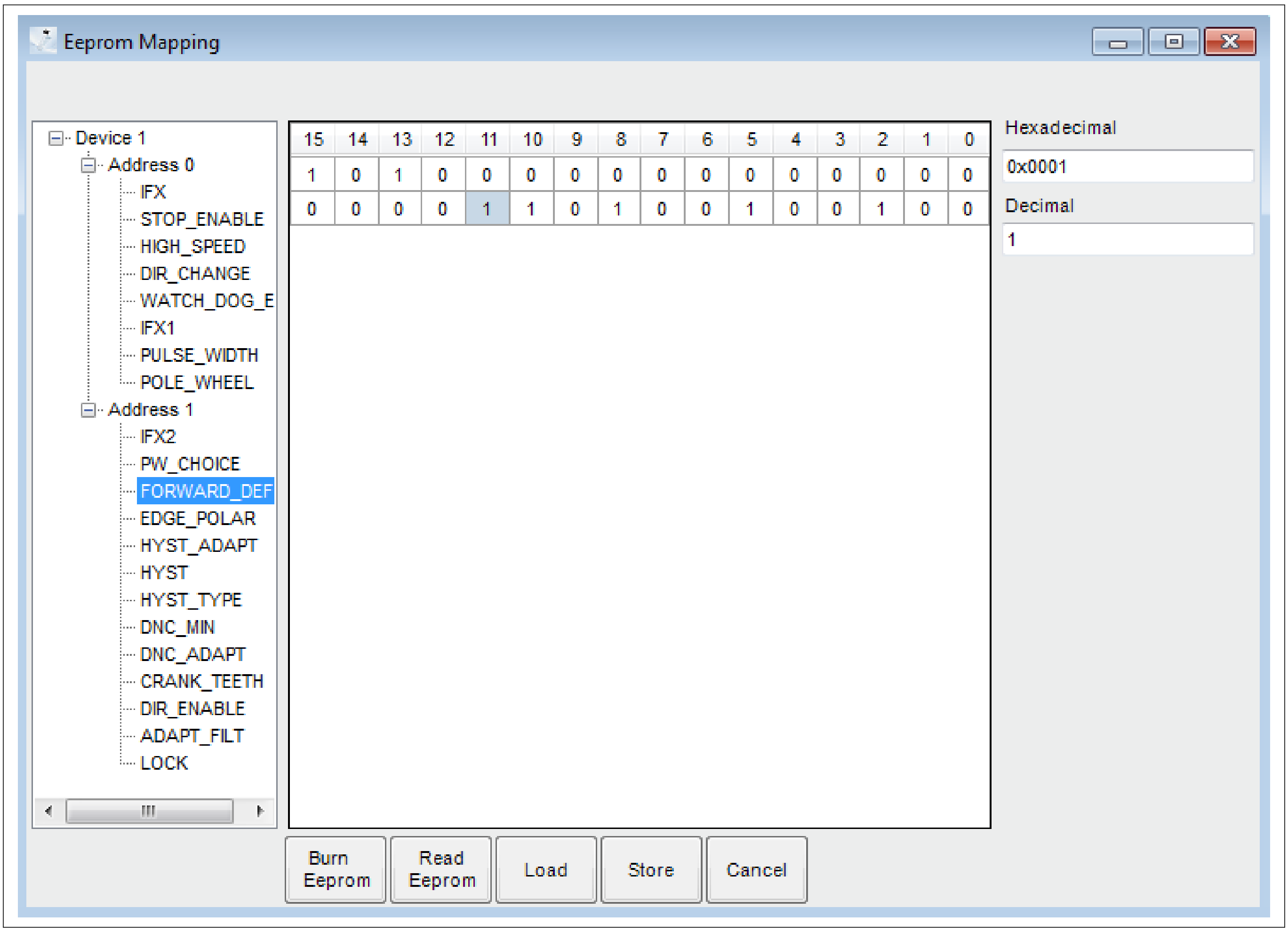

Figure 31 **EEPROM modification sheet in Evalkit TLE4929C/TLE4959x**

Once the correct setting is chosen it can be transferred to the TLE4929C/TLE4959x by choosing the "Burn EEPROM" button. An option for reading back is available as well.

The complete file can also be stored on the hard-disc of the computer using the buttons "Load" and "Store".

There is one important thing to remember: Once the EEPROM-Bit "LOCK" is set and burned into EEPROM it can not be reprogrammed any more.

4.4.2 Read and store internal signals

To get a good understanding on performance of TLE4929C/TLE4959x in the border-conditions of the application it is recommended to do "magnetic mapping" of speed channel. This means TLE4929C/TLE4959x is mounted with backbias-magnet in the module in the application. Various sensor-modules are build to the maximum and minimum tolerances of the production-spread. The internal signal "speed channel" has to be monitored on these worst-case positions.

4 Evaluation tool

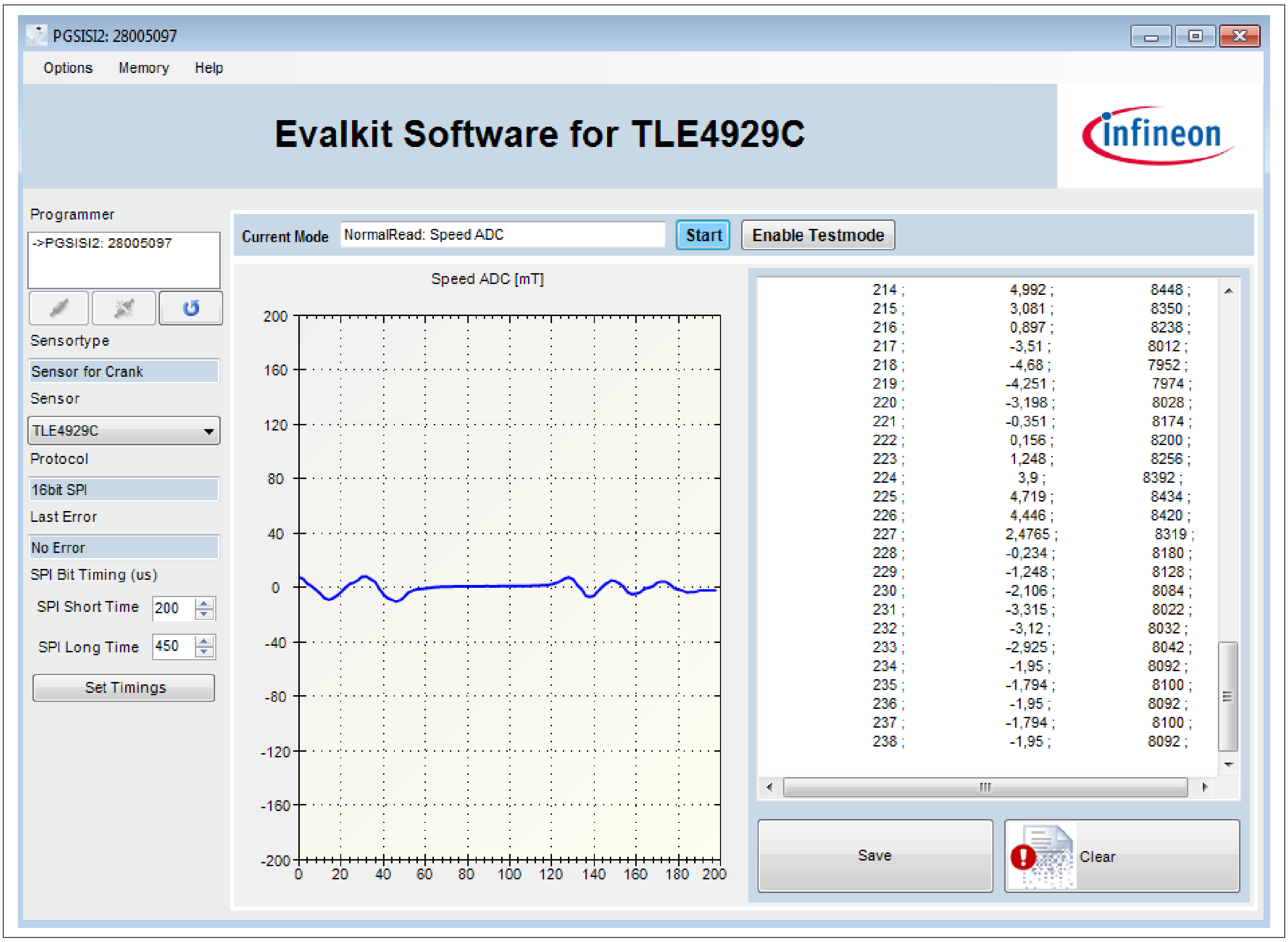

Figure 32 **Readout of speed-channel using Evalkit TLE4929C/TLE4959x**

In ***Figure 32*** the typical speed signal of TLE4929C is pictured in the center area of Evalkit software. On top of this graph there is the indicator for the actual readout-mode, the "Start"-button and the "Enable Testmode"-button.

Typically the signal are read in by pushing the start-button as the TLE4929C/TLE4959x is already in digital diagnosis interface mode (in short "Testmode"). In the case there was a change of sample in the application during measurement the test mode has to be activated again using the proper button.

On the right area a list of the actual values is displayed. These numbers are the raw data captured during the period, when the Start-button was pressed - the Start-button changed into a Stop-button - and the Stop-button was pressed.

Using the buttons "Save" and "Clear" the area can be stored onto the disc-drive of the computer or deleted from this area. In ***Chapter 5*** will explain how to process this data further.

In the lower left area the user can modify the Bit-timing of the SPI-interface to adapt to resistors and capacitors used in the Vdd-line or at the Q-output. By default a rather conservative timing is used like "SPI Short Time" = 200µs and "SPI Long Time" = 450µs. In laboratory usage without external passive components a timing of 3µs for short and 6µs for long is working well. It is important to keep the ratio (SPI Long Time) to (SPI Short Time) at a value above 1.5

To parametrize the Read-mode the user can find the option "settings" in the very left upper pull-down-menu called "Options".

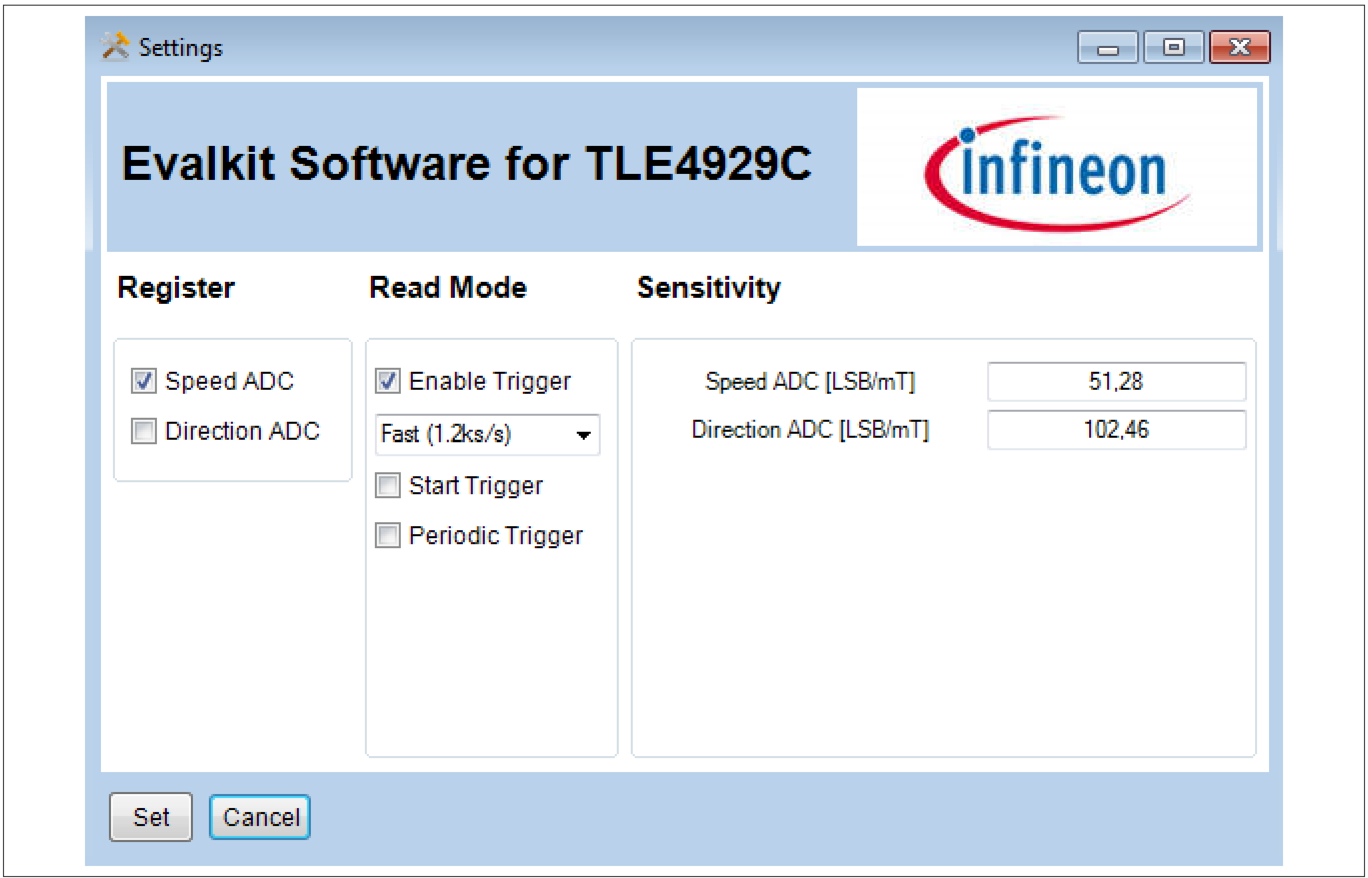

Figure 33 **Evalkit: Parametrization of readout-mode**

In the left section the user can choose the TLE4929C/TLE4959x-registers to be read by the Evalkit Software. It can be either speed-channel or direction-channel or alternating both channels.

The middle section allows to use synchronized readout. Using synchronized readout needs a digital 5V-signal at the BNC of the daughter-board. The "Start Trigger" is typically used to synchronize to the zero-position of the crankshaft. The "Periodic Trigger" is used to synchronize each sampling point and is typically driven by an rotational encoder which is connected to the test bench.

If no trigger is used a constant sampling interval is generated by the PGSISI2-box.

To adjust the scale of the graph in the main-window the sensitivity can be chosen by the user. Typical values are 52LSB/mT for the speed-channel and 92LSB/mT for the direction-channel.

5 Assessment-tool “iMAT”

Assessing captured data from the evaluation kit is traditionally done in any post-processing-tool like Matlab, Excel, NI-DIADEM or any other software. For standardized assessment of essential application parameters like:

- Minimum air gap assessment
- Maximum air gap assessment
- Maximum runout acceptance
- Bent tooth detection
- Phase accuracy

an Infineon-tool called “iMAT” can be used as well. For further details on this Infineon-software please contact your local Infineon field application engineer.

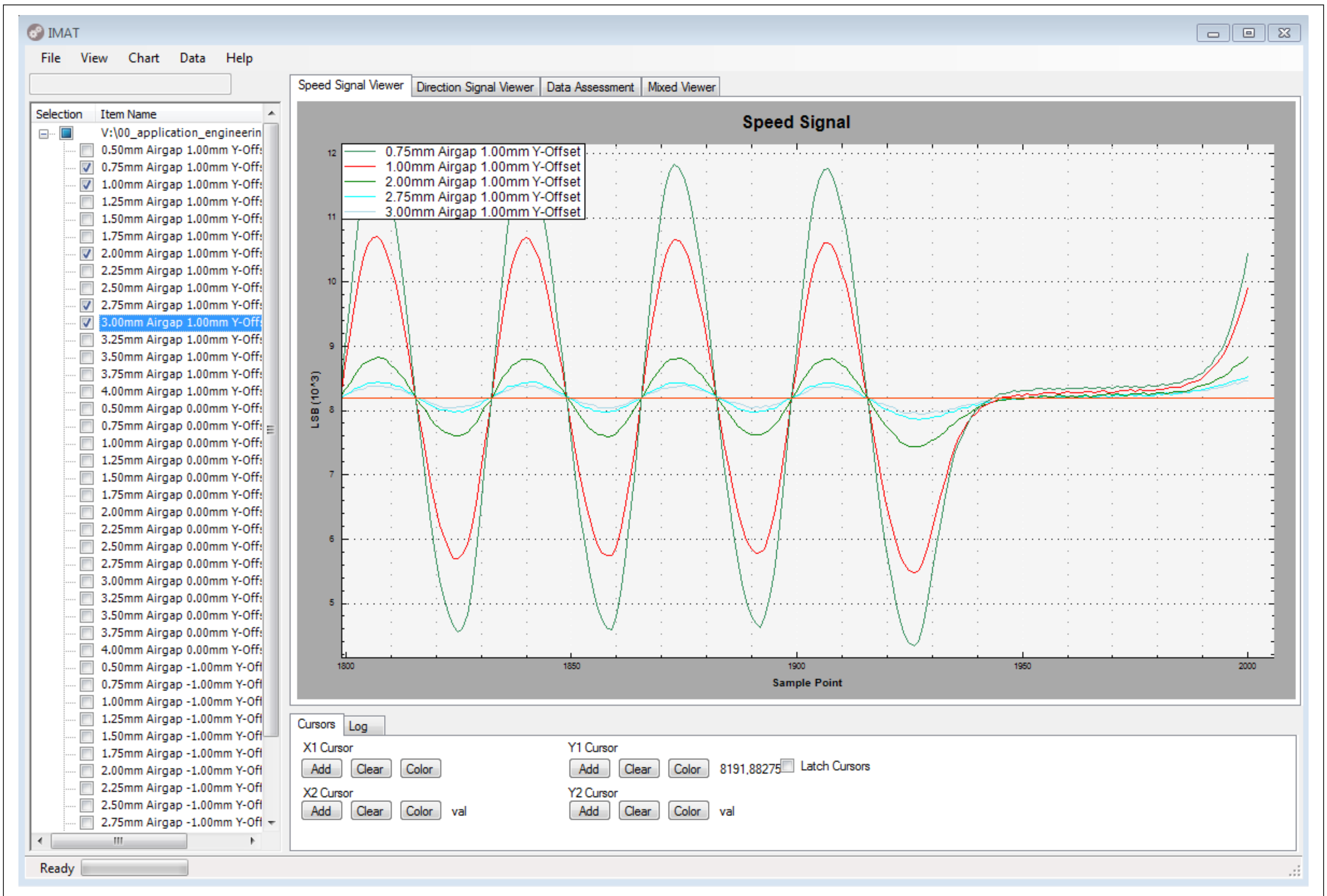

Figure 34 **Screenshot on iMAT**

In ***Figure 34*** a typical working chart is shown: Used tabular is “Speed Signal Viewer” as default after running this tool. Through “File”, “Load Data File” a text file following some syntax with a proper header or alternatively a tdms-file from NI-Labview(c) can be imported.

The left area shows the available mappings with a short description as imported from the file. There is one line for each mapping. With usage of checkboxes the lines will be displayed in the right area.

At the bottom there are 4 cursors available to be placed in the chart manually. These cursors help to measure phase accuracy, hysteresis, minimum switching signal and indicate the switching threshold which is in TLE4929C at 8192. Please find the red horizontal line in ***Figure 34*** .

5.1 Maximum air gap assessment

To assess the maximum air gap capability the mappings at the maximum position tolerance (maximum air gap) have to be accessed.

Considering following example for minimum air gap assessment:

- A narrow trigger-wheel: therefore the center position and an axial shift (Y-axis) of +/-1mm is captured
- 1.0mm to 3.0mm as used air gap range: 3.0mm is the maximum air gap
- TLE4929C/TLE4959x is programmed to a minimum threshold of 1.5mT: This value is reflected to 77LSB's in the digital core of TLE4929C/TLE4959x

The switching threshold of TLE4929C/TLE4959x is at 8192LSBs. To know upper and lower threshold for the minimum signal the calculation is as follows:

Upper limit = 8192 + 77/2 = 8231LSBs (red horizontal line in ***Figure 35***)

Lower limit = 8192 - 77/2 = 8153LSBs (blue horizontal line in ***Figure 35***)

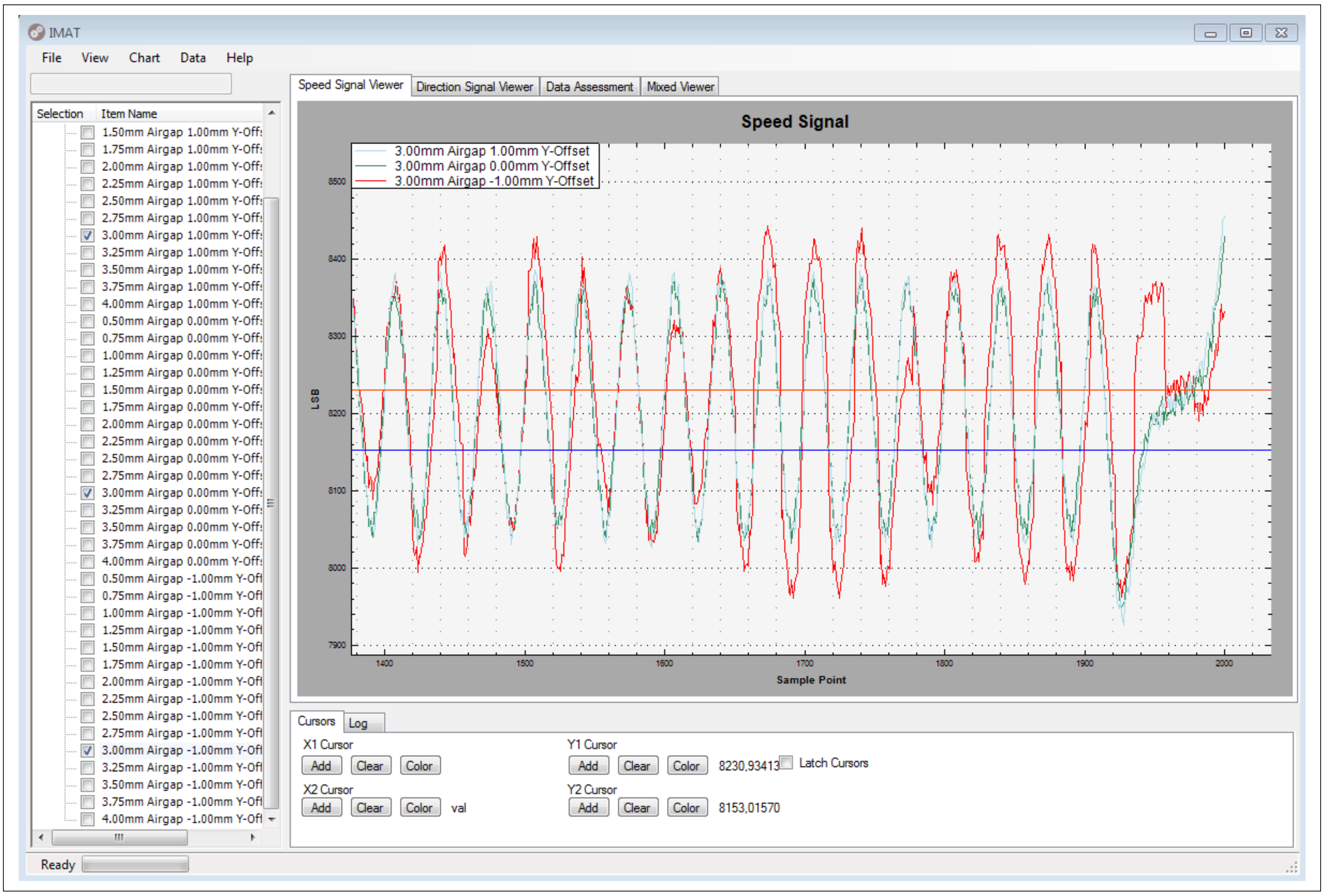

Figure 35 iMAT: maximum air gap assessment

Following all three traces from one end to the other we see each tooth and each notch are passing both thresholds and therefore this EEPROM-setting will work nice for all displacement at this 3.0mm air gap.

This assessment is so far preliminary as there was a magnet used, which was not at the minimum remanence specification and as there was a TLE4929C/TLE4959x used, which was not at the minimum specification as well. The technician calculating the magnet circuit has to add all tolerances not considered in the sample-build during measurement.

5.2 Minimum air gap assessment

Following the example from ***Chapter 5.1*** the minimum air gap is 1.0mm and the proper magnetic mappings of the speed-channel have to be checked in the box.

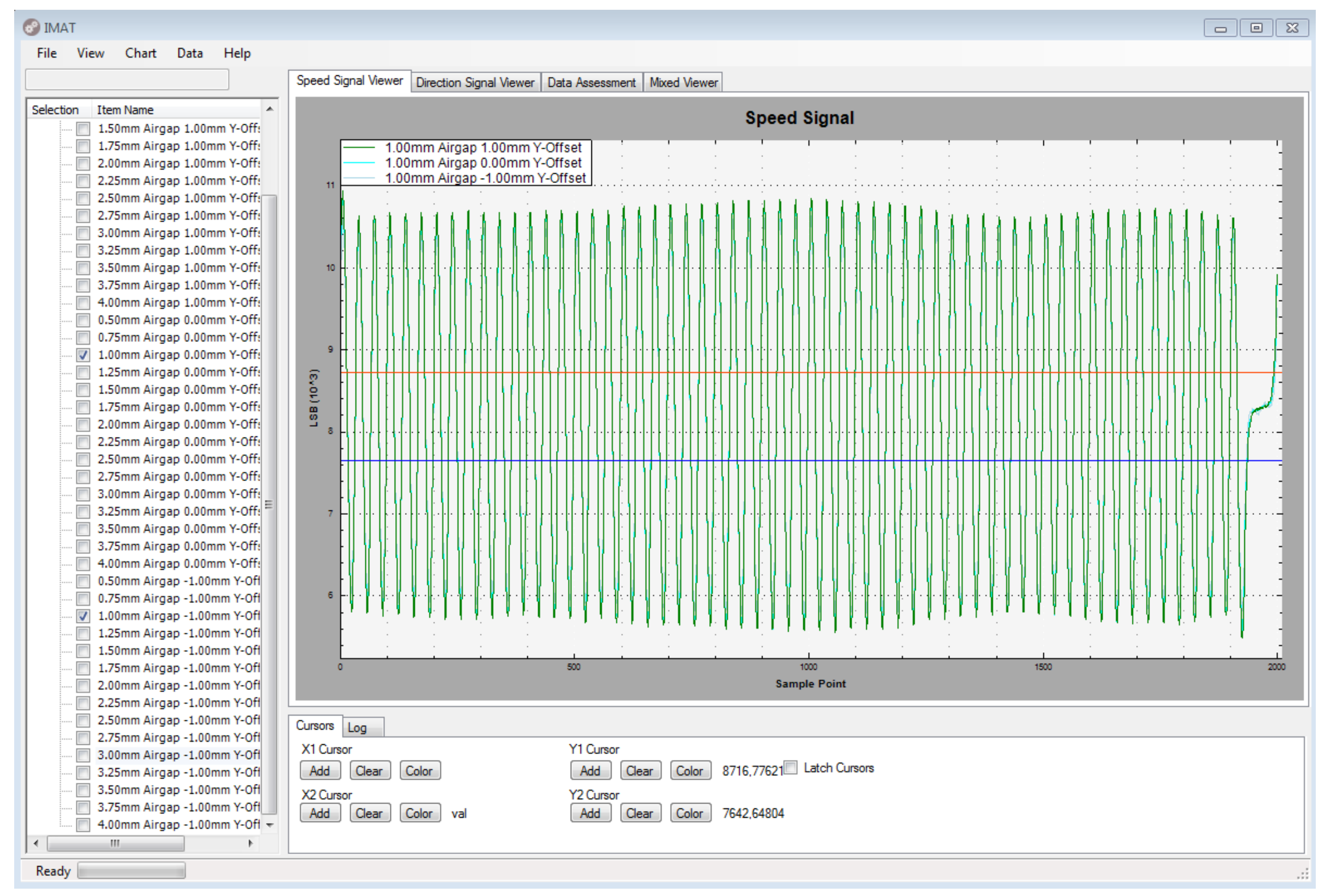

Figure 36 **iMAT: minimum air gap assessment**

Estimating the peak-to peak-signal over one revolution and finding slightly below 5000LSB's in ***Figure 36*** the 25%-hysteresis-threshold (hidden hysteresis) is calculated symmetrically around 8192LSB's.

Looking on all 58 teeth over one revolution no surprising behavior can be seen. There is a signature-region at the end of the mapping where zero-crossing is almost flat, which is typical behavior for two missing teeth. There is a slight overshoot on the teeth at the ends of the signature which is normal behavior as well.

5.3 Maximum runout acceptance / Bent tooth detection

Checking for maximum runout or any bent tooth is done during minimum and maximum air gap assessment.

Watching the traces in ***Figure 36*** a slight amplitude-modulation can be observed. This is the result of different height of each tooth.

When the amplitude is almost constant over one revolution, then we see only small deviation in the height of the speed signal: tooth to tooth runout.

When there is one sine-wave over the 58 teeth we see an eccentric behavior of the trigger wheel which is called global runout.

These assessment of the modulated amplitude can find a bent tooth in the application as well. A speed-channel mapping at the position the sensor is mounted at the engine using the digital diagnosis interface and an automated assessment of the modulation can detect a bent tooth. This check is recommended at end of line at the OEM.

For the case of a magnetic encoder wheel a defective polepair can be recognized as well.

5.4 Phase accuracy

To determine the phase accuracy there is a feature in iMAT. It is a function to normalize all traces to an amplitude of +1 to -1.

All captured traces in the operating area are loaded together in one chart, the switching threshold is set to 0 and on a certain edge two cursors are placed at the edges of the zero-crossing-deviation. Please have a look to ***Figure 37*** for better understanding.

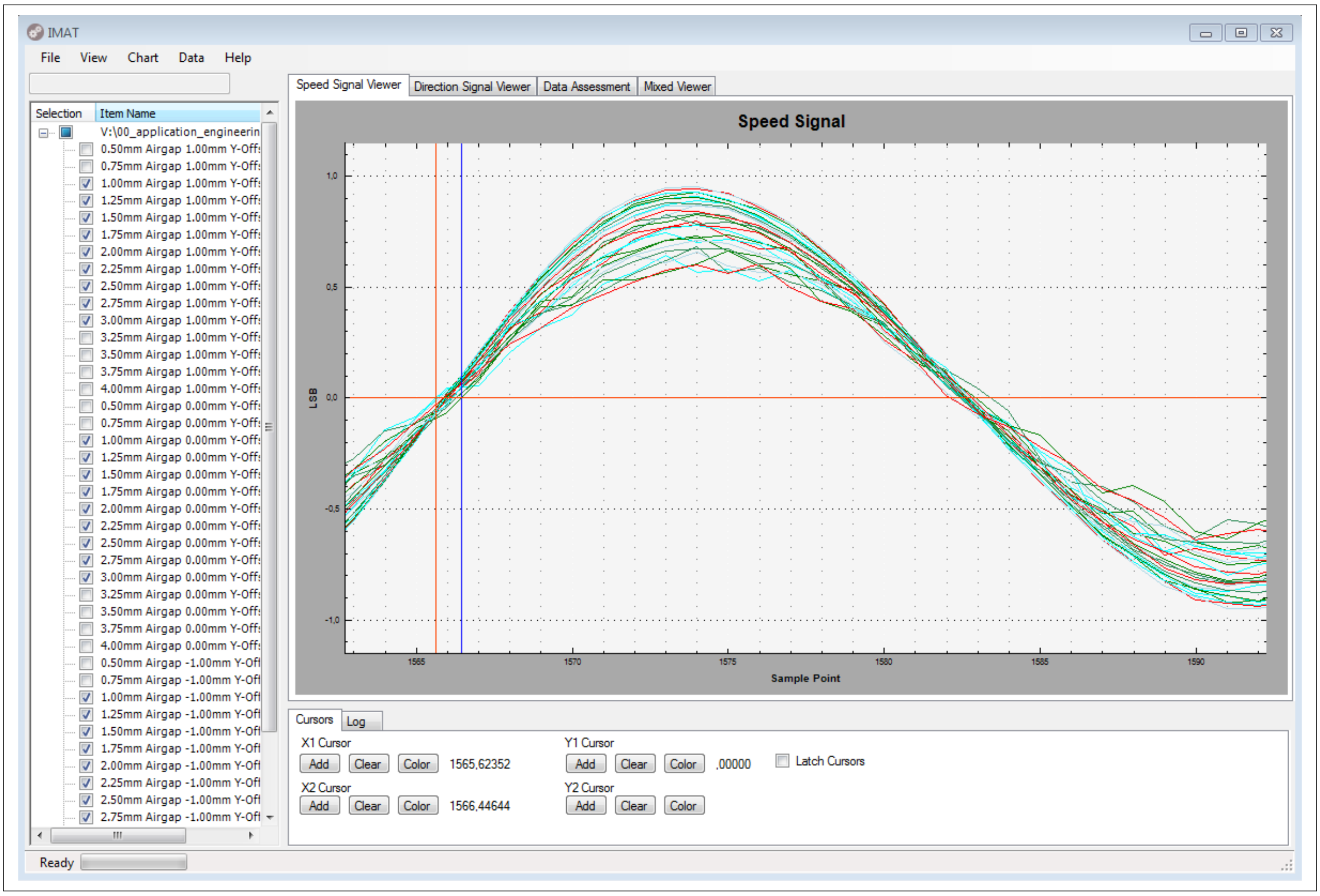

Figure 37 iMAT: assessment of phase accuracy

Now the calculation of phase accuracy follows a simple principle:

First 2000 sample points are considered as one revolution (=360°).

Second the two numbers at the X-axis cursors are read and the full spread of this sample in the allowed mounting position is considered as phase accuracy. The numbers are 1565.6 and 1566.4. The difference out of these two numbers is 0.8. This delta can now easily calculated into 0.14°crank phase accuracy or +/-0.07°crank phase accuracy.

The calculation is as follows: 360° / 2000 *(1566.4-1565.6) = 0.14°crank

6 Compatibility to magnetic speed sensors based on a voltage interface

The TLE4929C-family was designed to meet actual requirements of crankshaft-sensing as well as transmission-shaft-sensing. Through the usage of an EEPROM the TLE4929C, the TLE4959-5U-FX and the TLE4959C-FX can be configured to the functionality of allmost every known differential speed-sensors based on Hall-technology which is targeting the middle of a tooth as switching-point for the falling edge of the output. ***Table 2*** gives a brief summary how to cross-reference existing products in the market to TLE4929C:

Table 2 Cross-reference from existing products to TLE4929C/TLE4959x.

Product	Replaced by	Remark
Infineon: TLE4921-5U	TLE4959-5U-FX	The 4-pin-package of the TLE4921-5U was reused to enable a smooth transition from the existing product into a new technology. The EEPROM and the digital core allow to adjust TLE4959-5U-FX to the flavor of the customers application, which was done in the past with the external capacitor on TLE4921-5U external pin “C”.
Infineon: TLE4924Cx TLE4925Cx TLE4926Cx TLE4927Cx TLE4928Cx	TLE4929Cx	The compatible 3-pin-package allows a one-to-one-replacement of the former generation of crankshaft sensors without direction detection. Through the EEPROM of the TLE4929C various parameters of the former TLE492x-family can be mimiced: - Typical delay-time of 12.5µsec will be transformed to typical 14µsec of the TLE4929C - Switching threshold of 1.4mT or 0.7mT will be transformed to EEPROM-option 1.5mT of 0.75mT. (all values typical) - TLE4929C has options for hidden and visible hysteresis - The fixed hysteresis is replaced by a fixed minimum-hysteresis and for larger field by an adaptive hysteresis
Infineon: TLE4957Cx	TLE4959C-FX	Similar as the TLE4929Cx replaces the TLE492x-family the TLE4959C-FX can be programmed to mimic the TLE4957Cx. TLE4959C-FX is based on the same silicon as TLE4929Cx.
Competitor “A”: A142x A1659x A1692x A1694x A1696x	TLE4929Cx TLE4959C-FX TLE4959-5U-FX	The majority of the crankshaft-sensors in 2017 are based on Hall-technology and trigger the output-switching in the middle of the tooth of the toothed wheel. As long a speed-sensor follows this rule it can be replaced by TLE4929Cx or the twins from the TLE4959x family: - Delay-time can be adjusted in 4 steps: 14 / 17 / 20 / 23µsec - Minimum switching threshold can be adjusted in 4 steps: 0.75 / 1.5 / 2.5 / 5mT - Hidden and visible hysteresis can be adjusted as well. - 8 different protocol for crankshaft are available including the VW(c)-crankshaft-protocol - further 8 transmission-protocol are available including programmable pulses for “STAND STILL”, “HIGH_SPEED” and “START_UP”
Competitor “M”: MLX90294	TLE4929Cx	

7 Frequently Asked Questions

This section will be updated regularly as questions from our customers arrive. In the case your copy of this document is older than one year please verify the latest version at www.infineon.com.

7.1 Is there a tool for productive environment available?

Yes! HITEX(C) is a partner of Infineon and is providing a productive programming tool. A separate manual referring to the programming tool is available as well. Please find the following contact persons who will assist:

Technical: Dr. Kurt Böhringer, Head of Engineering, Tel. : +49-721-9628-195

Cell: +49 172 816 16 86, E-Mail: kurt.boehringer@hitex.de

Commercial: Michael Weiß, Senior Account Manager – Embedded Solutions, Tel. : +49-721-9628-144

Cell: +49-151-29196467, E-Mail: Michael.Weiss@hitex.de

7.2 Why not use the Evaluation-Tool instead of programming with productive programmer?

The Productive Programmer was designed to withstand harsh environment and doing millions of programming-cycles. There is support from HITEX(c) available on a base of 24h and seven days a week.

In opposite the Evaluation Tool was designed to support the evaluation in laboratory giving also a limited number of programming-cycles as there are electric-mechanical switches used. The software is a closed environment not allowing the user to interact with the line-control.

7.3 What is the robustness against stray field?

Based on a differential principle the TLE4929Cx -family is robust against external homogenous magnetic field as it is cancelled by subtracting the two outer Hall-probes from each other.

Tolerances in displacement will not affect the output-switching as the effect is too small to create wrong switching.

Direction-channel is a single sensing element and might be harmed by external magnetic stray field. The Hall element is not able to sense if magnetic field is induced from application or if magnetic field is induced from external distortion. Two internal mechanism avoid to follow the complete external distortion but cannot compensate completely. Wrong direction might be issued in the case external magnetic stray field is exceeding roughly 40% of the generated field by the application. To get a wrong direction information a certain ratio of speed-signal-frequency and external distortion frequency has to match.

7.4 How to increase robustness against stray field?

In an application with large magnetic distortion following measures can improve the behavior on magnetic distortion:

- Reducing the maximum air gap in the application avoids small signal amplitude in direction-channel.
- Increasing the strength of the back-bias magnet increases the direction-signal as well.

7.5 Is an EMC-report available?

The TLE4929C/TLE4959x-family has been characterized according to the IC level EMC requirements described in the "Generic IC EMC Test Specification" Version 2.1 from 2017.

An EMC-testreport can be shared on the following tests performed on IC level:

- Conducted Immunity - Direct Power Injection (IEC 62132-4)

- Conducted Emission - 150ohms Direct Coupling (IEC 61967-4)
- Pulse Immunity – Direct Coupling (ISO 7637-2)
- Pulse Immunity – Capacitive Coupling (IEC 62215-3)

Additionally component level EMC characterizations according to ISO 7637-2:2011, ISO 7637-3:2007 and ISO 16750-2:2010 regarding pulse immunity and other OEM-specific test have been performed.

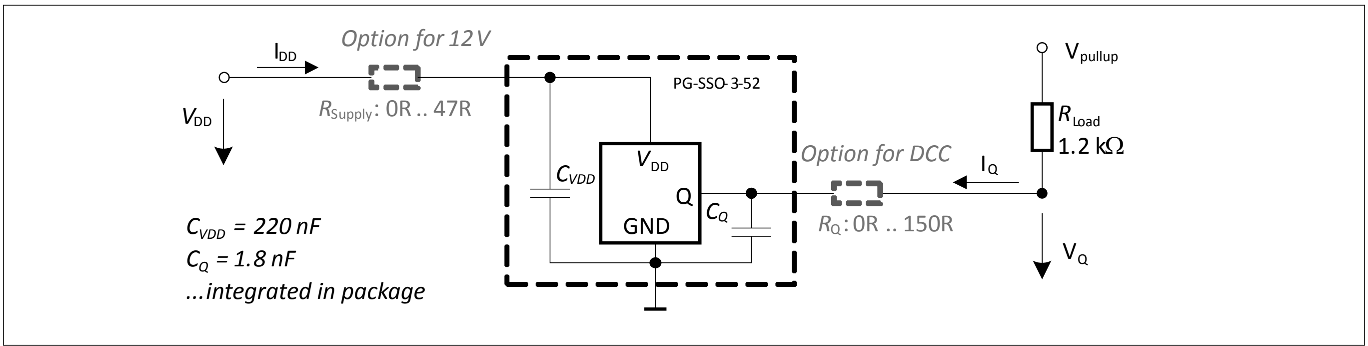

Figure 38 Application circuit: EMC passing all tests

Figure 38 outlines all needed external components to operate the DUT under application conditions. The (additional) outlined components can effect the final EMC result. They are treated as inherent part of the DUT during component level EMC characterizations.

7.6 Can TLE4929C withstand OEM-test EQ/IC11?

Yes, TLE4929C withstands EQ/IC11 in 5V application without external circuitry.

7.7 Can TLE4929C withstand OEM-test RI130?

Yes, TLE4929C withstands RI130 when using a RSupply of 47R as indicated in *Figure 38*.

7.8 Can TLE4929C withstand OEM-test DCC?

Yes, TLE4929C withstands DCC when using a RSupply of 47R and a RQ of 150R as indicated in *Figure 38*.

7.9 Can TLE4929C withstand OEM-test ICC?

Yes, TLE4929C withstands ICC when using a RSupply of 47R as indicated in *Figure 38*.

8 Revision History

Revision	Date	Changes
1.1	2018-09-20	Editorial changes; added TLE4959x; added TLE4929C-XVA; added chapter to explain TC
1.2	2020-11-16	Added XHA-Variants; addes X2A-Variant; added chapter Adjust the proper k.factor; added chapter Adjust the proper offset update algorithm; added chapter When to enable the HYBRID watchdog

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