Optical Sensors

Encoding and Code Wheel Proposal for TCUT1800X01

By Sascha Kuhn

INTRODUCTION AND BASIC OPERATION

The TCUT1800X01 is a 4-channel optical transmissive sensor designed for incremental and absolute encoder applications. The sensor combines two infrared (IR) emitters with four detector channels within a small surface-mount (SMD) package (see Fig. 1 and Fig. 2).

In combination with an application-specific code disc or strip, the sensor is ideally suited for a wide range of applications, such as rotary switches, incremental turn switches, speed and motion control systems, and many more.

The integration of four channels into one compact automotive-qualified package (to 110 °C) also makes the sensor an excellent selection for more complex applications, such as automotive steering wheel encoding, where multiple channels of redundancy are required.

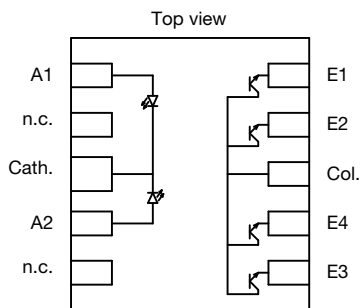Fig. 1 - TCUT1800X01 Multichannel Optical Sensor

Fig. 2 - Pin Layout

ABSOLUTE VS. INCREMENTAL ENCODING

Depending on the application, the sensor can work as an absolute or incremental encoder. The differences between the operating modes are shown in Fig. 3.

Used as an absolute encoder, the TCUT1800X01 provides up to 16 different binary states. The application can decode this binary code and directly translate the information to determine at which of the 16 different positions the object is located.

A typical example for this could be a climate control turn switch in a car. Here you might use the 16 stages to select between off and 15 °C to 30 °C, up to 16 airflow levels, or combinations of air exit locations.

For applications requiring more than 16 stages, incremental encoding could be the solution. Unlike absolute encoding, incremental encoding does not provide direct position information. However, it will provide information based on the relative distance a code wheel or strip moved and in what direction the motion was.

This information can be processed by a microcontroller counting up or down to virtually generate an unlimited number of stages.
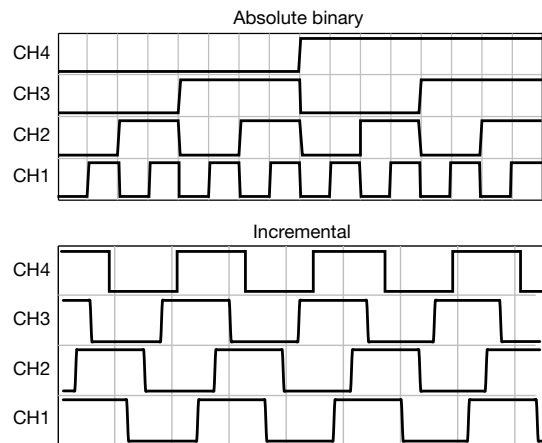

Fig. 3 - Signals for Absolute and Incremental Encoding on Each of the Four Channels CH1, CH2, CH3, CH4; Channels 1, 2, 3, 4 Are Equal to E1, E2, E3, E4 in the Pin Layout of Fig. 2

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Fig. 3 shows different output signal stages of the four detectors for the two operation modes.

In the example for absolute encoding, the four digital outputs change according to the binary code. Gray code is preferable in most applications to reduce the potential risk of a position error. More details about potential design margins will be explored in later sections of this document.

The incremental encoder example shows the transitions at every 45° of motion. This doubles the resolution vs. typical dual-channel sensors, which have only 90° phase shift information. However, this is only one application for incremental encoding. The sensor can also be used in fail-safe applications, where CH1 and CH2 have a phase shift of 90° and CH3 and CH4 sense the same. Depending on the application, the code disc may need to be adapted to have the correct phase shift between the channels.

Another application is to use two channels for incremental encoding and the other channels for absolute encoding.

CODE WHEEL OPTIONS

Regardless of absolute or incremental encoding, a code wheel or strip is required to operate the sensor. There are various technologies on the market for generating such code wheels or strips. The most common technologies are summarized in Table 1.

Each code wheel or strip is composed of optical translucent or opaque segments, which either block or pass the IR light. The four detector channels will translate the received IR light into electrical signals, which can be further processed by the next stage circuitry.

Fig. 4 shows an example of custom code wheels and strip geometries with code tracks adapted to the sensor geometry.
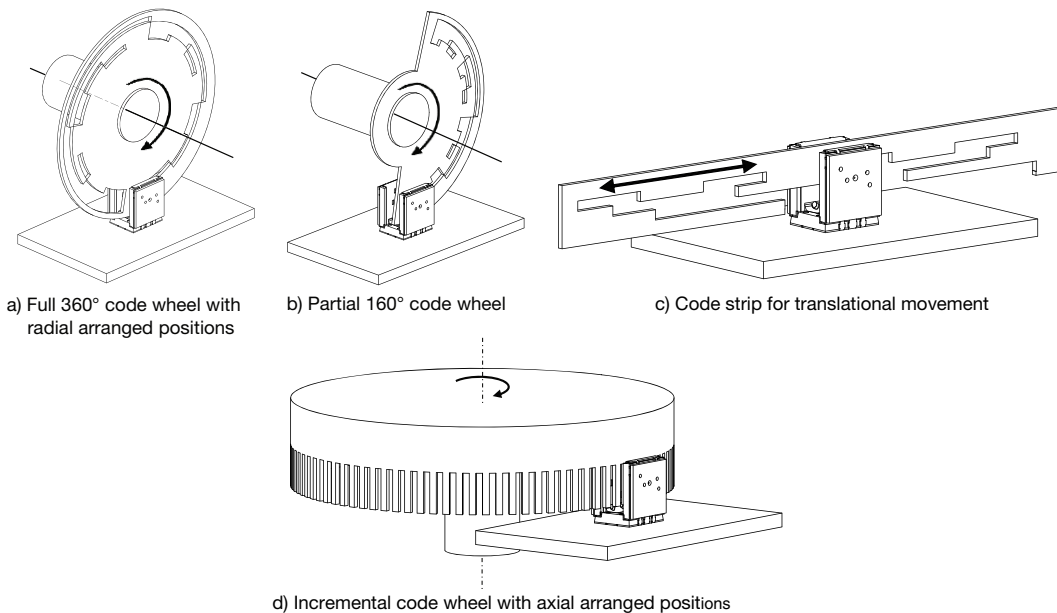

a) Full 360° code wheel with radial arranged positions

b) Partial 160° code wheel

c) Code strip for translational movement

d) Incremental code wheel with axial arranged positions

Fig. 4 - Example of Code Wheels and Code Strip

TABLE 1 - TECHNOLOGIES FOR CODE DISK, STRIPS, AND WHEELS			
TECHNOLOGY	**COST**	**ACCURACY**	**DESIGN FREEDOM**
Injection molding	Low	Good	Many geometries are possible, depending on the complexity of the molding tool
Blade punching	Low to high	Good	Difficult for complex geometries
Blade etching	High	Very good	Difficult for complex geometries
Hot foil molding / stamping	Low to high	Medium	Difficult for complex geometries
Foil printing	Low to high	Very good	Limited to plane geometries

Note
- REM: rating based on customer feedback and experience

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Table 1 only contains the most common technologies used for this kind of code disc / strips. Another technology not listed, which does have the capability to pass and block IR light and has enough resolution, might also be capable.

DESIGN MARGINS

The chapter "Limitations for Outer Code Wheel Dimensions" reviews the limitations for outer code wheel dimensions in terms of the sensor gap (see Fig. 5). Based on this, proposals are made in the chapter "Vertical Channel Displacement in the Sensor Gap" and "Horizontal Channel Displacement in the Sensor Gap" to find the best encoding structure.

LIMITATIONS FOR OUTER CODE WHEEL DIMENSIONS

For code wheels with radial arranged position encoding (see Fig. 4 a) and Fig. 4 b)), the limiting factor is the detented positions, which need to be arranged circumferentially around the code wheel. Therefore, in this case the limiting factor is not the sensor geometry. Instead it is the geometry and tolerances of the code wheel itself.

For code wheels with axial arranged positions (refer to Fig. 4 d)), some limitations are due to the width of the TCUT sensor (see Fig. 5).

TABLE 2		
TOLERANCE RANGE CODE WHEEL	THICKNESS OF CODE WHEEL	MINIMUM CODE WHEEL DIAMETER (CALCULATED)
± 0.5 mm	1.4 mm	> 32 mm
± 0.5 mm	1 mm	> 16 mm
± 0.5 mm	0.7 mm	> 12 mm
± 0.3 mm	1 mm	> 11 mm

Note
- Sensor parameters: tolerance of sensor = ± 0.15 mm, nominal gap of sensor = 3 mm, nominal width of sensor = 5.85 mm

VERTICAL CHANNEL DISPLACEMENT IN SENSOR GAP

The four apertures / detector channels, as well as the positions of the two IR emitters' sources, are well engineered (see Fig. 1) and controlled to guarantee that they function over a certain permissible range. The range for each channel is depicted in Fig. 6.

The TCUT1800X01 is designed to provide a constant vertical distance between the channel ranges in the center of the sensor (see Fig. 6). Fig. 6 helps to find suitable encoding tracks / segments for the sensor. The encoding structure can be adapted according to the distances and the orientation of the channels in the gap.
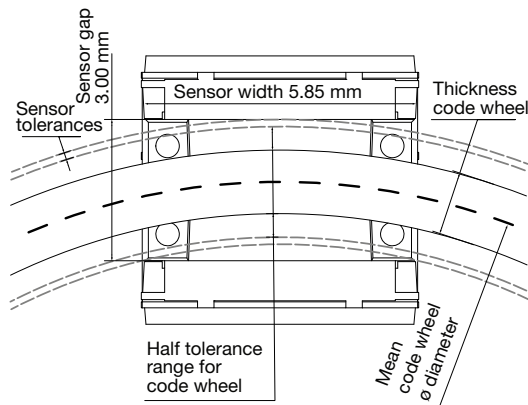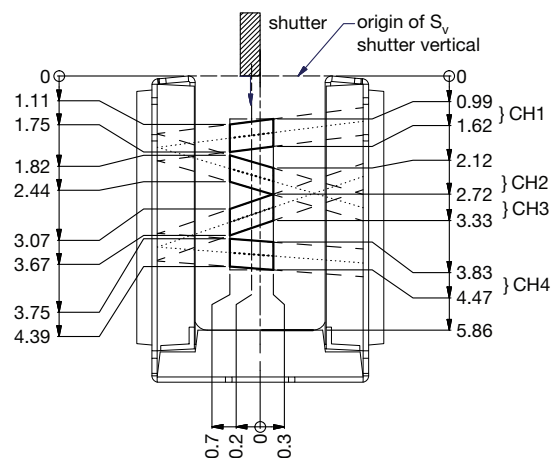

Fig. 5 - Code Wheel Design for Axial Arranged Encoding Positions: Picture Shows a TCUT Sensor From the Top View With the Encoder Ring Arranged at an Optimum Position

In Fig. 5, within the sensor gap the tolerances of the sensor and of the code wheel need to be considered (see dotted lines). Furthermore, the thickness of the code wheel and the sensor width determine the minimum allowed code wheel diameter (see Table 2).

Table 2: examples of code wheels with axially arranged encoding positions within the sensor gap. The minimum code wheel diameter is calculated by the geometrical conditions in Fig. 5.

Fig. 6 - Range for Each of the Channels in Vertical View on the Sensor

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Furthermore, with Fig. 6 and the code wheel or strip design, the allowed assembly sensor tolerances (code wheel, PCB, sensor soldering on the PCB) can be easily evaluated in the two dimensions: y and x. If the small portion of light scattering or multiple reflections can be neglected, which cause crosstalk issues, then the following description helps to identify the tolerance range or position between code tracks and the sensor (two directions: y and x):

1. As long as the code track edges do not overlap with the channel ranges in Fig. 6, no influence on the signal output is expected

2. If one of the code track edges moves into the channel range and the code track belonging to the channel, then a light shading can occur that reduces the signal of the one channel. The amount of signal reduction depends on the overlap of the code track edge and the channel

3. If a code track edge overlaps a neighboring channel, the crosstalk can cause a signal increase in that channel

Generally speaking, boxes in Fig. 6 within each of the channels are the optical active region used for optical encoding (light blocking and light passing features). Features outside do not influence the optical encoding application. For further details, refer to the chapter "Application of Absolute Encoding".

HORIZONTAL CHANNEL DISPLACEMENT IN SENSOR GAP

The TCUT1800X01 also features apertures on the emitter side (see Fig. 1). These apertures partially overlap the emitter die in order to cut off unwanted light and only allow for IR light in the wanted direction.

Therefore, emitter 1 only radiates the left side (to detector 1 and 2). The emitter aperture blocks direct light towards detector 3 and 4. Despite that, a sensor without a code wheel has a maximum crosstalk of 10 % to the other transistors, which are blocked by the aperture. This is due to the reflective metallic surfaces in the sensor gap. It is the same for emitter 2, just in the opposite way. Emitter 2 is directly irradiating detectors 3 and 4, and the emitter aperture blocks direct light towards detectors 1 and 2.

Sensor crosstalk can be eliminated by powering only one emitter of the two channels that are read. Then in the next step, switch the IR emitter off and the other on to read the other two channels.

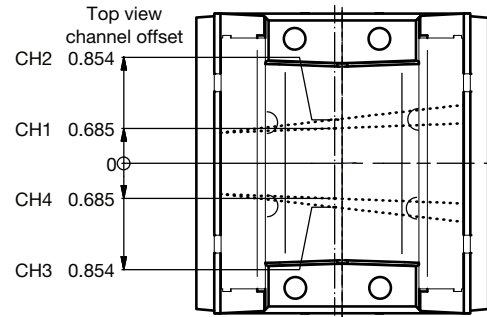The nominal optical centers of all four channels are shown in Fig. 7.

Fig. 7 - Top View of the TCUT1800X01 With Optical Axes of all Four Channels

EFFECT OF CODE WHEEL DISPLACEMENT

The structure of the code wheel geometry (see Fig. 4) has to be aligned to the channels within the sensor gap (see Fig. 6 and Fig. 7). In addition, the encoding structure needs to be aligned to the rotational axis so that the entire detection range can be used.

Therefore, in Fig. 4 (a to c) the code wheel is made of four circumferential code tracks (four is the maximum possible code tracks for the TCUT1800X01 - equal to 4 bits). Each of the code tracks has a different sequence of light-blocking and light-passing features, which enables a distinct determination of position for absolute encoding (also see Fig. 3).
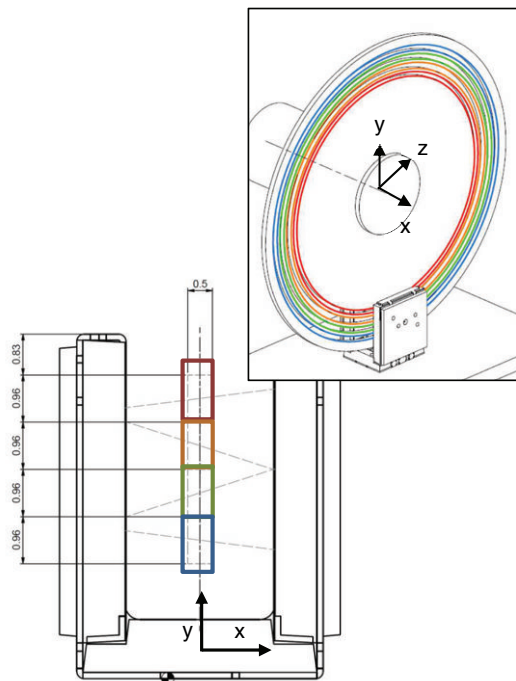

Fig. 8 - Each Code Track of the Code Wheel is Arranged to One Channel of the Sensor Over the Entire Rotation of the Code Wheel

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In Fig. 8, an error displacement of the code wheel in each direction (x, y, and z) can cause crosstalk or cut off a channel when the code tracks touch the other channels. Therefore, the displacement or tolerances between the sensor and code wheel or strip are limited.

Fig. 9 illustrates a large displacement of the code disc in the gap (x-direction). The light, which passes at nominal distance in the center, will be partially or even completely blocked when it is displaced within the gap.

The permissible offset depends on the size of the code wheel openings and also the width of the code wheel.
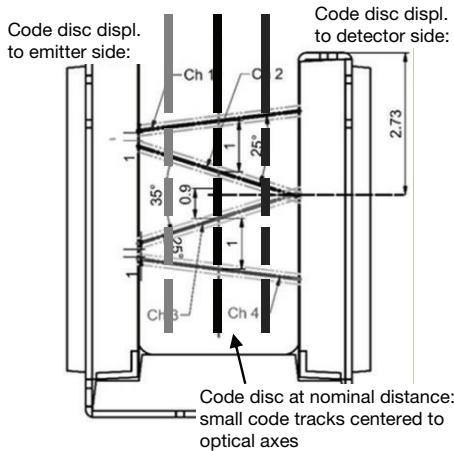

Fig. 9 - Side View of the TCUT1800X01 With Ray Path of the Emitters and Code Disc

Fig. 10 shows an example of permissible code wheel location tolerances. This example is only valid for a geometrically optimum code disc. The two directions shown in Fig. 10 are critical for tolerance in absolute encoding. Both directions influence each other in terms of absolute tolerance range. According to Fig. 10, if the tolerance of a code disc can be kept below ± 0.1 mm in the x-direction, then the allowed tolerance range in the y-direction is ± 0.25 mm.

Working Range of Code-Wheel With 0.5 mm Thickness and 0.96 mm Code-Track Height
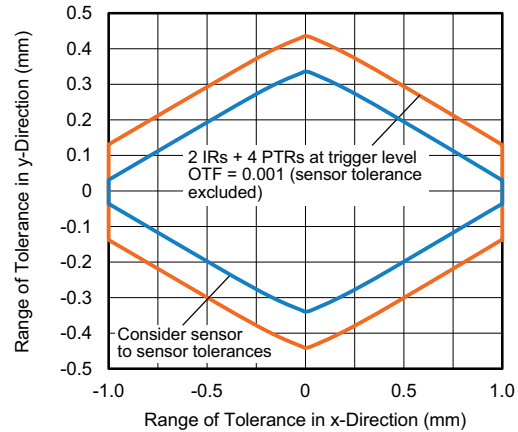
Fig. 10 - Tolerance Range of a Code Wheel (x-direction - horizontal position within the gap, and y-direction - vertical position within the gap (also see Fig. 8)) Using the Sensor-Optimized Code Wheel Geometry (refer to the chapter "Application of Absolute Encoding")

Fig. 10 misses the tolerance in the z-direction, e. g. when the rotary axis is not aligned to the sensor. Usually at z-tolerances < ± 0.5 mm and at a code disc radius of > 20 mm, the tolerance can be neglected. In principle the tolerance of the code disc in the z-direction reduces the tolerance range in the y-direction by

$$R - \sqrt{R^2 + \pm\, y^2},$$

or for a code wheel in the x-direction.

The above deals with consequences when there are code tracks arranged at different heights in the sensor gap. This is particularly of interest for absolute encoding. However, incremental encoding is only one code track in the entire sensor gap. Therefore, the vertical displacement (see Fig. 6) of channels is not of interest. For incremental encoding, only the x-direction has some influence on the relative distances between the signals. Fig. 7 shows the optical center between each channel.

APPLICATIONS OF ABSOLUTE ENCODING

In Fig. 3 the TCUT1800X01 sensor is used as an absolute encoder and can detect up to 16 different binary states. Due to signal processing reasons, the 16 binary states are arranged differently than standard binary counting. The gray code is a different sequence in which only one bit changes to the next position (see Fig. 11).

During operation, each channel of the sensor has to be kept within each of the four code tracks (X1 to X4). Ideally, the code tracks should not move relative to the sensor channels over the entire operational range. In each of the code tracks, different light-blocking and light-passing sequences are considered to determine absolute signal positions.

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In Fig. 11, four code tracks with different sequences together result in a 4-bit gray coding (X1 to X4) of the signal out of the sensor, which looks like Fig 3.
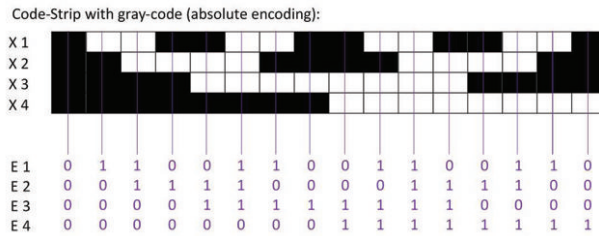

Fig. 11 - General 4-bit Gray Code: X1 to X4 Are the Code Tracks in the Code Wheel or Strip and E1 to E4 Are the Corresponding Signal Outputs of the Phototransistors of the Sensor

The code tracks X1 to X4 in Fig. 11 can be arranged in a strip or radial / axial to the code wheels. As an example, the position of the four code tracks are shown in a cross-sectional view in Fig. 12 (X1 to X4). In the current picture, X1 and X3 are transmitting the light (leads to "high" at the detector output) and X2 and X4 are blocking the light (leads to "low" at the detector output).

During operation (movement or rotation of the code wheel), the code tracks need to always be kept at the same position. Each of the code tracks includes individual light-blocking and light-transmitting states during movement or rotation.
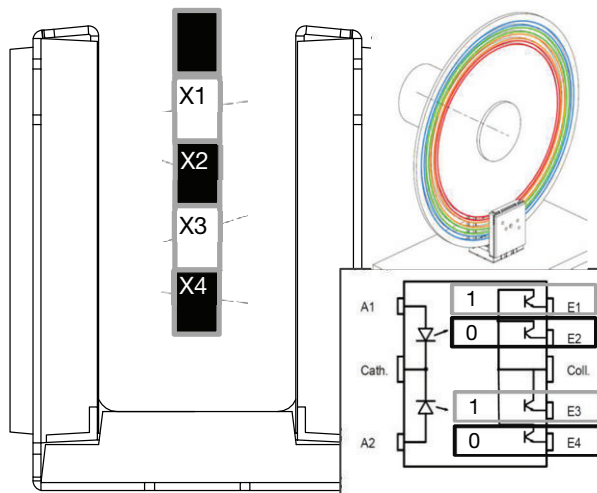

Fig. 12 - Side View of the TCUT1800X01 With Ray Path of Emitters and Sketch of the Code Tracks
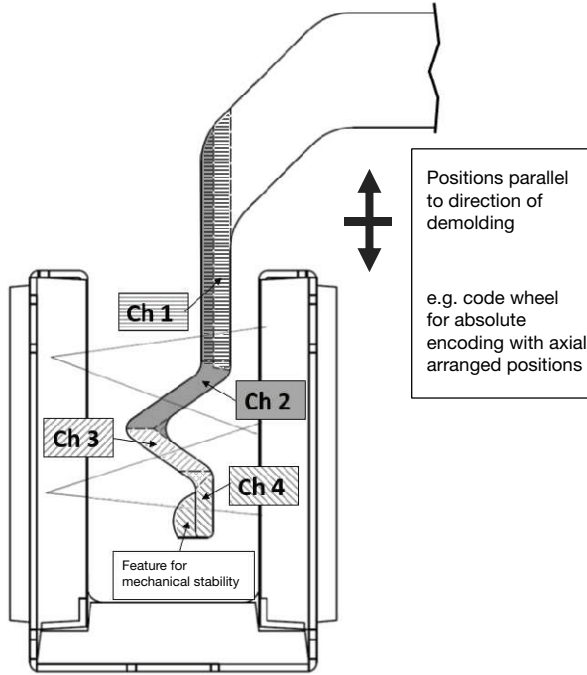
CODE TRACK PROPOSAL, 4-BIT

The code wheels and strips were designed according to the following sequence:

1. Cross-sectional 2D sketch of code tracks (X1 to X4) in Fig. 6: each code track fully overlaps the four channels in the figure. Code track edges are designed in between the channels outside the optical active region

2. The minimum distance between code track edges and the range of the four channels define the allowed tolerance range

3. Based on the 2D sketch design, the 3D model with code tracks and the mechanical interface

4. Arrange the gray code structures in each of the code tracks (see the chapter "Displacement Code Tracks")

5. Align the structures in each code track according to the horizontal displacement of the axes (see Fig. 7)
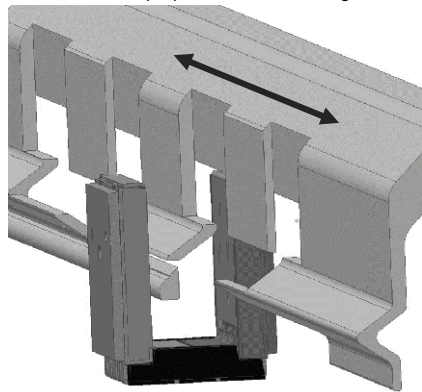
Code Tracks Parallel to the Direction of Demolding

Fig. 13 shows a proposal for how to best fit the code tracks into the TCUT1800X01. This arrangement is a proposal in terms of the maximum allowed tolerances of the code strip or wheel in the sensor gap (this approach is based on the description in the chapter "Limitations for Outer Code Wheel Dimensions"). Code track edges are nominal at the largest distances between the four channels. The drawing is only an example and designed according to design rules for an injection molding process and with the help of Fig. 6. The minimum mold wall thickness kept is 0.3 mm. Fig. 13 a) shows the arrangement of the code tracks in a cross-section cut. Fig. 13 (b and c) are an extrusion of a) in a strip and wheel, and the code tracks structured in gray code series as shown in Fig. 11.
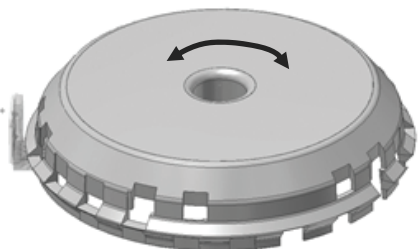
APPLICATION NOTE

Encoding and Code Wheel Proposal for TCUT1800X01

Positions parallel to direction of demolding

e.g. code wheel for absolute encoding with axial arranged positions

a) Cross-section view on four code tracks – direction of movement is perpendicular to drawing area above
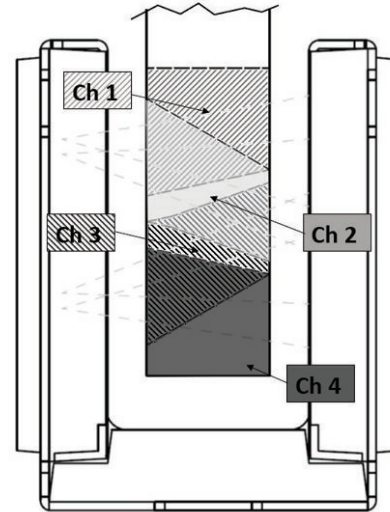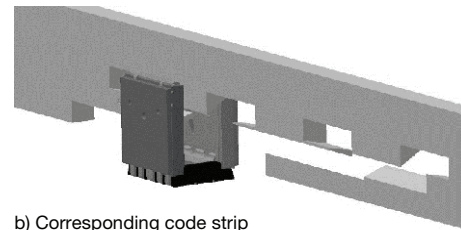

b) Corresponding code strip

c) Corresponding code wheel

Fig. 13 - Geometry Proposal for the Arrangement of Code Tracks (a) if They Are Arranged Parallel to the Direction of the Demolding of the Code Strip or Wheel (b and c)

Code Tracks Perpendicular to the Direction of Demolding

a) Cross-section view of four code tracks - direction of movement is perpendicular to drawing area above - overlaid in one picture. Clearer pictures of the code tracks are shown in APPENDIX II

b) Corresponding code strip

c) Corresponding code wheel

Fig. 14 - Geometry Proposal for the Arrangement of Code Tracks (a) if They Are Arranged Parallel to the Direction of the Demolding of the Code Strip or Wheel (b and c)
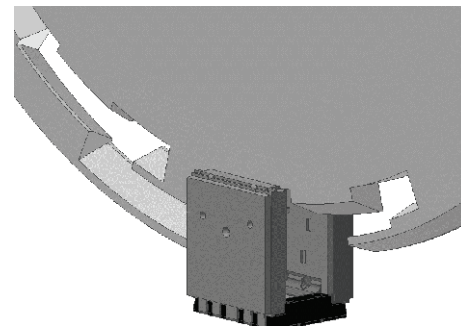
In other application cases, the manufacturing of the code wheel or strip can be realized differently. For example, the demolding direction can be arranged perpendicular to the encoding position features in the code wheels or strip. In this case the draft angles at each code track can be adapted according to the channels in the sensor gap.

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Encoding and Code Wheel Proposal for TCUT1800X01

CODE TRACK PROPOSAL, 3-BIT

The TCUT1800X01 sensor can also be used as a 3-bit absolute encoder. In that case, CH2 and CH3 can be connected in parallel. Fig. 15 is an example of the 3-bit code strip or wheel, which is designed with the help of Fig. 6.
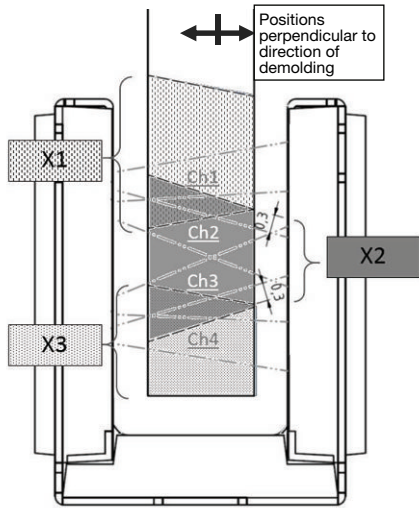
a) Cross-section view of three code tracks (X1 to X3 - direction of movement is perpendicular to drawing area above) and the range of the four channels (CH1 to CH4) within the sensor gap
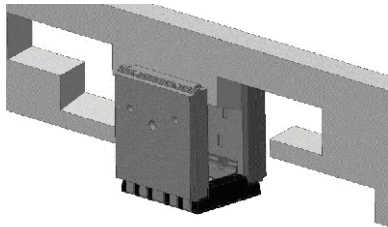
b) Corresponding code strip

Fig. 15 - Geometry Proposal for the Arrangement of Code Tracks (a) if They Are Arranged Parallel to the Direction of the Demolding of the Code Strip

DISPLACEMENT CODE TRACKS

First, the vertical position of code tracks in the sensor gap (refer to the chapters "Code Track Proposal, 4-Bit" and "Code Track Proposal, 3-Bit") in the x-y section of Fig. 6 is aligned. After that the horizontal shift of code tracks needs to be performed according to Fig. 16 in the z-direction.

The upper part of Fig. 16 shows a section of a standard gray code. Black segments blocking the light result in a low signal and white segments passing the light result in a high signal in the sensor.

Below, the four code tracks (X1 to X4) shift according to S1 to S4. The shift of code tracks in the z-direction is performed due to the different position of the channels in Fig. 7 (x-z direction).
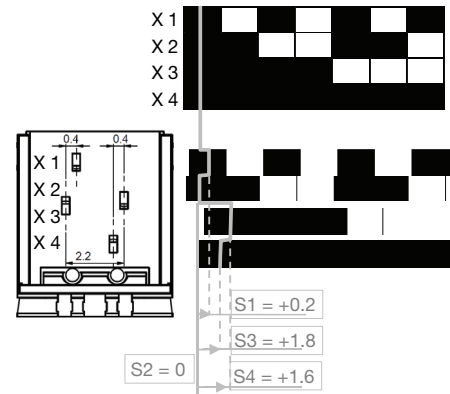

Fig. 16 - Code Track Shift of 4-Bit Binary Absolute Code

Considering the divergence of the light sources in Fig. 7, the following shift is estimated, assuming the code wheel or strip is in the center of the gap:

X2 to X1 = 0.2 mm shift

X2 to X3 = 1.8 mm shift

X2 to X4 = 1.6 mm shift

APPLICATIONS AND INCREMENTAL ENCODING

If the TCUT1800X01 is used for incremental encoding, then bars are arranged perpendicular to the direction of movement (vertically arranged bars).

For incremental encoding (see Fig. 3), a code wheel with a bar width of 1 mm is recommended.

In Fig. 17, a section of a binary absolute encoding strip is shown (gray rectangular blocks → blocked light 0; white → transmissive slit 1).

Depending on the application of the sensor, a suitable bar width and bar distance needs to be chosen.

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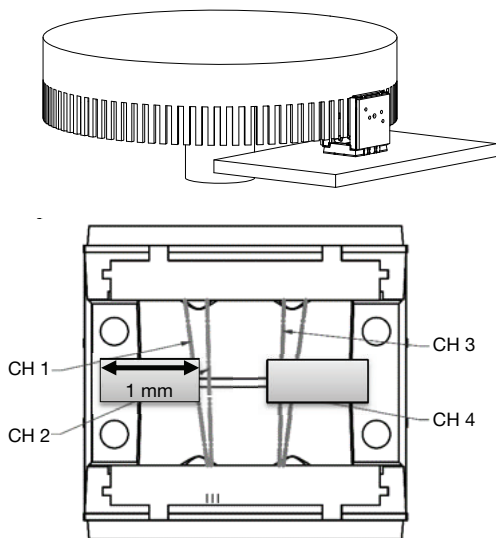# Encoding and Code Wheel Proposal for TCUT1800X01

Fig. 17 - Top View of Sensor and Bar Width for Incremental Encoding

SENSOR PROPERTIES AND SIGNALS

Fig. 18 shows the relative signal changes of the four detectors (CH1 to CH4) if a shutter with a thickness of 0.5 mm is moving between both domes from the top to the bottom. All four channels are blocked at a different height of the shutter (1 → 0).

In Fig. 19, the shutter is moved horizontally. At negative positions all channels are blocked by the shutter. When the shutter moves out of the sensor in a positive direction, the channels will be unblocked, starting with the outer CH2 and ending with CH3.
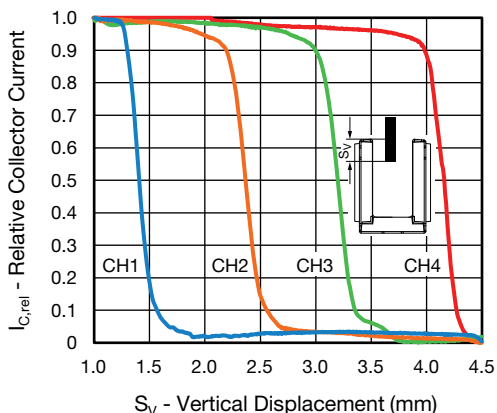

Fig. 18 - Vertical Shutter - a Mechanical Shutter is Moving in Between Both Domes
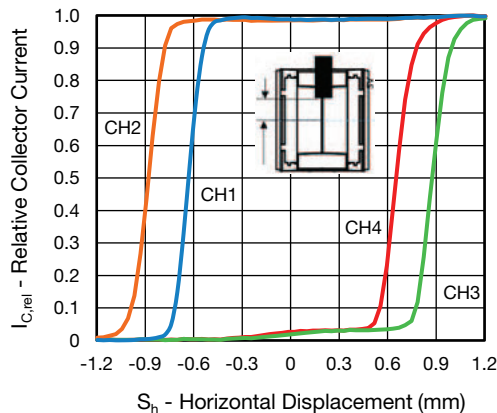

Fig. 19 - Horizontal Shutter - a Mechanical Shutter is Moving in Between Both Domes

SIGNALS

In Fig. 20, a simple electrical circuit is shown. The signal outputs are determined voltage levels at the four transistor outputs. Fig. 20 shows only half of the elements of the TCUT1800X01. Due to the symmetrical arrangement, the same is valid for emitter 2 on the left side and then the corresponding detectors 3 and 4 on the right side of Fig. 20.
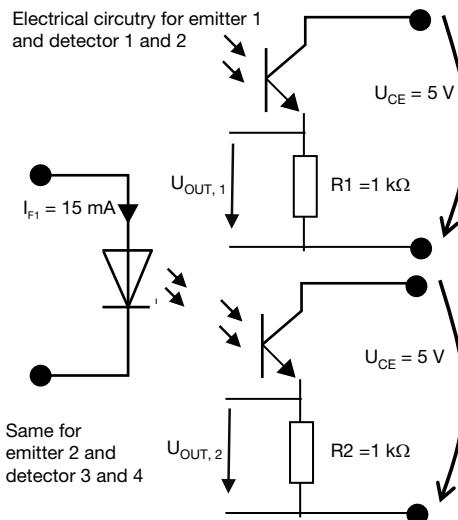

Fig. 20 - Electrical Circuitry Used for Signal Analysis

If a code disc such as the one shown in Fig. 1 a) is in between both domes, then the four output voltages of the detectors show the 4-bit code of the code disc by "high" voltage level (> 0.7 V) or "low" voltage level (< 0.4 V). For the optical encoding to work correctly, it is essential that the code tracks are always on the correct positions. Therefore, the code wheel or code disc needs to be correctly placed in the sensor gap and needs to be kept in a certain tolerance range during operation (refer to previous chapters).

A P P L I C A T I O N   N O T E

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Encoding and Code Wheel Proposal for TCUT1800X01

Below is an example of the electrical signal of the TCUT1800X01 operating with a code wheel, including four code tracks and binary codes.

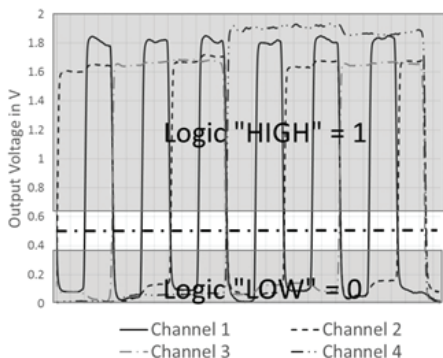Example: absolute signal encoding with code disk (T = 0.5 mm, R = 30 mm, trackwidth = 0.96 mm)

Fig. 21 - Signal Voltage of all Four Channels During 360° Turn of a Code Wheel. The Flat Signal at Voltage Level "High" Corresponds to Logic "High" and at Voltage Level "Low" to Logic "Low". In This Position, an Absolute Position of the Code Wheel Can be Detected by the Sensor. Signal Levels in Between Are in Transition and Cannot be Assigned

Correct signal readings of all the positions above can be achieved by defining a trigger point at 0.55 V. All signals below will be detected as "low" and all signals above will be detected as "high".

The current transfer ratio (CTR) varies from sensor to sensor and between the channels, and needs to be considered for the application (for further details, refer to the datasheet). Furthermore, the typical lifetime degradation of the semiconductor devices needs to be considered.

The gap between "low" and "high" can be improved by scaling the signal with the coupling characteristics of the sensor. This means that the electrical signal of each channel is related to the voltage values if all channels are open. This allows lifetime degradation and the coupling distribution from sensor to sensor to be compensated for.

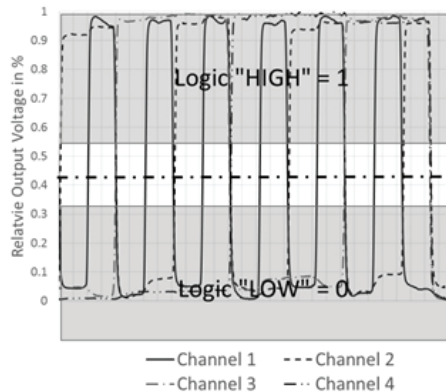Example: absolute signal encoding with code disk (T = 0.5 mm, R = 30 mm, trackwidth = 0.96 mm)

Fig. 22 - Signal Voltage on a Percentage Basis for all Four Channels During a 360° Turn of a Code Wheel

Encoding and Code Wheel Proposal for TCUT1800X01

**APPENDIX I - DESIGN PROPOSAL FOR ABSOLUTE ENCODING OF A CODE STRIP OR CODE DISC**

STEP BY STEP GUIDE OF THE DESIGN OF AN ABSOLUTE CODE WHEEL OR CODE STRIP

Vertical Code Track Positions / Size of Code Tracks in X-Y View of the Sensor
(refer to the chapter "Vertical Channel Displacement in the Sensor Gap")

Range of channels within the sensor gap   2D drawing of code track positions
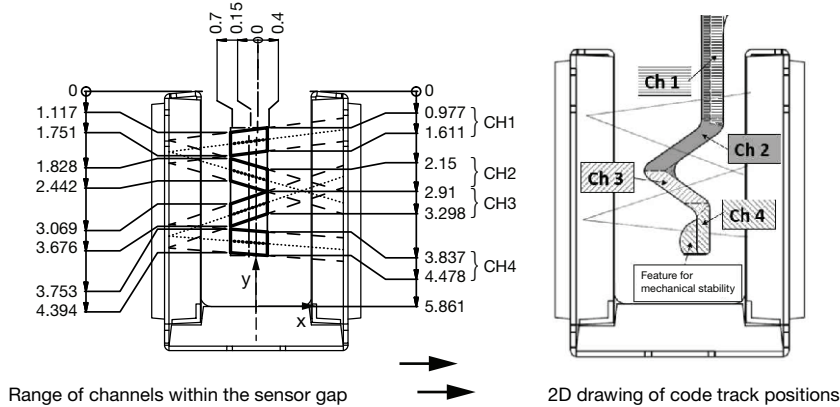
Encoding Principle

Binary or gray encoding are common and can be used for the optical encoding. Each code track structured with the corresponding light-passing (logic high) and light-blocking (logic low) features is considered. Below each code track shown as line CH1 is the code track for detector 1 … to CH4, which is for detector 4.
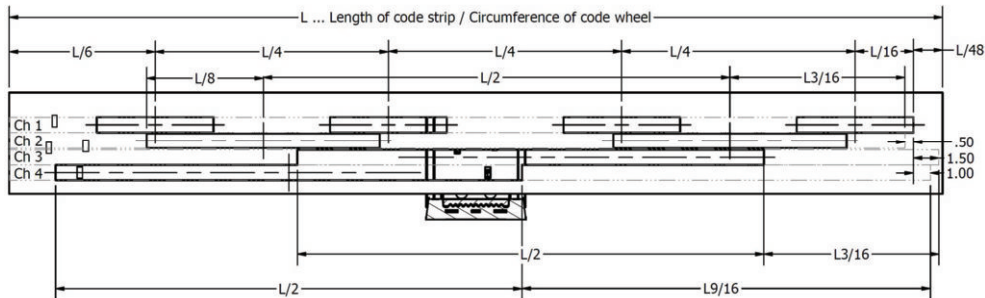
Horizontal Code Track Positions (X-Z direction)

Due to the horizontal displacement of the detectors within the sensor, the code tracks need to be shifted accordingly (in direction of movement or rotation).

Horizontal channel shift within the sensor gap   Each code-shifted acc. to offset of optical axes

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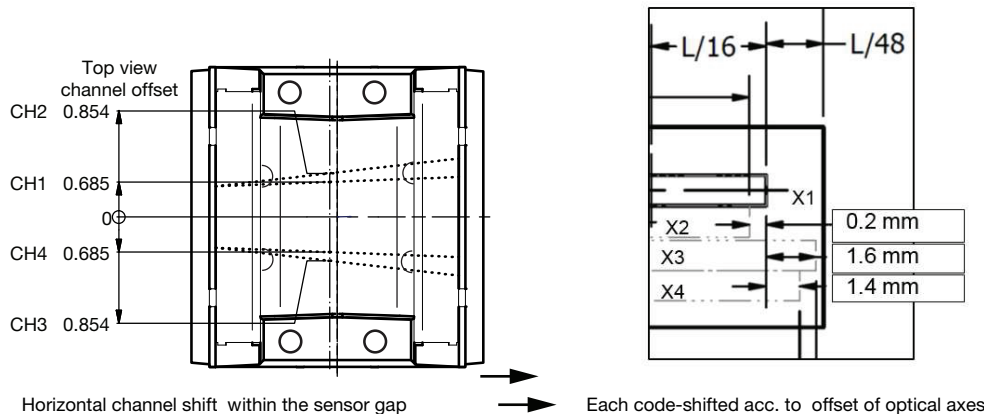
Encoding and Code Wheel Proposal for TCUT1800X01

3D Code Wheel or Strip

Finally, with consideration of the first three items, the 3D model with all the interfaces can be designed.
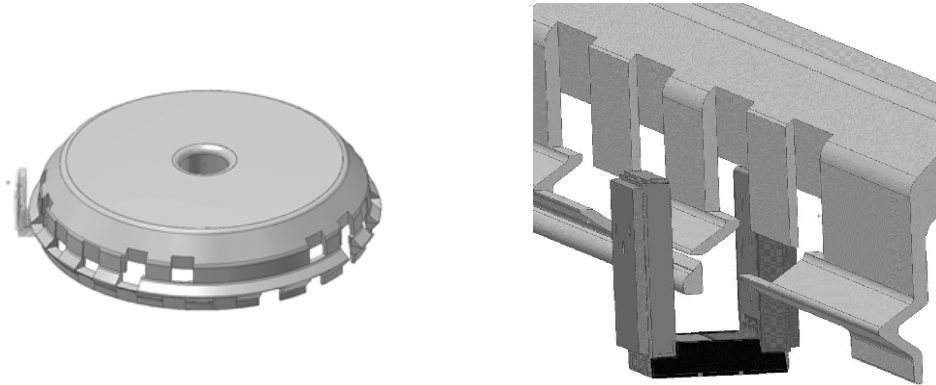
Tolerance Range

The allowed tolerance range between the sensor and code wheel or strip can be evaluated by the smallest distances between the edges of the code tracks to the region of the channels above and below. Distances in X-, Y-, and Z-directions are different and therefore the allowed tolerance ranges will be different. Furthermore, the tolerance ranges in the three directions interrelate with each other. This means with an increasing x-tolerance range, the allowed y-tolerance range will be reduced for a correct signal reading.

Encoding and Code Wheel Proposal for TCUT1800X01

APPENDIX II - SIMPLE CODE TRACKS OF A CODE STRIP (refer to Fig. 14)

Output signal of the four channels below (as an example): CH1, CH2, CH3, CH4
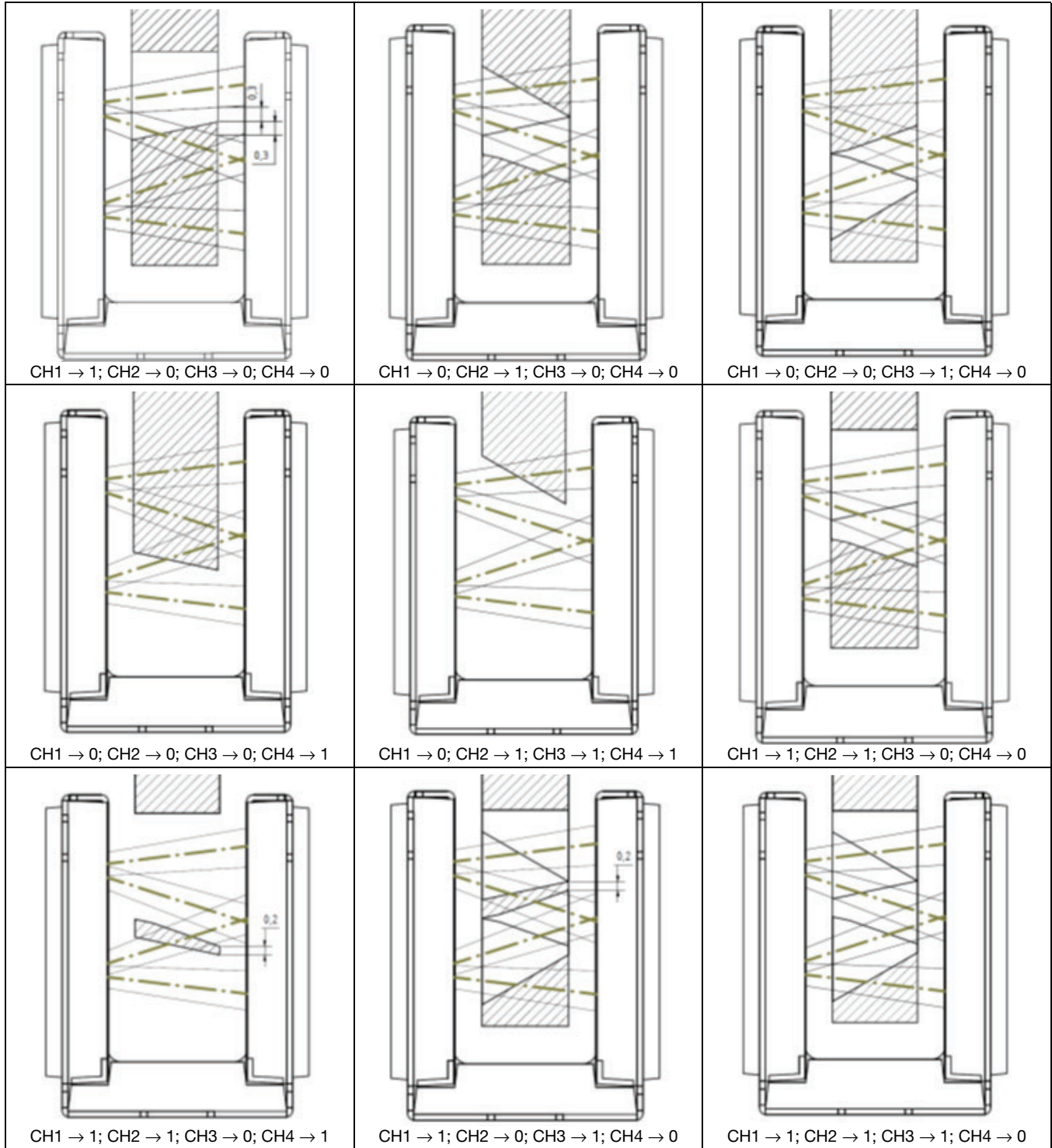
CH1 → 1; CH2 → 0; CH3 → 0; CH4 → 0	CH1 → 0; CH2 → 1; CH3 → 0; CH4 → 0	CH1 → 0; CH2 → 0; CH3 → 1; CH4 → 0
CH1 → 0; CH2 → 0; CH3 → 0; CH4 → 1	CH1 → 0; CH2 → 1; CH3 → 1; CH4 → 1	CH1 → 1; CH2 → 1; CH3 → 0; CH4 → 0
CH1 → 1; CH2 → 1; CH3 → 0; CH4 → 1	CH1 → 1; CH2 → 0; CH3 → 1; CH4 → 0	CH1 → 1; CH2 → 1; CH3 → 1; CH4 → 0

Encoding and Code Wheel Proposal for TCUT1800X01

CH1 → 1; CH2 → 0; CH3 → 0; CH4 → 1

APPLICATION NOTE
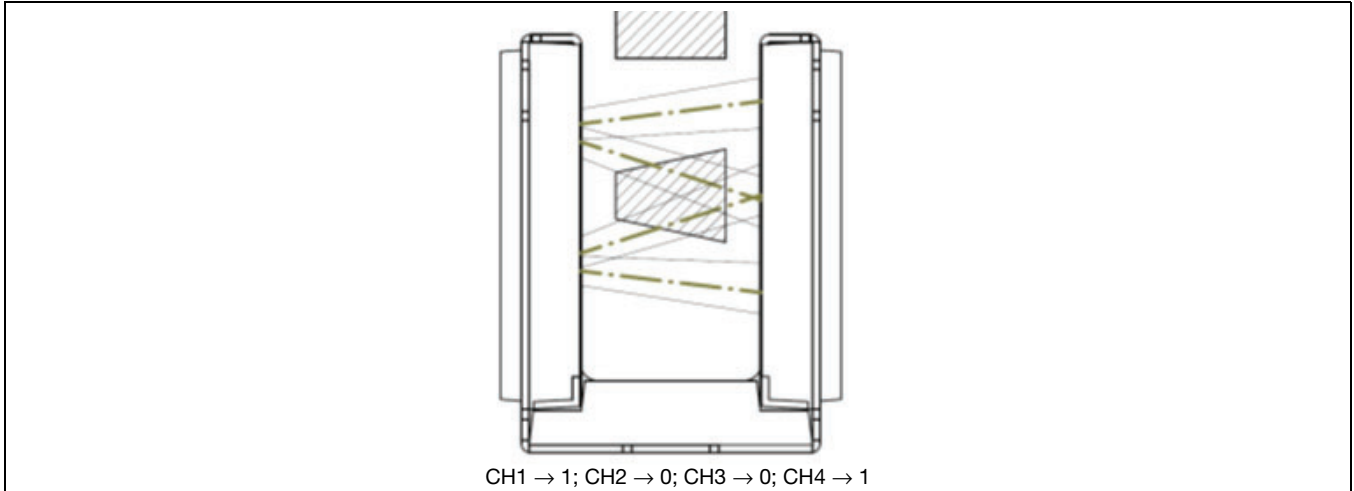
Encoding and Code Wheel Proposal for TCUT1800X01

APPENDIX III - SOLUTION FOR MORE THAN 4-BIT ENCODING

Fig. 11 on page 6 already shows how one possible code pattern, also called a "gray code" pattern, with 16 fixed positions using the TCUT1800X01 could look like.

An advantage of this code is that any two adjacent codes / positions differ only by one bit position.

Another arrangement could be to use standard binary coding, also shown with Fig. 16 and displayed below:

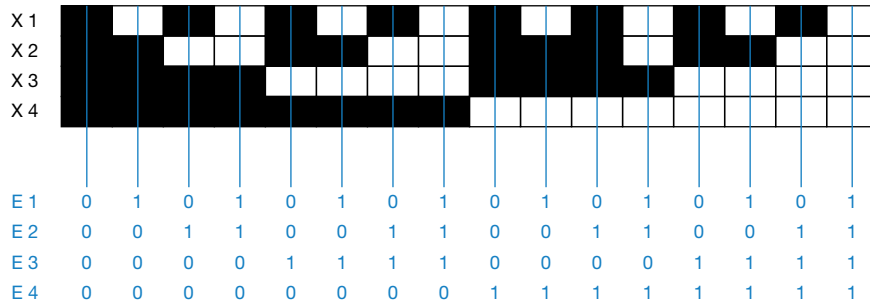| X 1																
X 2																
X 3																
X 4																
E 1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
E 2	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
E 3	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
E 4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

Fig. 23

A code wheel realisation using a 3D printer may need a different bit pattern to allow for a more stable construction.

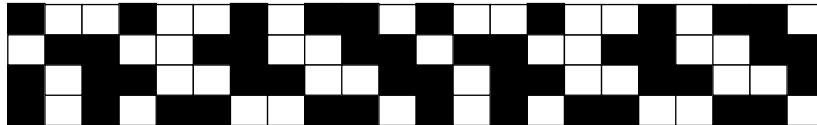An example could be as follows:

Fig. 24

Irrespective of what bit pattern is used, the TCUT1800X01 allows for the detection of a maximum of 16 defined positions. However, often applications may need more than this, e.g. 22 positions or even up to 32 positions.

This can also be made possible by using an additional TCPT1350X01 together with the TCUT1800X01, if these are mounted accordingly.

Because the aperture for the TCPT1350X01 is too close to the lower aperture of the TCUT1800X01, increasing the amount of possible positions by placing these two sensors together onto one code track is not possible.
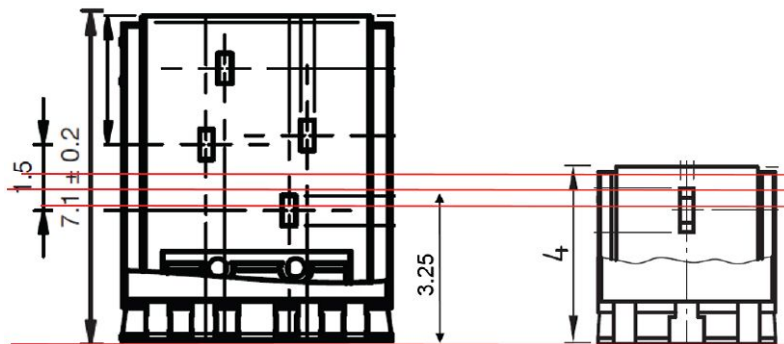

Fig. 25

APPLICATION NOTE

Encoding and Code Wheel Proposal for TCUT1800X01

Both sensors on the same code wheel track would need a total length of about 100 mm for 32 positions. So, the implementation using a wheel (instead of a straight code strip) would need even a bit more than the theoretical diameter of $\geq$ 32 mm, with an estimated final diameter of 40 mm.
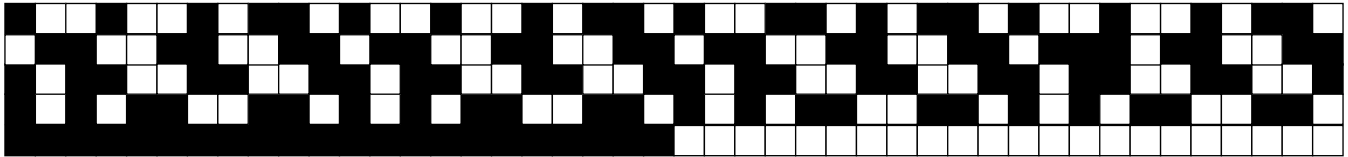

Fig. 26

For just 22 positions the total length would need to be relatively long, with a necessary length of about 70 mm for a straight strip, resulting in a required diameter of around 30 mm.

Most applications would also require that the fixed rotary positions, e.g. 22 positions, are within a smaller angle than whole 360°, as the user should not need to rotate the knob a full rotation in order to reach every position.

Reducing the angular movement of the knob to an angle of just e.g. of 240°, again requires a larger wheel diameter of about 360°/240° x 30 mm = 1.5 x 30 mm = 45 mm.

To fulfill the requirements without increasing the diameter of the wheel further, the TCPT1350X01 can be placed on an additional code wheel track that is situated on the inner diameter of the code wheel, i.e. having two tracks with different code patterns running in parallel. The outer, wider, ring for the TCUT1800X01 as this code wheel track contains more information and the inner, smaller, ring for the TCPT1350X01. This would allow for a total wheel diameter of about 30 mm. An example of this is shown below:
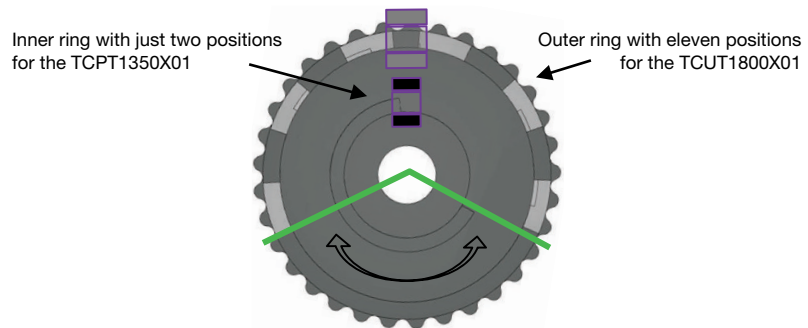

Inner ring with just two positions for the TCPT1350X01

Outer ring with eleven positions for the TCUT1800X01

Fig. 27

APPLICATION NOTE

Encoding and Code Wheel Proposal for TCUT1800X01

For the example of 22 positions it is not necessary to make use of all possible 16 positions that the TCUT1800X01 offers. A simpler approach is to divide the 22 end positions into two sets of eleven positions and use the extra bit denoted by the TCPT1350X01 within the inner ring to differentiate between these two. This results in a similar code pattern as shown below, where eleven positions are detected with the output of the TCPT1350X01 registering a "High" signal and the remaining eleven positions are detected with the output of the TCPT1350X01 registering a "Low" signal. What makes the code wheel pattern elegant is, that both sets of eleven positions detected by the TCUT1800X01 are the same, simplifying the detection logic used for the position detection and allowing for a simpler and more stable construction of the wheel itself.

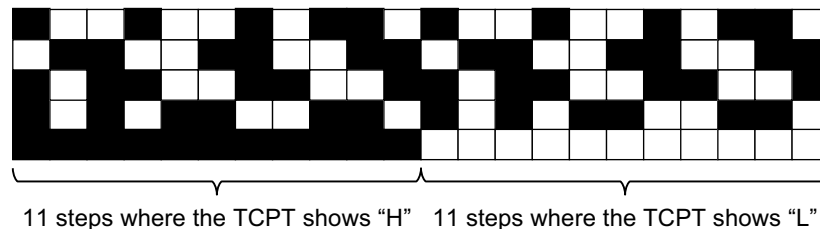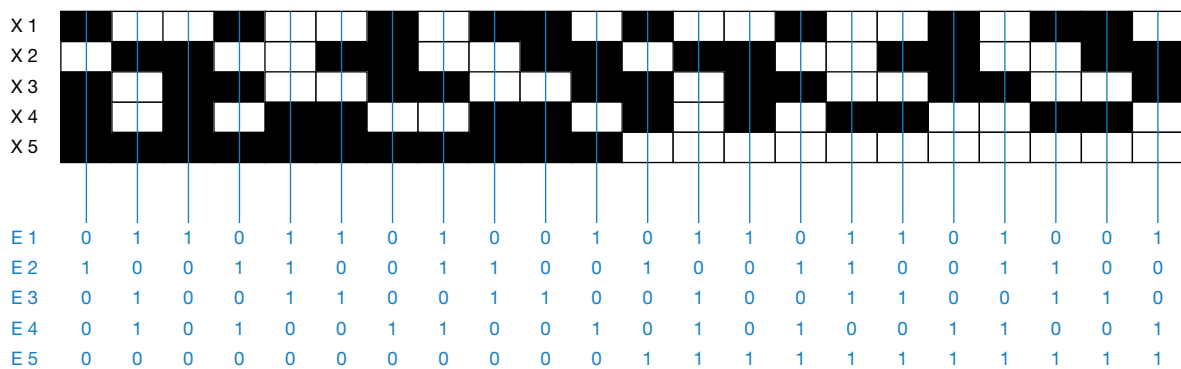11 steps where the TCPT shows "H"   11 steps where the TCPT shows "L"

Fig. 28

In this implementation the pattern for the 22 positions no longer follow a typical binary or gray code, but rather are in a selected order that aims to realize the most robust design of a the code wheel when printed with a 3D printer.

To clarify this further, one can express this in the form of a number by assigning all black fields with a "0" and all white fields with a "1". An example of this is shown below with "E 1" as the MSB and "E 4" as the LSB.

The code pattern for the TCPT1350X01 can be handeled in the same manner, taking "E5" as new MSB, to allow for a clear separation of the numbers. The resultant values are shown below and can be seen to have a range between 01h and 1Eh (1 to 29 dec) where not every value within this range occurs, as the code wheel only has 22 positions.

E 1	0	1	1	0	1	1	0	1	0	0	1	0	1	1	0	1	1	0	1	0	0	1
E 2	1	0	0	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	1	1	0	0
E 3	0	1	0	0	1	1	0	0	1	1	0	0	1	0	0	1	1	0	0	1	1	0
E 4	0	1	0	1	0	0	1	1	0	0	1	0	1	0	1	0	0	1	1	0	0	1
E 5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1

E 1 to E 4:	04	0B	08	05	0E	0A	01	0D	06	02	09	04	0B	08	05	0E	0A	01	0D	06	02	09
E 1 to E 5:	04	0B	08	05	0E	0A	01	0D	06	02	09	14	1B	18	15	1E	1A	11	1D	16	12	19
or as decimal value:	4	11	8	5	14	10	1	13	6	2	9	20	27	24	21	30	26	17	29	22	18	25

Fig. 29

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Encoding and Code Wheel Proposal for TCUT1800X01

Taking the above example of 22 positions, the final code wheel would look as follows:
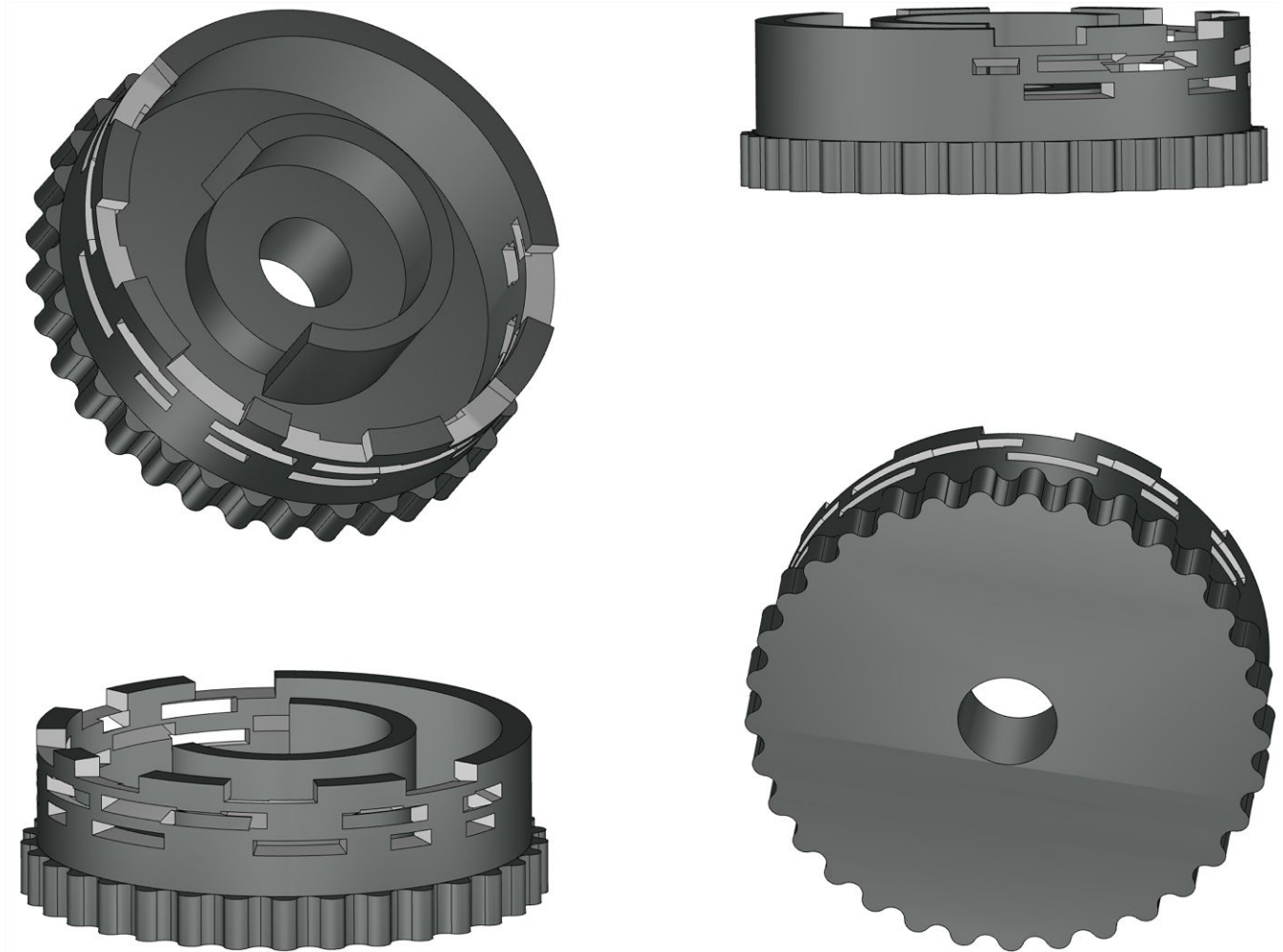

Fig. 30

For hardware- and application-related info, please also see the application note "Hardware Description and Design-In Proposals for Single and Dual SMD Transmissive Sensors" (www.vishay.com/doc?84873).

APPLICATION NOTE