White Paper

Reflective Encoders

Design Guidelines and Considerations for Reflective Codewheels/Codestrips

Abstract

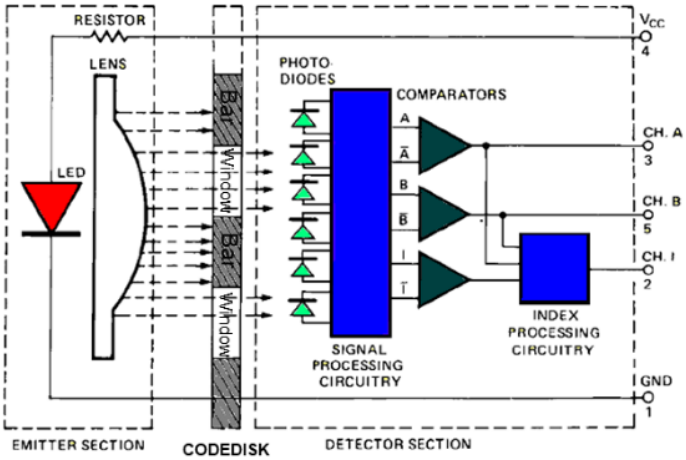
This white paper provides critical design guidelines and considerations for selecting codewheels that are compatible with Broadcom® reflective encoders. By addressing common challenges and presenting various material options, the white paper equips customers to achieve optimal performance and signal clarity.

There are many cases where users apply the same experience or knowledge from transmissive codewheel/ codestrip design when migrating to reflective encoders. Consequently, many unforeseen problems occur because important considerations are not addressed for reflective codewheels.

NOTE: The terms *codewheel* and *codestrip* are interchangeable in this white paper.

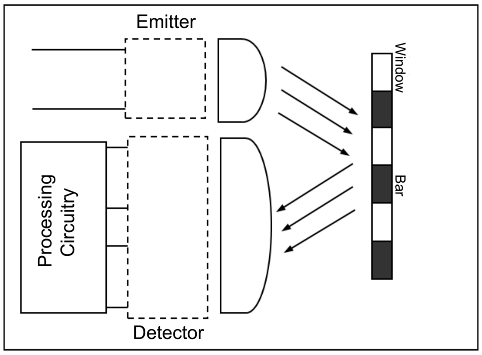
Introduction

Reflective encoders differ significantly from transmissive encoders in their design requirements. Transmissive encoders use a codewheel in which collimated light passes perpendicularly through the codewheel with an alternating transparent window and opaque bar, producing good optical contrast. To ensure good optical contrast, the transparent window must have good transmissivity and the opaque bar must block the light.



Transmissive Encoder

Reflective encoders, on the other hand, achieve optical contrast from the reflected light from the alternating reflective (window) and non-reflective (bar) patterns on the codewheel. The reflective pattern must exhibit high specular reflectance, whereas the non-reflective pattern requires low reflectance to generate the necessary signal clarity for the encoder detector.



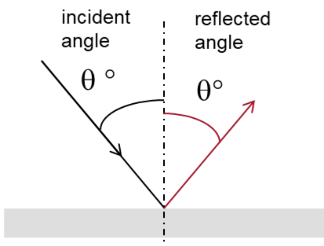
Reflective Encoder

Different Types of Reflectance

There are many types of surface reflectance: specular, diffuse, spread, and a mixture of them. For reflective codewheels, ideally specular reflectance is needed; diffuse and spread reflectance reduce the optical contrast, reducing the encoder signal strength, and should therefore be avoided.

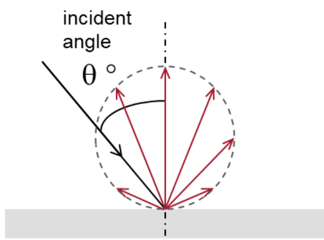
Specular Reflectance

Specular reflectance (https://en.wikipedia.org/wiki/Specular_reflection) is light reflection from a mirror-like surface, where the surface is smooth and the incident angle equals the reflected angle. Specular reflectance casts the codewheel pattern, which matches the encoder detector, and therefore produces a good encoder signal.



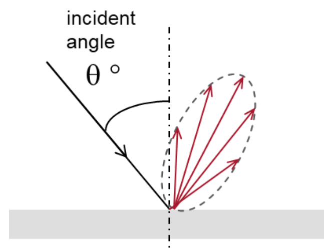
Diffuse Reflectance

Diffuse reflectance (https://en.wikipedia.org/wiki/Diffuse_reflection) is light reflection from a uniform rough surface, for example a paper or powdered surface, where the incident ray is reflected at many angles (not the angle as in the case of specular reflection). Diffuse reflectance increases the “dark” level and weakens the signal strength (reduces the peak-to-peak signal). And, therefore, diffuse reflectance should be minimized for reflective encoders.



Spread Reflectance

Spread reflectance (https://en.wikipedia.org/wiki/Specular_reflection) is light reflection that has a dominant directional component with partial diffuse light due to surface irregularities, for example a directional etched surface. Spread reflectance is worse than diffuse reflectance because it modifies the codewheel pattern cast onto the encoder detector; or in short, it modifies the encoder signal. The modified codewheel pattern cast on the encoder detector produces a weak encoder signal and phase mismatch and at worst causes functional failure for the encoder.

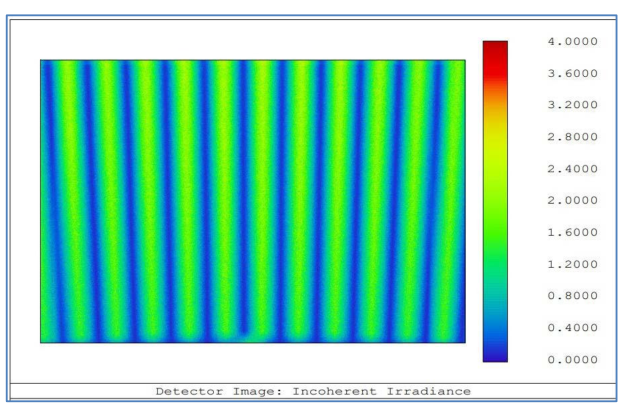


Basics of Reflective Codewheels

As a basic principle for choosing a reflective codewheel, the codewheel pattern must be able to reflect light that produces sufficient optical contrast for the encoder detector to convert into useful encoder signals.

To provide sufficient optical contrast, the reflective pattern (window) must have high specular reflectance, whereas the non-reflective pattern (bar) must have low specular reflectance.

The following example shows the codewheel pattern that is reflected from the reflective codewheel. Based on optical simulation, it shows a good optical contrast pattern with bright and dark lines.



Irradiance (Codewheel Pattern) versus Specular Reflectance

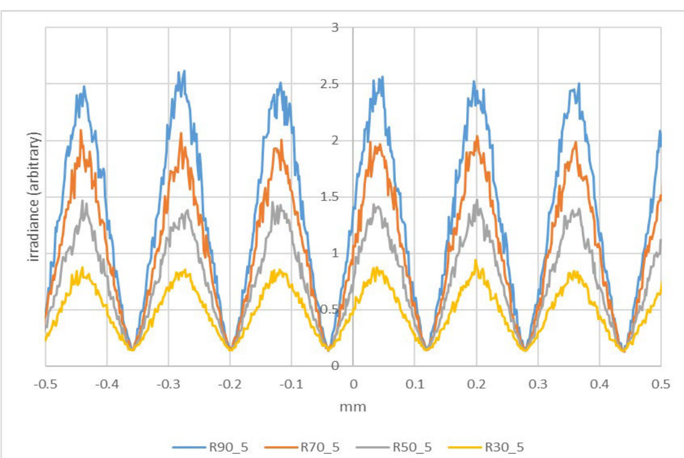
Irradiance obtained from optics simulation is correlated to the encoder signal strength, and therefore irradiance is used to explain the effect of specular reflectance on the encoder signal strength.

A simple comparison of the codewheel pattern cast on the encoder detector based on the different reflectance percentage of the reflective pattern (window) and the non-reflective pattern (bar) explains the relationship of specular reflectance to encoder signal strength.

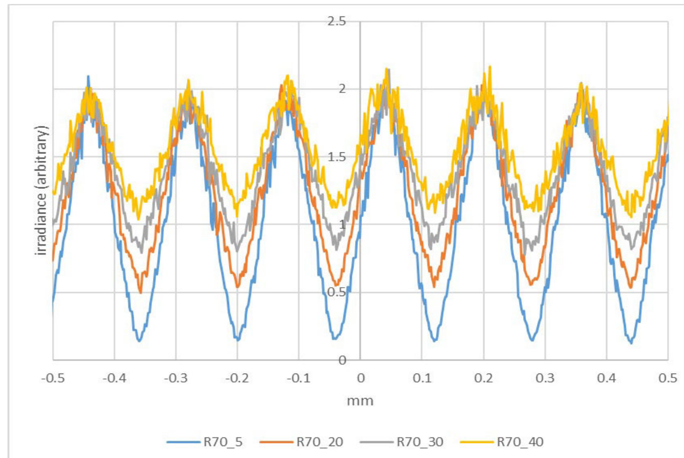
Example: The AEDR-9830/9830A (318 LPI, 625 CPR) at a nominal position is modeled in optics to obtain the irradiance by rotating the codewheel.

NOTE: Rxx_yy: xx = the reflective pattern reflectance %, yy = the non-reflective pattern reflectance %, for example R70_5 = reflective pattern R70% reflectance, non-reflective pattern R5% reflectance. LPI = lines per inch, CPR = counts per revolution.

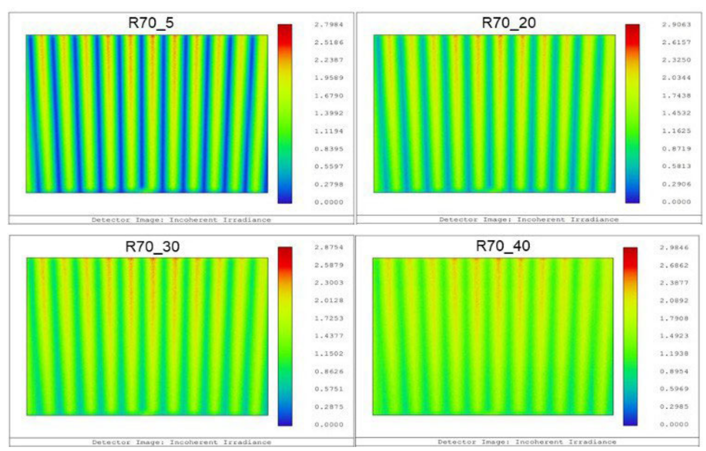
1. Irradiance (arbitrary) by varying reflective pattern reflectance versus fixed non-reflective pattern reflectance is simulated. It is observed that the higher the reflective pattern reflectance, the stronger the encoder signal received by the encoder detector.



2. Irradiance (arbitrary) with fixed reflective pattern reflectance (R70%) versus varying non-reflective pattern reflectance (R5% to R40%) is simulated. It is observed that the higher the non-reflective pattern reflectance, the weaker the encoder signal received by the encoder detector.



As shown in the following figure, it is obvious from optical simulation that the higher the non-reflective pattern reflectance, the poorer the optical contrast, where the “dark” lines become less “dark” and produce a weaker encoder signal. In short, by increasing the separation of the reflectance value between the reflective and non-reflective pattern, the encoder signal strength can be increased.



Different Types of Reflective Codewheels

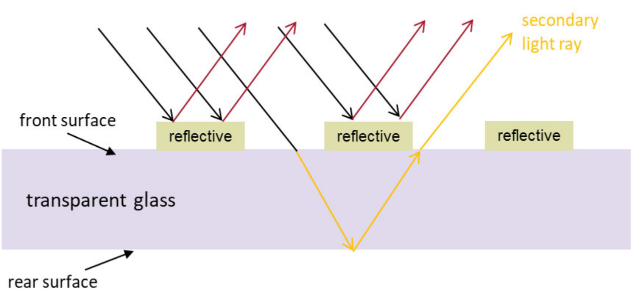
The following are common reflective codewheels used with Broadcom reflective encoders:

- Typical transmissive glass
- Modified transmissive glass
- Black glass codewheels
- Metal codewheels
- Mylar codewheels

Typical Transmissive Glass

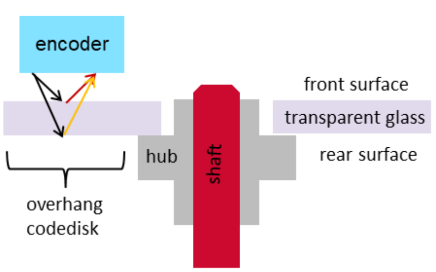
Most application problems occur when a customer with an existing transmissive encoder starts to use a reflective encoder with the same transmissive glass codewheel. With a reflective encoder that uses a transmissive glass codewheel, the application must avoid "ghosting" from light passing through the transparent glass and hitting the codewheel hub, which acts as a second light source and causes ghosting.

NOTE: With typical transmissive glass, the reflective pattern is chrome plated with reflectance ~ R60%.



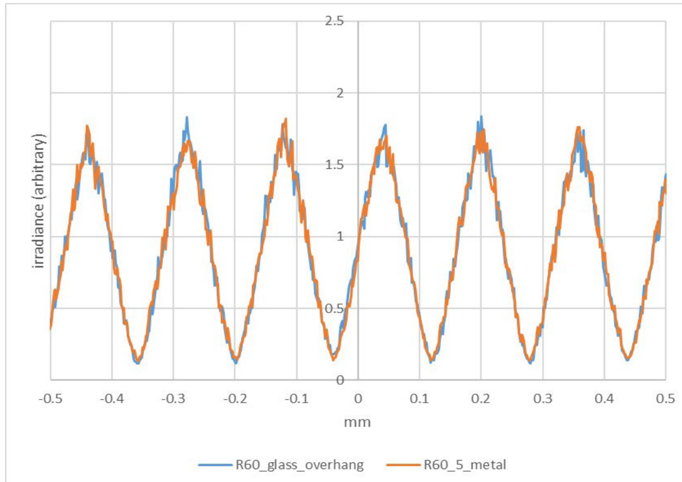
typical transmissive glass

1. Overhang transmissive glass mounting to the codewheel hub can be used with a reflective encoder with a resolution of 318 LPI and lower. Overhang mounting is to prevent reflection from the codewheel hub.



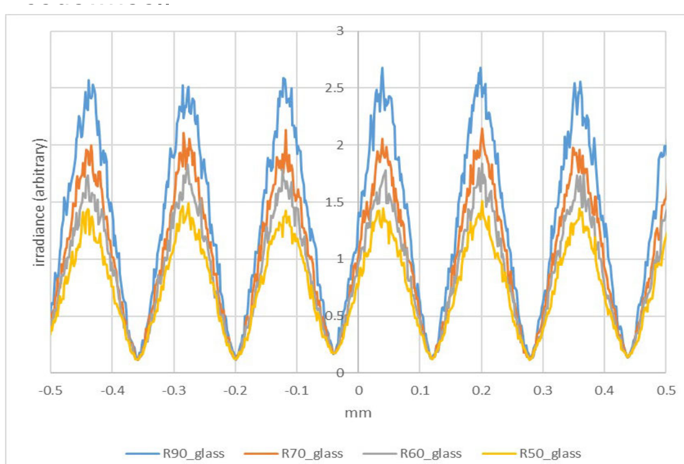
overhang transmissive glass mounting

Example optical simulation: The AEDR-9830/9830A (318 LPI, 625 CPR) at a nominal position between the transmissive glass (overhang) with an R60% reflective pattern and the metal codewheel with an R60% reflective pattern and R5% non-reflective pattern. Both encoder signal strengths are comparable, indicating that the overhang transmissive codewheel can be used with Broadcom reflective encoders.

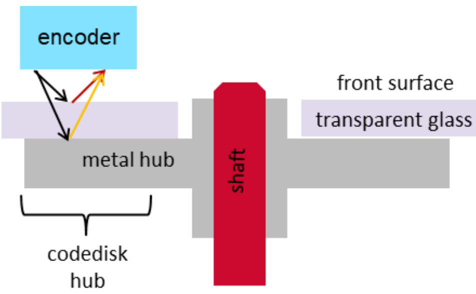


It is possible to improve the encoder signal strength for the overhang transmissive codewheel by using high reflectance for the reflective pattern on the transmissive glass.

Example optical simulation: The AEDR-9830/9830A (318-LPI or 80-µm pitch, 625 CPR) at a nominal position versus different reflectance R% for the reflective pattern. The result shows that higher reflectance on the reflective pattern produces a stronger encoder signal (irradiance). R90_glass = a reflective pattern with R90% reflectance on the glass codewheel.

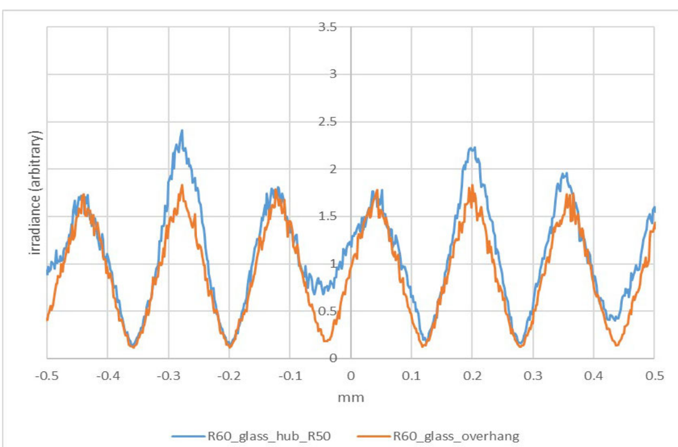


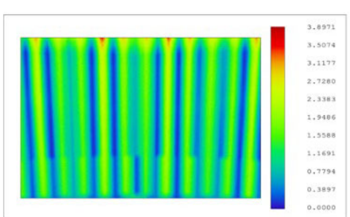
2. Transmissive glass mounting with the codewheel hub (metal) below the codewheel tracks cannot be used with a reflective encoder due to strong ghosting that disturbs the encoder signal.



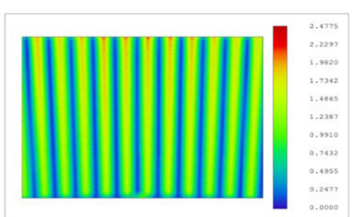
transmissive glass mounting on hub

Example optical simulation: The AEDR-9830/9830A (318 LPI, 625 CPR) at a nominal position. The result shows that strong and unpredictable ghosting (depending on the quality of the metal hub surface) occurs due to a strong secondary reflection from the metal hub.





transmissive glass mounting on hub

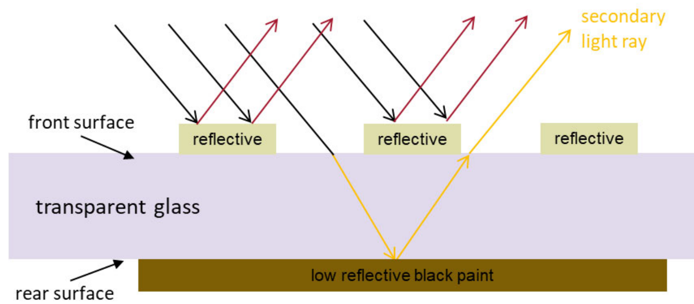


overhang transmissive glass mounting

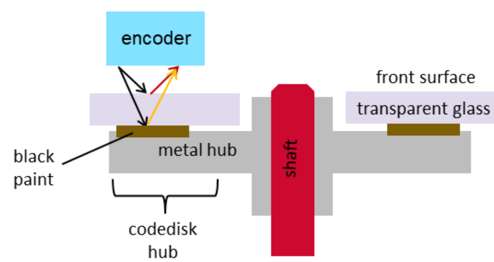
Modified Transmissive Glass

There are a couple of methods to minimize the ghosting effect from light passing through the transparent glass, reflected as secondary rays, for example from the hub.

1. The rear surface of the transmissive glass codewheel is coated with low-reflectance black paint (for example reflectance R5%).

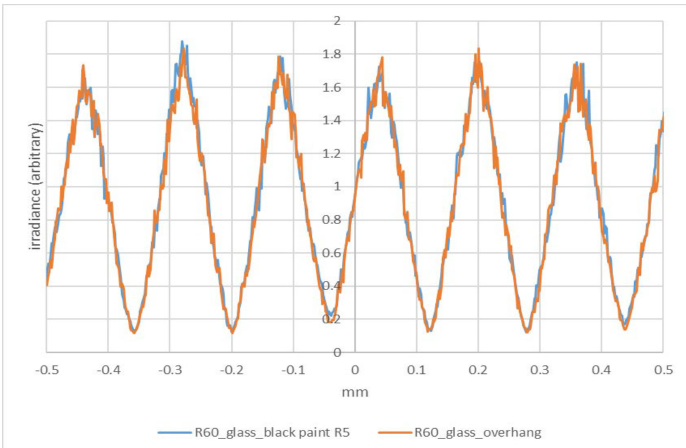


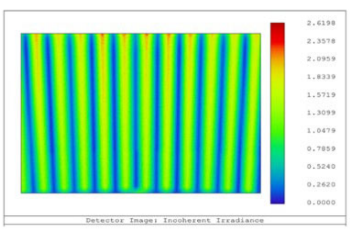
typical transmissive glass + low reflective black paint R5%



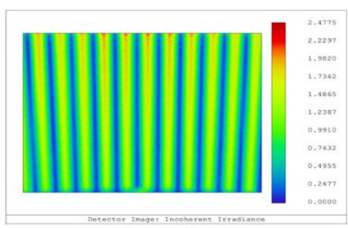
transmissive glass mounting + low reflective black paint R5% with mounting on metal hub

Example optical simulation: The AEDR-9830/9830A (318 LPI, 625 CPR) at a nominal position. Comparison between typical transmissive glass with black paint (rear surface) and typical transmissive glass with overhang codewheel mounting. The black paint (rear surface) eliminates the secondary light ray reflected from the metal hub.



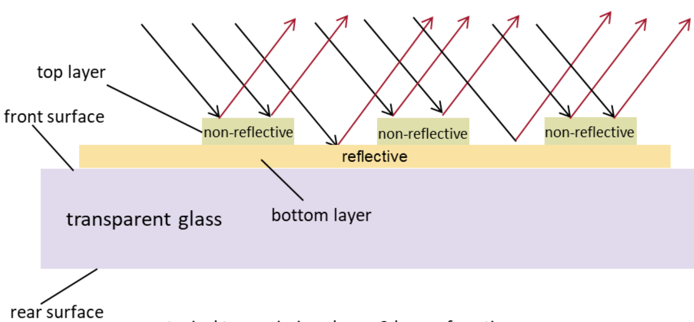


typical transmissive glass + low reflective black paint R5%



overhang transmissive glass mounting

2. The front surface is coated with two layers for a reflective and non-reflective pattern that mimics the construction of a metal codewheel.



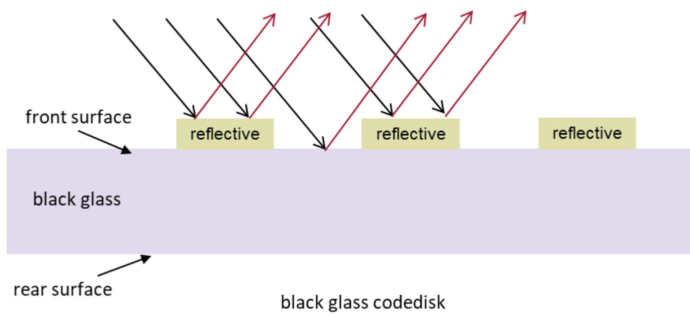
typical transmissive glass + 2 layer of coatings

Table 1: Examples of Different Coating Combinations

Bottom Layer	Top Layer	Remark
Chrome R60%	Chrome oxide R5%	Medium-reflective chrome
Chrome R85%	Chrome oxide R5%	High-reflective chrome
Niobium (Nb) R85%	Chrome oxide R5%	High-reflective Niobium

Black Glass Codewheels

To minimize the ghosting effect from light passing through the transparent glass, the glass material is changed to “black” glass (an opaque material) with very low transmittance (< 0.01). The black glass surface acts as a non-reflective surface for the codewheel, whereas the reflective pattern can be maintained as chrome with a reflectance of R60%, which is normally used for a transmissive glass codewheel.



black glass codedisk

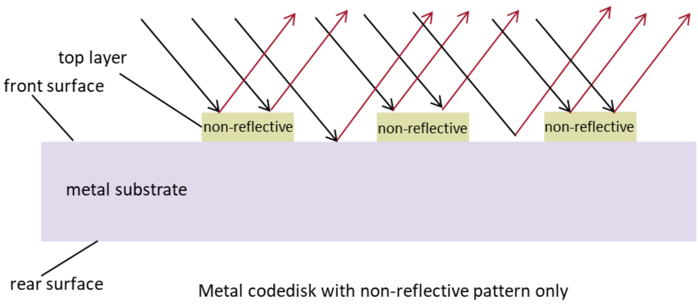
Metal Codewheels

To minimize the ghosting effect from light passing through the transparent glass, the glass substrate is changed to metal substrate. There are two types of construction for metal codewheels:

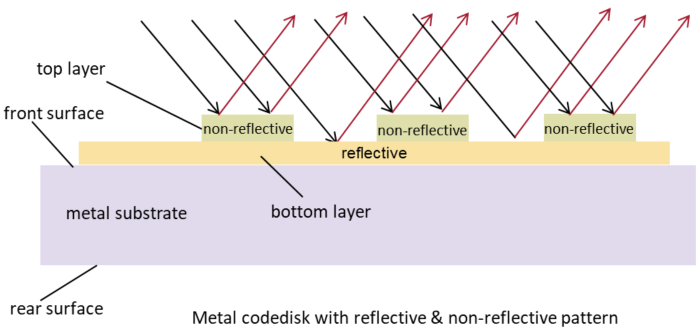
- The metal substrate acts as the reflective surface and is plated with a non-reflective pattern.
- The metal substrate is coated with a reflective pattern and a non-reflective pattern.

Table 2: Examples of Different Types of Metal Codewheels

Substrate	Bottom Layer	Top Layer	Remark
SUS	—	Chrome oxide R5%	Reflective SUS substrate
SUS	Chrome R60%	Chrome oxide R5%	Medium-reflective chrome
SUS	Chrome R85%	Chrome oxide R5%	High-reflective chrome
Ni	—	Copper oxide R5%	Reflective Ni substrate
Al	—	Black ink R5%	Reflective Al substrate



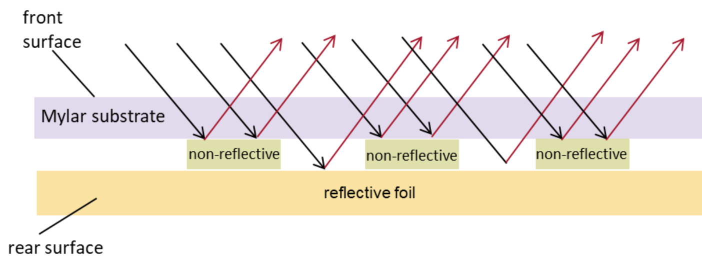
Metal codedisk with non-reflective pattern only



Metal codedisk with reflective & non-reflective pattern

Mylar Codewheels

A transmissive Mylar codewheel is modified as a reflective Mylar codewheel by laminating reflective foil to act as a reflective surface. The non-reflective pattern is formed by exposing the emulsion on the Mylar film itself similar to a transmissive Mylar codewheel.



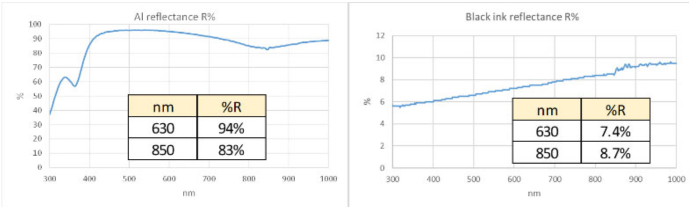
Mylar codedisk

Special Consideration: Reflectance versus Wavelength

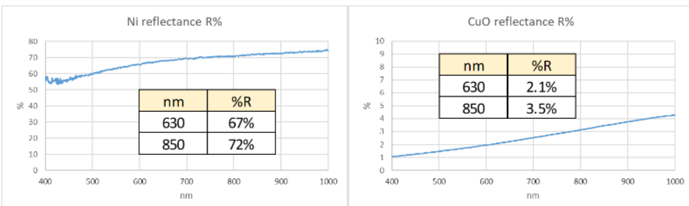
Some of the coatings (reflective and non-reflective) are wavelength dependent, for example high-reflective chrome, high-reflective Niobium, and non-reflective chrome oxide. Matching the reflectance and the wavelength is important when using a Broadcom reflective encoder, which has different peak wavelengths of 630 nm and 850 nm. A typical peak wavelength of 630 nm is applied for the AEDR-8501, AEDR-8600, and AEDR-8723; whereas 850 nm is applied for the AEDR-9820, 9830, 9920, 9930, 9940, and so on.

Most of the metal substrate material for reflective surfaces has a minimal reflectance versus wavelength dependency, for example Ni and Al, and a non-reflective surface, for example black ink or paint. Minimal wavelength dependency for reflectance has minimal changes of reflectance vs wavelength; for example, Al substrate, reflectance = 94% at 630 nm vs 83% at 850 nm. High wavelength dependency for reflectance has large changes of reflectance vs wavelength; for example, chrome (Cr), reflectance = 24% at 630 nm vs 88% at 850 nm.

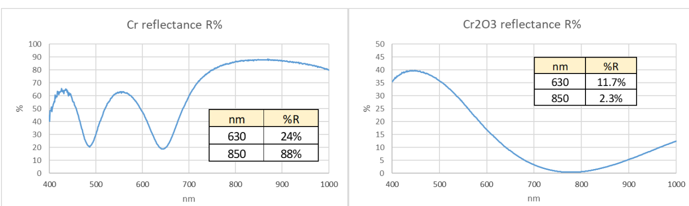
1. Al Substrate/Black Ink:
   Minimal Wavelength Dependency



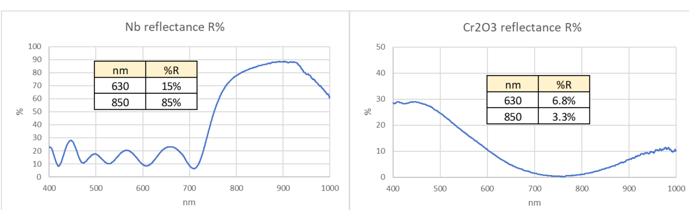
2. Ni Substrate/CuO:
   Minimal Wavelength Dependency



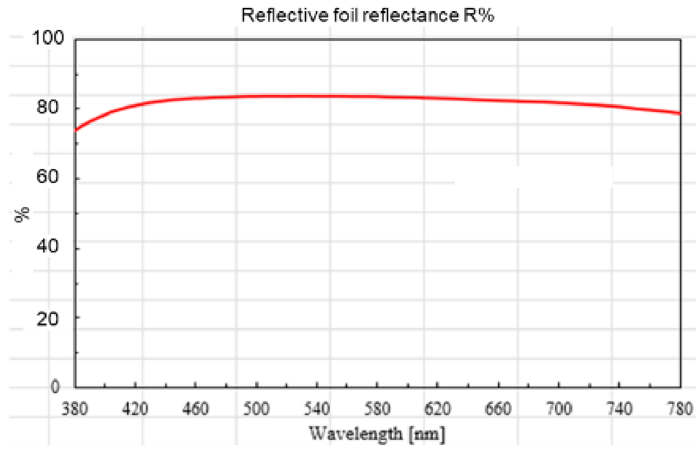
3. Modified Transmissive Glass: Glass/Cr/Cr_2O_3 –
   Highly Wavelength Dependent



4. Modified Transmissive Glass: Glass/Nb/Cr_2O_3 –
   Highly Wavelength Dependent



5. Mylar Codewheel: Reflective Foil/Emulsion/Mylar –
   Minimal Wavelength Dependency



Comparison of Different Reflective Codewheels

The following is a comparison of the performance, cost, and reliability. 1 = the lowest performance, cost, and reliability; and 10 = the highest performance, cost, and reliability.

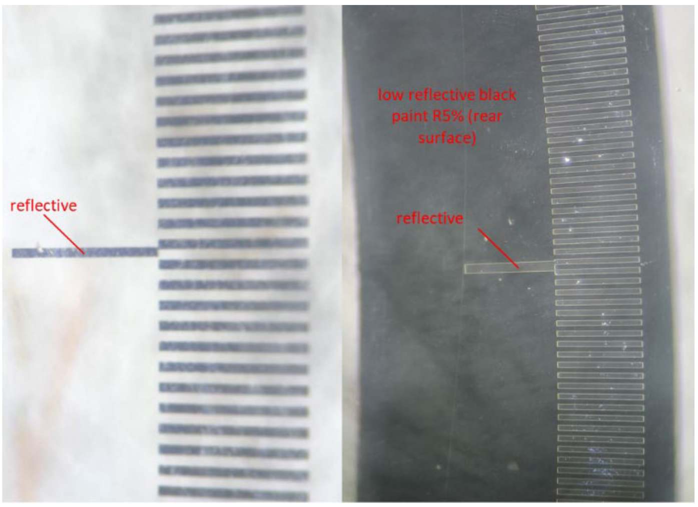
	low				performance					high
codewheel type	1	2	3	4	5	6	7	8	9	10
transmissive glass				O						
modified transmissive					black paint R5%		Cr 60%/Cr2O3	Cr 85%/Cr2O3 Nb 85%/Cr2O3		
black glass							Cr 60%	Cr 85%		
metal							SUS/Cr2O3 SUS/Cr 60%/Cr2O3 Ni/CuO Al/black ink	SUS/Cr 85%/Cr2O3		
Mylar				O						

	low				cost					high
codewheel type	1	2	3	4	5	6	7	8	9	10
transmissive glass				O						
modified transmissive					black paint R5%	Cr 60%/Cr2O3	Cr 85%/Cr2O3 Nb 85%/Cr2O3			
black glass							Cr 60%	Cr 85%		
metal							SUS/Cr2O3 SUS/Cr 60%/Cr2O3 Ni/CuO Al/black ink	SUS/Cr 85%/Cr2O3		
Mylar			O							

	low				reliability					high
codewheel type	1	2	3	4	5	6	7	8	9	10
transmissive glass								O		
modified transmissive							black paint R5%	Cr 85%/Cr2O3 Cr 60%/Cr2O3 Nb 85%/Cr2O3		
black glass								Cr 85% Cr 60%		
metal							Ni/CuO Al/black ink	SUS/Cr 85%/Cr2O3 SUS/Cr2O3 SUS/Cr 60%/Cr2O3		
Mylar			O							

Examples of Different Reflective Codewheels

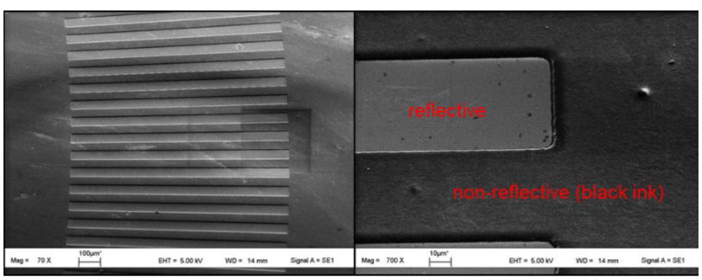
1. Modified Transmissive Glass: Typical Transmissive Glass + Low-Reflective Black Paint at Rear Surface



typical transmissive glass

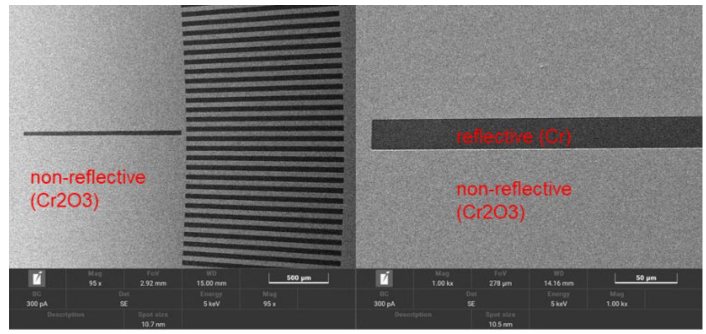
modified transmissive glass, glass + low reflective black paint R5% (rear surface)

2. Metal Codewheel: Al Substrate/Black Ink



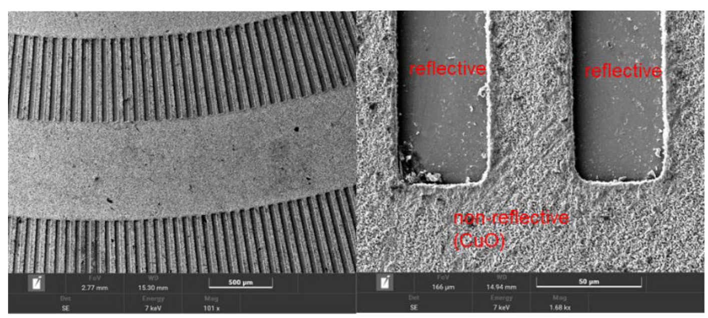
Metal codedisk (Al/black ink)

3. Metal Codewheel: SUS Substrate/Cr/Cr_2O_3



Metal codedisk (SUS/Cr/Cr2O3)

4. Metal Codewheel: Ni Substrate/CuO



Metal codedisk (Ni/CuO)

Conclusion

Many types of reflective codewheels are available in the market. Broadcom's reflective encoders provide unmatched performance by leveraging advanced optical design principles. By following the guidelines in this white paper, customers can minimize design challenges, enhance performance, and optimize cost.