Product Document

Published by
ams OSRAM Group

TAOS Inc.

is now

ams AG

The technical content of this TAOS document is still valid.

Contact information:

Headquarters:
ams AG
Tobelbader Strasse 30
8141 Premstaetten, Austria
Tel: +43 (0) 3136 500 0
e-Mail: ams_sales@ams.com

Please visit our website at **www.ams.com**

INTELLIGENT OPTO SENSOR

Number 38

DESIGNER'S NOTEBOOK

TAOS TEXAS ADVANCED OPTOELECTRONIC SOLUTIONS®

Proximity Detection and Link Budget

By Tom Dunn

July 2011

Overview

TAOS proximity sensors operate by flashing an infrared (IR) light towards a surface and measuring the amount of reflected energy returned. The response is inversely proportional to the distance from the reflecting surface raised to a power and proportional to the size and reflectivity of the reflector. Other variables also impact the responsiveness of the system and cause variations in the proximity readings. This document introduces the concept of a link budget that must be maintained for the system to work.

Link Budget and System Margin Definition

Communications systems transmit signals through a medium (air, cables, water, etc.) to a receiver. The link budget is the sum of the gains and losses throughout the communication link. It is used to manage the signal level and attenuation to ensure enough signal is received for signal processing. The system margin is the amount of signal (at the receiver) above the minimum signal level required for the system to work and must remain positive.

For optical systems with a large target area and small separation distances the signal energy declines as $1/d^2$, where d = the separation distance. As the target size decreases and/or the separation increases this can fall to $1/d^4$. So the signal energy falls off rapidly as a function of the separation distance and is also reduced by many other system impairments or losses.

Proximity sensors are an optical system where the LED emits IR energy, and the device receives reflected IR energy. Typically the energy received is inversely proportional to the distance squared and proportional to characteristics of the optical path and the reflecting body. Figure 1 shows a simplified proximity sensor with no impairments.

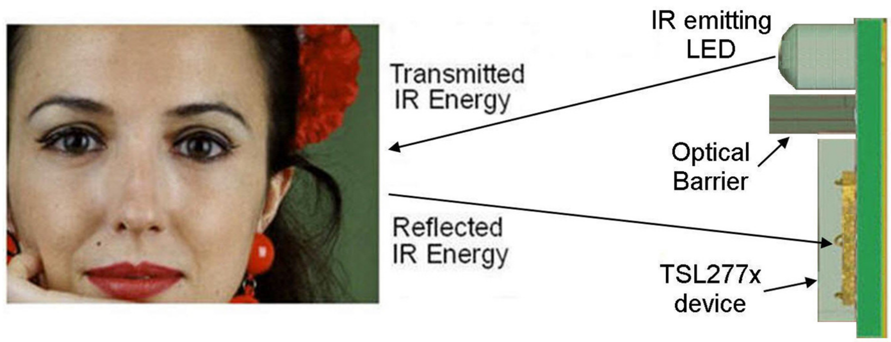


Figure 1. Simplified Proximity Detection System

The important facts surrounding a link budget are:

- An optical systems link budget is similar to that of communications system.
- Reflected proximity signals must be detectable above the noise, background radiation, offset and other undesirable optical energy reaching the device.
- Optical signal energy decreases as $1/d^2$ for large targets with a small separation distance, decreasing to $1/d^4$ as a function of target size relative to d (d=optical path distance).
- Margin must be maintained above the minimum operating threshold of the device.
- Many aspects of an optical system (impairments) degrade the system margin.
- Impairments are additive and collectively decrease the system margin.

Impairments

Impairments to the optical performance are created by anything in the optical path between the IR LED and the sensor. Additionally they include other aspects of the manufacture, test, user environment and design of the system. Here, some major contributors to imperfect optical performance are identified, and how they impact the system margin is shown.

Optical Crosstalk (Overview)

Optical crosstalk is introduced when objects are placed in the optical path. A common crosstalk generator is cover glass; see the red and blue rays in Figure 2. Partial reflectance of light occurs at each air-to-glass interface (referred to as "Fresnel reflections"). Fresnel reflection[1] is a function of incident angle, light polarization, indices of refraction etc.; however to a first approximation, each of the two glass surfaces will reflect back about 4% of the incident light power. (The term "glass" here refers to either glass or plastic).

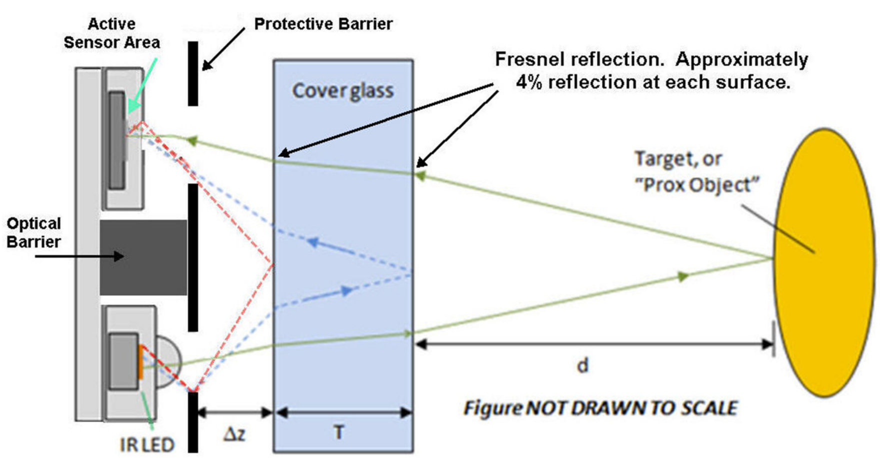


Figure 2: Typical Optical Proximity Sensor System

In Figure 2 the dotted red line shows a ray of IR light that scatters from the rim of the LED aperture, to the first surface of the glass, through the sensor aperture, and eventually reaching the active sensor area. The dotted blue line shows a ray scattering from the second surface of the cover glass. Finally the green solid line shows one of the DESIRED rays successfully completing the optical path from IR LED to the prox target, and back to the sensor.

With a large target surface area and comparatively small separation distance the proximity signal strength from the LED (green ray path) is proportional $1/d^2$. This can decrease to $1/d^4$ if the target size is small relative to the separation distance. Effectively the signal strength diminishes rapidly as a function of target distance (d). With the reflected signal orders of magnitude smaller in signal strength than the large optical crosstalk signal caused by the cover glass the crosstalk signal must be minimized or the system margin will decline.

Optical Alignment

Mechanical alignment of the IR LED, sensor, the cover glass (or plastic), and the optical apertures impact the amount of energy detected by the sensor. If the cover glass apertures are not correctly aligned to the IR LED and sensor, the IR LED energy is reflected back to the sensor as crosstalk, and the system margin is decreased. Bad lateral alignment is shown in Figure 3b along the X axis (Y axis misalignment is normal to the page).

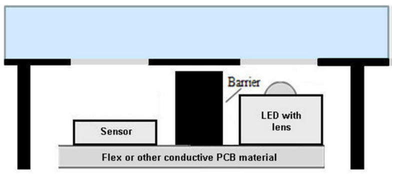


Figure 3a: Good Alignment

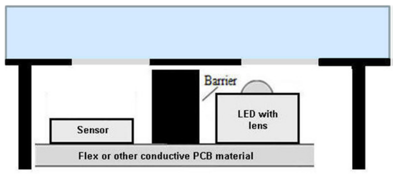


Figure 3b: Bad Lateral Alignment

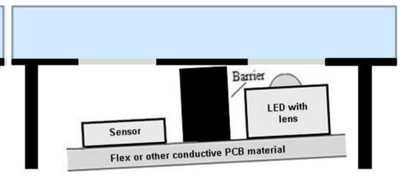


Figure 3c: Bad Rotational Alignment

Sensor Variation

Devices are designed to provide a specified response for a given stimulus, and the acceptance range is documented in datasheets. The photodiodes generate an analog signal, so there is always a standard deviation associated with each device type. This range of acceptability needs to be included in the margin analysis and link budget since the proximity detection thresholds are usually fixed numbers.

If a good device that tested close to the Maximum is compared to a good device that tested close to the Minimum (in an application), the proximity detection distance is different. Unit by unit calibration can correct for this variation and eliminate the impact on the system margin.

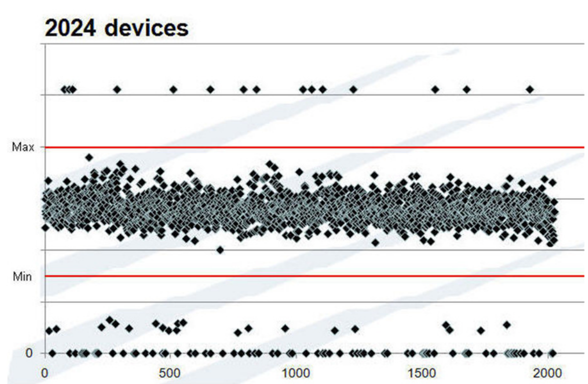


Figure 4: Distribution showing prox sensor variation

Plastic vs. Glass

Either glass or plastic may be used to cover the LED and sensor for protection. Although the two materials may appear visibly similar, there are different optical characteristics associated with them. Fresnel equations and Snell's Law determine the reflection and refraction of light travelling through media with different refractive indices. Search Wikipedia online for more information about these terms.

Manufacturers may start with one material then decide to change to another without considering the difference in the optical performance. If this is done without changes to the proximity detection or release thresholds the system margin is impacted.

Glass (or Plastic) Thickness

With varying thicknesses of glass the reflections from the far side (relative to the sensor) change. The simulation graphics below show the difference in crosstalk as a function of the glass thickness, using no barrier inking.

For each glass thickness, an ink barrier stripe is required on the sensor side of the glass to block the crosstalk path. These inks absorb IR wavelengths, so the IR reflections are blocked. See the section on inks for more information. The impact on the system margin is determined by the amount of crosstalk occurring in the system, so the glass thickness, ink stripe width, and air gap should all be optimized.

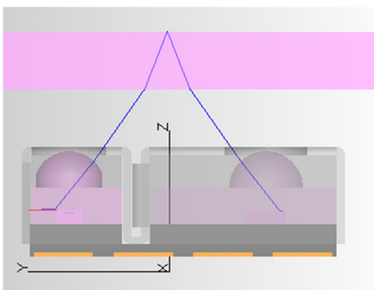


Figure 5a: 0.7mm Glass

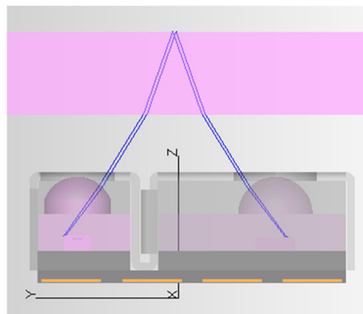


Figure 5b: 1.0mm Glass

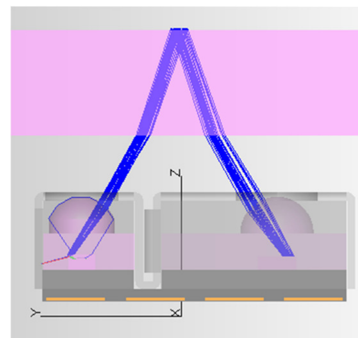


Figure 5c: 1.3mm Glass

Glass Transmittance

Transmittance measures the amount of light passing through the glass and is specified after application of ink or paint at a wavelength of interest. IR transmittance values from 65% to 85% are commonly used. Remember that the IR light reflected off the target and back to the sensor travels through the glass twice. A transmittance of 80% means 36% of the energy is blocked (1-(0.8*0.8)). For 70% transmissive glass, 51% of the energy is blocked (1-(0.7*0.7)).

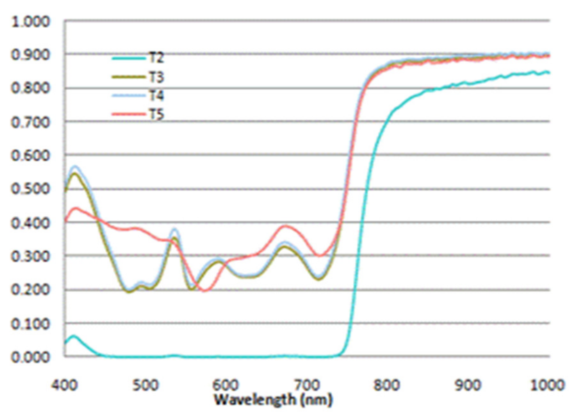


Figure 6: Glass Transmittance vs. Applied Ink

Please refer to Designer's Notebook DN35, Proximity Detection and IR Ink, for more detailed information. The system margin is highly influenced by the transmittance of the glass since a low transmittance value creates an optical attenuator and may also cause an increase to the amount of scattering.

Window Apertures

The inked glass apertures are sized so the light rays can travel to the target and be reflected. If the apertures are too small, a percentage of the desired light rays will be blocked. The optimum aperture size is influenced by the distance from the sensor to the glass, or air gap. For larger air gaps, the aperture needs to be larger, and for smaller air gaps the aperture should be smaller.

The stripe shown between the apertures is an IR blocking ink that reduces crosstalk caused by reflections off the glass. The stripe width, stripe material and apertures all affect the amount of crosstalk generated. This and the mechanical alignment of the apertures and ink stripe relative to the sensor and LED all impact the system margin.

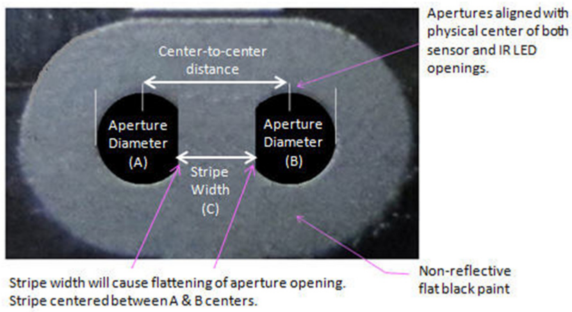


Figure 7: Aperture Template

Air Gaps

The air gap between the top of the sensor and the glass does not directly impact the system margin; in combination with other parameters it affects the amount of crosstalk which does impact the system margin. Figure 8 shows the proximity response with only the air gap changing for 5 different glass types of 4 different glass thicknesses.

If the crosstalk is a fixed offset to the proximity value, the crosstalk can be mathematically cancelled out. However if the crosstalk appears as a variable then mathematical cancellation is not possible without calibration. With the system operating near the knee of the curve, a slight amount of variation will cause a significant change to the proximity reading. For example if Glass #4 is designed into a system with a 0.5mm air gap and the gap is specified to be +/-0.2mm, then the proximity reading will vary from 121 to 337, which is not an acceptable amount of deviation. Small air gaps are the solution to this problem since the rate of change to the proximity count is low in this region. Inks and glass with the proper reflective characteristics will allow larger air gaps to be used when necessary. Air gaps impact the system margin depending on glass thickness.

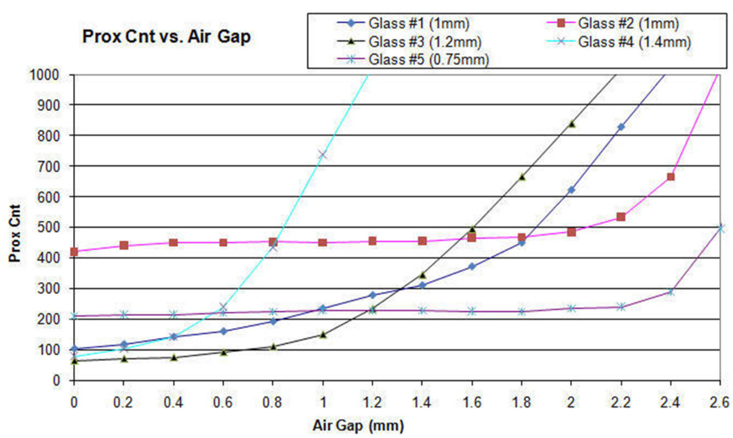


Figure 8: Crosstalk vs. Air Gap and Glass type

Ink Application/Smoothness, Scattering, Reflectance

Inks (or paint) on the glass are used in many applications to visibly hide the electronics and prevent unwanted reflections. These inks have different transmissive characteristics at different wavelengths. For proximity systems using an IR LED it is important for the inks in the desired light path to have minimal IR attenuation. Other inks are used to absorb light and prevent unwanted reflections so these need to have maximum attenuation.

Scattering is another key characteristic of ink and contributes significantly to the crosstalk if not well controlled. This is a complex topic related to ink particulate size and other parameters. Scattering is covered in depth in Designer's Notebook DN35, Proximity Detection and IR Ink. This document should be consulted for additional information. Ink deposition impacts the system margin depending on the transmissive characteristics of the ink.

Power Supply Design

The design of the power supply also affects the system margin. System designers need to design a high quality, high performance system for minimal cost. Proximity detection systems process very low currents generated by photodiodes and use a large amount of gain to create manageable signals. The power supply design also sinks a comparatively large current when the IR LED is being fired. As with most analog signal processing solutions, noise becomes an issue and should be well managed. As a result, care must be taken to devise a good low cost power supply circuit for the application. A recommended circuit is shown in Figure 9.

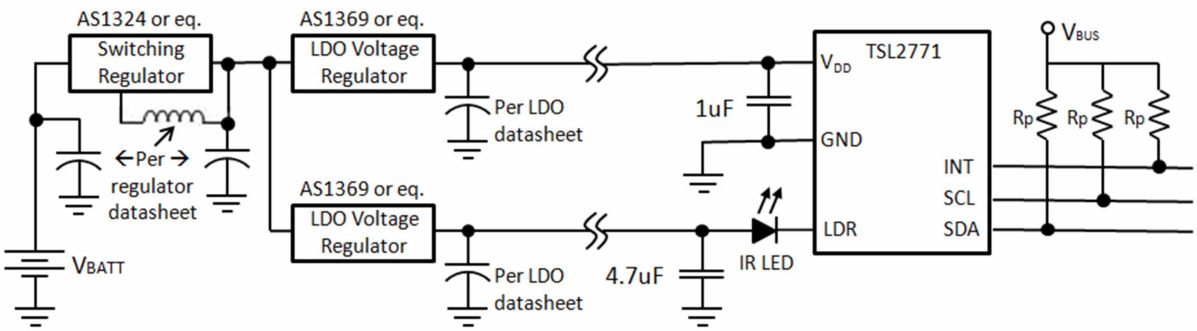


Figure 9: Preferred Dual Supply

If the preferred dual supply cannot be used, an alternative is a shared single supply with an RC filter on the Vdd supply line. This is shown in Figure 10.

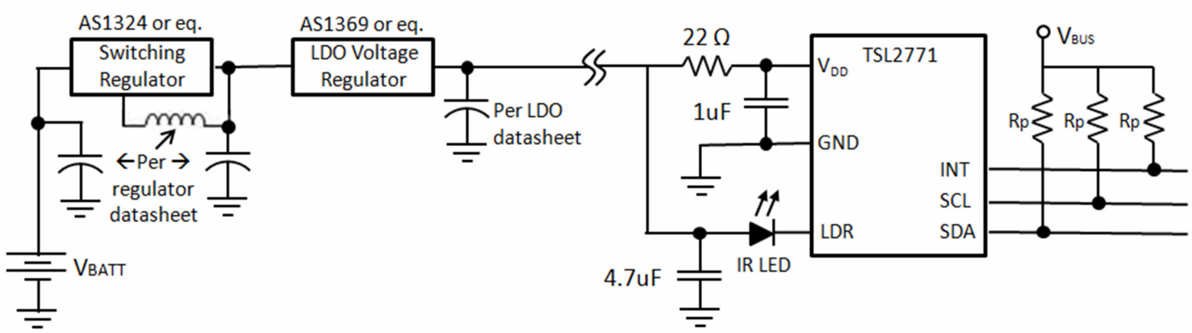


Figure 10: Shared Single Supply

Proximity count variations due to power supply design are another system attribute that reduces the system margin. Information provided in the Designer's Notebook DN32, "Proximity Detection Layout Recommendations" publication should be consulted for more information and additional alternatives regarding the power supply design for proximity detection systems.

Test Fixture Correlation / Calibration

Designers use development test systems (developed internally or with a TAOS evaluation system) to verify operation of their prototypes and to determine system threshold values for proximity detection or release. As test fixtures are developed for use on the production line differences between proximity readings will become evident. All of the factors discussed in this application note (and more) influence the value of the received proximity count on the tester so correlation is difficult. Clearly a system testing the device without glass will not achieve the same readings as a system tested behind glass.

Testers should be identical. This not only means the hardware is the same but the DC supply wiring needs to be the same (wire gauge, wiring length, routing and supply output capacitance & ESR). In addition, the optical environment needs to be identical. This includes the reflective target (Kodak Gray Cards have a specified reflectivity), the size of the target and the distance to the target. Although the TAOS proximity detectors are designed to reject ambient light, the test environment should be identical also. Tests performed in fluorescent light then in halogen light will cause subtle variations in proximity readings.

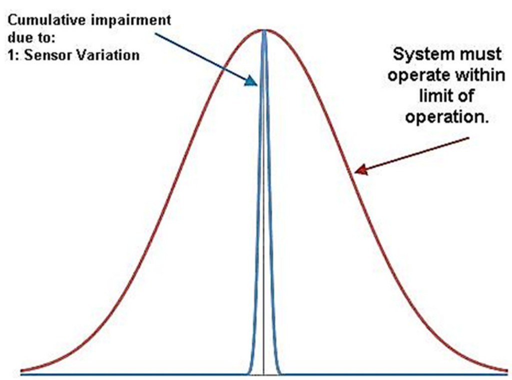
Conclusion

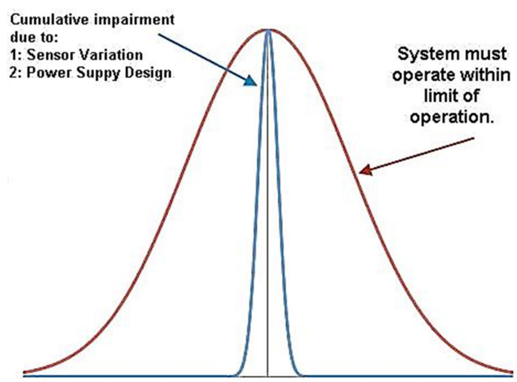
Receivers require a minimum amount of signal energy from the LED and the amount of received power that exceeds the minimum operating threshold is called the system margin. The system margin must be large enough to encompass the desired proximity detection range, manufacturing variation in the device, material anomalies, external system influences and other variations associated with production or system operation.

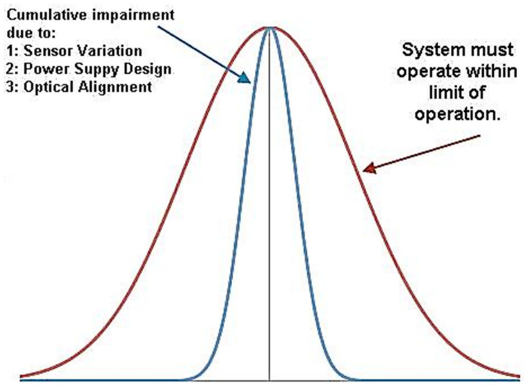
Every aspect of an imperfect optical system contributes negatively to the performance of the system. The contributions are additive and the cumulative total must be less than the amount of margin available. Any parameter that deviates in the negative direction from its expected value will require other parameters to be better than their normal value or the proximity detection range will be reduced.

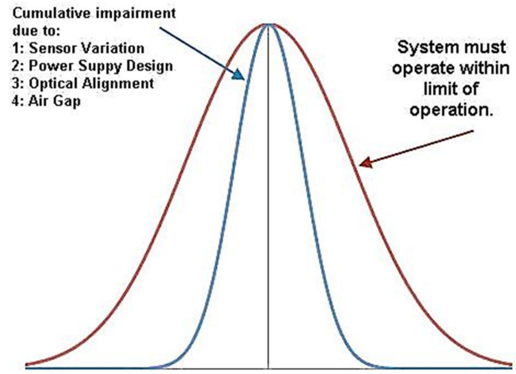
Analysis can be done using convolutions of statistical deviations for each individual parameter. In the graphical example below convolutions were performed on ten (10) variables to show the erosion of the system margin. It can be seen that the cumulative impairments encroach on the system limit of operation, until ultimately the limit is exceeded and the system becomes non-operational. At this point some parameter (or parameters) needs to be improved before the system can be made operational.

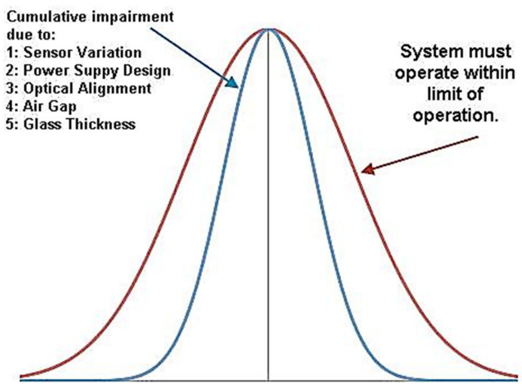
The line in RED (showing system limit of operation) will provide the desired detection range if the cumulative impairment line is kept within its boundary. If the limit of operation line is exceeded then the detection range will not be met. Impairments are being added sequentially (visible in the upper left corner of each graph) and the cumulative impairment is plotted along with the limit of operation. As long as the cumulative impairment line is contained within the limit of operation line the system has adequate margin to operate.

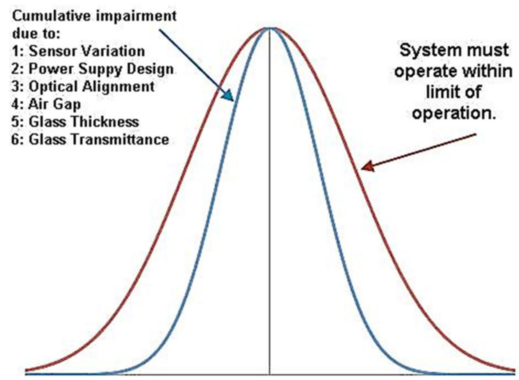


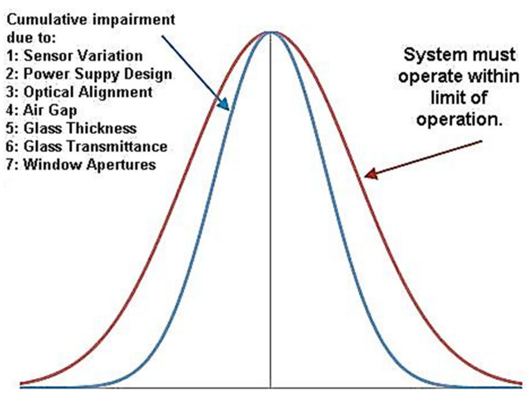


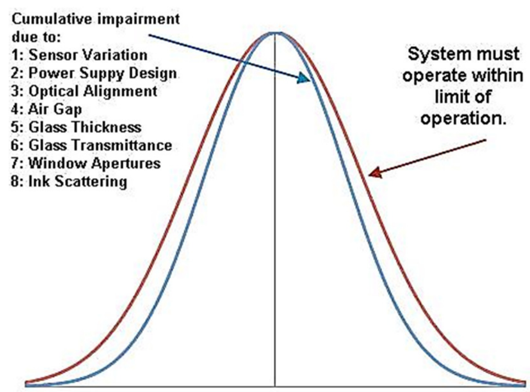

Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
System must operate within limit of operation.

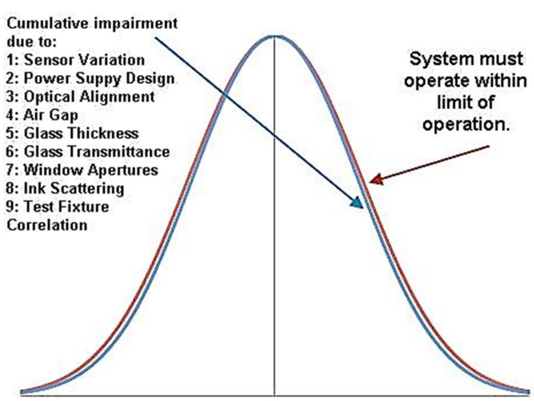

Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
System must operate within limit of operation.

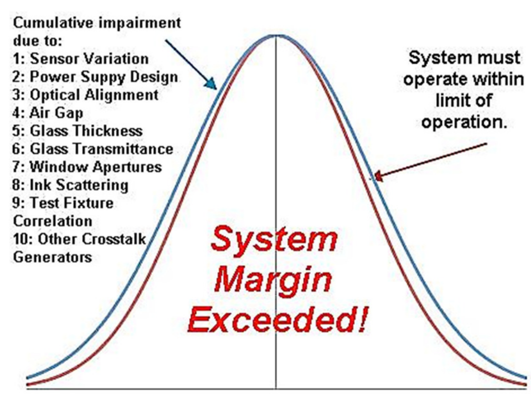

Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
5: Glass Thickness
System must operate within limit of operation.


Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
5: Glass Thickness
6: Glass Transmittance
System must operate within limit of operation.


Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
5: Glass Thickness
6: Glass Transmittance
7: Window Apertures
System must operate within limit of operation.


Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
5: Glass Thickness
6: Glass Transmittance
7: Window Apertures
8: Ink Scattering
System must operate within limit of operation.


Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
5: Glass Thickness
6: Glass Transmittance
7: Window Apertures
8: Ink Scattering
9: Test Fixture Correlation
System must operate within limit of operation.


Cumulative impairment due to:
1: Sensor Variation
2: Power Suppy Design
3: Optical Alignment
4: Air Gap
5: Glass Thickness
6: Glass Transmittance
7: Window Apertures
8: Ink Scattering
9: Test Fixture Correlation
10: Other Crosstalk Generators
System must operate within limit of operation.
System Margin Exceeded!

The sum influence of the impairments needs to be lower than the available system margin for the system to work. If one aspect of the system is poorly controlled and has lots of variation the system margin may be exceeded. Conversely if all the impairments become somewhat high that may cause the margin to be exceeded also. The best solution is to design, implement and fabricate the best solution possible so the amount of system margin is maximized. That way the impairments will not affect the link budget and the system will continue to function.

References:

1.) "Fresnel Equations", see url address: http://en.wikipedia.org/wiki/Fresnel_Equations