White Paper

Calculate Reliable LED Lifetime Performance in Optocouplers

Introduction

Optocouplers are used for high-voltage isolation and electrical noise rejection—important requirements for transmitting correct information between different voltage potentials within an electrical system. Such systems must be able to operate reliably for many years in industrial, medical, renewable energy environments, and any system that has a long expected operating lifetime.

Broadcom® optocouplers use high-reliability LEDs to fulfill the critical system reliability requirements. LED technology has matured over 40 years, and Broadcom has continually enhanced the manufacturing process to improve and refine LED performance. This allows Broadcom's optocouplers to be suitable in industrial, renewable energy, automotive, and even ultra-high mission critical applications, such as military and aerospace applications.

Despite harsh application uses, there are still concerns regarding the optocoupler operating lifetime. This may be valid for the inferior cheap phototransistors, but it does not apply to a high-performance optocoupler with photo-IC output. This white paper explains how Broadcom, an industry leader in optocouplers, uses LED reliability stress data under accelerated conditions to project expected lifetime performance based on Black Model (an accepted empirical model by J.R Black to estimate the mean-time-to-failure (MTTF) of wire associated with electro-migration[1]). The analysis gives designers the assurance and design flexibility so they can choose the most appropriate LED forward input current for their application.

LED Reliability Stress Tests

Optocouplers use LED to transmit digital or analog information across an isolation (or insulation) barrier. On the barrier's other side is a light-sensing detector that converts the optical signal into an electrical signal. Input current-limiting resistor defines a recommended input drive current (I_F) to the LED. However, the optocoupler's LED quantum efficiency (total photons per electron of input current) decreases over time due to thermal and electrical stressing of the LED PN junction[2]. Broadcom performs stress testing for thousands of hours of continuous operation to determine LED reliability. A High Temperature Operating Life (HTOL) test is performed with the LED operating at 125°C and a continuous I_F of 20 mA.

The Current Transfer Ratio (CTR) is an electrical parameter of an optocoupler. CTR, as a percentage, is defined as the ratio of the output collector current (IC) caused by the light detected from the photodiode to the forward LED input current (I_F). Designers can use the change in CTR over time to gauge the LED reliability.

$$\text{Current Transfer Ratio, CTR} = (I_C / I_F) \times 100\%$$

The input current and temperature cause heat stress in the LED crystalline structure. Thus, even though I_F stays constant, the light output from the LED decreases over time. The photodiode's IC and CTR will decrease. At each predetermined point of stress test hours (168 hours, 500 hours, 1000 hours, and so on), IC is measured and the CTR is calculated. LED lifetime performance is plotted using this collection of data points.

Acceleration Factor

An acceleration factor (AF) based on the Black Model correlates the actual HTOL stress test data points, taken at elevated temperatures and stress time, to the expected lifetime of the actual application operating conditions.

Equation 1:

$$AF = \left(\frac{J_{acc}}{J_{norm}}\right)^N \exp\left(\frac{E_a}{K}\left\{\frac{1}{T_{norm}} - \frac{1}{T_{acc}}\right\}\right)$$

AF	=	Acceleration factor
J_{acc}	=	Accelerated current density (HTOL stress input current)
J_{norm}	=	Nominal operation current density (application operating input current at 100% duty cycle)
Ea	=	Activation energy of 0.43 eV
K	=	Boltzmann's constant of 8.62 x 10^{-5} eV/K
T_{norm}	=	Nominal operating temperature (application operating temperature)
T_{acc}	=	Accelerated operating temperature (HTOL stress temperature)
N	=	Model parameter of 2

For the same CTR lifetime performance, the LED field lifetime can be projected.

Equation 2:

$$\text{LED projected field hours} = \text{AF} \times \text{LED stress hours}$$

To illustrate the AF as multiplier, consider numerical example of a Broadcom optocoupler's stress data conditions:

I_F = 20 mA, temperature = 125°C, and LED type "AA". At a stress test length of 1000 hours, the CTR is measured as 99.2%. If an optocoupler is used with application conditions of I_F = 5 mA (assume 100% duty cycle operation) and an ambient temperature of 60°C, the AF is calculated as:

$$AF = \left(\frac{20\text{ mA}}{5\text{ mA}}\right)^2 \exp\left(\frac{0.43}{8.62 \times 10^{-5}}\left\{\frac{1}{273+60} - \frac{1}{273+125}\right\}\right) \approx 184.7$$

The projected field lifetime for the LED = AF × stress hours = 184.7 × 1,000 = 184,767 hours (or 21 years). With the AF value calculated, all data points of stress hours map to the expected field lifetime time.

The LED in Broadcom optocouplers is fabricated from Aluminum Gallium Arsenide (AlGaAs) or Gallium Arsenide Phosphide (GaAsP). Table 1 through Table 5 show the Broadcom optocoupler product families and part numbers' LED type.

All LED types have similar characteristics, with CTR < 10% loss after 30 field years of typical operations.

Table 1: Broadcom Optocouplers with AlGaAs (Type 1) LED

Product Family	Broadcom Optocoupler Part Number
10 MBD LOGIC	ACNV2601, ACNW261L, ACPL-C61L
5 MBD LOGIC	ACPL-M21K/024L/W21L/K24L, HCNW2211
1 MBD TRANSISTOR	ACPL-M50L/054L/W50L/K54L
100 KBD DARLINGTON	HCNW138
ANALOG	HCNR200/201, HCNW4562
ISOLATION AMPLIFIER	ACPL-796J/C784/785J, ACPL-7900/7970/C797/C790, HCPL-7840/7860
GATE DRIVER	ACPL-352J/337J/339J, ACPL-331J/332J, ACNW3190, HCPL-316J/314J
IPM DRIVER	ACNV4506, ACPL-P484/W484, HCNW4503/4506

Table 2: Broadcom Optocouplers with AlGaAs (Type 2) LED

Product Family	Broadcom Optocoupler Part Number
10 MBD LOGIC	ACPL-M61L/064L/W61L/K64L
8 MBD LOGIC	HCPL-0300/2300
100 KBD DARLINGTON	HCPL-070A/4701
ANALOG	ACPL-K376, HCPL-4562
HERMETIC	ACPL-5160, HCPL-5200/5400/7850

Table 3: Broadcom Optocouplers with AlGaAs (Type 3) LED

Product Family	Broadcom Optocoupler Part Number
AUTOMOTIVE	ACFL-5211T/6211T, ACPL-M49T/M71T, ACPL-344JT/K30T, ACPL-C87BT
1MBD TRANSISTOR	ACFL-5211U
10MBD LOGIC	ACFL-6211U/6212U

Table 4: Broadcom Optocouplers with GaAsP LED

Product Family	Broadcom Optocoupler Part Number
HIGH SPEED CMOS	HCPL-0708/0738
15 MBD CMOS	ACPL-071L/074L
10 MBD LOGIC	HCPL-2611/2630/M611
5 MBD LOGIC	HCPL-0201/2231
1 MBD TRANSISTOR	HCPL-050L/053L, HCPL-250L/253L
100 KBD DARLINGTON	HCPL-070L/073L, HCPL-270L/273L/M700
GATE DRIVER	ACPL-3130/W302/P314/H312, HCPL-3120
IPM DRIVER	ACPL-4800/P480/W454, HCPL-0453/0454/4504/ M456
HERMETIC	ACPL-5600L/6750L, HCPL-5300/5500

Table 5: Broadcom Optocouplers with AlGaAs/Ge LED

Product Family	Broadcom Optocoupler Part Number
10 MBD LOGIC	ACNT-H61L
1 MBD TRANSISTOR	ACNT-H50L, ACNT-H511
GATE DRIVER	ACNT-H313, ACNW3430/3410, ACNU-3430/3410

Figure 1 through Figure 5 show the lifetime performance for the different LED types over 30 field years of operation. CTR drops no more than 10%. Depending on the system's expected lifespan and usage, the projection calculation allows designers more flexibility in selecting an appropriate I_F value. They can optimize their system designs for better trade-off between reliable operating lifetime and power consumption.

Figure 6 illustrates the LED performance at different forward LED input current (I_F) for AlGaAs (type 2) LED. The LED has minimal change of less than 10% across the optocoupler’s recommended operating range of I_F and for over a 20+ year lifetime. There are three factors to maximize the LED operating lifetime:

- Operate at lower LED input driving current I_F.
- Operate at lower duty cycle.
- Operate at lower ambient temperature.

Remarkably, Broadcom optocouplers project a lifetime performance of just a 10% CTR drop for as long as millennium (few centuries). Figure 7 shows the centennial lifetime performance.

Figure 1: CTR Performance vs. Field Years for AlGaAs (Type 1) LED (Operating I_F = 16 mA, 50% Duty Cycle, T_A = 80°C)

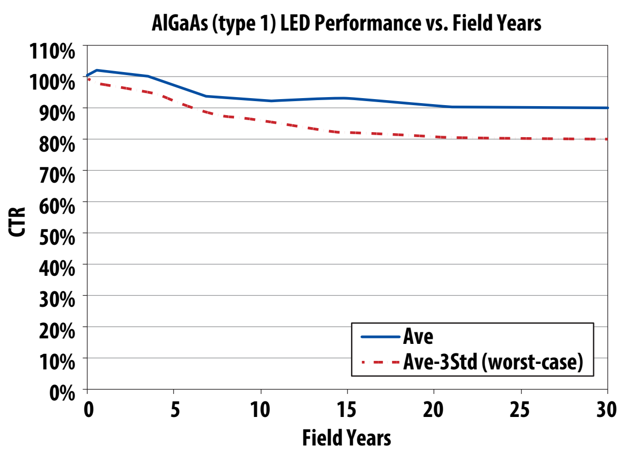


Figure 2: CTR Performance vs. Field Years for AlGaAs (Type 2) LED (Operating I_F = 5 mA, 100% Duty Cycle, T_A = 80°C)

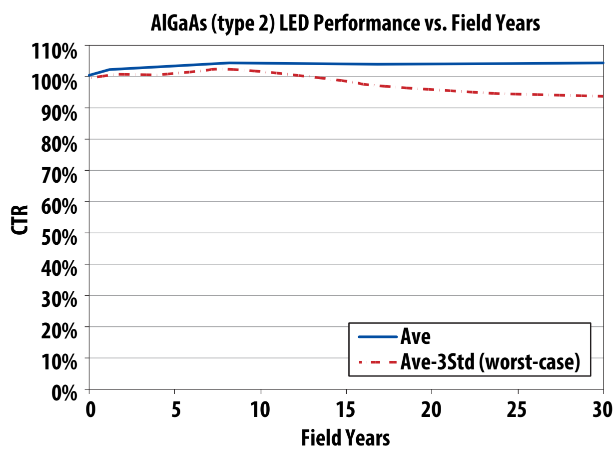


Figure 3: CTR Performance vs. Field Years for AlGaAs (Type 3) LED (Operating I_F = 12 mA, 50% Duty Cycle, T_A = 110°C)

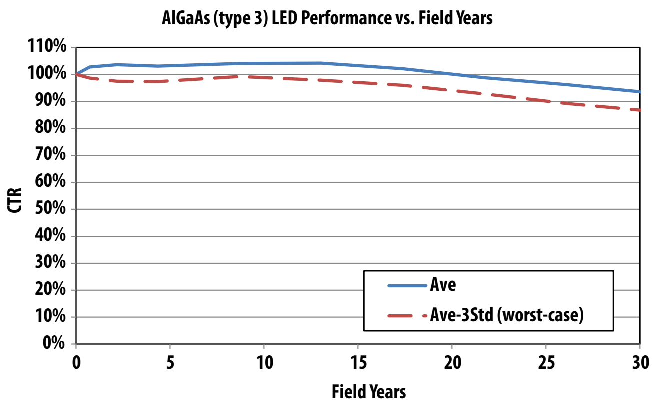


Figure 4: CTR Performance vs. Field Years for GaAsP LED (Operating I_F = 16 mA, 50% Duty Cycle, T_A = 80°C)

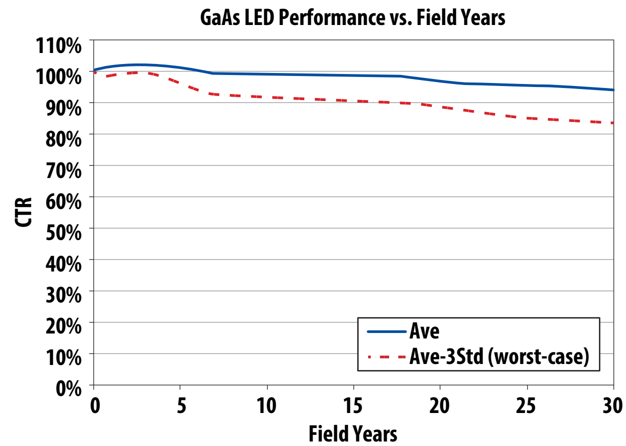


Figure 5: CTR Performance vs. Field Years for AlGaAs/Ge LED (Operating I_F = 12 mA, 50% Duty Cycle, T_A = 80°C)

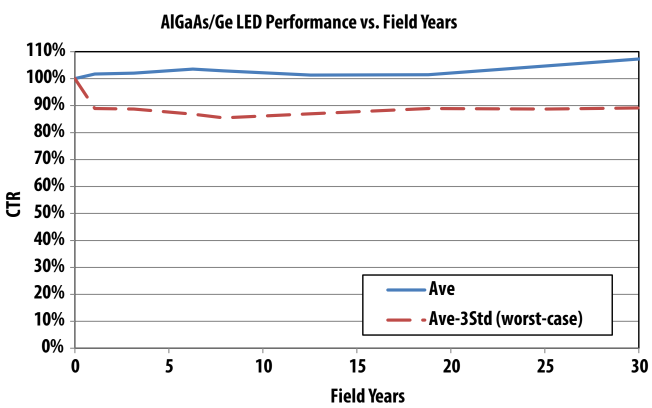


Figure 6: CTR Performance vs. Field Years for AlGaAs (Type 2) LED at different IF (50% Duty Cycle, T_A = 80°C)

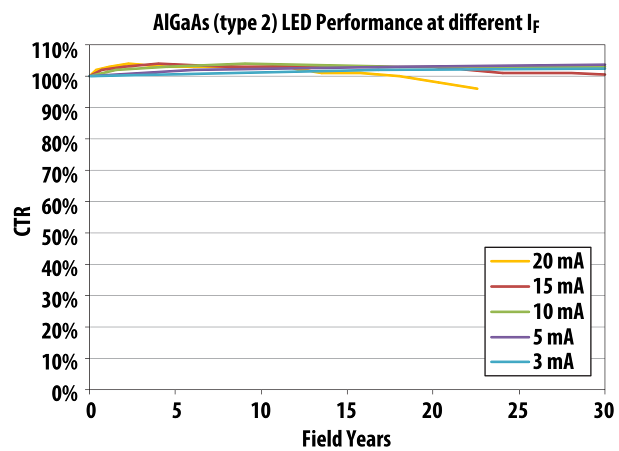
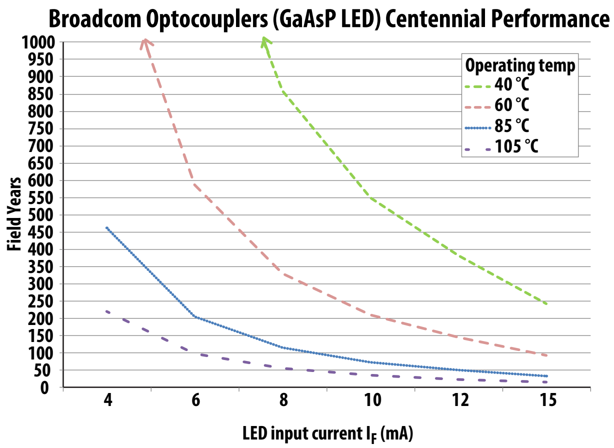


Figure 7: Centennial Performance for GaAsP LED



NOTE: I_F = 20 mA condition ends projection at 22.6 field years due to actual stress data collected up to 10,000 hours. This does not mean LED fails at 22.6 projected field years. Longer >10,000 hours stress data points will be needed for projecting more field years.

Summary

Broadcom optocouplers have been operating in harsh and hazardous applications, handling high voltages and transients with continued success, for many years. The LED in Broadcom optocouplers, unlike inferior phototransistors, has excellent reliability performance (< 10% drop) over 30 years of field operation. The LED long lifetime gives designers greater flexibility when selecting optocouplers for their application. Designers can make the most cost-effective trade-off between the optimal level of reliable operating lifetime for their system and low power consumption.

Reference

1. "Reliability Prediction Methods for Electronic Products", Reliability EDGE volume 9, Issue 1, June 2008.
2. "CTR Degradation and Ageing Problem of Optocouplers", Bajenesco, Electrotechnical Conference, 1994.

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