Understanding of Long-Term Parametric Shift and Acceleration Factor

Prepared by Marek Lis

- Long-Term Stability (Life-Time Shift)
  - for specs centered around a zero or a mean value
  - for parameters defined as an absolute value

- Thermal Acceleration Factor (AF)
  - Arrhenius equation and the Acceleration Factor
  - Effect of AF on the life of a product

Long-Term Stability

Normal Gaussian Distribution

Standard deviation and confidence intervals

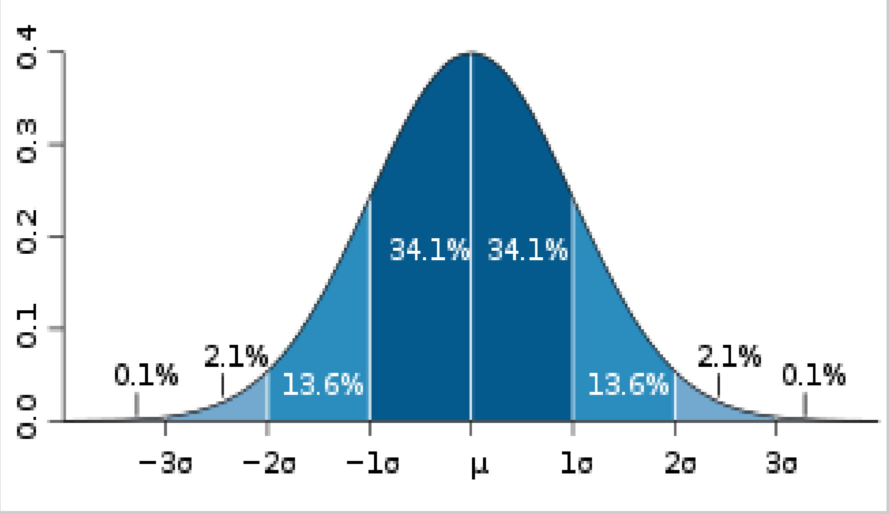
[edit]

About 68% of values drawn from a normal distribution are within one standard deviation σ away from the mean; about 95% of the values lie within two standard deviations; and about 99.7% are within three standard deviations. This fact is known as the *68-95-99.7 rule*, or the *empirical rule*, or the *3-sigma rule*. To be more precise, the area under the bell curve between $\mu - n\sigma$ and $\mu + n\sigma$ is given by

$$F(\mu + n\sigma;\, \mu, \sigma^2) - F(\mu - n\sigma;\, \mu, \sigma^2) = \Phi(n) - \Phi(-n) = \mathrm{erf}\left(\frac{n}{\sqrt{2}}\right),$$

where erf is the error function. To 12 decimal places, the values for the 1-, 2-, up to 6-sigma points are:[16]

n	$\mathrm{erf}\left(\frac{n}{\sqrt{2}}\right)$	i.e. 1 minus ...	or 1 in ...
1	0.682 689 492 137	0.317 310 507 863	3.151 487 187 53
2	0.954 499 736 104	0.045 500 263 896	21.977 894 5080
3	0.997 300 203 937	0.002 699 796 063	370.398 347 345
4	0.999 936 657 516	0.000 063 342 484	15,787.192 7673
5	0.999 999 426 697	0.000 000 573 303	1,744,277.893 62
6	0.999 999 998 027	0.000 000 001 973	506,797,345.897



Dark blue is less than one standard deviation from the mean. For the normal distribution, this accounts for about 68% of the set, while two standard deviations from the mean (medium and dark blue) account for about 95%, and three standard deviations (light, medium, and dark blue) account for about 99.7%.

Life-Time Shift Qual Guidelines

In a case of specs centered around zero or a mean value like Vos, Vos Drift, Vref, AOL, etc., they may shift over 10-year life up to:

+/-100% of the max (min) PDS specified value

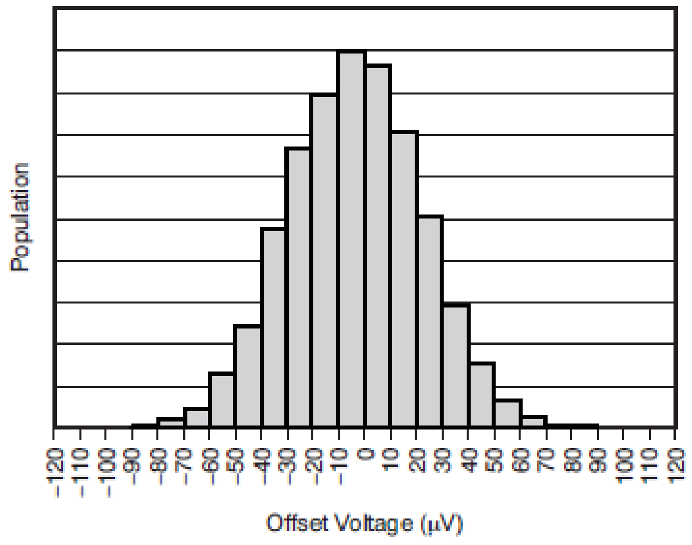
In a case of parameters specified as an absolute value like IQ, Slew Rate (SR), Isc, etc. they may shift over 10-year life up to:

+/-10% of the max (min) PDS specified value

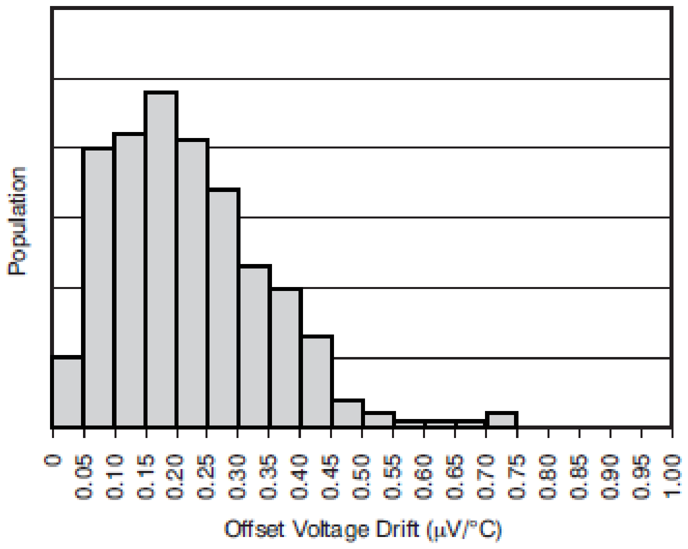
Understanding Statistical Distributions
(specs centered around a zero)

PARAMETER		CONDITIONS	OPA140, OPA2140, OPA4140			UNIT
			MIN	TYP	MAX	
OFFSET VOLTAGE						
Offset Voltage, RTI	V_{OS}	$V_S = \pm 18V$		30	120	μV
Over Temperature		$V_S = \pm 18V$			**220**	**μV**
Drift	dV_{OS}/dT	$V_S = \pm 18V$		±0.35	**1.0**	**μV/°C**

OFFSET VOLTAGE PRODUCTION DISTRIBUTION



OFFSET VOLTAGE DRIFT DISTRIBUTION



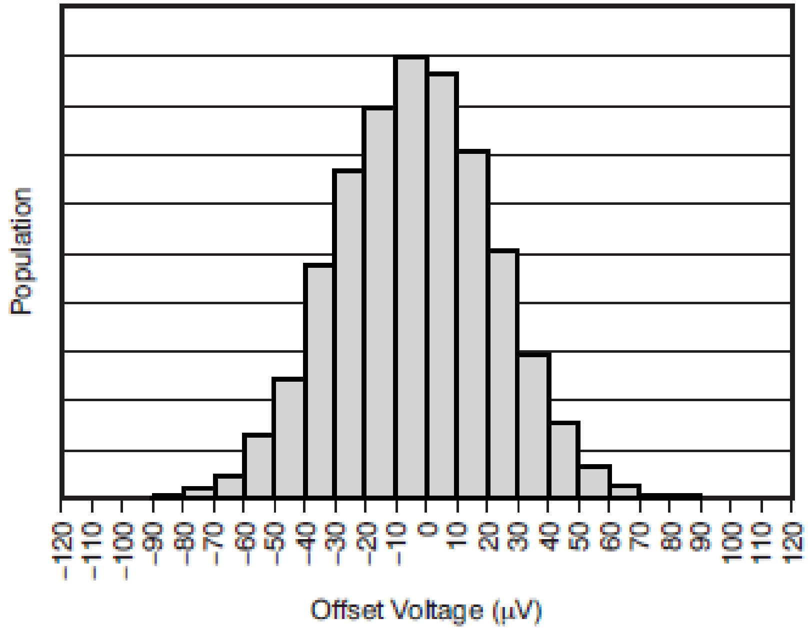
Understanding statistical distributions

OPA140

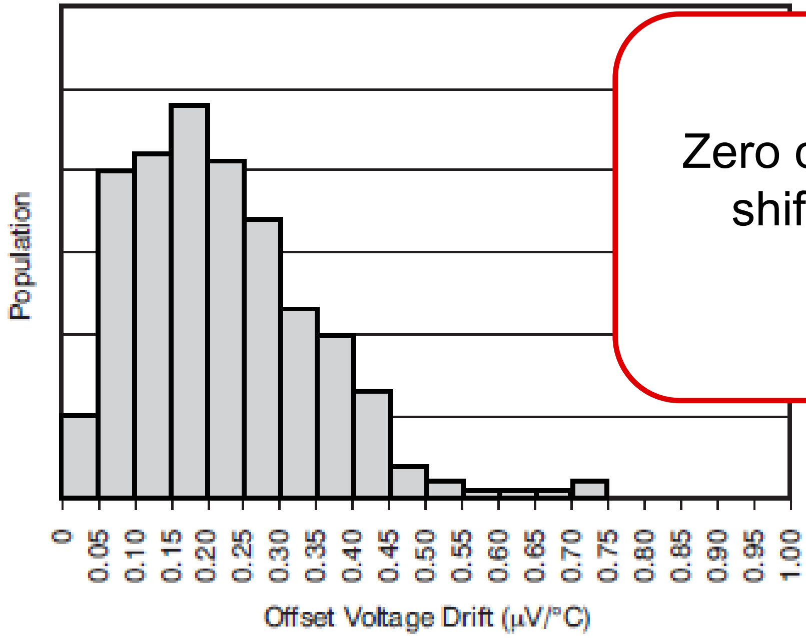
PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
Offset Voltage, RTI	V_{OS}	VS = ±18V		30	120	μV
Over Temperature					220	μV
Drift	dV_{OS}/dT			±0.35	1.0	μV/C

Both offset and offset drift are zero centered specifications

OFFSET VOLTAGE PRODUCTION DISTRIBUTION



OFFSET VOLTAGE DRIFT DISTRIBUTION

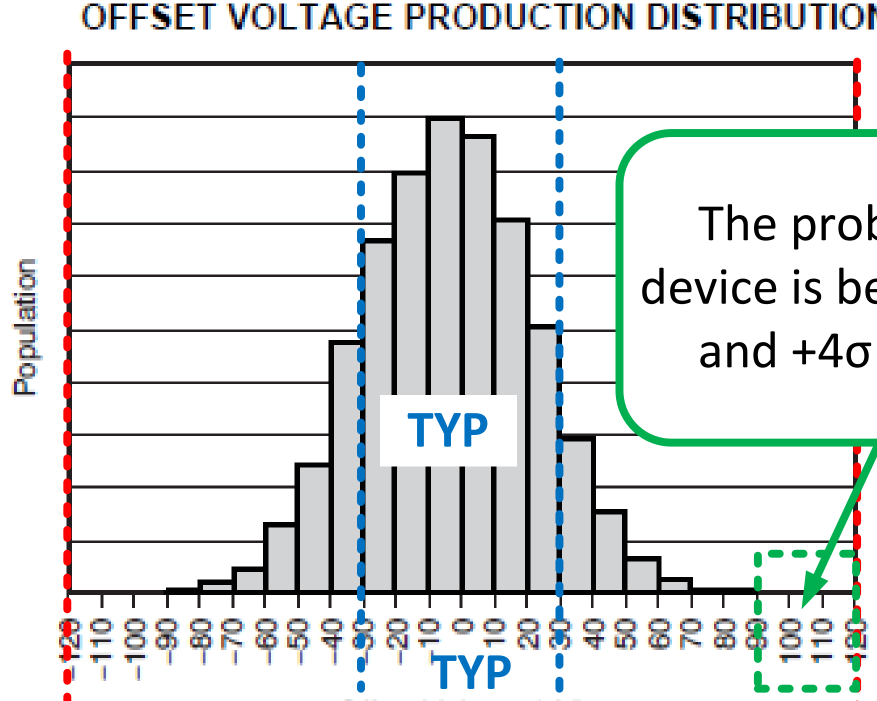


Zero centered errors can shift double the max specification

Understanding statistical distributions

OPA140

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
Offset Voltage, RTI	V_{OS}	VS = ±18V		30	120	µV



±σ 68.2% of Population

The probability a device is between +3σ and +4σ is 0.13%

MAX is ±4σ 99.994% of Population in this example

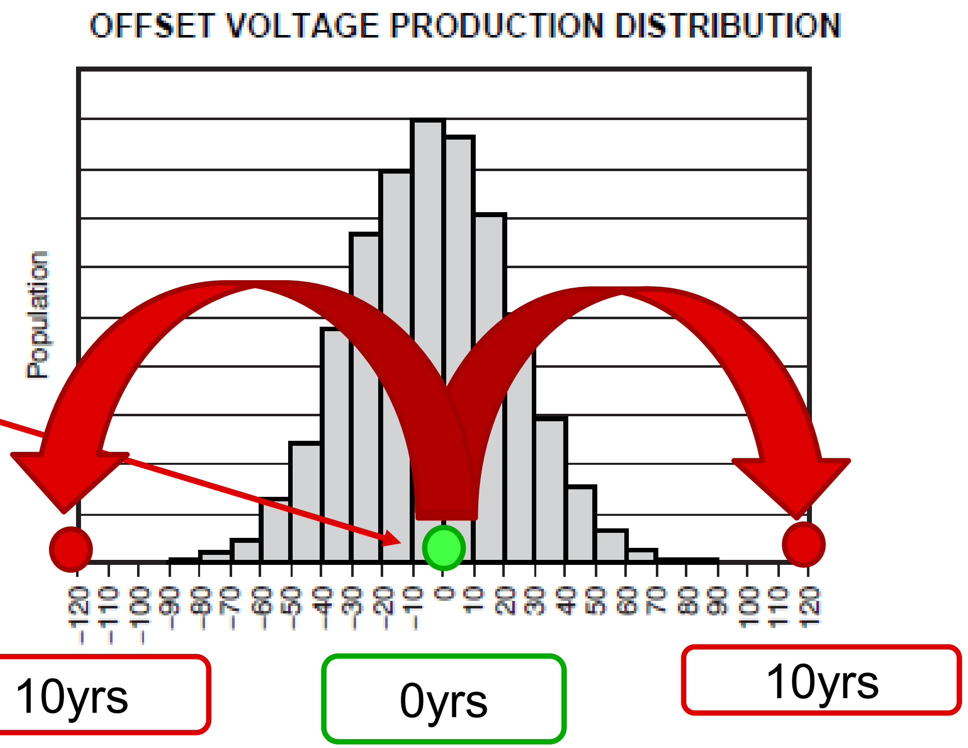
Typical represents 1 standard deviation of 68% of the population

Understanding statistical distributions

OPA140

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
Offset Voltage, RTI	V_{OS}	VS = ±18v		30	120	µV
Over Temperature					220	µV
Drift	dV_{OS}/dT			±0.35	1.0	µV/C

A device at 0V over the 10 year lifespan at 25C can shift at most by the maximum spec limit or ±120µV

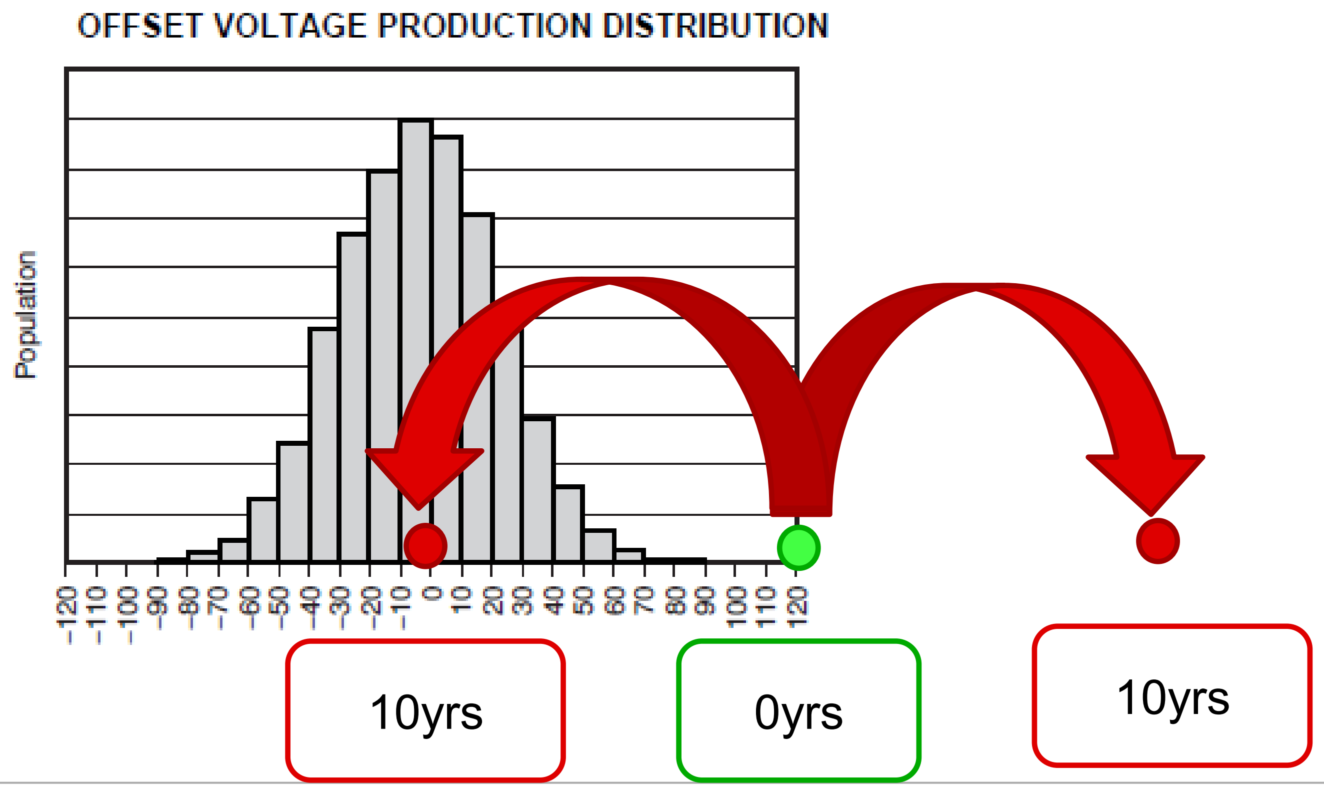


Understanding statistical distributions

OPA140

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
Offset Voltage, RTI	V_{OS}	VS = ±18v		30	120	µV
Over Temperature			-0.05		0.05	%
Drift	dV_{OS}/dT			±0.35	1.0	µV/C

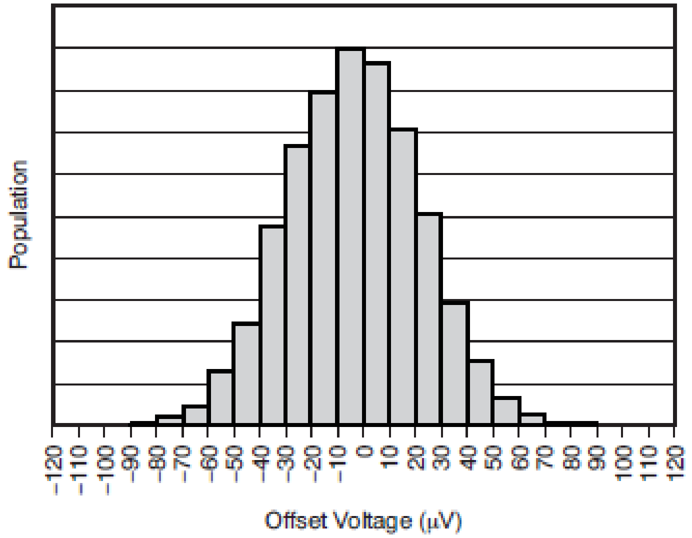
A device at the max limit (120µV) over the 10 year lifespan at 25C can shift at most by the max spec limit of ±120µV or anywhere between 0 to 240uV



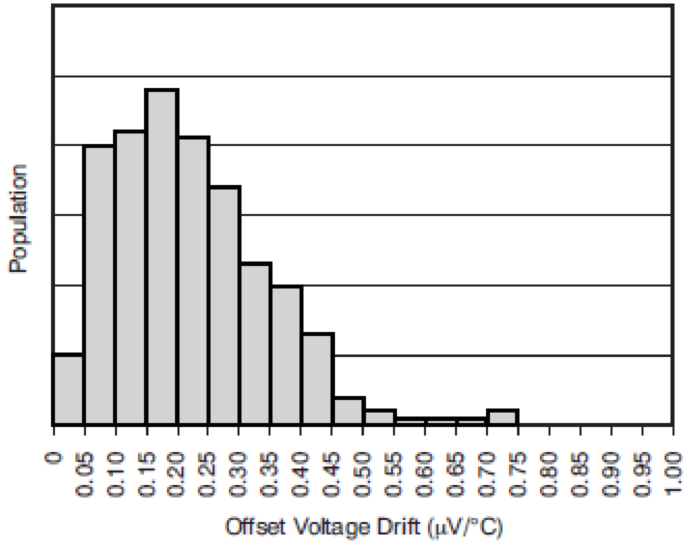
Life-Time Vos and Vos Temp Drift Shift

PARAMETER		CONDITIONS	OPA140, OPA2140, OPA4140			UNIT
			MIN	TYP	MAX	
OFFSET VOLTAGE						
Offset Voltage, RTI	V_{OS}	$V_S = \pm18V$		30	120	µV
Over Temperature		$V_S = \pm18V$			220	µV
Drift	dV_{OS}/dT	$V_S = \pm18V$		±0.35	1.0	µV/°C

OFFSET VOLTAGE PRODUCTION DISTRIBUTION



OFFSET VOLTAGE DRIFT DISTRIBUTION



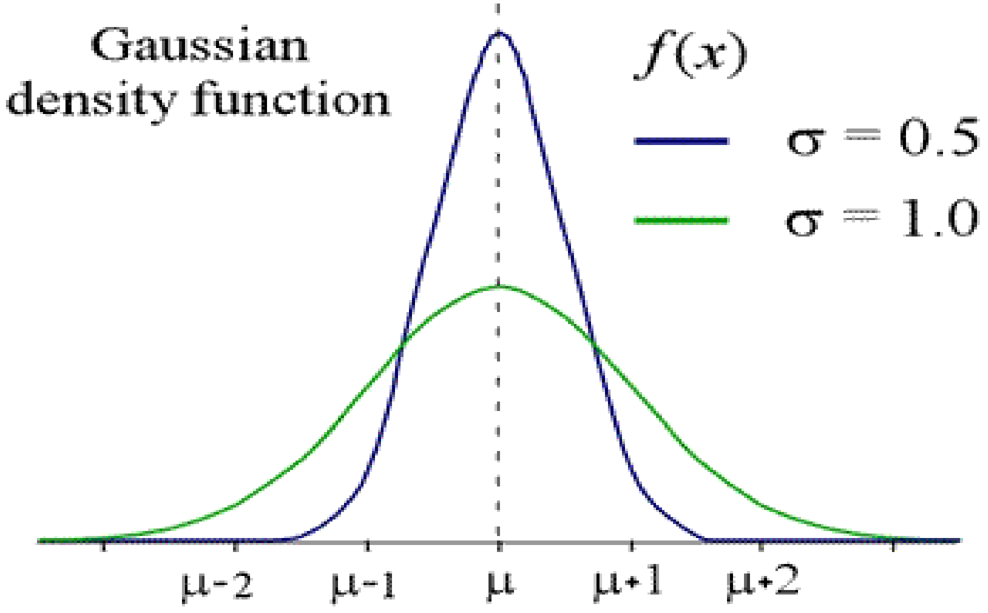
Max LT Vos = 240uV

Max LT Vos Drift = 2.0uV/C

Life-Time Max Shift (ten-year) = Max Initial Value

Long-Term Max Spec = 2 * Initial Spec

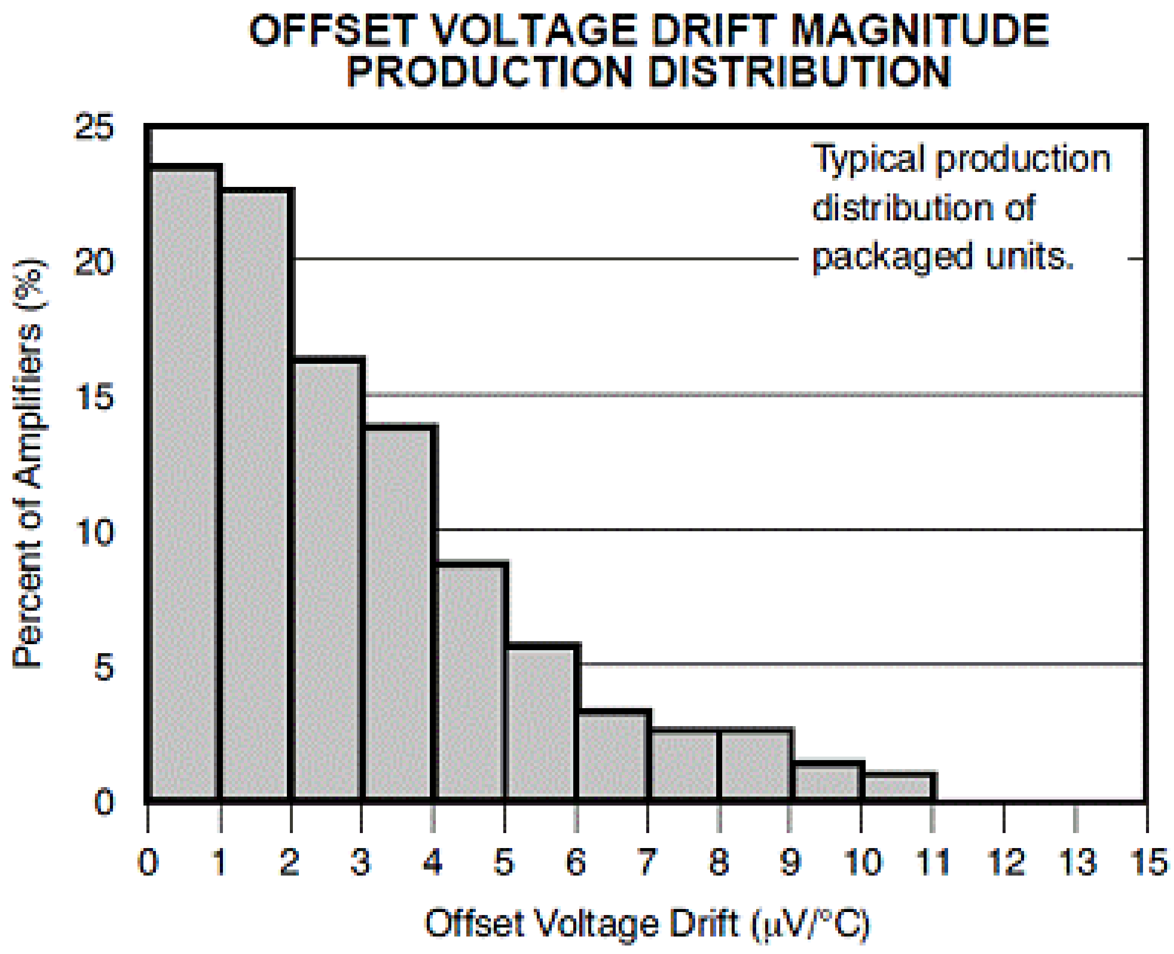
Long-Term Shift for Normal Gaussian Distributions
(Centered around a Mean Value)



$$f(x) = \sqrt{\frac{1}{4\pi\sigma^2}}\, e^{-(x-\mu)^2/2\sigma^2}$$

Initial PDS Distribution (blue) vs Long-Term Parametric Shift (green)

What is the Vos Drift Maximum Value?



Use of the Statistics to Determine Relative Maximum Value

Estimating a value of standard deviation (sigma)

n	$\mathrm{erf}\left(\frac{n}{\sqrt{2}}\right)$	i.e. 1 minus ...	or 1 in ...
1	0.682 689 492 137	0.317 310 507 863	3.151 487 187 53
2	0.954 499 736 104	0.045 500 263 896	21.977 894 5080
3	0.997 300 203 937	0.002 699 796 063	370.398 347 345
4	0.999 936 657 516	0.000 063 342 484	15,787.192 7673
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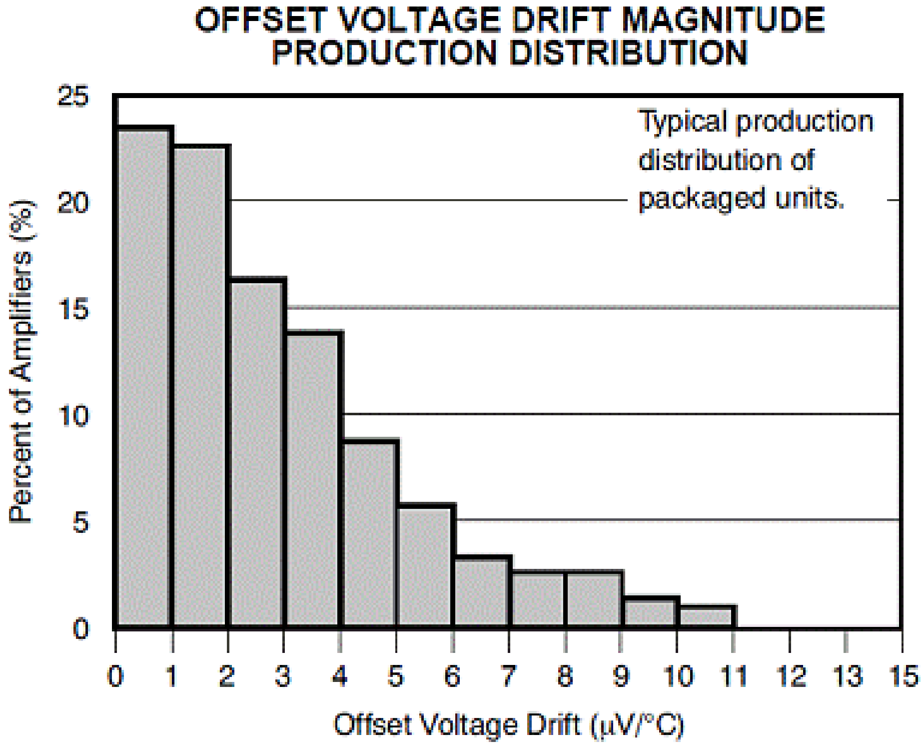


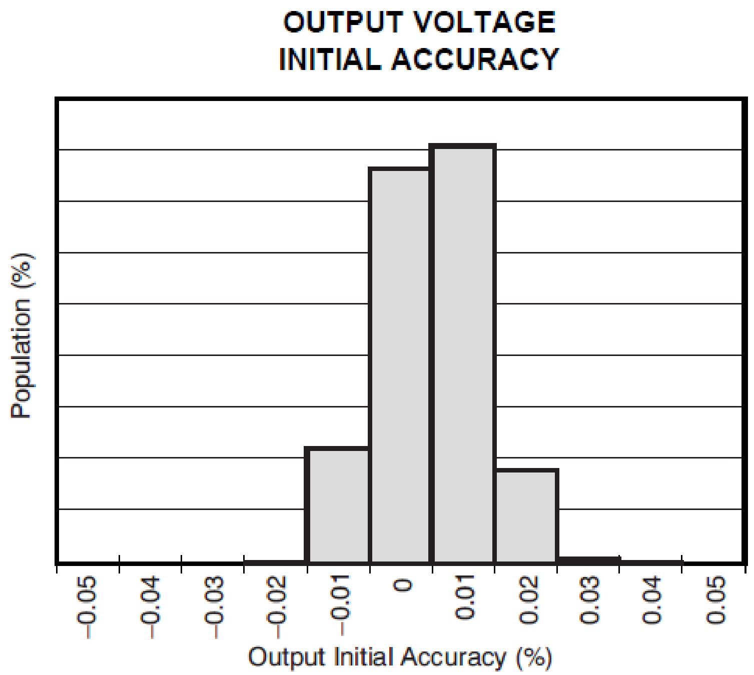
Knowing one-sigma is about ~4uV/C, customer may assume the maximum offset drift to be:

12uV/C (3*sigma) where 1 out of 370 units will NOT meet this max spec
16uV/C (4*sigma) where 1 out of 15,787 units will NOT meet this max spec
20uV/C (5*sigma) where 1 out of 1,774,277 units will NOT meet this max spec
24uV/C (6*sigma) where 1 out of 506,797,345 units will NOT meet this max spec

Life-Time Reference Voltage Initial Accuracy Shift

(specs centered around a mean value)

PARAMETER		CONDITIONS	PER DEVICE MIN	TYP	MAX	UNIT
REF5020 (V_{OUT} = 2.048V)[1]						
OUTPUT VOLTAGE						
Output Voltage	V_{OUT}	2.7V < V_{IN} < 18V		2.048		V
Initial Accuracy: High-Grade			–0.05		0.05	%

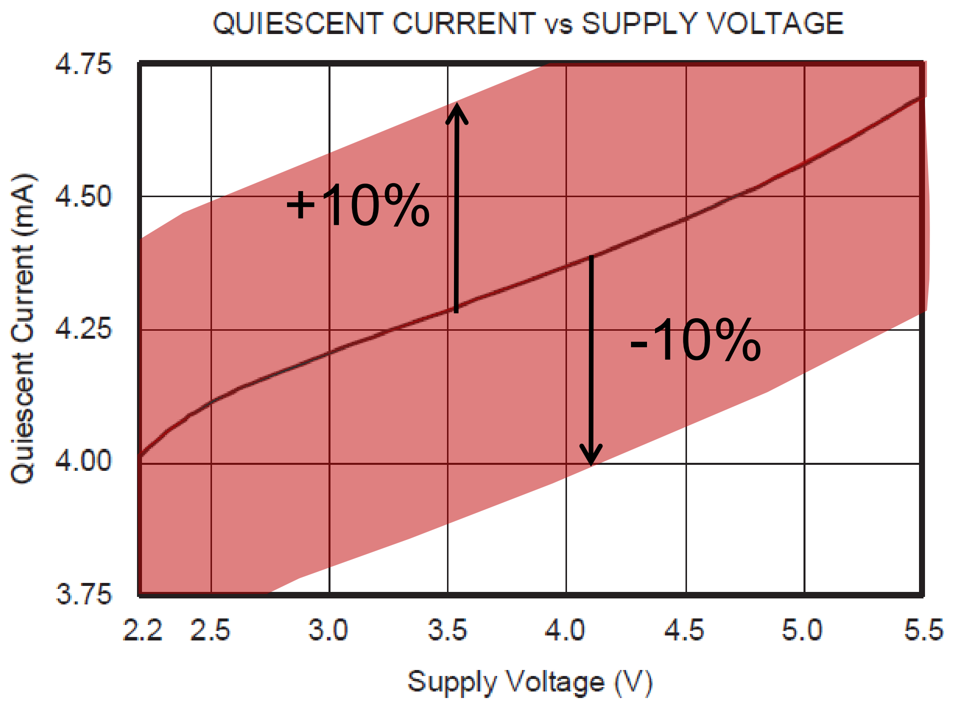


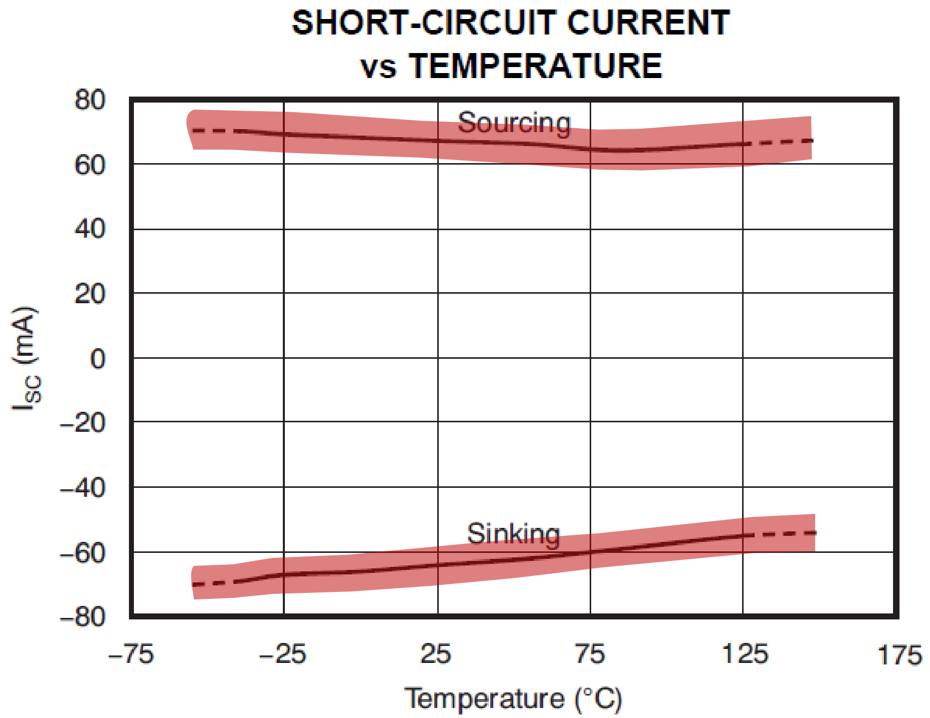
Max LT Vref = +/-0.1%

Long-Term IQ and Isc Shift

(specs centered around an absolute value)

PARAMETER		CONDITIONS	OPA827AI MIN	OPA827AI TYP	OPA827AI MAX	UNIT
Quiescent Current (per amplifier)	I_Q	I_{OUT} = 0A		4.8	5.2	mA
Short-Circuit Current	I_{SC}		±55	±65		mA

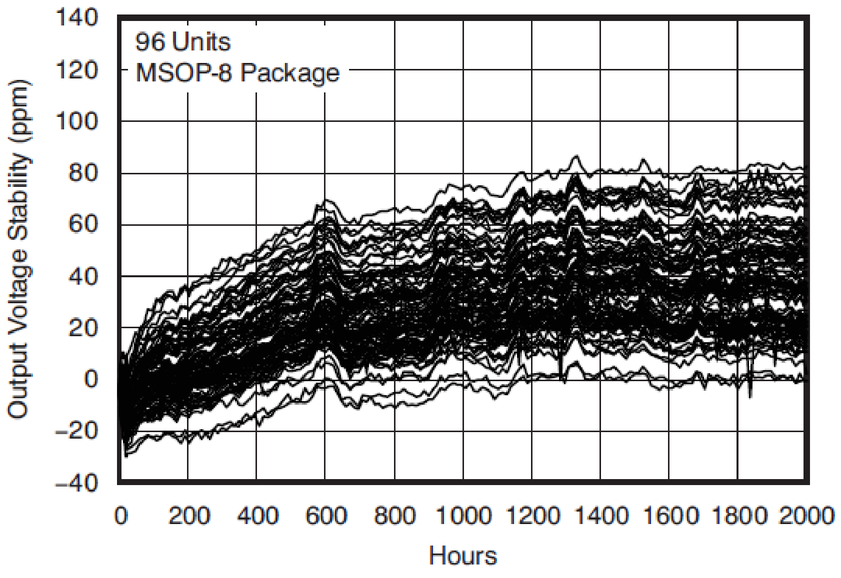




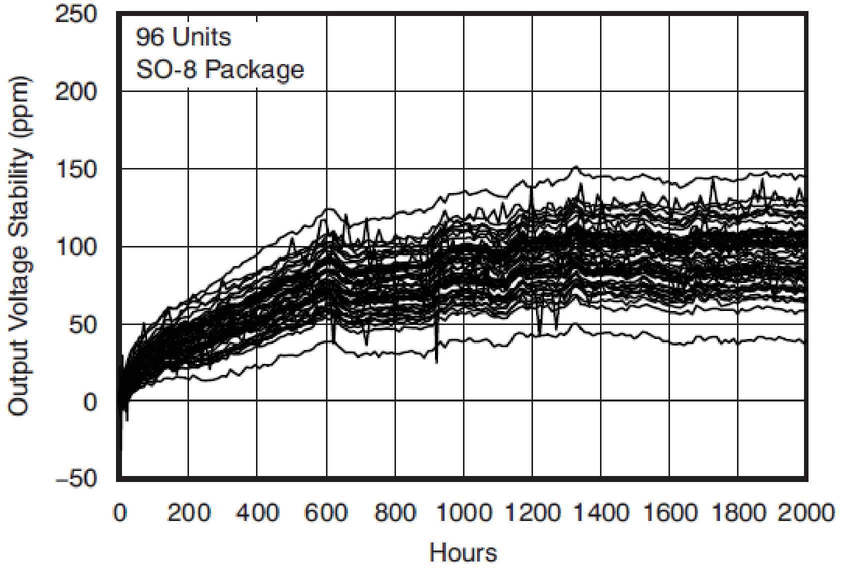
Long-Term Vref Stability

PARAMETER	CONDITIONS	REF50xx MIN	REF50xx TYP	REF50xx MAX	UNIT
LONG-TERM STABILITY					
MSOP-8	0 to 1000 hours		50		ppm/1000 hr
MSOP-8	1000 to 2000 hours		5		ppm/1000 hr
SO-8	0 to 1000 hours		90		ppm/1000 hr
SO-8	1000 to 2000 hours		10		ppm/1000 hr

REF50xx
LONG-TERM STABILITY (2000 HOURS)



REF50xx
LONG-TERM STABILITY (2000 HOURS)



Life-Time Shift Formula

To illustrate the life-time shift for an actual IC, let's consider the long-term stability of the low-noise, low-drift REF5025 precision voltage reference and its output initial accuracy specification.

Figure 3 shows the initial accuracy of REF5025 output voltage of +/-0.05% and the long-term stability for 0 to 1000 hours specified at 50ppm. As explained above, the long-term shift of the REF5025 must not exceed the life-test shift of +/-100% of the max/min initial accuracy; therefore, the maximum output voltage shift after 10 years (87,600 hours), under constant operation at room temperature, must be less than +/-0.05%, or an equivalent of +/-500ppm.

PARAMETER	CONDITIONS	REF50xx MIN	REF50xx TYP	REF50xx MAX	UNIT
LONG-TERM STABILITY					
MSOP-8	0 to 1000 hours		50		ppm/1000 hr
MSOP-8	1000 to 2000 hours		5		ppm/1000 hr

PARAMETER		CONDITIONS	PER DEVICE MIN	PER DEVICE TYP	PER DEVICE MAX	UNIT
REF5020 (V_{OUT} = 2.048V)[1]						
OUTPUT VOLTAGE						
Output Voltage	V_{OUT}	2.7V < V_{IN} < 18V		2.048		V
Initial Accuracy: High-Grade			–0.05		0.05	%

Figure 3 - Excerpts from REF5025 datasheet

Since the long-term shift clearly cannot be a linear function of time and simultaneously satisfy both conditions, the shift rate must initially be higher (having a steeper slope) and then gradually slow down (becoming more linear) over time. Therefore, it may be estimated by the square-root function normalized to 1000th of hours and shown below in Figure 4.

Output Voltage Shift = 50ppm*√[time(hours)/1000hrs]

Life-Time Shift Estimation Graph

Output Voltage Shift = 50ppm*√[time(hours)/1000hrs]

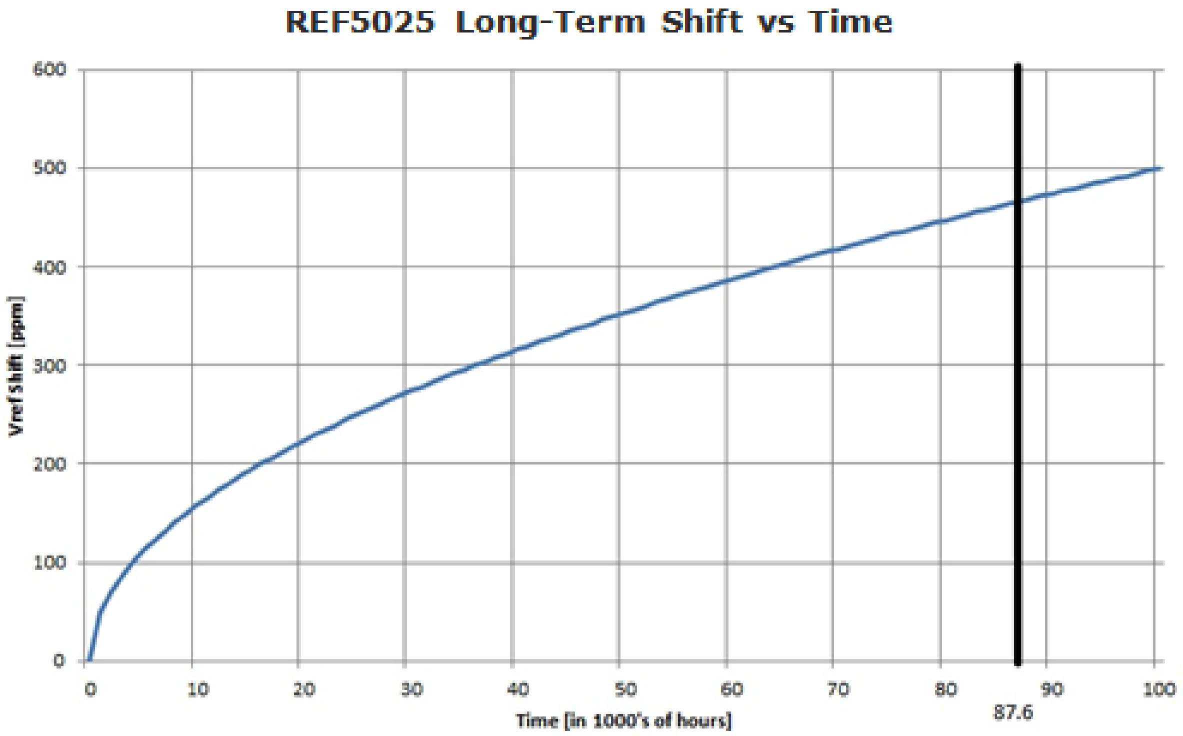


Figure 4 – REF5025 **long-term stability**

For example, after 25,000 hours of nonstop operation in the field, the typical output voltage shift in the REF5025 can be calculated using above equation, 50ppm*√25=250ppm, while after 10 years (87,600 hours) the shift would be 50ppm*√87.6=468pp. Therefore, at the end-of-life the REF5025 output voltage shift as expected is within the 500ppm allowable shift which equals to 0.05% of the datasheet maximum initial accuracy spec.

Life-Time Shift Rule Summary

You may estimate the maximum expected parametric shift over any given period of time by using:

- **100% of the max (min) PDS guaranteed value in the case of specs centered around a mean value** (Vos, Vos Drift, Vref, AOL, etc.)

- **10% of the max (min) guaranteed value for parameters specified as an absolute value** (IQ, slew rate, Isc, etc).

One may pro-rate the shift based on the expected ten-year life of the product

It needs to be understood that the long-term shift is NOT exactly a linear function of time – the shift is greater (curve is steeper) initially and slows down (become linear) over time. Therefore, the linear character of shift usually excludes the first month due to continuing self-curing of the molding compound used for packaging of IC.

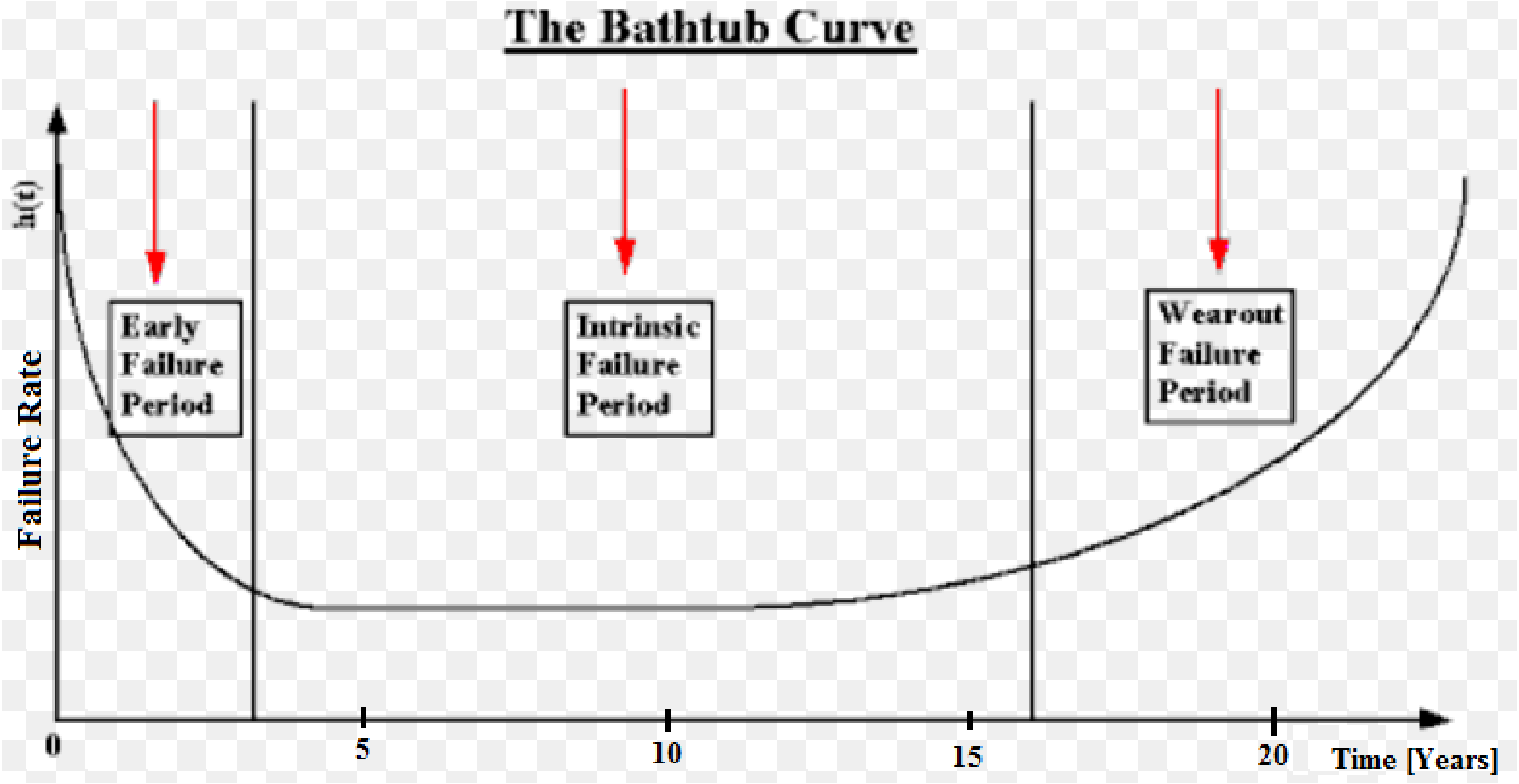
Acceleration Factor

HTOL (High Temperature Operating Life)

- HTOL is used to measure the constant failure rate region at the bottom of the bathtub curve as well as to assess the wear-out phase of the curve for some use conditions.
- Smaller sample sizes than EFR but are run for a much longer duration
- Jedec and QSS default are Ta=125C for 1000 hours
- Q100 calls for 1000 hours at max temperature for the device’s grade
- Most modern IC’s undergo HTOL at Ta=150C for 300 hours

Semiconductor Quality and Reliability

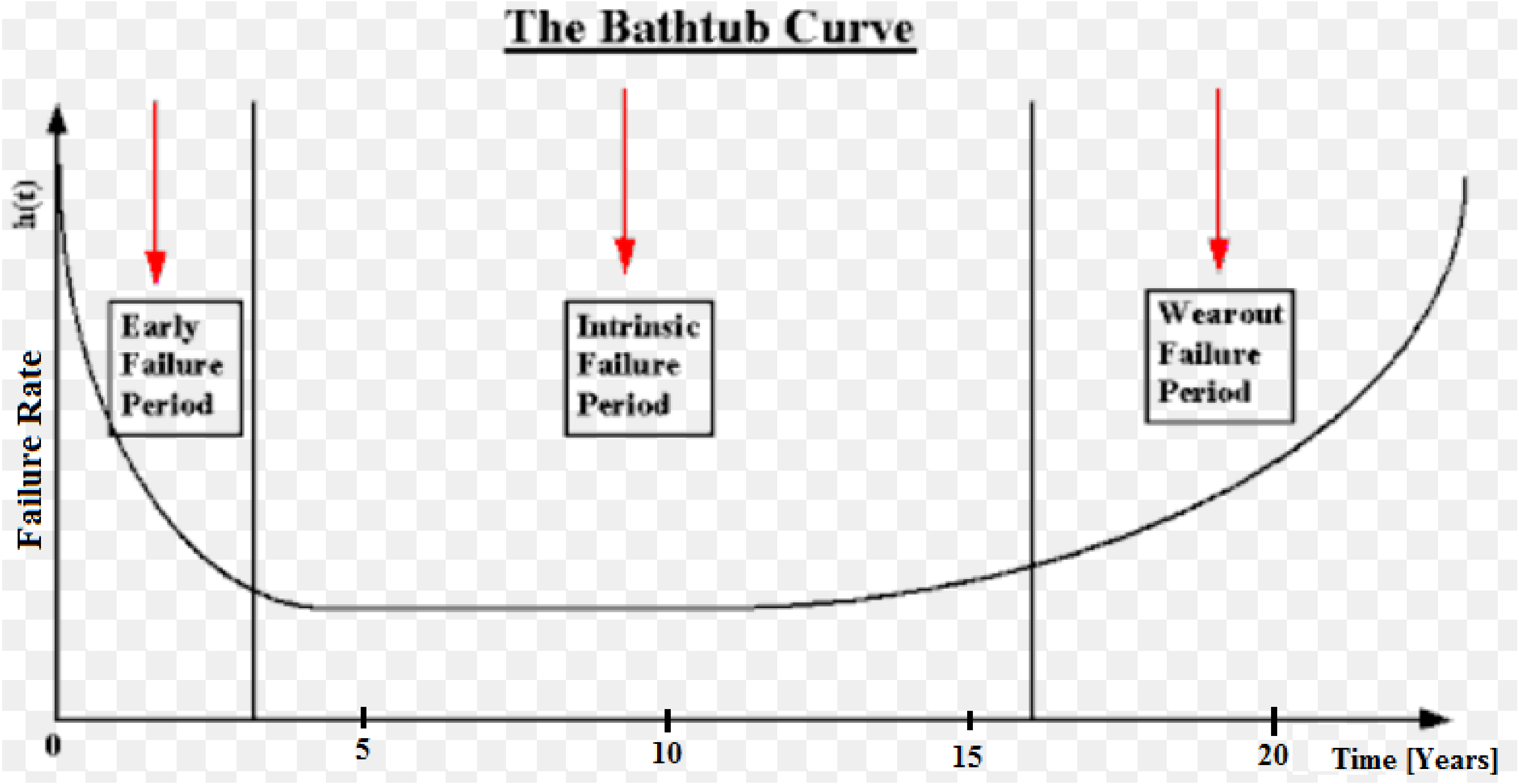
	Early life failure rate	MTBF / FIT		Early life failure rate supporting data				MTBF / FIT supporting data						
Part number	ELFR-DPPM	MTBF	FIT	Conf level (%)	Test temp (°C)	Sample size	Fails	Usage temp (°C)	Conf level (%)	Activation energy (eV)	Test temp (°C)	Test duration (hours)	Sample size	Fails
OPA192ID	22	4.89x 10^9	0.2	60	125	41306	0	55	60.0	0.7	125	1000	57098	0



Tambient = 25C

Semiconductor Quality and Reliability

	Early life failure rate	MTBF / FIT		Early life failure rate supporting data				MTBF / FIT supporting data						
Part number	ELFR-DPPM	MTBF	FIT	Conf level (%)	Test temp (°C)	Sample size	Fails	Usage temp (°C)	Conf level (%)	Activation energy (eV)	Test temp (°C)	Test duration (hours)	Sample size	Fails
OPA192ID	22	4.89x 10⁹	0.2	60	125	41306	0	55	60.0	0.7	125	1000	57098	0



Tambient = 25C

Failure Rate = Time / MTBF

FR (10 years)= 87,600/(4.89*10^9)

FR (10 years) = 1/55,822 or ~0.0018%

The Arrhenius Equation

The Arrhenius equation is a simple, but remarkably accurate, formula for the temperature dependence of the reaction rate constant of a process.

Process Rate (PR) = $Ae^{-(Ea/kT)}$

A = A constant

Ea = Thermal activation energy in electron-volts (eV)

k = Boltzman's constant, 8.62×10^{-5} eV/K

T = Absolute temperature in degrees Kelvin (Deg C + 273.15)

Acceleration Factor

Acceleration Factors are the ratio of the Process Rate at two temperatures.

$$\mathbf{AF(T1\ to\ T2) = PR2 / PR1 = Ae^{-(Ea/kT2)} / Ae^{-(Ea/kT1)}}$$

$$\mathbf{AF(T1\ to\ T2) = e^{(Ea/k)(1/T1\ -\ 1/T2)}}$$

A = A constant (has canceled out of the formula)
Ea = Thermal activation energy in electron volts (eV)
k = Boltzman's constant, 8.62×10^{-5} eV/K
T = Absolute temperature in degrees Kelvin (degrees C + 273.15)

Acceleration Factors Calculation Example

Calculate the thermal acceleration factor (AF) between the stress test temperature at 150C and the product junction temperature of **53C:**

T1 (application) = 53.5C -> 326.5K

T2 (life-test stress) =150C -> 423K

Ea=0.7eV

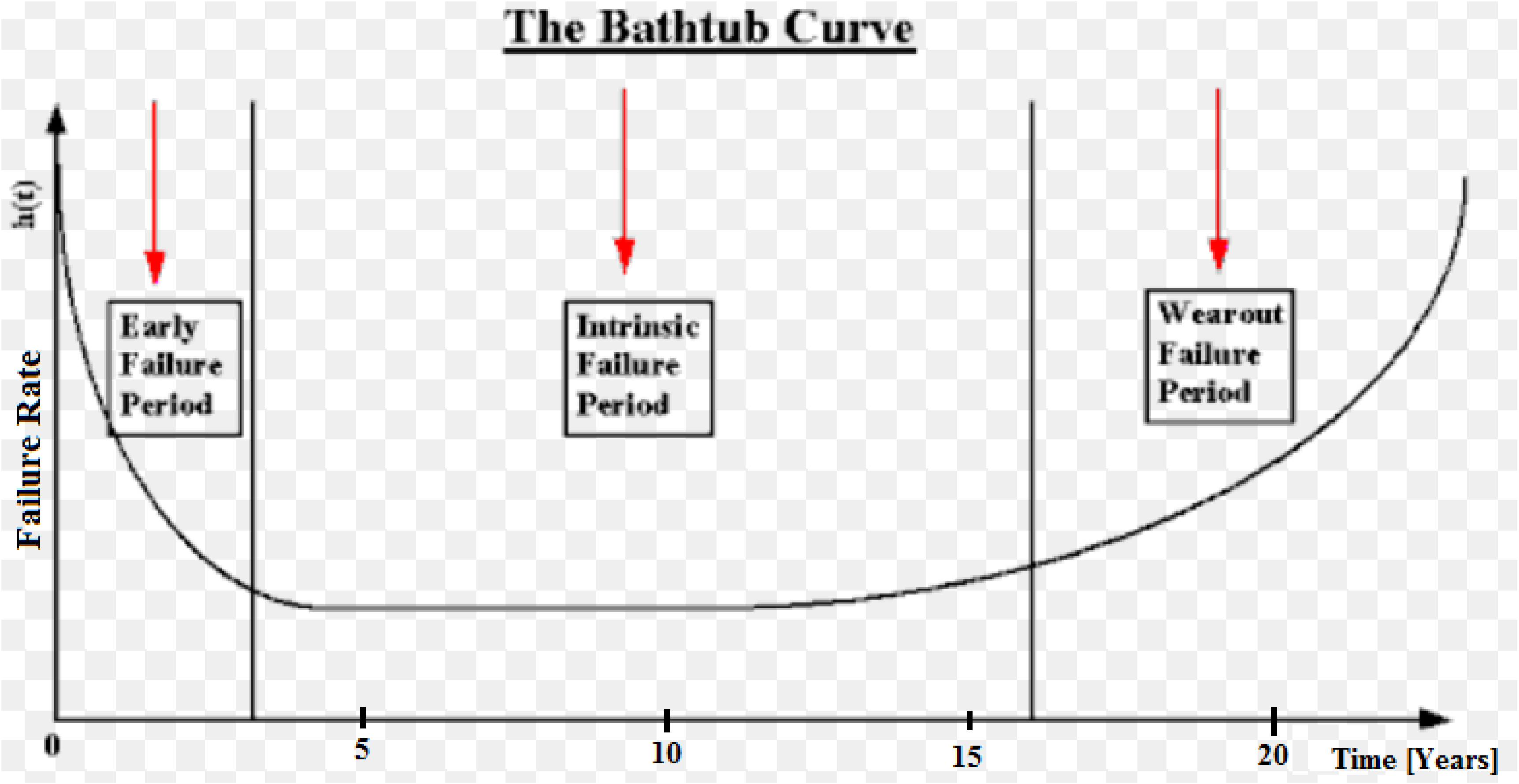
$$\mathbf{AF(53.5C\ to\ 150C)} = e^{(0.7eV/8.62x10\text{^}-5)(1/326.5\ -\ 1/423)} = \mathbf{291}$$

This means every hour of stress at 150C is equivalent to 291 hours of use in the application at 53.5 deg C junction temperature.

Thus 300-hour life-test at 150C used to qualify the product would cause similar shift as 87,365 hours (291*300hrs), or about 10 years, in the field at 53.5C junction (or at 25C ambient temperature).

Semiconductor Quality and Reliability

	Early life failure rate	MTBF / FIT		Early life failure rate supporting data				MTBF / FIT supporting data						
Part number	ELFR-DPPM	MTBF	FIT	Conf level (%)	Test temp (°C)	Sample size	Fails	Usage temp (°C)	Conf level (%)	Activation energy (eV)	Test temp (°C)	Test duration (hours)	Sample size	Fails
OPA192ID	22	4.89×10^{9}	0.2	60	125	41306	0	55	60.0	0.7	125	1000	57098	0



Tambient = 25C

Acceleration Factors Calculation Example

Calculate the thermal acceleration factor (AF) between the stress test temperature at 150C and the product junction temperature of **125C:**

T1 (application) = 125C -> 398K

T2 (life-test stress) =150C -> 423K

Ea=0.7eV

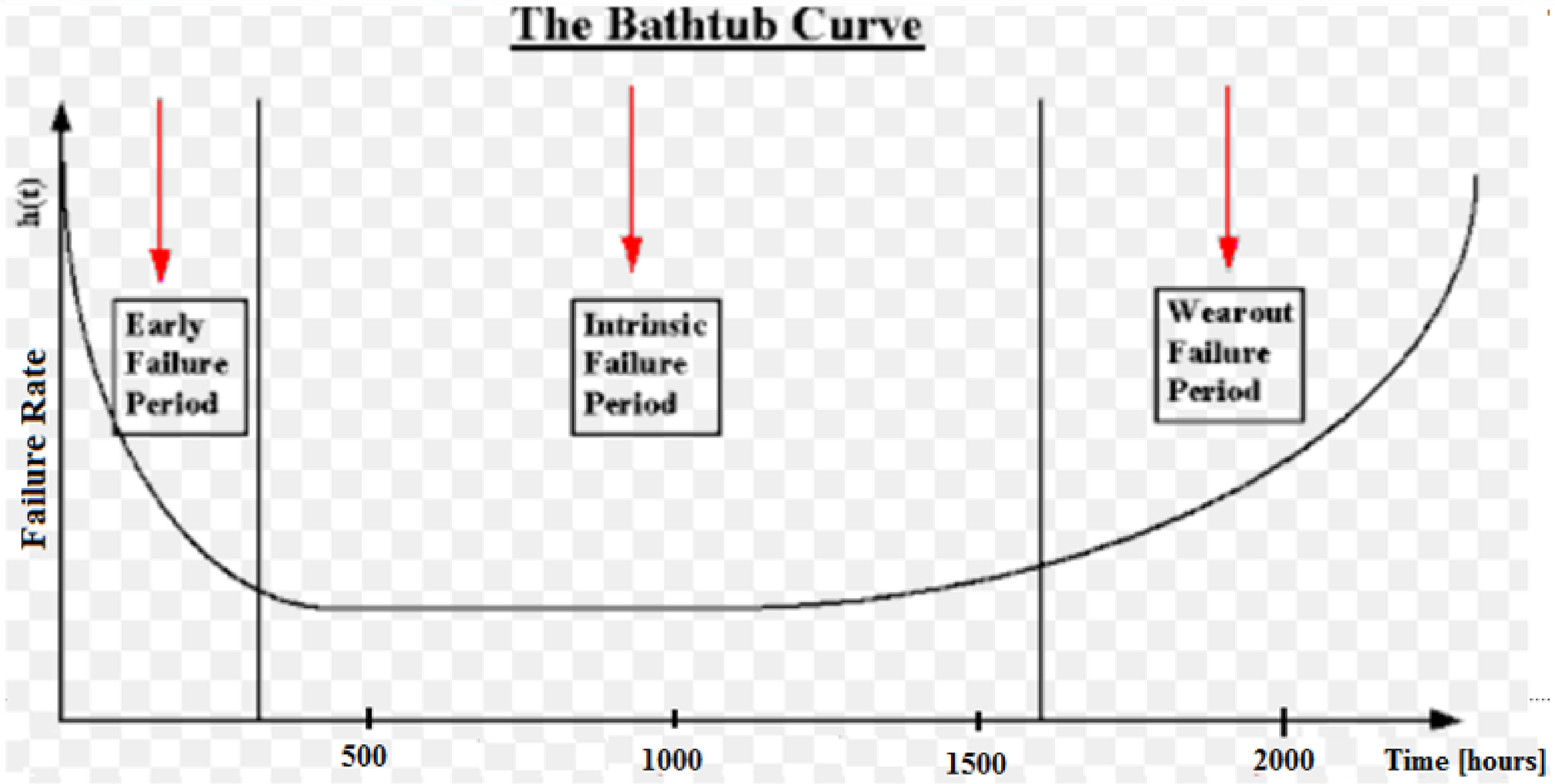
$$\mathbf{AF(125C\ to\ 150C)} = e^{(0.7eV/8.62x10\text{^}{-5})(1/398\ -\ 1/423)} = \mathbf{3.34}$$

This means every hour of stress at 150C is equivalent to 3.34 hours of use in the application at 125 deg C junction temperature.

Thus 300-hour life-test at 150C used to qualify the product would cause similar shift as 1,000 hours (3.34*300hrs), or about 1000hours in the field at 125C junction temperature.

Semiconductor Quality and Reliability

	Early life failure rate	MTBF / FIT		Early life failure rate supporting data				MTBF / FIT supporting data						
Part number	ELFR-DPPM	MTBF	FIT	Conf level (%)	Test temp (°C)	Sample size	Fails	Usage temp (°C)	Conf level (%)	Activation energy (eV)	Test temp (°C)	Test duration (hours)	Sample size	Fails
OPA192ID	22	4.89x 10 7	0.2	60	125	41306	0	55	60.0	0.7	125	1000	57098	0



Tambient = 125C

Questions ?

Comments, Questions, Technical Discussions Welcome:

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Thank you for your time!