

High Reliable BAW Oscillator MTBF and FIT Rate Calculations



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ABSTRACT

Bulk acoustic wave (BAW) resonator technology provides high reliability for BAW-based oscillators in mean time between failures (MTBF) and failure in time (FIT) values. Oscillators are typically integral to the system and often have to perform reliably over the lifetime of the product.

Product developers need to develop products that can run reliably over the product lifetime and having the best MTBF for BAW oscillators helps product developers easily select the oscillator component.

This application note provides calculation and results for MTBF and FIT values for BAW oscillators and provides the procedure for these calculations.

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1 Introduction

The calculation of failure rates is an important metric in assessing the reliability performance of a product. JEDEC describes a method for calculating FIT rates in [JEDEC JESD85 METHODS FOR CALCULATING FAILURE RATES IN UNITS OF FITS](#). In this method, a known sample size of the component is placed under environmental stress such as High Temperature Operating Life (HTOL) test. HTOL tests operate at high temperatures, such as 125 °C, for a certain duration and the number of components that fail during the test are noted and used in the calculation of FIT rates.

Reliability data is expressed either in failure in time (FIT) or mean time between failure (MTBF), or other similar parameters. FIT is equal to one failure occurring in 10×10^8 device hours (or 1 billion hours). FIT is typically the unit used to express the failure rate and can be defined as 1 parts per million (PPM) per 1000 hours of operation or one failure per 1000 devices run for 1 million hours of operation.

MTBF is the inverse of the FIT value ($10 \times 10^8 / \text{FIT}$). Most of these methods only apply to constant failure rates. These methods assume that a χ^2 (chi-square) distribution is a reasonable approximation of the failure distribution over time. The examples provided in this application note use failures that exhibit an Arrhenius behavior. A higher MTBF value (or lower FIT value) corresponds to a more reliable product that experiences fewer problems or failures over the lifetime, resulting in lower repair costs and unplanned downtime.

2 MTBF and FIT Calculations for BAW Oscillators

Having a FIT rate of 1 indicates one failure over 1 billion hours of operation. A preferable method for calculating FIT is to use HTOL reliability data and use the Arrhenius equation for acceleration, assuming a χ^2 distribution as a reasonable approximation of the failure distribution over time. The JESD85 standard document, referenced in [Section 1](#) is used for the calculations. While JESD85 shows methodologies for assessing FIT due to different fail mechanisms, for most modern-day semiconductor technologies, the qualification acceptance is 0 failures.

Sample sizes for running HTOL vary from different qualification standards. For the LMK6x BAW oscillators from Texas Instruments, see www.ti.com for the HTOL test data under the quality, reliability, and packaging information for the [LMK6x](#) device. Select the part number in the web site for view or download the reliability data for that particular device. Based on the [LMK6C](#), [LMK6D](#), [LMK6P](#), [LMK6H](#) data, sample size for HTOL is 7859, test duration is 1000 hours, the number of failures is zero, and the test temperature is 125 °C. This data is valid at the time this application note is written. For latest data, refer to the above product page links.

The step-by-step procedure for FIT calculation for LMK6x BAW oscillators is as follows:

Step 1: Calculate Acceleration Factor (AF)

Calculate the Acceleration Factor (AF) using the data in [Table 2-1](#). A common practice to gauge FIT is to de-rate to 55 °C (operating or use temperature) based on the activation energy of 0.7 eV. The equation for calculating AF is shown in [Equation 1](#).

$$\text{Acceleration Factor} = \exp\left[\left(\frac{E_a}{k}\right) \times \left(\frac{1}{T_{\text{use}}} - \frac{1}{T_{\text{stress}}}\right)\right] \quad (1)$$

Substituting the values from [Table 2-1](#) into the AF equation results in an factor of 78.6.

$$\exp\left[\left(\frac{0.7 \text{ eV}}{8.6 \times 10^{-5} \text{ eV/K}}\right) \times \left(\frac{1}{55^\circ\text{C}} - \frac{1}{125^\circ\text{C}}\right)\right] = 78.6 \quad (2)$$

Table 2-1. Data for Acceleration Factor Calculation

Variable	Value
Accelerated Test Temperature (T_{stress})	125 °C
Operating or Use Temperature (T_{use})	55 °C
Activation Energy (E_a)	0.7 eV
Boltzmann's Constant (k)	8.6×10^{-5} eV/K

Step 2: Calculate the Failure Rate

After calculating the acceleration factor, the next step is to calculate the failure rate (FIT). For this calculation, the confidence level is 60% (which is typical for industrial calculations) and the data in [Table 2-2](#) is used.

Table 2-2. Data for Failure Rate Calculation

Variable	Value
Number of Samples (ss)	7859
Test Duration (t)	1000 hours
Confidence Level (CL)	60%

The equation for calculating FIT rate is shown in the following equation. Where χ^2 is the chi-square value and f is the number of failures.

$$\text{Failure Rate (FIT)} = \frac{\chi^2(\%CL, 2 \times f + 2) \times 10^9}{2 \times t \times ss \times AF} \quad (3)$$

[Table 2-3](#) provides a quick reference for χ^2 (chi-squared) values for different failures and different confidence levels (60% and 90%).

Table 2-3. Chi-squared Values for Failure Number and Confidence level

Number of Failures (f)	Confidence Level (60%)	Confidence Level (90%)
0	1.833	4.605
1	4.045	7.779
2	6.211	10.645
3	8.351	13.362

With a confidence level of 60% and the number of failures equal to zero, (f) = 0, a χ^2 value of 1.833 is obtained from [Table 2-3](#). HTOL data for BAW oscillators is 0 failures in 7859 samples for 1000 hours of HTOL operation at 125 °C, which when substituted into [Equation 3](#), the FIT value is calculated to be 1.5 for 55 °C operation.

$$\text{Failure Rate (FIT)} = \frac{1.833 \times 10^9}{2 \times 1000 \times 7859 \times 78.6} \cong 1.5 \quad (4)$$

As described in [Section 1](#), the MTBF value is the inverse of the FIT value, as demonstrated in [Equation 5](#).

$$\text{MTBF} = \frac{1}{\text{FIT}} = 6.66666667 \times 10^8 = 6.7 \times 10^8 \quad (5)$$

This result indicates that the BAW oscillator mean time between failure is approximately 0.67 billion hours under the conditions used in this section. [Figure 2-1](#) shows a snapshot from TI online data for LMK6x BAW oscillators, which supports these results.

MTBF/FIT estimates

MTBF/FIT		MTBF/FIT supporting data							
MTBF	FIT	Usage temp (°C)	Conf level (%)	Activation energy (eV)	Test temp (°C)	Test duration (hours)	Sample size	Fails	Additional comments
6.667x10 ⁸	1.5	55	60	0.7	125	1000	7859	0	—

Figure 2-1. Snapshot of Online MTBF and FIT Estimates for the LMK6x

To find the MTBF or FIT data information shown in [Figure 2-1](#), refer to the LMK6x data sheet folder **Ordering & quality** tab and click on the **View or Download** link under **Quality reliability & packaging information** column.

As a final example of how to use the information available on www.ti.com, for 35 °C operation, the FIT rate is calculated to be 0.3 with the exact same conditions used throughout this section. The MTBF is 3.32×10^9 . This result indicates that the BAW oscillator can operate for 3.32 billion hours without a fail at 35 °C usage temperature.

3 Using the Online Estimator to Calculate MTBF and FIT

TI provides an online calculator, the [MTBF/FIT estimator](#) tool, for calculating MTBF and FIT. [Figure 3-1](#) shows a snapshot of the online calculator. This section describes how to use the estimator tool using the LMK6C as an example.

Enter the TI part number in the input provided under the MTBF and FIT estimator, shown [Figure 3-1](#). Then click on **Search** button.

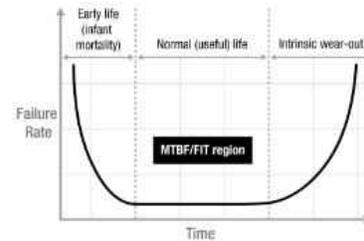
MTBF/FIT estimator

The purpose of qualification testing is to determine the life of a product, and most device lifetimes can be represented by this simple curve from the potential early fail rates to the eventual life wear out.

Mean Time Between Fails (MTBF) and Failures in Time (FIT) rates are typical statistics customers ask for when inquiring about a device's reliability. These measures of a product's life are calculated via the data taken to understand these questions. These values are calculated by TI's internal [reliability testing](#).

TI's MTBF/FIT estimator search tool allows you to find generic data based on technology groupings to estimate these typical questions and shows conditions under which the rates were derived.

Simply enter a part number, and the tool will present the data. All terms used in the tool and definitions can be found on our [reliability terminology](#) page.



Part type TI part number
 Customer part number

Part number

A minimum of four characters are required for a part number search.
 Use commas to separate multiple part numbers.
 Full part numbers are required with multiple part searches.

Search

Figure 3-1. Snapshot of the Online MTBF and FIT Estimator Tool

Select the specific part number under the LMK6x list provided. Clicking on the individual part generates MTBF and FIT information, as shown [Figure 3-2](#).

The following failure rates are summarized by technology and mapped to the associated material part numbers. The failure rates are highly dependent on the number of units tested, therefore, it is not recommended to compare failure rates.

Part number	MTBF / FIT		MTBF / FIT supporting data							
	MTBF	FIT	Usage temp (°C)	Conf level (%)	Activation energy (eV)	Test temp (°C)	Test duration (hours)	Sample size	Fails	Additional comments
LMK6CE00400CDLER	6.667x 10 ⁸	1.5	55	60.0	0.7	125	1000	7859	0	-

Definition of Table Terminology

Part #:The TI orderable part number

MTBF: Mean Time Between Failures

FIT: Failures-in-Time. The number of failures per 1E9 device-hours

Conf level %: Statistical confidence level

Test temp (°C): Temperature at which the stress test is performed

Sample size: Sample size is how many units were tested and would be based on the normalized value for duration

Fails: The number of failures per test

Usage temp (°C): Estimated usage temperature

Activation energy (eV): Energy in electron volts (eV) for a particular process to occur

Test duration (hrs): Test duration is a field that comes from the qualification testing of a product. Since more than one test is conducted and the duration varies, this field will be normalized based on calculations using temp, quantity and fails. This value would be equivalent unit hours.

NA: Not Applicable

TBD: To Be Determined

Figure 3-2. Generated MTBF and FIT Information for the LMK6C

Above the information shown in [Figure 3-2](#) is a button for the de-rating tool. Use this de-rating tool to find the FIT calculation for different usages and operating temperatures other than the calculations for 55 °C calculated in the previous section. Enter the BAW oscillator FIT rate of 1.5 at 55 °C operation and use the scrolling option to increase/decrease the application temperature to determine the MTBF numbers at different operating temperatures.

Temperature change FIT

The Arrhenius equation is a formula that correlates temperature to the rate of an accelerant (in our case, time to failure). Using the Arrhenius equation, you can estimate temperature related FIT given the qualification and the application temperatures.

Application Temperature: 35°C



FIT at Reference Temperature of 55C

1.5

App Temp	FIT at Activation Energy			MTBF at 0.7 eV hours
	0.3 eV	0.7 eV	1.0 eV	
35°C	0.8	0.3	0.2	3.32e+9

For example, if you have a FIT of 16.7 at a reference temperature of 55C, you can predict FIT at application temperature of 75C to be 69.2 with 0.7Ea

Equation

$$AF = \exp\left(\frac{E_a}{k} * \left(\frac{1}{T_{low}} - \frac{1}{T_{high}}\right)\right)$$

Figure 3-3. Snapshot of De-rating Tool Using 55 °C Use Case

As [Figure 3-3](#) shows, for 35 °C operating temperature use case, the FIT value is 0.3.

4 Importance of Mission Profiles for FIT Rate Calculations

Mission profile is an important method for evaluating FIT rates in more practical use cases. The [Calculating FIT for a Mission Profile](#) application note explains how to use de-rating tools provided by TI in more detail.

The FIT rate calculations are worst-case FIT values assuming one single operating temperature throughout the lifetime of the device. But in reality, the end system or end product where the oscillator is mounted is not experiencing the same higher temperature throughout the full device lifetime. The oscillator typically experiences a variety of temperatures over a period of time. The FIT value can be better than the worst-case value if the exact operating (use) temperatures are known and also the approximate percentage of time the oscillator is experiencing this temperature over the lifetime of the device.

[Table 4-1](#) provides an example mission profile along with the FIT calculations. For specific applications, creating a similar table to [Table 4-1](#), can help in calculating the FIT rate for a real system. This table values are different for different application use cases.

Table 4-1. De-rated FIT Calculation

Operating or Use Temperature (°C)	% Time	De-Rated FIT	FIT x (% Time)
20	25	0.1	0.025
30	35	0.2	0.07
60	30	2.2	0.66
85	10	11.9	1.19
Mission Profile FIT rate			1.945

The FIT number is 1.945 for this example use-case. If this example is calculated just at 85 °C operation temperature with 100% time, the FIT number is 11.9, which is much higher than the practical use-case. Hence, understanding the use case of the system and using the MTBF or FIT calculator to find out the FIT number for the actual use-case is crucial.

5 Summary

This application note demonstrates how to calculate FIT rates for BAW oscillators using actual HTOL test data. As shown in these calculations, at 35 °C usage temperature, the BAW oscillator FIT rate is 0.3, which is the industry best for the oscillators across all the technologies of crystals and MEMS-based devices. A FIT rate of 0.3 is equivalent to 3.3 billion hours of MTBF. Typical crystal oscillator FIT rates are 15 to 30, indicating improved reliability in BAW oscillators in comparison to crystal oscillators with similar specifications.

6 References

- JEDEC, [JESD85 METHODS FOR CALCULATING FAILURE RATES IN UNITS OF FITS JESD85](#) standard
- Texas Instruments, [Calculating FIT for a Mission Profile](#) application note
- Texas Instruments, [LMK6x Low Jitter, High-Performance BAW Oscillator](#) data sheet

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