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Lifetime of BLF574XR in broadcast and ISM applications

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Document information

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Keywords	BLF574XR, lifetime, electromigration, broadcast, ISM
Abstract	This application note describes the expected lifetime of BLF574XR when used in broadcast and ISM applications.

Revision history

Rev	Date	Description
v.2	20150901	Modifications • The format of this document has been redesigned to comply with the new identity guidelines of Ampleon. • Legal texts have been adapted to the new company name where appropriate.
v.1	20130528	initial version

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1. Introduction

BLF574XR is a device capable of delivering 600 W in CW or pulsed CW mode. The device has no internal matching and can be used in very different applications such as broadcast FM / VHF and ISM (Industrial, Scientific, Medical). The wide variety of applications means that both RF parameters and reliability must be considered during the design. This report explains the expected lifetime of the product in both typical and the more severe applications.

2. Failure mechanism at high temperature

The bath-tub curve, as shown in Figure 1, describes the failure rate of an LDMOS transistor. Early failures temporarily dominate the failure rate but during useful life, random failures determine the failure rate which is flat. After the useful life, the failure rate increases due to deterioration failures.

High temperature electromigration is the known dominating deterioration failure mechanism. It has a lognormal distribution.

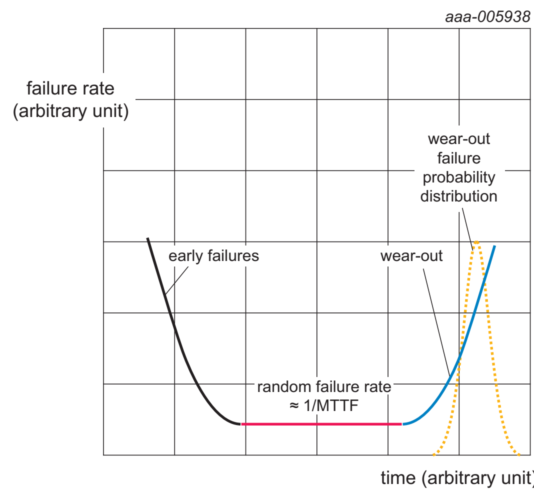


Fig 1. Failure rate bath-tub curve

Electromigration can be analyzed with Equation 1:

$$MTF = \frac{C}{J^n} \cdot e^{\frac{Ea}{k \cdot T}} \quad (1)$$

where:

Ea = activation energy [eV]

k = bolzmann constant [eV/K]

n = current density acceleration exponent

J = current density [A/m^2]

C = constant

$$TTF = qlnom(p, \mu, \sigma) \quad (2)$$

qlnom (p, μ, σ) is the inverse log normal distribution, where:

μ = mean = ln(MTF)

p = failure fraction, 0 < p < 1, for example, p = 0.001 (0.1 %)

σ = standard deviation

Electromigration is dependent on temperature and current density. Current density can be calculated using the DC current, the number of parallel cells of the device and the width/thickness of the total metallization. The generation 6 LDMOS High-Voltage process of Ampleon is designed to have excellent electromigration behavior, also under the most severe conditions. The parameters Ea, n, C and metallization are specific for the Gen6 HV process.

MTF = median time to failure, this number gives the time where 50 % of the population has failed.

TTF = time to failure, this number gives the time where p [%] of the population has failed.

p = normally given for 0.1 % failure fraction (0.1 % of the population has failed).

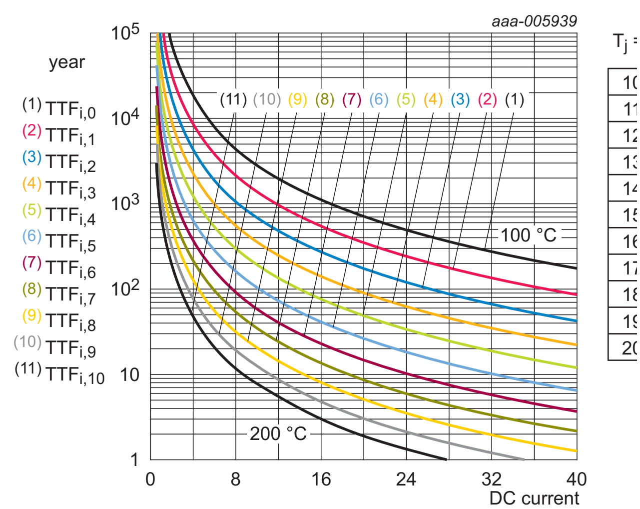
I_{DC} = DC current [A]

Note:

Ea is strongly material and process dependent and is determined and verified for each major process change during process development.

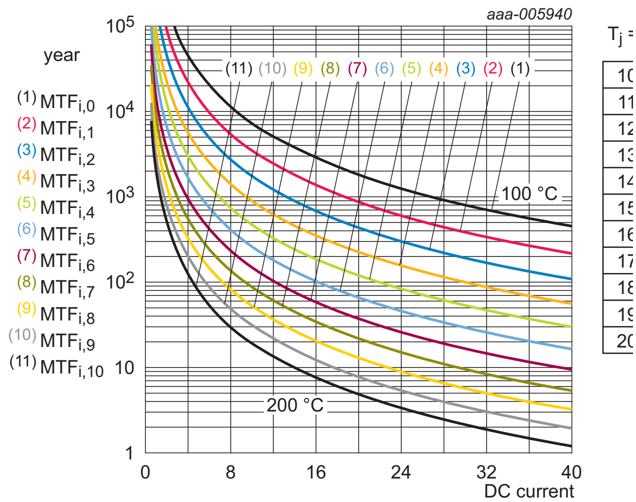
Figure 2 and Figure 3 provide the TTF (p = 0.1 %) and MTF (p = 50 %) as a function of temperature and DC current (I_{DC} of total device).

For pulsed applications, define lifetime during the pulse and correct it with 1/duty-cycle.



(1) TTF$_i$, T_j = 200 °C: **(5)** TTF$_i$, T_j = 160 °C: **(9)**: TTF$_i$, T_j = 120 °C
(2) TTF$_i$, T_j = 190 °C: **(6)** TTF$_i$, T_j = 150 °C: **(10)** TTF$_i$, T_j = 110 °C
(3) TTF$_i$, T_j = 180 °C: **(7)** TTF$_i$, T_j = 140 °C: **(11)** TTF$_i$, T_j = 100 °C
(4) TTF$_i$, T_j = 170 °C: **(8)** TTF$_i$, T_j = 130 °C

Fig 2. Graph TTF BLF574XR (p = 0.1 %)



(1) MTF$_i$, T_j = 200 °C: **(5)** MTF$_i$, T_j = 160 °C: **(9)** MTF$_i$, T_j = 120 °C
(2) MTF$_i$, T_j = 190 °C: **(6)** MTF$_i$, T_j = 150 °C: **(10)** MTF$_i$, T_j = 110 °C
(3) MTF$_i$, T_j = 180 °C: **(7)** MTF$_i$, T_j = 140 °C: **(11)** MTF$_i$, T_j = 100 °C
(4) MTF$_i$, T_j = 170 °C: **(8)** MTF$_i$, T_j = 130 °C

Fig 3. Graph MTF BLF574XR (p = 50 %)

Figure 2 provides the time where the first failures due to electromigration can be expected. In broadcast applications, the expected lifetime is 20 years or more. If the lifetime is below the required lifetime, then the following can be done:

- more cooling (lower T_h, T_c and T_j)
- lower $R_{th(c-h)}$ by soldering or using better compound (for example, graphite-based compound)
- increase drain efficiency using improved matching (optimum efficiency load instead of optimum power load) or high efficiency architectures such as Doherty (for modulated signals)
- reduce power (and dissipation)

3. Thermal definitions and limitations

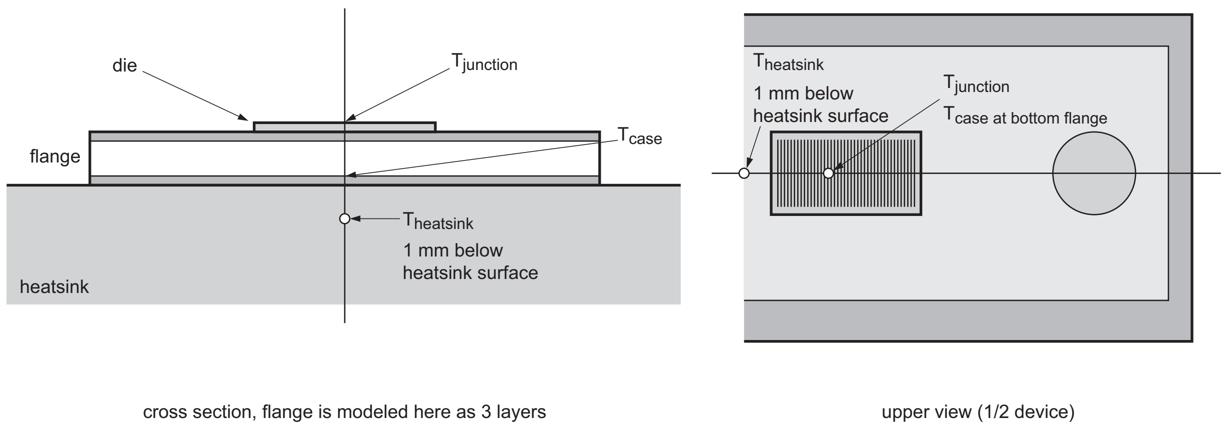


Fig 4. Junction, case and heatsink temperature definitions of the device

BLF574XR $R_{th(j-c)}$ = 0.18 K/W

The device can be soldered or mounted with thermal compound. Soldering the device gives best thermal and electrical performance. A typical $R_{th(c-h)}$ for compound is 0.15 K/W to 0.2 K/W and for soldering, it is lower than 0.05 K/W.

The maximum junction temperature for BLF574XR is 200 °C.

The advised operational junction temperature for BLF574XR is approximately 150 °C.

A case temperature of 110 °C is considered as maximum to prevent any damage to the device or PCB. A T_c of 110 °C is used in the examples given on the following pages.

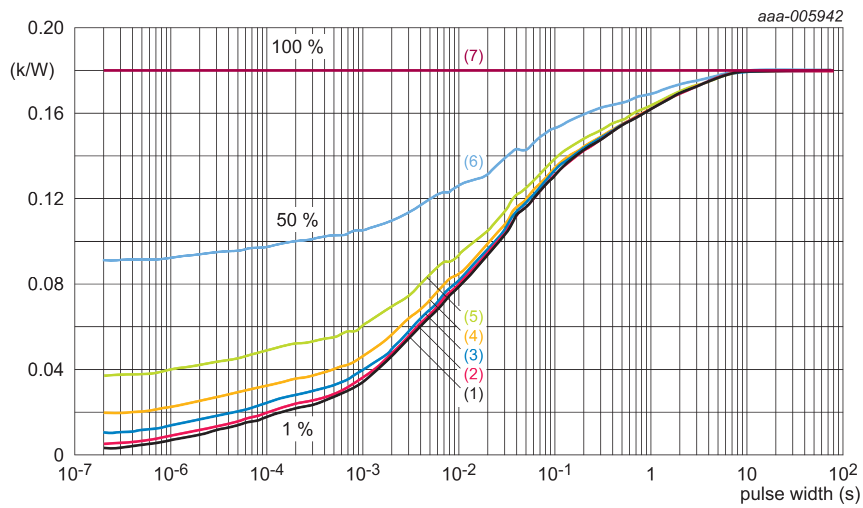
The maximum case temperature is limited by:

- the MOT (Maximum Operating Temperature) of the PCB material used. MOT is the maximum temperature at which the PCB can be operated for an indefinite period without significant degradation
- the maximum allowed flange/case temperature of the device

3.1 Thermal resistance under pulsed condition (Z_{th})

Figure 5 provides the $Z_{th(j-c)}$ for a duty cycle of 1 %, 2 %, 5 %, 10 %, 20 % and 50 % (100 % = CW).

$R_{th(j-c)} = Z_{th(j-c)}$ at t_p = 10 s.



(1) $Z_{th(j-c)}$ for a duty cycle of 1 %
(2) $Z_{th(j-c)}$ for a duty cycle of 2 %
(3) $Z_{th(j-c)}$ for a duty cycle of 5 %
(4) $Z_{th(j-c)}$ for a duty cycle of 10 %
(5) $Z_{th(j-c)}$ for a duty cycle of 20 %
(6) $Z_{th(j-c)}$ for a duty cycle of 50 %
(7) $Z_{th(j-c)}$ for a duty cycle of 100 %

Fig 5. $Z_{th(j-c)}$ for various duty cycles

examples:

tp = 100 μs, d = 10 %: $Z_{th(j-c)}$ = 0.046

tp = 100 μs, d = 20 %: $Z_{th(j-c)}$ = 0.060

tp = 1 ms, d = 10 %: $Z_{th(j-c)}$ = 0.084

tp = 1 ms, d = 20 %: $Z_{th(j-c)}$ = 0.094

4. Broadcast applications

BLF574XR can be used in broadcast applications such as VHF band 3 (DVB-T) and FM. Electromigration has been calculated for both of these applications in the following examples.

4.1 Example 1: Broadcast, DVB-T VHF Band-3

P_o = 100 W DVB-T, frequency = 225 MHz, efficiency = 30 %, T_c = 110 °C

V_{DS} = 50 (V)

P_o = 100 (W)

η = 0.30

I_{DC} = 6.67 (A)

P = 233 (W)

$\theta_{j\text{-}c}$ = 0.18 (K/W)

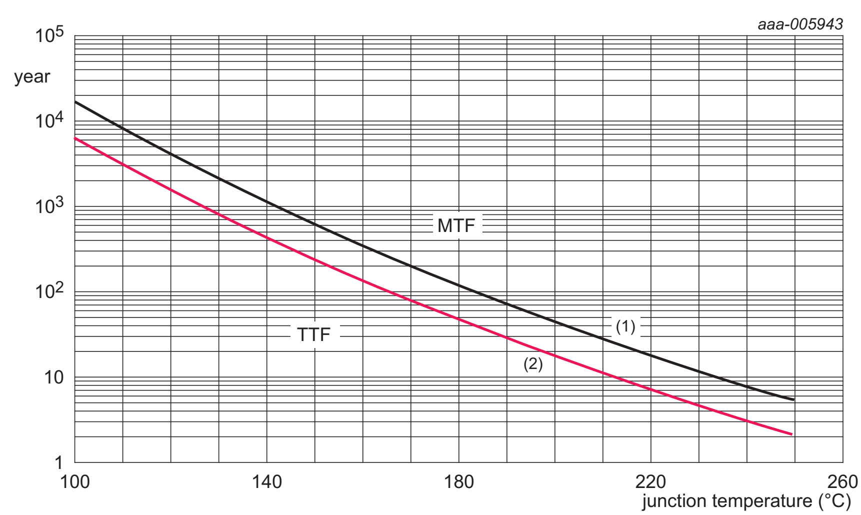
T_c = 110 (°C)

T_j = 146 (°C)

TTF = 209 (year)

MTF = 528 (year)

For this example: I_{DC} = 6.7 A, TTF 0.1 % and MTF [year] as functions of T_j is as follows:



(1) MTF as a function of junction temperature

(2) TTF as a function of junction temperature

Fig 6. Example 1: TTF and MTF as a function of junction temperature

4.2 Example 2: Broadcast, FM

P_o = 600 W CW, frequency = 108 MHz, efficiency = 75 %, T_c = 110 °C

V_{DS} = 50 (V)

P_o = 600 (W)

η = 0.75

I_{DC} = 16 (A)

P = 200 (W)

$\theta_{j\text{-}c}$ = 0.18 (K/W)

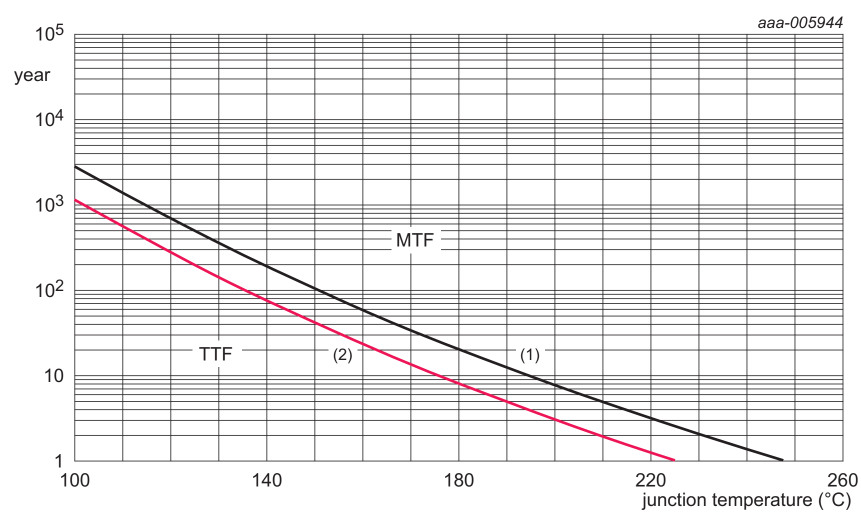
T_c = 110 (°C)

T_j = 146 (°C)

TTF = 52 (year)

MTF = 130 (year)

For this example: I_{DC} = 16 A, TTF 0.1 % and MTF [year] as functions of T_j is as follows:



(1) MTF as a function of junction temperature

(2) TTF as a function of junction temperature

Fig 7. Example 2: TTF and MTF as a function of junction temperature

5. Industrial Scientific Medical (ISM) and Synchrotron applications

BLF574XR is used increasingly in ISM applications, for example to ignite a plasma. In general, synchrotron applications belong to the most severe applications because high CW power and an extreme ruggedness and reliability is needed. An example of a frequency used in Synchrotron applications is 352 MHz or 500 MHz. BLF574XR requires power levels of 500 W to 600 W pulsed or CW. Clearly for electromigration, CW is the worst case signal (highest current density and temperature). Some examples are given for typical and worst case synchrotron applications, on the following pages.

In the worst case situation (Section 5.2: 600 W, 65 % efficiency), approximately 11 years lifetime (TTF 0.1 %) was calculated. To increase the lifetime, a reduced power level of 500 W results in an increased lifetime of 27 years (Section 5.3).

5.1 Example 1: Typical efficiency

P_o = 600 W CW, frequency = 500 MHz, efficiency = 70 %, T_c = 110 °C

V_{DS} = 50 (V)

P_o = 600 (W)

η = 0.70

I_{DC} = 17.14 (A)

P = 257 (W)

$\theta_{j\text{-}c}$ = 0.18 (K/W)

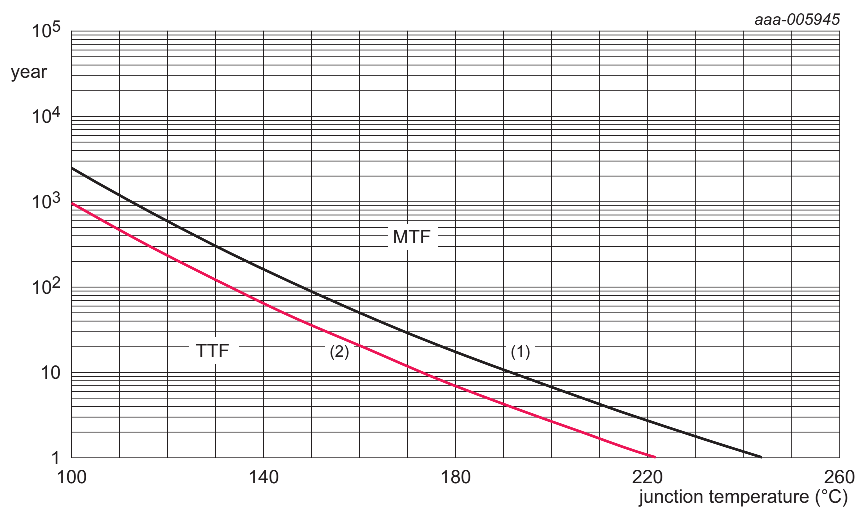
T_c = 110 (°C)

T_j = 156 (°C)

TTF = 25 (year)

MTF = 63 (year)

For this example: I_{DC} = 17.1 A, TTF 0.1 % and MTF [year] as functions of T_j is as follows:



(1) MTF as a function of junction temperature

(2) TTF as a function of junction temperature

Fig 8. Example 1: TTF and MTF as a function of junction temperature (typical efficiency)

5.2 Example 2: Worst case

P_o = 600 W CW, frequency = 500 MHz, efficiency = 65 %, T_c = 110 °C

V_{DS} = 50 (V)

P_o = 600 (W)

η = 0.65

I_{DC} = 18.46 (A)

P = 323 (W)

$\theta_{j\text{-}c}$ = 0.18 (K/W)

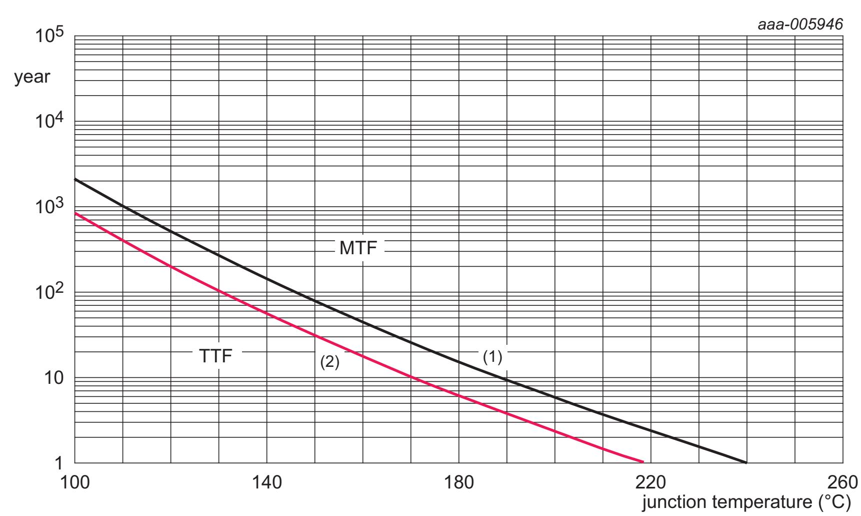
T_c = 110 (°C)

T_j = 168 (°C)

TTF = 11 (year)

MTF = 28 (year)

For this example: I_{DC} = 18.5 A, TTF 0.1 % and MTF [year] as functions of T_j is as follows:



(1) MTF as a function of junction temperature

(2) TTF as a function of junction temperature

Fig 9. Example 2: TTF and MTF as a function of junction temperature (worst case)

5.3 Example 3: Reduced power level (500 W)

P_o = 500 W CW, frequency = 500 MHz, efficiency = 65 %, T_c = 110 °C

V_{DS} = 50 (V)

P_o = 500 (W)

η = 0.65

I_{DC} = 15.39 (A)

P = 269 (W)

$\theta_{j\text{-}c}$ = 0.18 (K/W)

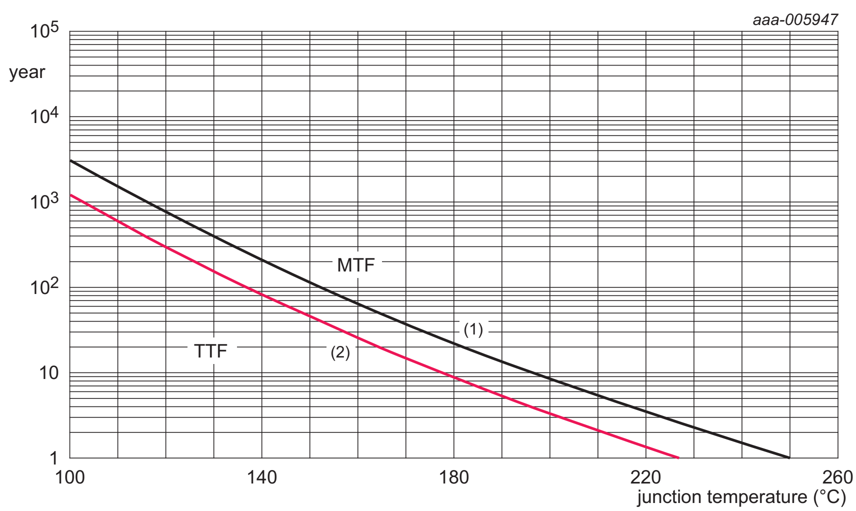
T_c = 110 (°C)

T_j = 158 (°C)

TTF = 27 (year)

MTF = 69 (year)

For this example: (I_{DC} = 15.4 A), TTF 0.1 % and MTF [year] as functions of T_j is as follows:



(1) MTF as a function of junction temperature

(2) TTF as a function of junction temperature

Fig 10. Example 1: TTF and MTF as a function of junction temperature (reduced power)

6. Conclusion

BLF574XR is a device suitable for broadcast and ISM applications. It can handle CW power levels up to 600 W with very high ruggedness. Whether the full specified power level gives sufficient lifetime, is dependent on cooling and efficiency of the device. Synchrotron applications are among the most severe applications for electromigration. In a worst case situation for a synchrotron application (for example, 600 W, 65 % efficiency, T_c = 110 °C), lifetime (TTF 0.1 %) becomes critical (just above 10 years). In case more lifetime is needed, reduce the junction temperature and/or lower the power level. For 500 W, 65 % efficiency and a case temperature of 110 °C, the lifetime TTF 0.1 % ≥ 27 years and MTF ≥ 68 years.

7. Abbreviations

Table 1. Abbreviations

Acronym	Description
CW	Continuous Wave
DVB	Digital Video Broadcast
DVB-T	Digital Video Broadcast - Terrestrial
FM	Frequency Modulation
ISM	Industrial, Scientific and Medical
MTF	Median Time to Failure
PCB	Printed Circuit Board
RF	Radio Frequency
TTF	Time to Failure
UHF	Ultra High Frequency
VHF	Very High Frequency

8. Glossary

I_{DC} — DC current

η — efficiency

P — Power dissipation

P_o — Output power

R_{th} — Thermal resistance

$R_{th(c\text{-}h)}$ — Thermal resistance case to heatsink

$R_{th(j\text{-}c)} = \theta_{j\text{-}c}$ — Thermal resistance junction to case

T_c — Case temperature

T_h — Heatsink temperature

T_j — Junction temperature

V_{DS} — Drain source voltage

Z_{th} — Thermal impedance

$Z_{th(c\text{-}h)}$ — Thermal impedance case to heatsink

$Z_{th(j\text{-}c)}$ — Thermal impedance junction to case

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