LE910Cx mPCIe Thermal Design Guide

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DOCUMENTATION

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APPLICABILITY TABLE

PRODUCTS

- LE910C4-NF MPCIE

Contents

1. INTRODUCTION

The aim of this document is to provide thermal model and design guidelines useful for developing a product with the Telit LE910Cx mPCIe.

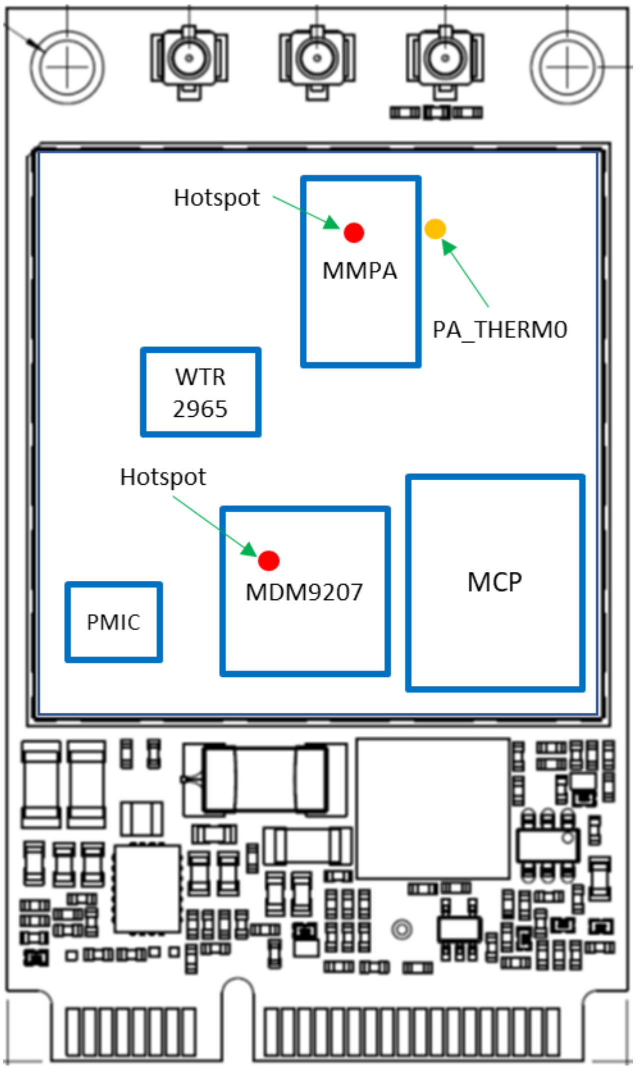
Information – Proper thermal protection design protects against human or component damage for worst-case conditions.

And it reduces the probability of failure and does not adversely affect the use of the module, and greatly extends the operation time with maximum performance.

2. THERMAL MODEL

2.1. Temperature Sensor and Hotspot

LE910Cx mPCIe has two thermistors inside the module. The internal temperature can be monitored by the AT command.



<LE910Cx mPCIe Temp Sensor & Hotspot>

As you can see in the figure above, there is a temperature sensor(PA_THERM0) inside the LE910Cx mPCIe. And it can be read by the internal temperatures using the AT#TEMPMON command.

2.1.1. Temperature Reading and Monitoring

AT#TEMPMON command provides several methods to read the internal temperature like instantaneous reporting and to monitor the internal temperature using URC and GPIO.

#TEMPMON – Temperature monitor	
AT#TEMPMON= **<mod>** **[,<urcmode>** **[,<action>** **[,<GPIO>]]]**	Set command sets the behavior of the module internal temperature monitor. **Parameters:** **<mod>** 0 - sets the command parameters. 1 - triggers the measurement of the module internal temperature, reporting the result in the format: **#TEMPMEAS: <level>,<value>** **where:** **<level>** - threshold level -2 - Extreme temperature lower bound. -1 - Operating temperature lower bound. 0 - normal temperature. 1 - Operating temperature upper bound. 2 - Extreme temperature upper bound. (see note 1) **<value> -** actual temperature expressed in Celsius degrees. Setting of the following optional parameters has meaning only if <mod>=0: **<urcmode>** - URC presentation mode. (Default 1) 0 - It disables the presentation of the temperature monitor URC. 1 - It enables the presentation of the temperature monitor URC, whenever the module internal temperature reaches either operating or extreme levels. The unsolicited message is in the format: **#TEMPMEAS: <level>,<value>** **where:** **<level>** and **<value>** are as before. **<action>** - sum of integers, each representing the action to be done whenever the module internal temperature reaches either operating or extreme levels (default is 1). 0 - (00) - No action. 1 - (01) - Activating of thermal mitigation according to thermal configuration file. 2 - (10) - Output pin <GPIO> is tied HIGH when operating temperature bounds are reached; when the temperature is back to normal the output pin <GPIO> is tied LOW. If this <action> is required, it is mandatory to set the <GPIO> parameter too. 3- (11) - This value contains <action=1> and <action=2> i.e. activate thermal mitigation and a GPIO indication. If this <action> is required, it is mandatory to set the <GPIO> parameter too. **<GPIO>** - GPIO number. Valid range is any TGPIO pin as described in #GPIO command. This parameter is needed and required only if <action>=2 or 3 are enabled.

AT#TEMPMON?	Read command reports the current parameter settings for #TEMPMON command in the format: **#TEMPMON: <urcmode>,<action> [,<GPIO>]**
AT#TEMPMON=?	Test command reports the supported range of values for parameters **<mod>, <urcmode>, <action>, and <GPIO>**
Notes	1. Thresholds levels are defined in #TEMPCFG command. See there for detailed description on thermal mitigation configuration. 2. Last **<action>** setting is saved in the 'config.ini' file ('mitigate'/'none mitigate'), and in the NVM ('gpio indication'/'none gpio indication'). 3. Last **<GPIO>** is saved in the NVM. 4. Thermal mitigation is disabled automatically when using laboratory test SIM.

2.2. Thermal Mitigation Algorithm

LE910Cx mPCIe has built-in thermal mitigation algorithm to reduce the probability of failure and extend the operation time with maximum performance.

The thermal mitigation algorithm operates according to the internal temperature value read through the temperature sensor.

Thermal mitigation algorithm limits the performance(UL throttling, Tx power back off, call drop.. etc) when the temperature is above a defined certain level.

Thermal Mitigation Level

Temperature sensor have several thermal mitigation levels. Each level has predefined actions as below table and it work in sensor individually.

Performs following actions according to mitigation level to reduce/control temperature.

Sensor	Level	Action	Comment
PA_THERM	0	-	Normal
	1	Enable MTPL back-off	Limit maximum Tx power (23dBm)
	2	Emergency Calls Only	

After entering mitigation level 2, the device will register to the network after PA_THERM sensor reaches mitigation level 0. That is, the sensor reading falls below the level 1 clear thresholds.

2.2.1. How to Change Thermal Mitigation Level Range

Thermal mitigation level range and action could be modified through AT#TEMPCFG command.

#TEMPCFG – Temperature Monitor Configuration	
AT#TEMPCFG=<etlz_clr>,<etlz>,<etlz_act_in>,<otlz_clr>,<otlz>,<otlz_act_in>,<otnz_clr>,<otnz>,<otnz_act_in>,<otuz_clr>,<otuz>,<otuz_act_in>,<etuz_clr>,<etuz>,<etuz_act_in>	Set command sets the Temperature zones used in the #**TEMPMON** command. **Parameters:** <**etlz_clr**>: Extreme low zone temperature threshold clear. Has only one valid value: -273°C. see notes <**etlz**>: Extreme low zone temperature threshold. Default value -33°C. **<etlz_act_in**>: Extreme low zone action info. Default value 0. <**otlz_clr**>: Operate low zone temperature threshold clear. Default value -35°C. **<otlz>**: Operate low zone temperature threshold. Default value -28°C. **<otlz_act_in** >: Operate low zone action info. Default value 0. <**otnz_clr>**: Operate normal zone temperature threshold clear**.** Default value -30°C. **<otnz>**: Operate normal zone temperature threshold**.** Default value 97°C. **<otnz_act_in**>: Operate normal zone action info. Default value 0. <**otuz_clr>**: Operate up zone temperature threshold clear. Default value 95°C. **<otuz>**: Operate up zone temperature threshold. Default value 102°C. **<otuz_act_in**>: Operate up zone action info. Default value 2. <**etuz_clr>**: Extreme up zone temperature threshold clear. Default value 100°C. **<etuz>**: Extreme up zone temperature threshold. Has only one valid value: 528°C. see notes **<etuz_act_in**>: Extreme up zone action info. Default value 3. See notes for detailed description of thermal mitigation configuration.
AT#TEMPCFG?	Read command reports the current parameter setting for #**TEMPCFG** command in the format: #TEMPCFG: **<etlz_clr>,<etlz>,<etlz_act_in>,<otlz_clr>,<otlz>,<otlz_act_in>,<otnz_clr>,<otnz>,<otnz_act_in>,<otuz_clr>,<otuz>,<otuz_act_in>,<etuz_clr>,<etuz>,<etuz_act_in>**
AT#TEMPCFG =?	Test command reports the supported range values for parameters **<x_clr>,<x>,<x_action_info>**. Where "x" is substitute for "**etlz**", "**otlz**", "**otnz**", "**otuz**", "**etuz**". Values are: #**TEMPCFG**: (-40-102),(-40-102),(0-5)

Notes:

After setting new values, it is must to execute power cycle or #**REBOOT** command in order the mitigation algorithm will operate by them.

Thermal mitigation mechanism works like this:

The whole temperature scale is divided into 5 states (zones).

Each measured temperature should be belonging to a particular state called the "**current state**".

State is defined by the following fields:

"**thresholds**" – upper temperature boundary of the state. Values are in °C.

"**thresholds_clr**" – lower temperature boundary of the state. Values are in °C.

"**actions**" – indicator that indicates if an action should be taken or not in the "**current state**". Values are: "**none**"/"**mitigate**".

"**action_info**" – thermal mitigation action type that should be taken care if "**actions**" field is "**mitigate**".

Values are:

0 - No mitigation action is required.

1 - Mitigation action - data throttling (reducing uplink baud rate).

2 - Mitigation action - TX backoff (reducing MTPL - Max Tx Power Limit).

3 - Emergency Calls Only.

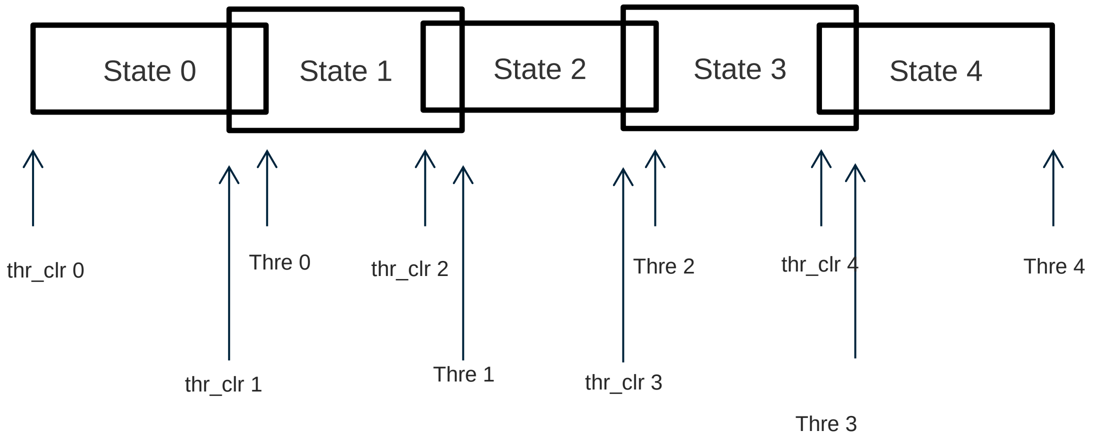
4 - RF OFF. RX and TX circuits automatically disabled (using +CFUN=4).

5 - Automatic shutdown. Module is powered off.

There are five limitations on setting temperature and actions, in-order to keep module safety.

- User is prohibited to set an action of "automatic shutdown" to ‘operate normal zone’.
- User is prohibited to set an action of “no mitigation” or "data throttling "to “operate up zone”.
- User is prohibited to set an action of "no mitigation" or "data throttling" or "tx backoff" to “extreme up zone”.
- User is prohibited to set “normal zone” above 97deg.
- If the module enters into a state of "emergency only" calls, registration again to a regular call, happens just when the module returns to "no mitigation" state **only**.
- A **“+CME ERROR: operation not supported**” error will be received as a response.

Here is the graph that illustrates the temperatures configuration.



When temperature exceeds the "**current state**" "**threshold**", the thermal mitigation algorithm searches the next state that this temperature is **lower** than its "**threshold**". After it finds it, the "**current state**" is updated to that "**state**" and then it checks whether "**action**" is "**mitigate**", if yes, then it activates the mitigation according to the "**action info**" of the "**current state**".

When temperature decreases below "**threshold_clr**" then it does the same algorithm as above, but in the opposite direction. It searches the next state that this temperature is **greater** than its " **threshold_clr** ", updates the "**current state**" to that state, and activates mitigation as described above.

There are 2 rules in which states definition should obey:

0- Overlap between 2 adjacent states of at least 2 deg, i.e. ("thre state(x)" – "thre_clr state(x+1)") >= 2
1- Every state shall have "free" temperature range which has no part in any overlap range. This range should be at least 2 deg, i.e. ("thre_clr(x+2)" – "thre(x)") >= 2 .

Rule '1' comes to ensure hysteresis in the transition between two states.

Rule '2' comes to ensure a minimum range for a stable state.

State 0 is **'Extreme low zone**'.

State 1 is '**Operate low zone**'.

State 2 is '**Operate normal zone**'.

State 3 is '**Operate up zone**'.

State 4 is '**Extreme up zone**'.

etlz_clr – Extreme low zone threshold clear is enforced to have value of '-273'. Module doesn't operate in such temperature, but this value is logically set in order to define clearly 'thermal state' to temperatures below -40 deg.

etuz – Extreme up zone threshold is enforced to have value of '528'. Module doesn't operate in such temperature, but this value is logically set in order to define clearly 'thermal state' to temperatures above 102 deg.

"**#TEMPMON**" set command, changes field "actions" to "**mitigate**" or "**none**" to all zones.

All above parameters are saved in a configuration file in the module file system.

Examples:

AT#TEMPCFG= -273,-33,3,-35,-28,2,-30,80,0,78,90,3,88,528,3

OK

Explain:

zone	**Thr_clr**	**Thr**	**Action info**
'**Extreme low zone**'	-273	-33	3 – emergency call only
'**Operate low zone**'	-35	-28	2 – TX backoff
'**Operate normal zone**'	-30	80	0 – no mitigation
'**Operate up zone**'	78	90	3 - emergency call only
'**Extreme up zone**'	88	528	3 - emergency call only

All zones have hysteresis and free temperature range.

AT#TEMPCFG=-273,-33,3,-35,-28,2,-30,**80**,0,**79**,90,3,88,528,3
+CME ERROR: operation not supported
Explain:

zone	**Thr_clr**	**Thr**	Action info
'**Extreme low zone**'	-273	-33	3 – emergency call only
'**Operate low zone**'	-35	-28	2 – TX backoff
'**Operate normal zone**'	-30	**80**	0 – no mitigation
'**Operate up zone**'	**79**	90	3 - emergency call only
'**Extreme up zone**'	88	528	3 - emergency call only

('**Thr**' of '**Operate normal zone**') - ('**Thr_clr**' of '**Operate up zone**') = 1 < 2
Rule 1 was braked - Hysteresis is lesser than 2 deg.

AT#TEMPCFG=-273,-33,3,-35,-28,2,-30,**80**,0,78,90,3,**81**,528,3

+CME ERROR: operation not supported

Explain:

zone	**Thr_clr**	**Thr**	Action info
'**Extreme low zone**'	-273	-33	3 – emergency call only
'**Operate low zone**'	-35	-28	2 – TX backoff
'**Operate normal zone**'	-30	**80**	0 – no mitigation
'**Operate up zone**'	78	90	3 - emergency call only
'**Extreme up zone**'	**81**	528	3 - emergency call only

('**Thr_clr**' of '**Extreme up zone**') - ('**Thr**' of '**Operate normal zone**') = 1 < 2

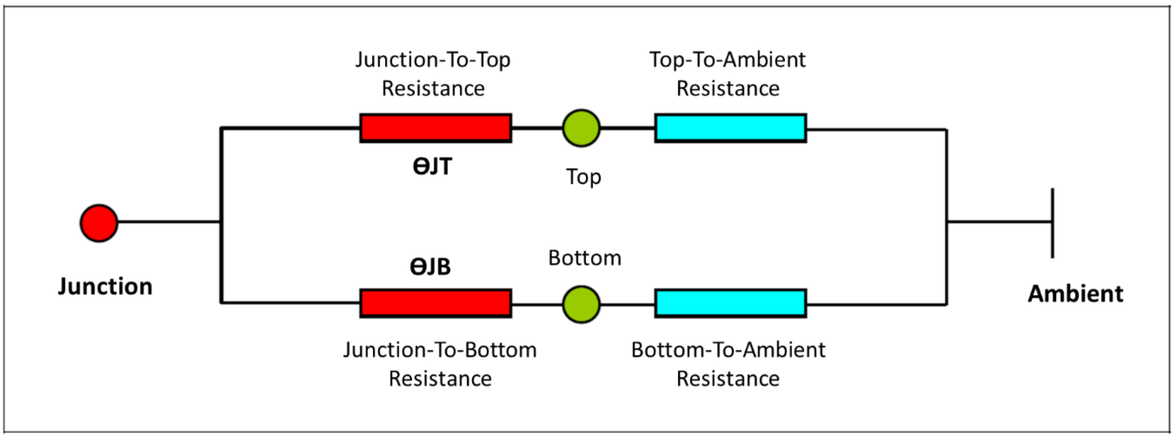
Rule 2 was braked - free temperature range is lesser then 2 deg.

NOTE:

- After moving to zone with activity 3(emergency call only), only when moving to zone with activity 0(no mitigation) the device will register to the network.
- <action> for high-zone can't be <no action> or <data throttling>.
- <action> for extreme high zone can't be <no action> or <data throttling> or <tx backoff>.

2.3. Thermal Model -TBD

Thermal Model is evaluated by thermal simulation and RF test with thermal chamber.



<Equivalent thermal resistance model>

The two-resistor compact model is calculated according to JEDEC standard.

Θ_{JT} is the thermal resistance from junction to the top side: 8 °C/W

Θ_{TA} is the thermal resistance from the top side to the air side: 25 °C/W

Θ_{JB} is the thermal resistance from junction to the bottom side: 4 °C/W

Θ_{BA} is the thermal resistance from the bottom to the air side: 17 °C/W

**Measure condition:

- Thernal resistances were measured in 100mm * 90mm * 1mm FR4 Evaluation board
- Network condition
  Downlink 2*2MIMO 150Mbps throughput (B71)
  Uplink QPSK and maximum power status

2.4. Temperature Range

The allowable maximum operating temperature is +105°C which can be read by AT#TEMPMON. It is not recommended to operature LE910Cx mPCIe above the allowable maximum operating temperature.

Operating Condition

Condition	Min	Typ	Max
The Temperature read by AT#TEMPMON=1	-	-	+105°C

2.5. Current consumption in each mode

LE910Cx mPCIe Current Consumption

Mode	Average [Typ.]	Mode Description
IDLE Mode		
CFUN=1	30mA	No call connection USB3.0 is connected to a host
Operative Mode (LTE)		
Non-CA mode (1DL / 1UL)	750mA	Non-CA, Band 71, Single carrier, BW 20MHz, 22dBm, 12RB
Operative Mode (WCDMA)		
WCDMA Voice	650 mA	WCDMA voice call (Tx = 23 dBm)
WCDMA HSPA (22 dBm)	650 mA	WCDMA data call (Cat4, Max Throughput)

* Worst/best case current values depend on network configuration

** Loop-back mode in call equipment

*** 3.3 voltage / room temperature

Information – The electrical design for the power supply must ensure a peak current output of at least 2A.

3. THERMAL DESIGN

This chapter provides the thermal design guide for customer to help their thermal design.

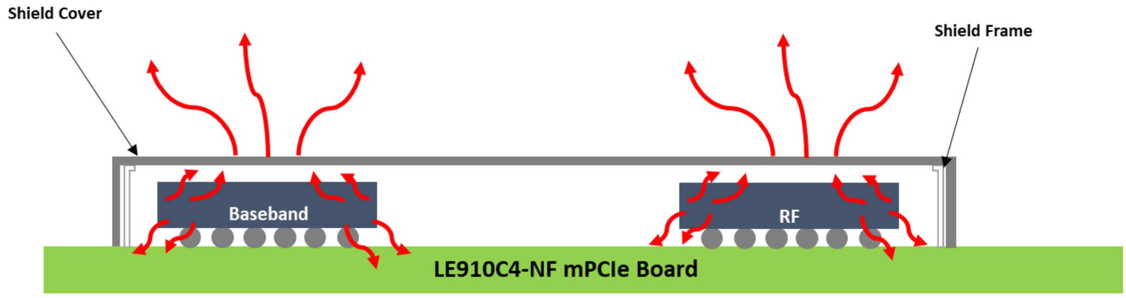
3.1. Thermal Design Guidelines

To enhance heat dissipation:

- Ensure that the air flow around the LE910Cx mPCIe is sufficient. (Spread the heat)
  - Balance the heat flow between front and back of the PCB
  - Insulate hot spots on the device skin from hot areas below
- Separate hottest components (Spread the heat)
- Optimize the ground plane and connections. (Spread the heat)
  - Use larger copper weight for a solid ground plane layer
  - Connect each ground pad of LE910Cx mPCIe directly.
- Use Thermal Interface Material. (Spread the heat)
  - Eliminate air gaps between the top/bottom of LE910Cx mPCIe and heat spreaders; use TIM under compression and thermal grease for better thermal conduction
  - Use large surface areas with high thermal conductivity
- Use phase change material or heat pipes. (Absorb the heat)
- Keep the TCXO or any XO away from heat sources/gradients near the LE910Cx mPCIe.
- If the thermal conductive material is attached between LE910Cx mPCIe and the customer board, the heat dissipation is better for multilayer PCB.
- Attach the conductive material and heat sink at top and bottom side of module for the heat dissipation.

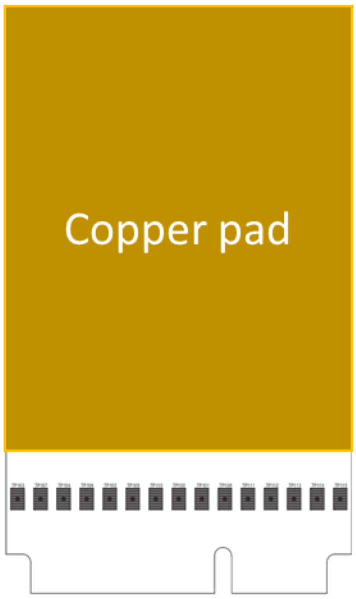
3.2. Thermal Design Solution

There are the LE910Cx mPCIe for the heat dissipation.



<LE910Cx mPCIe Side View>

RF and Baseband areas must be heat dissipation.

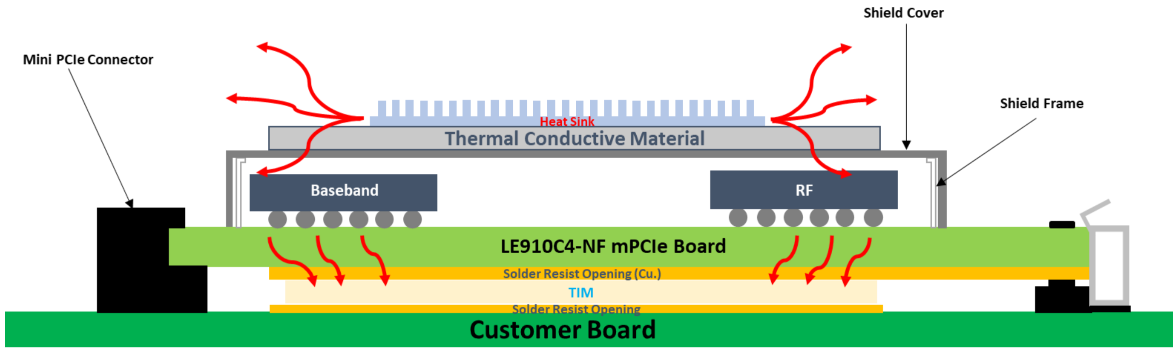


<Copper Pad Location on Bottom of LE910Cx mPCIe>

There is the large solder resist opening area on the back of LE910Cx mPCIe for the better heat dissipation to heat sinks which are on a customer's application board.

This chapter defines the heat sink or TIM for your application as a basic element of the heat sink design. LE910Cx mPCIe is able to get very hot when operating at the upper limit of its range.

A heat sink or TIM is a component that is attached to a module for the sake of transferring heat from the device into the surrounding environment. This environment is most commonly air, but it can also be other fluids. Heat sinks are typically made of aluminum or copper. It expedites the heat transfer to the surrounding fluid.



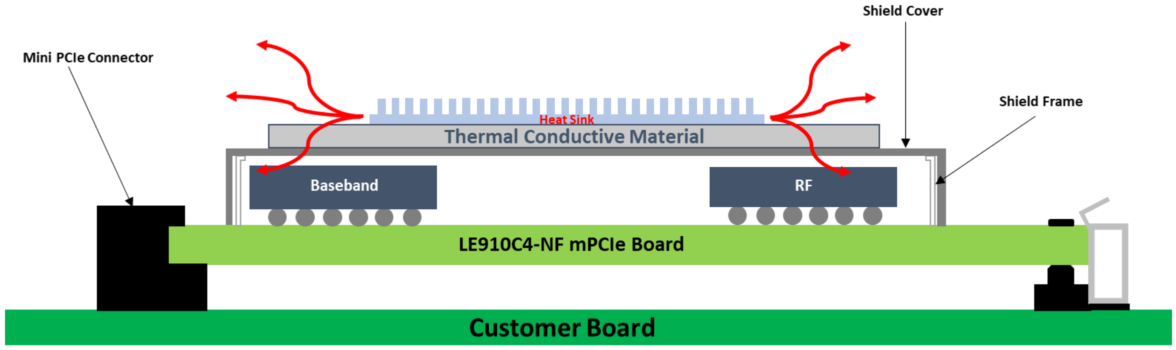
<Thermal Solution on Both sides>

The best method is that attaching a heat sink on top and a TIM on bottom side.

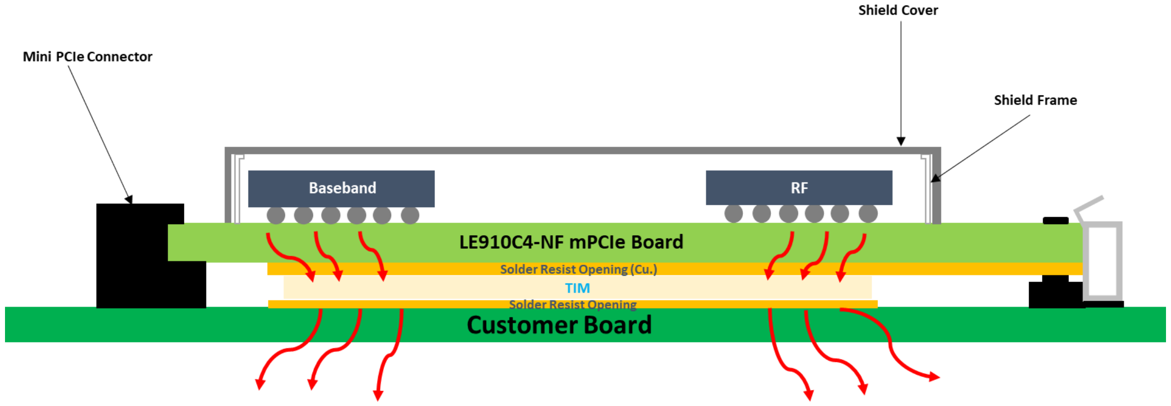
Inevitable environment where heat sink or TIM cannot be attached to both sides, it is able to attach a heat sink or TIM only one side, but this is not the best option.

We recommend that you attach a TIM pad to the bottom side of customer PCB.

Please refer to the figure as below.



<Heat Sink on Top Side>



<TIM on Bottom Side>

Information – If ignore the above contents, network connection might be terminated due to overheating. When the temperature drops, it will be restart the network connection.

4. DOCUMENT HISTORY

Revision	Date	Changes
1	2019-09-24	Initial Release

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Telit Communications S.p.A.
Via Stazione di Prosecco, 5/B
I-34010 Sgonico (Trieste), Italy

Telit Wireless Solutions Inc.
3131 RDU Center Drive, Suite 135
Morrisville, NC 27560, USA

Telit Wireless Solutions Ltd.
10 Habarzel St.
Tel Aviv 69710, Israel

Telit IoT Platforms LLC
5300 Broken Sound Blvd, Suite 150
Boca Raton, FL 33487, USA

Telit Wireless Solutions Co., Ltd.
8th Fl., Shinyoung Securities Bld.
6, Gukjegeumyung-ro8-gil, Yeongdeungpo-gu
Seoul, 150-884, Korea

Telit Wireless Solutions
Technologia e Servicos Ltda
Avenida Paulista, 1776, Room 10.C
01310-921 São Paulo, Brazil