RG50xQ&RM5xxQ Series Software Thermal Management Guide

5G Module Series

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Quectel Wireless Solutions Co., Ltd.
Building 5, Shanghai Business Park Phase III (Area B), No.1016 Tianlin Road, Minhang District, Shanghai 200233, China
Tel: +86 21 5108 6236
Email: info@quectel.com

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About the Document

Revision History

Version	Date	Author	Description
-	2020-08-06	Floyd WANG	Creation of the document
1.0	2021-09-23	Floyd WANG/ Aydan DING	First official release
2.0	2023-03-28	Aydan DING	1. Updated the applicable module list by modifying RG501Q series to RG501-EU and modifying the RM502Q series to RM502Q-AE (Chapter 1.1); 2. Added AT+QTHERMAL and its sun-commands (Chapter 2.4); 3. Added the note of the applicable modules supported by AT+QCFG="thermal5g/mdm" (Chapter 2.6); 4. Added the introduction to sub-commands of AT+QTHERMAL in the corresponding thermal management mechanism (Chapter 3.1 and 3.2); 5. Added the description of the thermal management mechanism of LTE MDM (Table 3 and Chapter 3.4); 6. Updated the description of LTE PA thermal management mechanism (Chapter 3.3).

Contents

Table Index

1 Introduction

This document describes the software thermal management mechanism and related AT commands for Quectel 5G RG50xQ family and RM5xxQ family. When the temperature reaches a specific threshold, any one of the thermal management mechanisms will be adopted to achieve thermal management.

1.1. Applicable Modules

Table 1: Applicable Modules

Module Family	Model
RG50xQ	RG500Q Series
	RG501Q-EU
	RG502Q Series
RM5xxQ	RM500Q Series
	RM502Q-AE
	RM510Q-GL
	RM505Q-AE

2 AT Command Description

2.1. AT Command Introduction

2.1.1. Definitions

- **<CR>** Carriage return character.
- **<LF>** Line feed character.
- **<...>** Parameter name. Angle brackets do not appear on the command line.
- **[...]** Optional parameter of a command or an optional part of TA information response. Square brackets do not appear on the command line. When an optional parameter is not given in a command, the new value equals to its previous value or the default settings, unless otherwise specified.
- **Underline** Default setting of a parameter.

2.1.2. AT Command Syntax

All command lines must start with **AT** or **at** and end with **<CR>**. Information responses and result codes always start and end with a carriage return character and a line feed character: **<CR><LF><response><CR><LF>**. In tables presenting commands and responses throughout this document, only the commands and responses are presented, and **<CR>** and **<LF>** are deliberately omitted.

Table 2: Types of AT Commands

Command Type	Syntax	Description
Test Command	**AT+<cmd>=?**	Test the existence of the corresponding command and return information about the type, value, or range of its parameter.
Read Command	**AT+<cmd>?**	Check the current parameter value of the corresponding command.
Write Command	**AT+<cmd>=<p1>[,<p2>[,<p3>[...]]]**	Set user-definable parameter value.
Execution Command	**AT+<cmd>**	Return a specific information parameter or perform a specific action.

2.2. Declaration of AT Command Examples

The AT command examples in this document are provided to help you learn about the use of the AT commands introduced herein. The examples, however, should not be taken as Quectel's recommendations or suggestions about how to design a program flow or what status to set the module into. Sometimes multiple examples may be provided for one AT command. However, this does not mean that there is a correlation among these examples, or that they should be executed in a given sequence.

2.3. AT+QTEMP Query Module Temperature

This command queries the module's temperature.

AT+QTEMP Query Module Temperature	
Test Command **AT+QTEMP=?**	Response **OK**
Execution Command **AT+QTEMP**	Response **+QTEMP:<sensor>,<temp>** **…** **OK**
Maximum Response Time	300 ms
Characteristics	/

Parameter

<sensor>	String type. Sensor type.	
	"qfe_wtr_pa0"	4G/5G low band ET PA module
	"qfe_wtr_pa1"	4G/5G mid/high band ET PA module
	"qfe_wtr_pa2"	5G LB/MB GHz ET PA module
	"qfe_wtr_pa3"	5G n41 PA module
	"aoss0-usr"	Always-on subsystem unit
	"mdm-q6-usr"	DSP processor
	"ipa-usr"	IP accelerator unit
	"cpu0-a7-usr"	ARM processor
	"mdm-5g-usr"	Modem processor core1
	"mdm-vpe-usr"	Modem processor core2
	"mdm-core-usr"	Modem processor core3
	"xo-therm-usr"	Crystal oscillator
	"sdx-case-therm-usr"	BB chipset

	"ambient-therm-usr"	Ambient temperature detection
<temp>	Integer type. The temperature. Unit: ºC.	

Example

```
AT+QTEMP                          //Query the module's temperature.
+QTEMP:"qfe_wtr_pa0","35"
+QTEMP:"qfe_wtr_pa1","32"
+QTEMP:"qfe_wtr_pa2","30"
+QTEMP:"qfe_wtr_pa3","29"
+QTEMP:"aoss0-usr","31"
+QTEMP:"mdm-q6-usr","30"
+QTEMP:"ipa-usr","30"
+QTEMP:"cpu0-a7-usr","31"
+QTEMP:"mdm-5g-usr","30"
+QTEMP:"mdm-vpe-usr","30"
+QTEMP:"mdm-core-usr","30"
+QTEMP:"xo-therm-usr","29"
+QTEMP:"sdx-case-therm-usr","29"
+QTEMP:"ambient-therm-usr","29"

OK
```

NOTE

If the queried temperature is 0 ºC or -273 ºC, the corresponding sensor is inactive, and these queried values are invalid.

2.4. AT+QTHERMAL Extended Commands of Thermal Management Mechanism

These extended commands configure the thermal management mechanism.

AT+QTHERMAL Extended Commands of Thermal Management Mechanism	
Test Command **AT+QTHERMAL=?**	Response **+QTHERMAL: "thermal_sensor",<sensor>** **+QTHERMAL: "thermal_level"** **+QTHERMAL: "urc_enable",(**list of supported **<enable>**s**)** **+QTHERMAL: "pa_trigger",<level>,<trig>,<clr>** **+QTHERMAL: "mdm_trigger",<level>,<trig>,<clr>**

	OK
Maximum Response Time	300 ms
Characteristics	/

2.4.1. AT+QTHERMAL="thermal_sensor" Query Temperature of a Specific Sensor

This command queries all the thermal sensors supported by the module and the temperature of a specific thermal sensor.

AT+QTHERMAL="thermal_sensor" Query Temperature of a Specific Sensor	
Write Command **AT+QTHERMAL="thermal_sensor"[,<sensor>]**	Response If the optional parameter is omitted, query all the thermal sensors supported by the module: **+QTHERMAL: "thermal_sensor",<sensor1>,…,<sensorN>** **OK** If the optional parameter is specified, query the temperature of a specific thermal sensor: **+QTHERMAL: "thermal_sensor",<sensor>,<temp>** **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	/

Parameter

<sensorN>	String type. Sensor type. Commonly used sensor types are as follows: "pa" PA "mdm" MDM
<temp>	Integer type. The temperature. Unit: ºC.

Example

```
AT+QTHERMAL="thermal_sensor"                    //Query the thermal sensors supported by the module.
+QTHERMAL: "thermal_sensor","pa","mdm"
```

```
OK
AT+QTHERMAL="thermal_sensor","pa"          //Query the temperature of PA.
+QTHERMAL: "thermal_sensor","pa",31

OK
```

2.4.2. AT+QTHERMAL="thermal_level" Query Thermal Management Level

This command queries current thermal management level of thermal management mechanism.

AT+QTHERMAL="thermal_level" Query Thermal Management Level	
Write Command **AT+QTHERMAL="thermal_level"**	Response **+QTHERMAL: "thermal_level",<thermal_mitigation>,<level>** **+QTHERMAL: "thermal_level",<thermal_mitigation>,<level>** **…** **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	/

Parameter

<thermal_mitigation>	String type. Thermal management mechanism. "pa" PA thermal management mechanism "mdm" MDM thermal management mechanism
<level>	Integer type. Thermal management level. Range: 0–3. See ***Chapter 3*** for details.

Example

```
AT+QTHERMAL="thermal_level"          //Query current thermal management level.
+QTHERMAL: "thermal_level","pa",0
+QTHERMAL: "thermal_level","mdm",0

OK
```

NOTE

The higher the temperature of the module, the greater the thermal management level triggered.

2.4.3. AT+QTHERMAL="urc_enable" Control Thermal Management Level URC

This command enables or disables the URC **+THERMAL: <thermal_mitigation>,<level>** for reporting the changes of the thermal management level.

AT+QTHERMAL="urc_enable"	Control Thermal Management Level URC
Write Command **AT+QTHERMAL="urc_enable"[,<enable>]**	Response If the optional parameter is omitted, query the current setting: **+QTHERMAL: "urc_enable",<enable>** **OK** If the optional parameter is specified, enables or disables the thermal management level URC: **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	The command takes effect immediately. The configuration is saved automatically.

Parameter

<enable>	Integer type. Whether to enable the thermal management level URC. 0 Disable 1 Enable (The URC is reported once it is enabled. The URC format is: **+THERMAL: <thermal_mitigation>,<level>**)
<thermal_mitigation>	String type. Thermal management mechanism supported by the module. "pa" PA thermal management mechanism. "mdm" MDM thermal management mechanism.
<level>	Integer type. Thermal management level. Range: 0–3. See ***Chapter 3*** for details.

Example

```
AT+QTHERMAL="urc_enable"      //Query whether the thermal management level URC is enabled.
```

```
+QTHERMAL: "urc_enable",0

OK
AT+QTHERMAL="urc_enable",1   //Enable the thermal management level URC.
OK
AT+QTHERMAL="urc_enable"     //Query whether the thermal management level URC is enabled.
+QTHERMAL: "urc_enable",1

OK

+THERMAL: "pa",0             //The URC is reported when the thermal management level changes.
```

2.4.4. AT+QTHERMAL="pa_trigger" Set PA Thermal Management Mechanism

This command sets and queries the PA thermal management mechanism. This command is identical with **AT+QCFG="thermal5g/modem"** in ***Chapter 2.5***. **AT+QTHERMAL="pa_trigger"** is recommended.

AT+QTHERMAL="pa_trigger"	Set PA Thermal Management Mechanism
Write Command **AT+QTHERMAL="pa_trigger"[,<level>,<trig>,<clr>]**	Response If the optional parameters are omitted, query the current setting: **+QTHERMAL: "pa_trigger",1,<trig>,<clr>** **+QTHERMAL: "pa_trigger",2,<trig>,<clr>** **+QTHERMAL: "pa_trigger",3,<trig>,<clr>** **OK** If the optional parameters are specified, set the thermal management mechanism of the PA: **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	The command takes effect after the module is rebooted. The configurations are saved automatically.

Parameter

<level>	Integer type. Thermal management level of the PA. Each level corresponds to a set of **<trig>** and **<clr>**. 1 Level 1, limiting the UL data rate (see ***Chapter 3.1.1***) 2 Level 2, restricting the PA power based on Level 1 (see ***Chapter 3.1.2***)

	3 Level 3, entering Limited-Service Mode (see ***Chapter 3.1.3***)
<trig>	Integer type. Triggering temperature threshold. When the temperature reaches **<trig>**, the corresponding thermal management level (**<level>**) is triggered. Range: 0–120. Unit: ºC. When **<level>**=1, **<trig>** is the temperature threshold to trigger the UL data rate limit. Default: 105. When **<level>**=2, **<trig>** is the temperature threshold to trigger the PA power restriction. Default: 110. When **<level>**=3, **<trig>** is the temperature threshold to enter Limited-Service Mode. Default: 115.
<clr>	Integer type. Terminating temperature threshold. When the temperature drops to **<clr>**, the corresponding thermal management level (**<level>**) is terminated. Range: 0–120. Unit: ºC. When **<level>**=1, **<clr>** is the temperature threshold to terminate the UL data rate limit. Default: 100. When **<level>**=2, **<clr>** is the temperature threshold to terminate the PA power restriction. Default: 105. When **<level>**=3, **<clr>** is the temperature threshold to exit the Limited-Service Mode. Default: 110.

Example

```
AT+QTHERMAL="pa_trigger",1,105,100      //Level 1 lowers the temperature by limiting the data rate
                                          When the temperature reaches 105 ºC, it limits the uplink
                                          data rate; when the temperature drops to 100 ºC, it stops
                                          limiting the UL data rate.
OK
AT+QTHERMAL="pa_trigger"                //Query the current settings of the PA thermal management
                                          mechanism.
+QTHERMAL: "pa_trigger",1,105,100
+QTHERMAL: "pa_trigger",2,110,105
+QTHERMAL: "pa_trigger",3,115,110

OK
```

2.4.5. AT+QTHERMAL="mdm_trigger" Set MDM Thermal Management Mechanism

This command sets the MDM thermal management mechanism. This command is identical with **AT+QCFG="thermal5g/mdm"** in ***Chapter 2.6***. **AT+QTHERMAL="mdm_trigger"** is recommended.

AT+QTHERMAL="mdm_trigger" Set MDM Thermal Management Mechanism	
Write Command **AT+QTHERMAL="mdm_trigger"[,<level>,<trig>,<clr>]**	Response If the optional parameters are omitted, query the current setting: **+QTHERMAL: "mdm_trigger",1,<trig>,<clr>** **+QTHERMAL: "mdm_trigger",2,<trig>,<clr>** **+QTHERMAL: "mdm_trigger",3,<trig>,<clr>**

	OK If the optional parameters are specified, set the thermal management mechanism of the MDM: **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	The command takes effect after the module is rebooted. The configurations are saved automatically.

Parameter

<level>	Integer type. Thermal management level of the MDM. Each level corresponds to a set of **<trig>** and **<clr>**. 1 Level 1 (currently not supported) 2 Level 2, falling back to LTE (see ***Chapter 3.2.1***) 3 Level 3, entering Limited-Service Mode (see ***Chapter 3.2.2***)
<trig>	Integer type. Triggering temperature threshold. When the temperature reaches **<trig>**, the corresponding thermal management level (**<level>**) is triggered. Range: 0–120. Unit: ºC. When **<level>**=1, **<trig>** is the temperature threshold to trigger Level 1. Default: 100. (Currently not supported). When **<level>**=2, **<trig>** is the temperature threshold to trigger the fallback to LTE. Default: 105. When **<level>**=3, **<trig>** is the temperature threshold to enter Limited-Service Mode. Default: 110.
<clr>	Integer type. Terminating temperature threshold. When the temperature drops to **<clr>**, the corresponding thermal management level (**<level>**) is terminated. Range: 0–120. Unit: ºC. When **<level>**=1, **<clr>** is the temperature threshold to terminate Level 1. Default: 97. (Currently not supported) When **<level>**=2, **<clr>** is the temperature threshold to terminate the fallback to LTE. Default: 98. When **<level>**=3, **<clr>** is the temperature threshold to exit Limited-Service Mode. Default: 103.

Example

```
AT+QTHERMAL="mdm_trigger",2,105,98    //Level 2 lowers the temperature by falling back to LTE network. When the temperature reaches 105 ºC, it falls back to LTE; when the temperature drops to 98 ºC, it recovers to 5G.
```

OK **AT+QTHERMAL="mdm_trigger"** **+QTHERMAL: "mdm_trigger",1,100,97** **+QTHERMAL: "mdm_trigger",2,105,98** **+QTHERMAL: "mdm_trigger",3,110,103** **OK**	//Query the current settings of the MDM thermal management mechanism.

NOTE

For modules whose firmware version numbers contain “R13” (such as RM502QAEAA**R13**A02M4G), this command is not supported.

2.5. AT+QCFG="thermal5g/modem" Set PA Thermal Management Mechanism

AT+QCFG="thermal5g/modem" Set PA Thermal Management Mechanism	
Write Command **AT+QCFG="thermal5g/modem"[,<level>,<trig>,<clr>]**	Response If the optional parameters are omitted, query the current setting: **+QCFG: "thermal5g/modem",1,<trig>,<clr>** **+QCFG: "thermal5g/modem",2,<trig>,<clr>** **+QCFG: "thermal5g/modem",3,<trig>,<clr>** **OK** If the optional parameters are specified, set the thermal management mechanism of the PA: **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	The command takes effect after the module is rebooted. The configurations are saved automatically.

Parameter

<level>	Integer type. Thermal management level of the PA. Each level corresponds to a set of **<trig>** and **<clr>**. 1 Level 1, limiting the UL data rate (see ***Chapter 3.1.1***) 2 Level 2, restricting the PA power based on Level 1 (see ***Chapter 3.1.2***) 3 Level 3, entering Limited-Service Mode (see ***Chapter 3.1.3***)
<trig>	Integer type. Triggering temperature threshold. When the temperature reaches **<trig>**, the corresponding thermal management level (**<level>**) is triggered. Range: 0–120. Unit: ºC. When **<level>**=1, **<trig>** is the temperature threshold to trigger the UL data rate limit. Default: 105. When **<level>**=2, **<trig>** is the temperature threshold to trigger the PA power restriction. Default: 110. When **<level>**=3, **<trig>** is the temperature threshold to enter Limited-Service Mode. Default: 115.
<clr>	Integer type. Terminating temperature threshold. When the temperature drops to **<clr>**, the corresponding thermal management level (**<level>**) is terminated. Range: 0–120. Unit: ºC. When **<level>**=1, **<clr>** is the temperature threshold to terminate the UL data rate limit. Default: 100. When **<level>**=2, **<clr>** is the temperature threshold to terminate the PA power restriction. Default: 105. When **<level>**=3, **<clr>** is the temperature threshold to exit the Limited-Service Mode. Default: 110.

Example

```
AT+QCFG="thermal5g/modem",1,105,100 //Level 1 lowers the temperature by limiting the data rate
                                    When the temperature reaches 105 ºC, it limits the uplink
                                    data rate; when the temperature drops to 100 ºC, it stops
                                    limiting the UL data rate.
OK
AT+QCFG="thermal5g/modem"           //Query the current settings of the PA thermal management
                                    mechanism.
+QCFG: "thermal5g/modem",1,105,100
+QCFG: "thermal5g/modem",2,110,105
+QCFG: "thermal5g/modem",3,115,110

OK
```

2.6. AT+QCFG="thermal5g/mdm" Set MDM Thermal Management Mechanism

AT+QCFG="thermal5g/mdm" Set MDM Thermal Management Mechanism	
Write Command **AT+QCFG="thermal5g/mdm"[,<level>,<trig>,<clr>]**	Response If the optional parameters are omitted, query the current setting: **+QCFG: "thermal5g/mdm",1,<trig>,<clr>** **+QCFG: "thermal5g/mdm",2,<trig>,<clr>** **+QCFG: "thermal5g/mdm",3,<trig>,<clr>** **OK** If the optional parameters are specified, set the thermal management mechanism of the MDM: **OK** If there is an error: **ERROR**
Maximum Response Time	300 ms
Characteristics	The command takes effect after the module is rebooted. The configurations are saved automatically.

Parameter

<level>	Integer type. Thermal management level of the MDM. Each level corresponds to a set of **<trig>** and **<clr>**. 1 Level 1 (currently not supported) 2 Level 2, falling back to LTE (see ***Chapter 3.2.1***) 3 Level 3, entering Limited-Service Mode (see ***Chapter 3.2.2***)
<trig>	Integer type. Triggering temperature threshold. When the temperature reaches **<trig>**, the corresponding thermal management level (**<level>**) is triggered. Range: 0–120. Unit: ºC. When **<level>**=1, **<trig>** is the temperature threshold to trigger Level 1. Default: 100. (Currently not supported). When **<level>**=2, **<trig>** is the temperature threshold to trigger the fallback to LTE. Default: 105. When **<level>**=3, **<trig>** is the temperature threshold to enter Limited-Service Mode. Default: 110.
<clr>	Integer type. Terminating temperature threshold. When the temperature drops to **<clr>**, the corresponding thermal management level (**<level>**) is terminated. Range: 0–120. Unit: ºC. When **<level>**=1, **<clr>** is the temperature threshold to terminate Level 1. Default: 97.

	(Currently not supported) When **<level>**=2, **<clr>** is the temperature threshold to terminate the fallback to LTE. Default: 98. When **<level>**=3, **<clr>** is the temperature threshold to exit Limited-Service Mode. Default: 103.

Example

```
AT+QCFG="thermal5g/mdm",2,105,98          //Level 2 lowers the temperature by falling back to LTE. When the temperature reaches 105 ºC, it falls back to LTE; when the temperature drops to 98 ºC, it recovers to 5G.

OK
AT+QCFG="thermal5g/mdm"                   //Query the current settings of the MDM thermal management mechanism.

+QCFG: "thermal5g/mdm",1,100,97
+QCFG: "thermal5g/mdm",2,105,98
+QCFG: "thermal5g/mdm",3,110,103

OK
```

NOTE

For modules whose firmware version numbers contain “R13” (such as RM502QAEAA**R13**A02M4G), this command is not supported.

3 Thermal Management Mechanism

Table 3: Software Thermal Management Mechanisms

Mechanism	Level / Sensor	Level 1	Level 2	Level 3
5G NR Sub-6 GHz PA	qfe_wtr_pa0–qfe_wtr_pa3	Limit UL data rate	Restrict PA power (MTPL)	Limited-Service
5G NR Sub-6 GHz MDM	mdm-core-usr	-	Fallback to LTE	Limited-Service
LTE PA	qfe_wtr_pax	Limit UL data rate	Restrict PA power (MTPL)	Limited-Service
LTE MDM	mdm-core-usr	-	● Drop SCells ● 4RX to 2RX Fallback	Limited-Service

3.1. 5G NR Sub-6 GHz PA Thermal Management Mechanism

3.1.1. Limit UL Data Rate

The PA temperature is lowered by limiting PUSCH transmission duty cycle, reducing the PA turn-on time and reducing the power consumption.

The module limits the UL data rate at different target rates based on the configured temperature thresholds within a certain period after you executes **AT+QCFG="thermal5g/modem",1,<trig>,<clr>** or **AT+QTHERMAL="pa_trigger",1,<trig>,<clr>**.

Taking **AT+QCFG="thermal5g/modem",1,105,100** (the triggering threshold is 105 ºC and the terminating threshold is 100 ºC) as an example, the thermal management mechanism is implemented as below:

1. When the temperature obtained by any one of the sensors from "qfe_wtr_pax0" to "qfe_wtr_pax3" reaches 105 ºC (the triggering threshold), the module enters Level 1 and limits the UL data rate to 100 Mbps.
2. The module detects the temperature every 15 s. If the temperature keeps higher than 100 °C (the terminating threshold), the limited UL data rate will be reduced by 20 Mbps after each detection cycle until it reduces to the lowest value of 20 Mbps. The UL data rate will remain at 20 Mbps.

3. At the same time, the UL data are transmitted at a regular interval (the transmitting cycle and interval are both 130 ms). The PA enters sleep mode during the interval to reduce PA output power. PA will be turned off when there is no data transmission.
4. The module exits Level 1 and stops the UL data rate limit when the temperature drops to 100 °C.

NOTE

The principle of the UL data rate limit and data transmission at intervals is that the UE sends a false BSR to the base station, and the base station controls the UL channel throughput rate of the UE.

3.1.2. Restrict PA Power

The PA's workload can be reduced by restricting the PA TX power.

The module restricts the PA power with the specified power backoff values based on the configured temperature thresholds within a certain period after you executes **AT+QCFG="thermal5g/modem",2,<trig>,<clr>** or **AT+QTHERMAL="pa_trigger",2,<trig>,<clr>**. The power backoff is with a 50 % duty cycle of 60 ms.

Power backoff information is listed in the following table:

Table 4: PA Power Backoff Information

Parameter Type	Parameter Name	Value	Remark
Reference power backoff	P_backoff	3 dBm	Taking a normal PA power of 21 dBm as an example, the backoff powers are in the following order: 21 dBm, 18 dBm, 15 dBm, 15 dBm, 15 dBm...
Maximum power backoff	Max_backoff	15 dBm	
Duration of normal power	T_on	30 ms	
Duration of power backoff	T_off	30 ms	
Detection cycle	Step_timer	15 s	

Taking **AT+QCFG="thermal5g/modem",2,110,105** (the triggering threshold is 110 °C and the terminating threshold is 105 °C) with a normal PA power of 21 dBm as an example, the thermal management mechanism is implemented as below:

1. When the temperature obtained by any one of the sensors from "qfe_wtr_pax0" to "qfe_wtr_pax3" reaches 110 ºC (the triggering threshold), the module enters Level 2 and starts to reduce the PA power to 18 dBm from 21 dBm (the reference power backoff is 3 dBm) for 30 ms (*T_off*), after which the power recovers to 21 dBm for another 30 ms (*T_on*). The PA power switches between 21 dBm and 18 dBm, which lasts for 15 s (*Step_timer*).

2. After the power backoff of 3 dBm lasts 15 s, the backoff value will increase to 6 dBm if the temperature is still over 105 ºC (the terminating threshold). The PA power switches between 21 dBm and 15 dBm at the interval of 30 ms for 15 s.
3. After the power backoff of 6 dBm lasts 15 s, the backoff value will remain to be 6 dBm if the temperature is still over 105 ºC. The PA power keeps switching between 21 dBm and 15 dBm at the interval of 30 ms.
4. The module exits Level 2 and stops the power backoff when the temperature drops to 105 °C.

NOTE

When the software thermal management enters Level 2, Level 1 remains effective. That is, the UL data rate limit and PA power restriction will be implemented simultaneously.

3.1.3. Enter Limited-Service Mode

If the UL data rate limit and PA power restriction mechanisms can hardly achieve the thermal management, the module enters Limited-Service Mode and stops all services to protect the hardware from damage due to overheating. Under this circumstance, only the emergency voice call is available.

After you executes **AT+QCFG="thermal5g/modem",3,<trig>,<clr>** or **AT+QTHERMAL="pa_trigger",3,<trig>,<clr>**, the module enters Limited-Service Mode based on the configured temperature threshold and lower the temperature by limiting the services.

Taking **AT+QCFG="thermal5g/modem",3,115,110** (the triggering threshold is 115 ºC and the terminating threshold is 110 ºC) as an example, the module enters Level 3 when the temperature obtained by any one of the sensors from "qfe_wtr_pax0" to "qfe_wtr_pax3" reaches 115 ºC. After entering Level 3, the module allows emergency voice calls only.

NOTE

After the module enters Level 3, its operation will recover only when the temperature drops to the terminating threshold of Level 1 (that is, the highest temperature obtained by any one of the sensors from "qfe_wtr_pax0" to "qfe_wtr_pax3" drops to the terminating threshold of the UL data rate limit).

3.2. 5G NR Sub-6 GHz MDM Thermal Management Mechanism

3.2.1. Fall Back to LTE

When the module is in a 5G NSA network, it will implement the fallback to LTE to reduce MDM CPU workload for thermal management after you execute **AT+QCFG="thermal5g/mdm",2,<trig>,<clr>** or **AT+QTHERMAL="mdm_trigger",2,<trig>,<clr>.**

Taking **AT+QCFG="thermal5g/mdm",2,105,98** (the triggering threshold is 105 ºC and the terminating threshold is 98 ºC) as an example, the module enters Level 2 and starts to fall back to LTE when the temperature obtained by the sensor "mdm-core-usr" reaches 105 ºC. When the temperature drops to 98 ºC, the module exits Level 2 and stops the fallback to LTE.

NOTE

The network falls back to LTE only under 5G NSA and no operation is performed under 5G SA.

3.2.2. Enter Limited-Service Mode

The module enters Limited-Service Mode and stops all services to protect the hardware from damage due to overheating. Under this circumstance, only the emergency voice call is available.

After you executes **AT+QCFG="thermal5g/mdm",3,<trig>,<clr>** or **AT+QTHERMAL="mdm_trigger",3,<trig>,<clr>**, the module enters Limited-Service Mode based on the configured temperature threshold and lower the temperature by limiting the services.

Taking **AT+QCFG="thermal5g/mdm",3,110,103** (the triggering threshold is 110 ºC and terminating threshold is 103 ºC) as an example, when the temperature obtained by "mdm-core-usr" reaches 110 ºC, the module enters Level 3. After entering Level 3, the module only allows emergency voice calls.

NOTE

After the module enters Level 3, its operation will recover only when the temperature drops to the terminating threshold of Level 1.

3.3. LTE PA Thermal Management Mechanism

The thermal management mechanism of the LTE PA is independent of but similar to that of the 5G NR Sub-6 GHz PA (see ***Chapter 3.1*** for details). The difference is provided below:

Under LTE, the UL data rate is limited to 1 Mbps at most and the PA power restriction has a maximum backoff value of 5 dBm.

3.4. LTE MDM Thermal Management Mechanism

The thermal management mechanism of the LTE MDM is similar to that of the 5G NR Sub-6 GHz MDM (see ***Chapter 3.2*** for details). The difference lies in the mechanism of Level 2. Under an LTE network, the module drops SCells or falls back from 4RX to 2RX to achieve thermal management.

3.4.1. Drop SCells

The module reports CQI-0 (indicating dropping SCells) in LTE network and CQI-0 and Rank 1 in 5G NR network to reduce carrier aggregation envelope and reduce power consumption.

3.4.2. Fall Back from 4RX to 2RX

The module falls back from 4RX to 2RX to reduce the power on the RF transceiver and the modem baseband.

NOTE

This mechanism is not triggered when the module supports 2RX only.

4 Appendix Reference

Table 5: Terms and Abbreviations

Abbreviation	Description
5G NR	5 Generation New Radio
BB	Baseband
BSR	Buffer Status Request
CC	Component Carrier
CPU	Central Processing Unit
ET	Envelope Tracking
LTE	Long-Term Evolution
MDM	Modem
MT	Mobile Termination
MTPL	Maximum Transmission Power Level
NSA	Non-Standalone
PA	Power Amplifier
PUSCH	Physical Uplink Shared Channel
RX	Receive
SA	Standalone
TA	Terminal Adapter
TX	Transmit
UE	User Equipment
UL	Uplink
XO	Crystal Oscillator

URC	Unsolicited Result Code