ACKNOWLEDGEMENT

By utilizing this website and/or documentation, I hereby acknowledge as follows:

Effective October 1, 2012, QUALCOMM Incorporated completed a corporate reorganization in which the assets of certain of its businesses and groups, as well as the stock of certain of its direct and indirect subsidiaries, were contributed to Qualcomm Technologies, Inc. (QTI), a wholly-owned subsidiary of QUALCOMM Incorporated that was created for purposes of the reorganization.

Qualcomm Technology Licensing (QTL), the Company's patent licensing business, continues to be operated by QUALCOMM Incorporated, which continues to own the vast majority of the Company's patent portfolio. Substantially all of the Company's products and services businesses, including QCT, as well as substantially all of the Company's engineering, research and development functions, are now operated by QTI and its direct and indirect subsidiaries[1]. Neither QTI nor any of its subsidiaries has any right, power or authority to grant any licenses or other rights under or to any patents owned by QUALCOMM Incorporated.

No use of this website and/or documentation, including but not limited to the downloading of any software, programs, manuals or other materials of any kind or nature whatsoever, and no purchase or use of any products or services, grants any licenses or other rights, of any kind or nature whatsoever, under or to any patents owned by QUALCOMM Incorporated or any of its subsidiaries. A separate patent license or other similar patent-related agreement from QUALCOMM Incorporated is needed to make, have made, use, sell, import and dispose of any products or services that would infringe any patent owned by QUALCOMM Incorporated in the absence of the grant by QUALCOMM Incorporated of a patent license or other applicable rights under such patent.

Any copyright notice referencing QUALCOMM Incorporated, Qualcomm Incorporated, QUALCOMM Inc., Qualcomm Inc., Qualcomm or similar designation, and which is associated with any of the products or services businesses or the engineering, research or development groups which are now operated by QTI and its direct and indirect subsidiaries, should properly reference, and shall be read to reference, QTI.

[1] The products and services businesses, and the engineering, research and development groups, which are now operated by QTI and its subsidiaries include, but are not limited to, QCT, Qualcomm Mobile & Computing (QMC), Qualcomm Atheros (QCA), Qualcomm Internet Services (QIS), Qualcomm Government Technologies (QGOV), Corporate Research & Development, Qualcomm Corporate Engineering Services (QCES), Office of the Chief Technology Officer (OCTO), Office of the Chief Scientist (OCS), Corporate Technical Advisory Group, Global Market Development (GMD), Global Business Operations (GBO), Qualcomm Ventures, Qualcomm Life (QLife), Quest, Qualcomm Labs (QLabs), Snaptracs/QCS, Firethorn, Qualcomm MEMS Technologies (QMT), Pixtronix, Qualcomm Innovation Center (QuIC), Qualcomm iSkoot, Qualcomm Poole and Xiam.

Thermal Protection

Algorithm Overview

80-VT344-1 Rev. F

QUALCOMM Incorporated
5775 Morehouse Drive
San Diego, CA 92121-1714
U.S.A.

Revision History

Revision	Date	Description
A	July 2009	Initial release
B	August 2009	Updated basic concepts
C	September 2009	Updated basic concepts; added graphs on data rates and Tx power; added GCF information
D	December 2009	Updated slides 3, 4, 6 through 10, 12, 13, 15, 23 through 25, and 28
E	March 2010	Updated slides 7 and 12
F	December 2010	▪ Updated for generic thermal protection. ▪ Broadened the scope of slides 6, 7, 8, 9, and 14 to include MSM™ and APQ™ devices.

Contents

Introduction

- Device heating continues to be a challenge due to:
  - Desire for attractive industrial design
    - Refer to [Q3] for the *Thermal Design Considerations Application Note* (80-VU794-5)
  - Growth in features and capabilities (high data rates, advanced signal processing, multimedia and application processors)
- Concern can be categorized into two types:
  - Health and safety
    - Can we ensure no component damage or human body damage due to excessive heating under extreme scenarios that are rare but valid?
      - For example, sustained high Tx power and high data rates
      - The thermal protection algorithm covered in this document addresses this concern
  - User experience during normal use
    - What is the likelihood of encountering the extreme conditions in real life?
    - For normal real-life use, is the level of heating at an acceptable level?
    - This will be addressed through design optimizations (for power efficiency and thermal properties), field studies, and so forth

Basic Concepts

- Thermal protection algorithm protects against human or component damage for rare worst-case conditions
  - User experience is traded off in these extreme thermal conditions
  - Does not alter basic power efficiency or heat dissipation properties of the device
  - Extreme heat up expected to be rare during normal use (depends on product heat dissipation properties and likelihood of sustained maximum power or high data rates in a real network)
- Emergency shutdown feature
  - Designed to prevent heating beyond a defined maximum temperature
- Mitigation feature (the focus of this application note)
  - Entered at a lower temperature threshold than emergency shutdown
  - Preserve user experience to the maximum extent possible, prior to entering emergency shutdown
  - Reduce likelihood of emergency shutdown
- Performance/user experience
  - Unaffected when temperatures < thresholds
  - Performance traded off gracefully for protection when temperatures > thresholds

Chipsets Using the Thermal Mitigation Algorithm

- Potential for high-temperature scenarios are dependent on these issues:
  - Power amplifier level: from both voice and data calls
  - High data throughput: from data services and applications/multimedia
  - Powerful application processor: from running applications
  - Multimedia features: from video and graphics
- New modem chipsets and advanced application processor chips (MSM and MDM devices) will typically be equipped with this algorithm
- Heating issues have existed in the past and will continue to be present
  - Conclusion of previous studies: The form factor size is the predominant indicator of heating problems
  - Advanced features, such as high throughput, new receiver architectures, application processors, and multimedia may contribute to heating issues
  - USB dongles magnify the problem: The form factor is smaller than a phone

Feature Summary: Thermal/USB Mitigation on MDM and MSM Devices

MDM8200™/MDM8200A Devices

Feature	Airlink		
	LTE	HSPA	DO
Thermal mitigation			
Tx power limit	Not supported	Yes	Not supported
Rx diversity disable	Not supported	Yes	Not supported
Data throttling	Not supported	Yes	Not supported
KPI logging*	Not supported	Yes	Not supported
USB current mitigation**			
USB current-limit support	Not supported	Yes (not tested)	Not supported
USB current sense	Not supported	Yes	Not supported

MDM9K™/MDM8220™ Devices

Feature	Airlink		
	LTE	HSPA	DO
Thermal mitigation			
Tx power limit	Yes	Not supported	Not supported
Rx diversity disable	Not supported	Not supported	Not supported
Data throttling	Yes (9K only)	Yes	Yes
KPI logging*	Yes	Yes	Yes
USB current mitigation**			
USB current-limit support	Yes (not tested)	Yes (not tested)	Yes (not tested)
USB current sense	Yes	Yes	Yes

MSM7x30/MSM8x55/MSM8x60/APQ8060 devices

Application processor operating clock speed limiting***

*KPI logging: key performance indicators logging
**USB current mitigation: uses the same mitigation features as thermal mitigation to reduce the current consumption of USB.
***Operating clock speed of Scorpion processor will be lowered if sensed temperature reaches to mitigation threshold.

Grey = Supported today
Yellow = Under development (future support is not guaranteed)

Hardware Requirements

- Thermal mitigation algorithm
  - Temperature sensors
    - External temperature sensors placed near critical dissipating ICs (MSM, MDM, and PA devices)
    - Built in to some existing MSM/MDM, RTR, and PMIC devices
      - Not all MSM/MDM, RTR, and PMIC devices use internal temperature sensors
      - For those devices lacking internal sensors, it is recommended to place external temperature sensors next to the PA and MSM/MDM device
- USB current limit and sensing can be supported providing HW present. Examples:
  - External USB current limiter (hard cutoff), such as LTC4088
  - External USB current sensor (intelligent cutoff with mitigation)

The thermal mitigation algorithm can use sensor data as an input to its algorithm for determining when to enable the mitigation features.

Thermal Protection Algorithm Overview

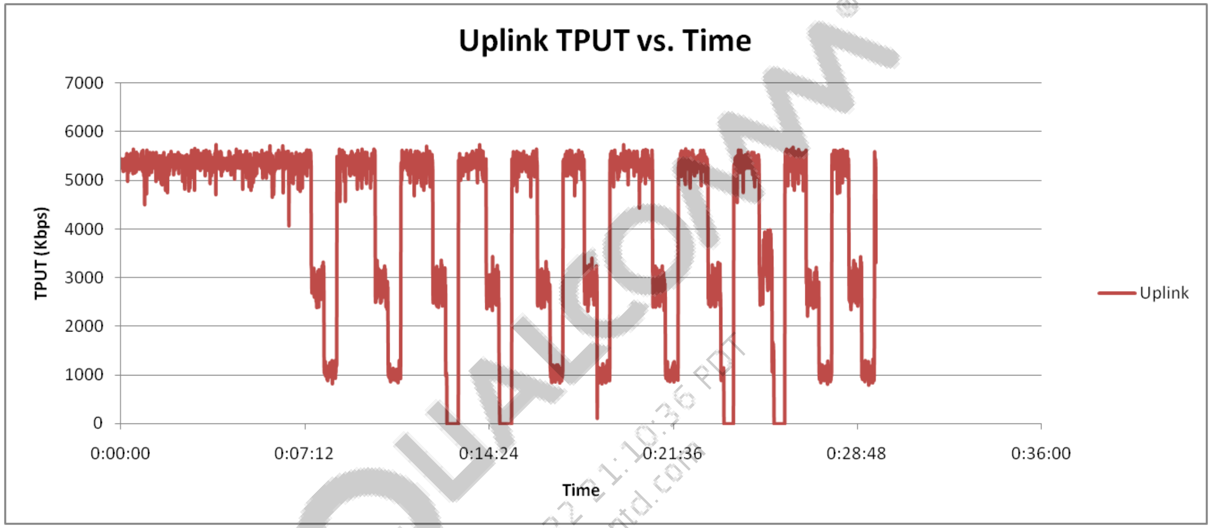
- Active mechanism included in future MSM/MDM device production software
- Sensor-based feedback mechanism
  - Need at least one onboard thermistor
  - Non-volatile (NV) memory interface to set parameters (thresholds, timers, etc.)
- Defines three states of operation
  - Normal – passive monitoring of temperature
  - Mitigation
    - Disables or reduces modem, application, and receiver features
      - Detailed description in [Q2]
  - Emergency – mandatory shutdown of transmitter to prevent damage
- The USB current limit can also be monitored and power controlled if a current sensor is available

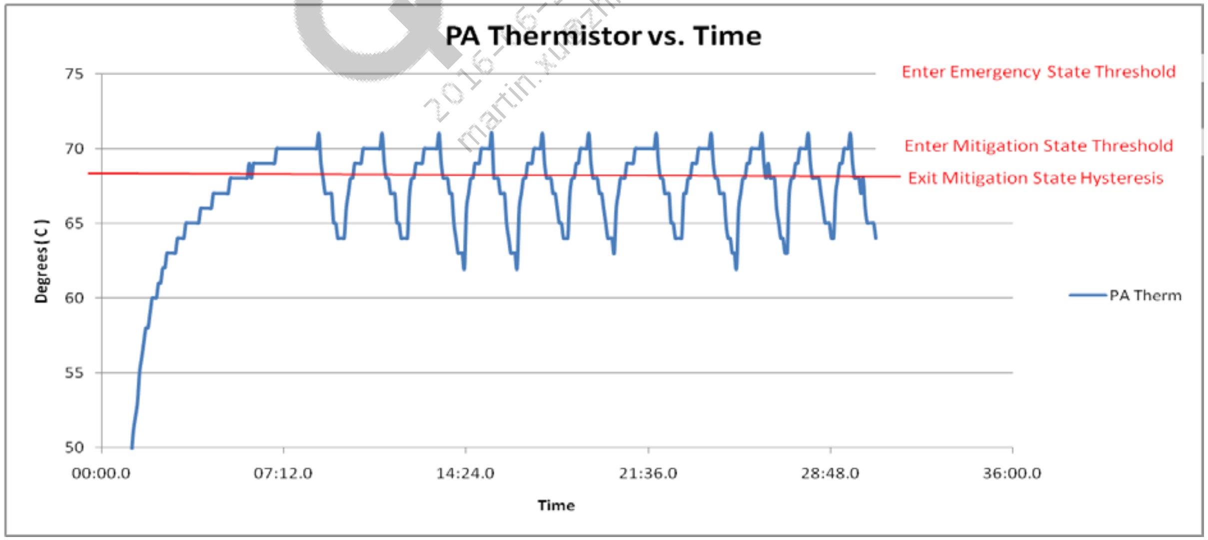
Thermal Protection Algorithm Operation

- Device begins in the normal state
  - Full Tx power capability, full data rate capability, maximum user experience
- Bad heating scenario for several minutes causes high temperatures
  - Measured internal temperatures > NV threshold
- Mitigation state entered
  - Reduced power consumption at limited expense of user experience.
    - Option to turn off advanced modem features (interference cancellation, RX diversity)
    - Option to fully limit maximum Tx power by an amount in NV
    - Option to limit UL/DL throughput (data throttling)
    - Option to limit capacity of application processor
  - If temperatures drop below threshold-hysteresis, return to the normal state
  - If temperatures > emergency threshold, the call is dropped
  - If temperatures remain in mitigation region, the maximum Tx power can be further limited

Note: All time durations, levels, and thresholds should be configured to the specific form-factor product via NV settings

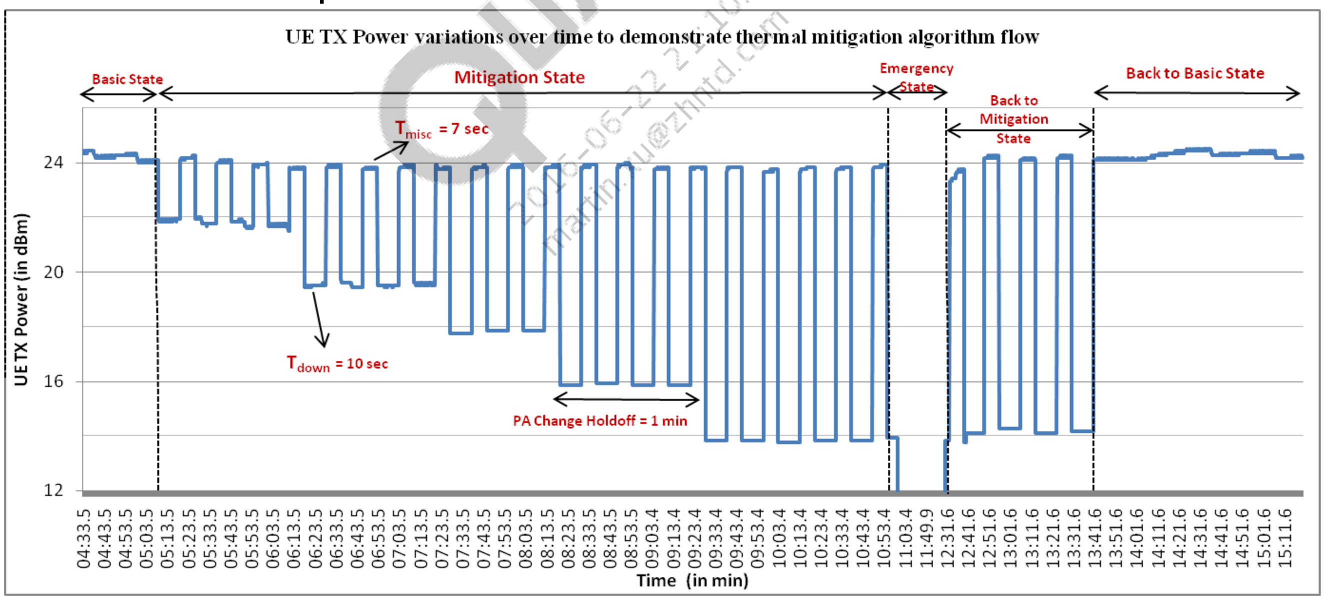
Mitigation State: Example of UL Data Throttling





Mitigation State: Tx Power Back-off Approach

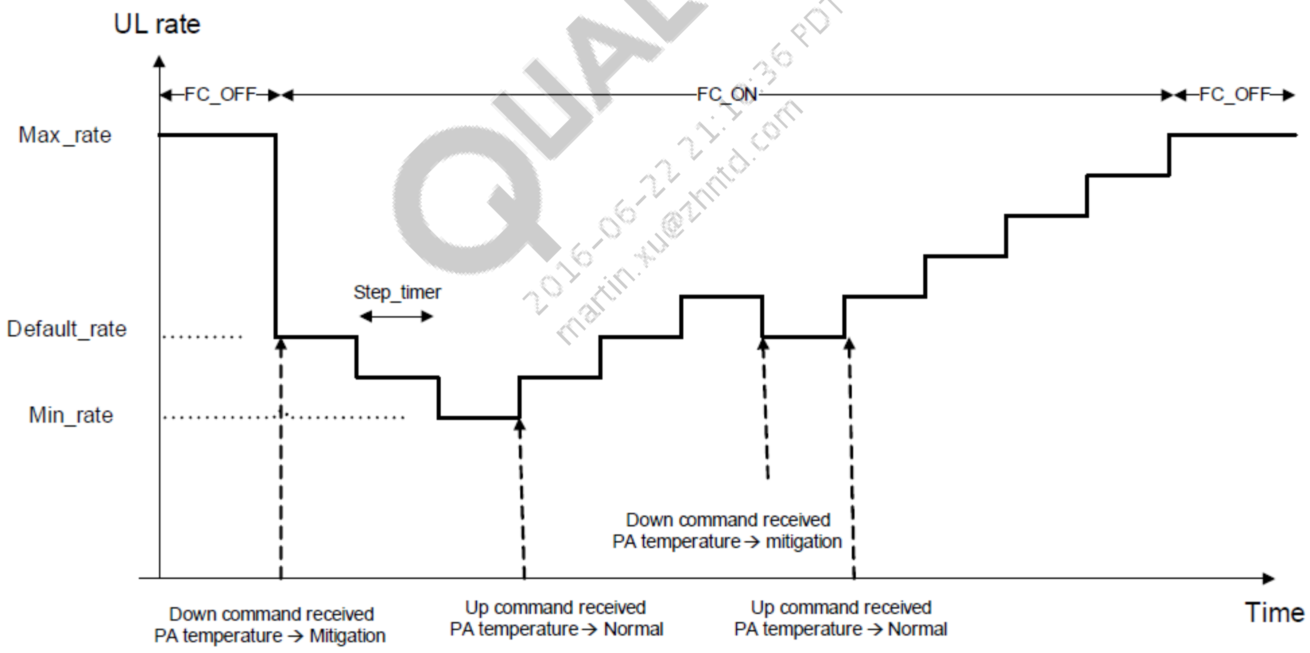
- Tx power backoff is illustrated below.
- The mitigation state is configured with a duty-cycled configuration
  - Peak power held at 24 dBm, while average power is backed off gradually
  - Parameters allow any duty cycle from 0% to 100% of Tx limit
  - Duty-cycling availability of full power transmission, while reducing average power
  - User experience impacted only when required transmit power exceeds the maximum power limit envelope



Note: The duty-cycled configuration is not available for LTE

Mitigation States: Data Throttling

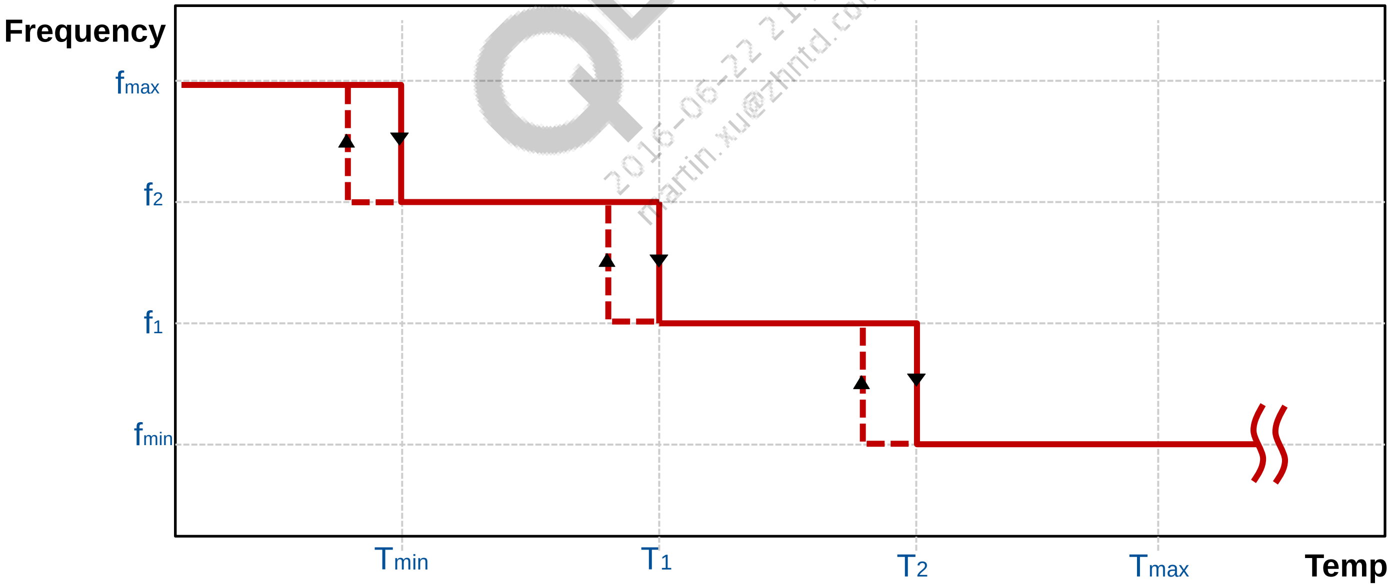
- Data throttling
  - Limits the UL and DL throughput by shrinking the window size incrementally until the data transfer is completely halted
  - UL data throttling effectively limits Tx power required



Sample path for uplink flow-control algorithm

Mitigation States: Clock Speed Limiting

- Clock speed limiting
  - Reducing the clock speeds of the processors by multiple SW defined thermal mitigation thresholds
  - Configuration SW building block provides capability of configuring max/min frequencies, number of thermal thresholds, temperature of thermal thresholds and thermal hysteresis on each operating frequencies
    - Thermal mitigation threshold and corresponding frequencies have to be distributed proportionally across its range
  - Available on MSM7x30, MSM8x55, and MSM8x60/APQ8060 (both cores)



Sample of clock speed limiting with multiple mitigation thresholds

Mitigation States: KPI Logging

- Key performance indicators (KPI) for thermal logging
  - Mainly used as a debugging tool to help phone manufacturers and carriers better understand thermal characteristics of the device
  - Logs information relating to the thermal state of the device
    - All configured temperature sensors
    - Recent history of high transmit powers (trend)

USB Current Limit and Sensing

- USB current limiter (highly recommended)
  - Limits USB current draw to 500 mA to meet USB compliance
  - The MDM9k reference design is using an external USB power manager IC (LTC4088) that can limit USB current to a predefined level
- USB current sensing (highly recommended)
  - The internal ADC in MDM8200 and PM8208™ devices can sample the USB current (with respect to the proportional voltage)
    - Requires an external USB current sensor that outputs USB current in terms of voltage
  - If the current is above a predefined threshold, the mitigation state will be entered

Appendix

Appendix

- QCT Internal Lab Experiments
- Test 1: No Thermal Mitigation (Temperature vs. Time)
- Test 1: No Thermal Mitigation (DL Tput and Tx Power vs. Time)
- Test 2: Example of Emergency Shutdown
- Test 2: Example of Emergency Shutdown (DL Tput and Tx Power vs. Time)
- Test 3: Detailed Parameters
- Test 3: Mitigation State (Temperature vs. Time Plot)
- GCF Compliance Testing
- Supplementary Information: Chipset Power Consumption Basics
- Supplementary Information: Comments on Typical Usage Scenario
- Supplementary Information: Field Example – Poor RF DL/Bidirectional FTP Transfers
- References

QCT Internal Lab Experiments

- QCT MDM8200 USB dongle
  - Larger form factor than most commercial dongles
  - Two onboard thermistors, near the PA and MDM
  - Thermocouples were placed in physical contact with MDM, PA, and dongle surfaces
- Radio bearer test mode
  - DL 7.2 Mbps RxD on, UL 174 kbps
  - Tx power set to 23 dBm
- Three test runs (see the plots on the following slides)
  - No thermal mitigation algorithm
  - Thermal mitigation algorithm with low emergency shutdown threshold
  - Thermal mitigation algorithm with mitigation state behavior

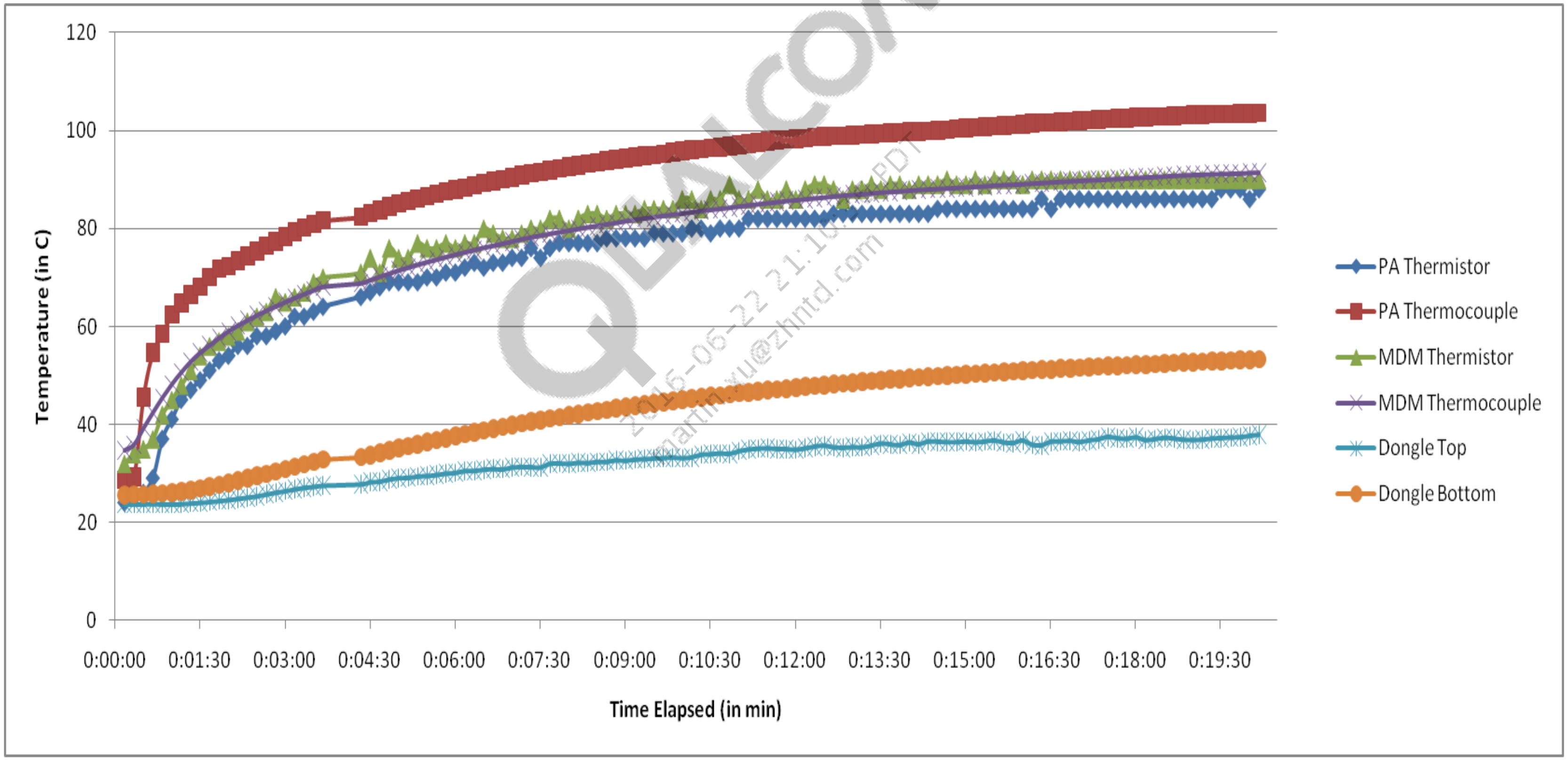
Note: The thermal mitigation algorithm testing done above only includes Tx power backoff.

QCT Internal Lab Experiments (cont.)

- Notable results
  - The mitigation state can prolong a user's experience before shutting down
  - Steady state cooling is observed, but is not the primary goal
  - Experimentation is needed to optimize configuration for a specific form factor and intended level/manner of protection
    - Example – thermistor reading vs. actual temperature, due to location of thermistor

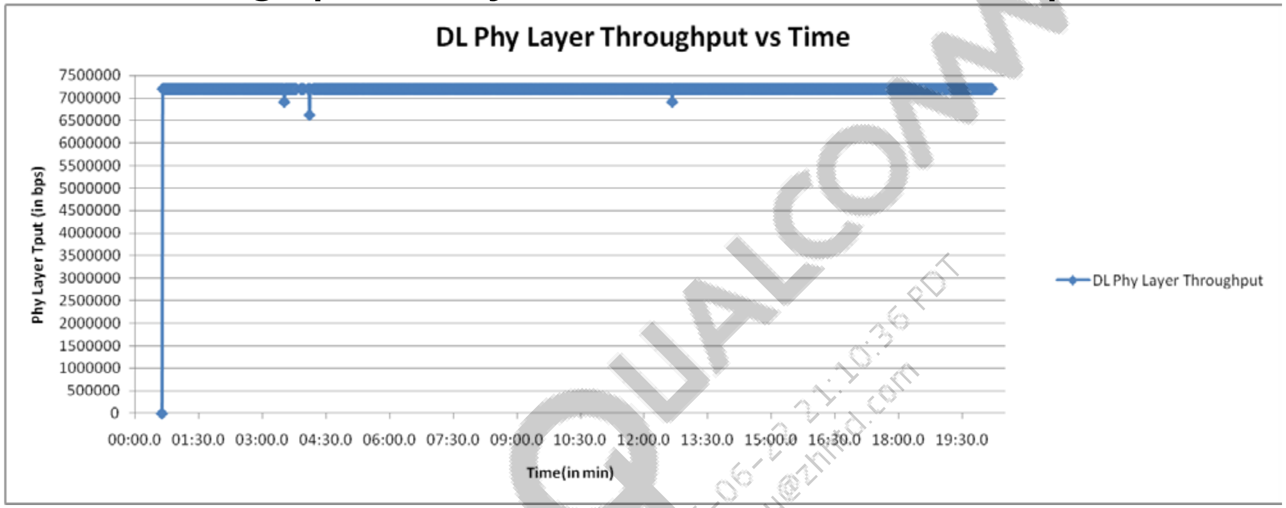
Test 1 – No Thermal Mitigation (Temperature vs. Time)

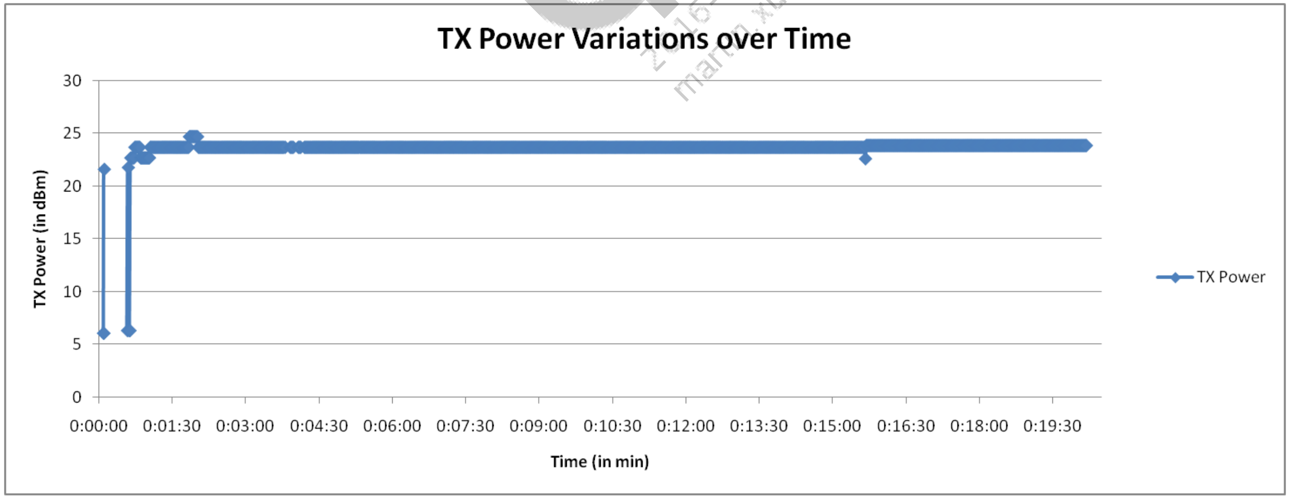
- Maximum temperatures: PA = 104°C, MDM = 91°C, dongle case = 53°C



Test 1 – No Thermal Mitigation (DL Tput and Tx Power vs. Time)

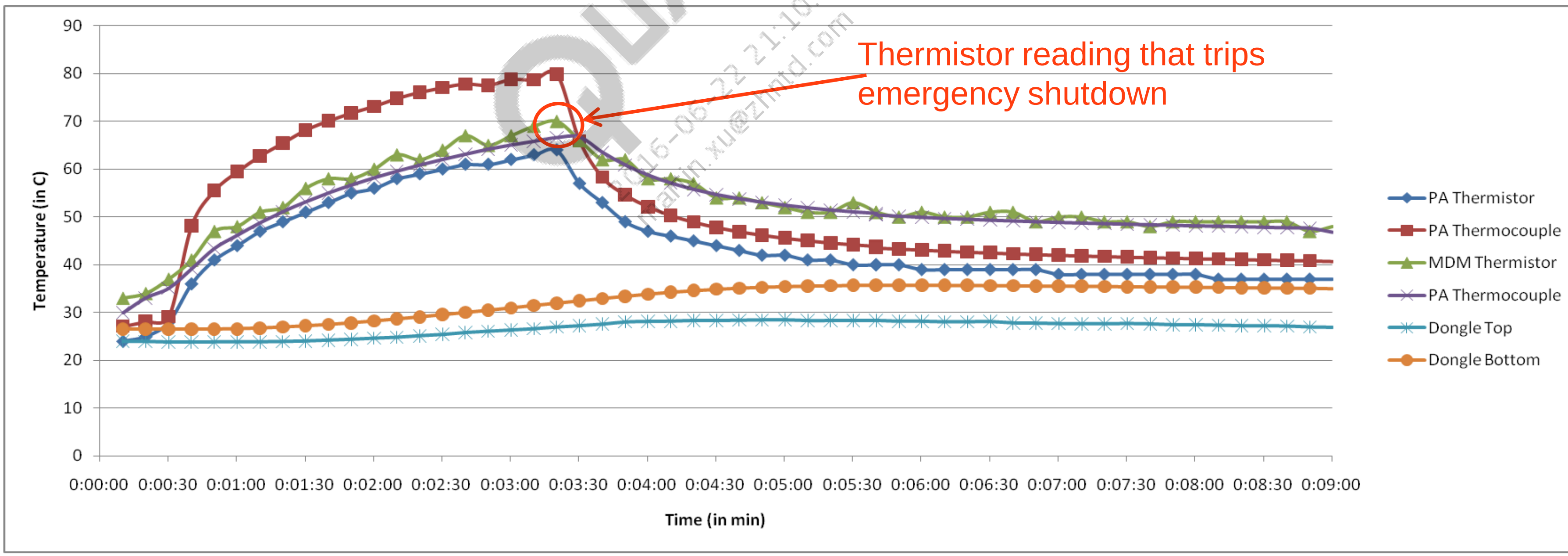
- DL throughput stays constant at 7.2 Mbps





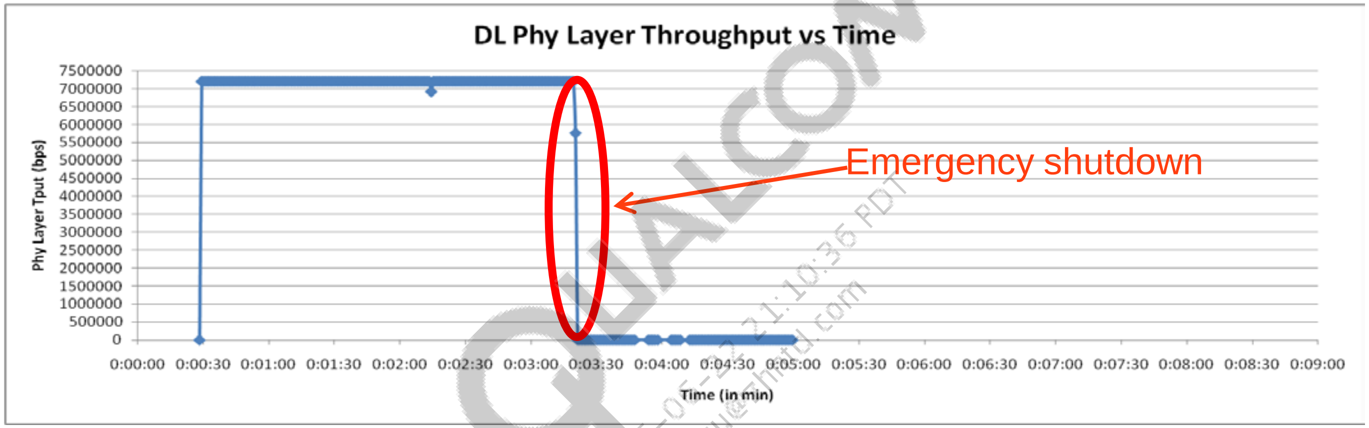
Test 2 – Example of Emergency Shutdown

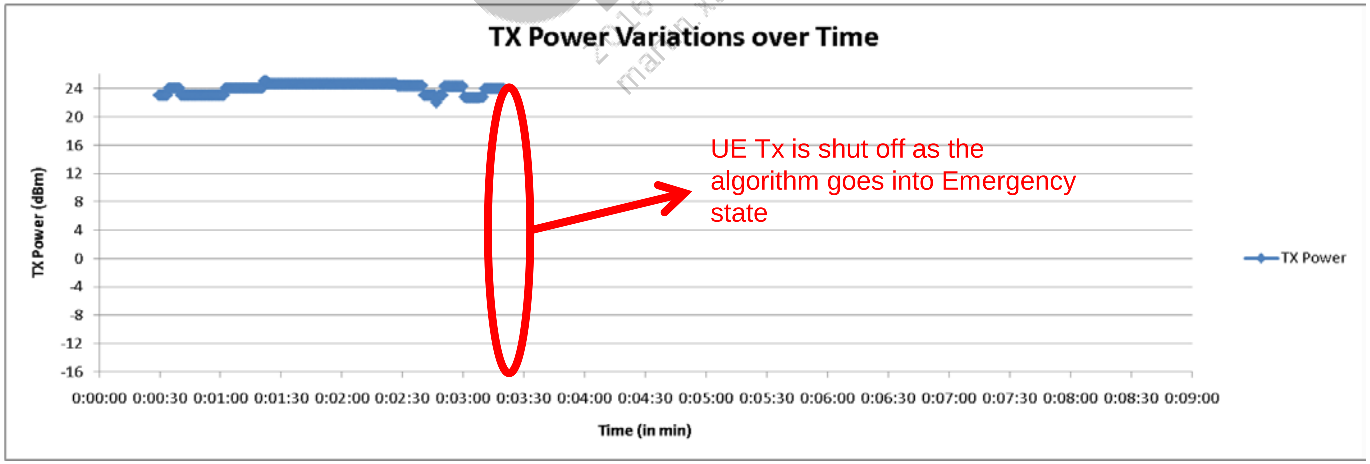
- The thermal mitigation algorithm is activated
  - Threshold settings for MDM and PA thermistors – Mitigation state 65°C, emergency state 70°C
- Threshold values were set artificially low to demonstrate shutdown



Test 2 – Example of Emergency Shutdown (DL Tput and Tx Power vs. Time)

- Mbps until the emergency state is reached. Thereafter, the UE Tx shuts off; the result is that the DL throughput stays at 7.2 g



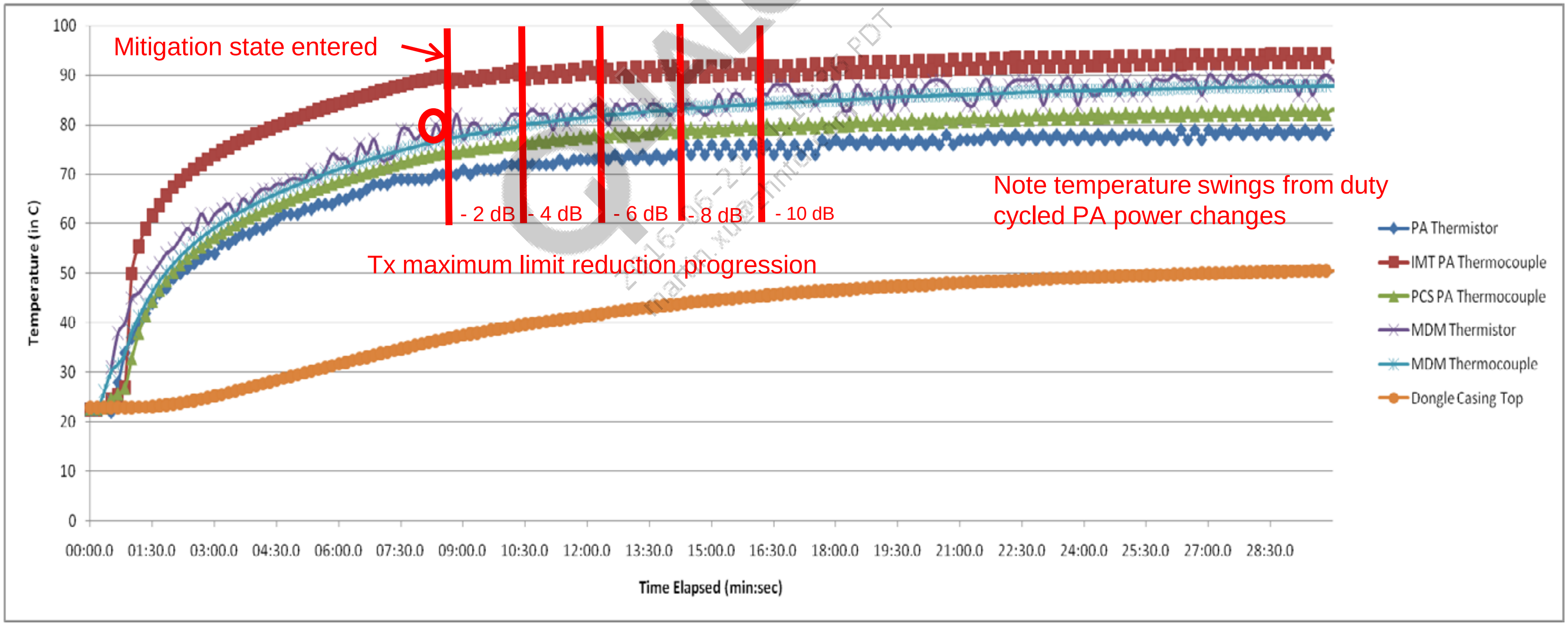


Test 3 – Detailed Parameters

- The settings listed below helped enable component protection while maintaining the user experience for the Qualcomm USB dongle:
  - Tx power reduction step size: -2 dB
  - Duty cycle of Tx power change: 10 sec
  - Mitigation/emergency hysteresis: 5°C
  - PA mitigation threshold: 85°C
  - PA emergency threshold: 95°C
  - MDM mitigation threshold: 80°C
  - MDM emergency threshold: 98°C
- With the above parameters, the emergency state was never reached, even after 50 minutes. A smaller form factor may enter the emergency state.
  - Thresholds settings will be very sensitive to the form factor size
  - Thermistor placement within the device requires compensation
    - For example, the Qualcomm USB dongle has a constant offset of ~ 15°C between actual PA temperature and the PA thermistor temperature due to the distance between the two

Test 3 – Mitigation State (Temperature vs. Time Plot)

- The plot below demonstrates the mitigation state
- The mitigation state helps in prolonging the user experience by lowering the average power dissipation
- Maximum temperatures: PA = 95^{o}C; MDM = 89^{o}C; casing = 53^{o}C



GCF Compliance Testing

- The protection algorithm should not cause performance issues in GCF testing
- Take care to ensure that it does not interfere with test procedures adopted in some GCF test cases
  - Test procedures involving long sustained periods of high transmit power may activate the protection algorithm, depending on the form factor size
  - Example – TC 8.7.9 UE transmission power headroom of TS 34.121-1
- Test cases from 34.121-1 UE conformance specification that may be affected by the protection algorithm include:
  - The majority of the chapter 5 test cases
  - All the chapter 6 test cases
  - Some chapter 8 test cases (TC 8.7.3C, 8.7.3D, and 8.7.9)
- Software disables the protection algorithm if a GCF test SIM is inserted
  - MCC values should be in the range of 001 to 012
  - NV variables also allow for enabling/disabling the algorithm as mentioned
  - Contact Software Applications Engineering if you need help in this area

Supplementary Information – Chipset Power Consumption Basics

- PA
  - Dissipated power depends on Tx power, which depends on:
    - UL data rate
    - Distance from base station
    - Channel conditions
    - Network loading
  - When operating at the high end of the Tx power, it is the dominant source of heat dissipation
    - Example PA current draw:

UE transmit power	PA gain state	Current draw from PA
0 dBm Tx	Low	10 mA
10 dBm Tx	Mid	53 mA
23 dBm Tx	High	446 mA

Supplementary Information – Chipset Power Consumption Basics (cont.)

- MDM9600 example
  - Main factors for dissipated power include:
    - Modem processing mode, e.g., Rx diversity ON/OFF
    - DL and UL data rates

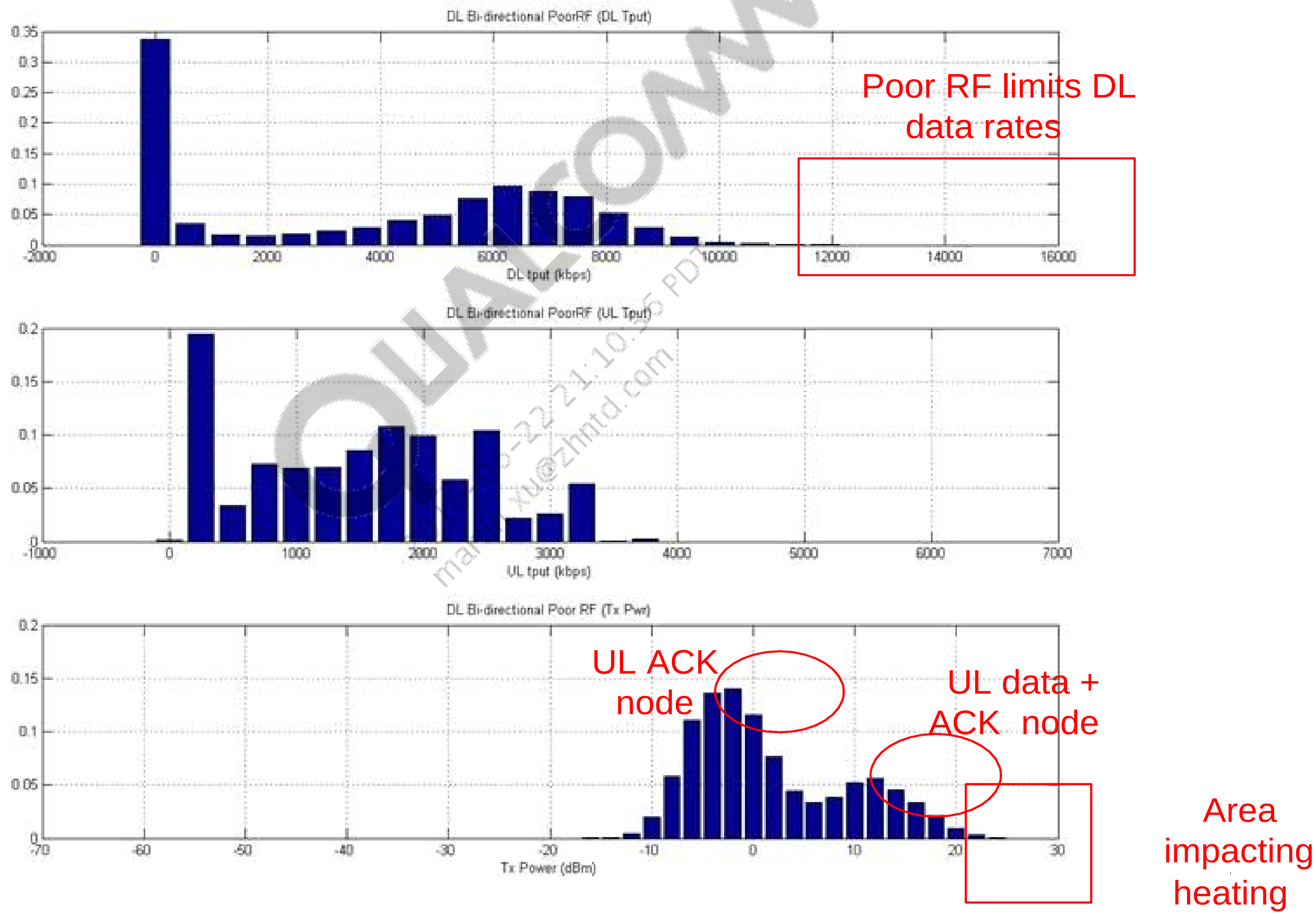
Mode of operation	Current draw from a 3.7 V battery (mA)	Assumptions
LTE 100/50 Mbps Cat 3	373	0 dBm Tx, 20 MHz bandwidth
LTE 50/25 Mbps Cat 2	321	0 dBm Tx, 10 MHz bandwidth
HSDPA 14.4 Mbps Cat 10	252	0 dBm Tx
LTE standby	1.0	DRx cycle of 2.56 sec
WCDMA standby	2.0	DRx cycle of 2.56 sec
GSM standby	1.7	DRx cycle of 1.15 sec
QPCH CDMA standby	1.8	Slot cycle of 5.12 sec

Note: The above projections are based on design simulations and are subject to change following actual device characterizations.

Supplementary Information – Comments on Typical Usage Scenario

- Worst case
  - Continuous high Tx power
  - Continuous high data rates
- Realistically
  - Probability of high Tx power is low
    - Field example on the next slide
  - Continuous high rate transfer is unlikely due to:
    - RF condition
    - Scheduling
    - User data transfer need (weak function of peak rate availability)
  - Mixture of active vs. idle states
    - High peak rate can reduce active time for same data transfer need
  - Large Tx power (cell edge) unlikely to happen with high data rates

Supplementary Information – Field Example – Poor RF DL/Bidirectional FTP Transfers



References

Ref.	Document	DCN
Q1	*Application Note: Software Glossary for Customers*	CL93-V3077-1
Q2	*Application Note: MDM9600 Thermal Protection Algorithm Details*	80-VP146-15
Q3	*Thermal Design Considerations Application Note*	80-VU794-5

Questions?

https://support.cdmatech.com