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RF VERIFICATION FOR THE NARROWBAND IOT CHIPSET

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Esa Kuusisto
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Opinnäytetyön pääasiallisena tavoitteena oli verifioida Mediatekin NB-IoT-piirisarjan RF-suorituskyky 3GPP-spesifikaatioiden mukaisesti. Toisena tavoitteena oli esitellä LPWAN-radioteknologioita ja vertailla eri teknologioita NB-IoT-teknologian näkökulmasta. Ensiksi luotiin yleiskatsaus eri IoT-radioihin, joista tarkemmin esiteltiin LPWAN-radioita. NB-IoT-radioteknologia esiteltiin vielä muita tarkemmin, koska tämän työn pääpaino oli siinä teknologiassa.

Ehkä kaikkein tärkeimmät tekijät massiivisessa IoT-kommunikoinnissa ovat pitkä kantama, pitkä akun kesto, alhainen hinta ja korkea verkon kapasiteetti. Eri LPWAN-radioteknologioita vertailtiin näiden tekijöiden pohjalta. Näihin kriteereihin perustuen NB-IoT osoittautui varteenotettavaksi LPWAN-radioteknologiavaihtoehdoksi.

Mediatekin näkemys on, että NB-IoT tulee olemaan tärkein radioteknologia IoT-alalla. Mediatekin kehittämä NB-IoT-piirisarja täyttää pienten ja kustannustehokkaiden IoT-laitteiden asettamat vaatimukset ja tukee 3GPP Release 14 laajennettua standardia.

Piirisarjan RF-verifiointi perustuu 3GPP-standardin asettamiin vaatimuksiin NB-IoT:n RF-suorituskyvylle. Päätelaitteen lähettimelle ja vastaanottimelle asetetut 3GPP-spesifikaatiovaatimuskohdat on esitetty yksityiskohtaisesti. Niiden perusteella on johdettu RF-mittauksissa käytetyt testirajat. RF-automaattimittausympäristö on esitelty, ja lopuksi saatujen testitulosten tila on listattu spesifikaatiokohtien mukaisesti.

Asiasanat: LPWAN, NB-IoT, MediaTek, 3GPP, RF-verifiointi

ABSTRACT

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The main objective of this bachelor’s thesis was to verify the RF performance of MediaTek’s NB-IoT chipset according to 3GPP specifications. The objective was also to introduce LPWAN radio technologies and compare different technologies from the NB-IoT point of view. An overview of different IoT radios was made with a deeper approach to LPWAN radios. The NB-IoT radio technology was introduced more precisely than other ones because the main focus was on NB-IoT in this thesis.

Maybe the most important factors for massive IoT communication devices are a long communication range, a long battery lifetime and a low cost and high network capacity. A comparison between different LPWAN radio technologies was made based on those factors. The NB-IoT proved to be considerable option according to these criterions set to the LPWAN radio technology.

MediaTek believes that NB-IoT will be a key radio technology in the IoT industry. MediaTek’s first NB-IoT chipset meets the requirements of cost efficiency and small IoT devices and supports 3GPP Release 14 enhanced standards.

The chipset RF verification is based on 3GPP standard requirements for the NB-IoT RF performance. 3GPP specification items for UE, both a transmitter and a receiver, are introduced in detail and RF measurement test limits are based on them. The RF automatic measurement environment is introduced and finally test result verdicts are listed according to specification items.

Keywords: LPWAN, NB-IoT, MediaTek, 3GPP, RF verification

PREFACE

This thesis was made in MediaTek Wireless Finland site during the spring season 2018. First of all, I would like to thank MediaTek's site manager Ville Salmi, who in the first place gave me the opportunity to do this thesis work.

I also thank my supervisors Asko Ruotsalainen and Jukka Väyrynen from MediaTek and lecturer Veijo Väisänen from OUAS. They all gave me a good guidance through the whole thesis making process. I would also like to thank lecturers Kaija Posio and Tuula Hopeavuori from OUAS. They guided me in grammatical concerns.

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Oulu, 17.5.2018
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TABLE OF CONTENTS

TIIVISTELMÄ 3

ABSTRACT 4

PREFACE 5

TABLE OF CONTENTS 6

ABBREVIATIONS 8

1 INTRODUCTION 11

2 RADIO TECHNOLOGIES FOR THE IOT 12

- 2.1 Licensed LPWAN radios 13
  - 2.1.1 NB-IoT 13
  - 2.1.2 LTE-M 17
  - 2.1.3 EC-GSM-IoT 18
- 2.2 Unlicensed LPWAN radios 19
  - 2.2.1 LoRa 19
  - 2.2.2 Sigfox 20

3 IOT RADIO TECHNOLOGIES SUMMARY AND MEDIATEK IOT SOLUTION 21

4 3GPP REQUIREMENTS FOR THE NB-IOT RF PERFORMANCE 25

- 4.1 Transmitter characteristics 27
  - 4.1.1 Maximum output power 27
  - 4.1.2 Maximum Power Reduction (MPR) 28
  - 4.1.3 Configured UE transmitted output power 29
  - 4.1.4 Minimum output power 29
  - 4.1.5 Transmit ON/OFF time mask 30
  - 4.1.6 NPRACH time mask 30
  - 4.1.7 Power control absolute power tolerance 31
  - 4.1.8 Power control relative power tolerance 32
  - 4.1.9 Aggregate power control tolerance 33
  - 4.1.10 Frequency error 33
  - 4.1.11 Error Vector Magnitude (EVM) 34
  - 4.1.12 Carrier leakage 34
  - 4.1.13 In-band emissions for non-allocated tone 35

        - 4.1.14 Occupied bandwidth 36
    - 4.2 Receiver characteristics 37
        - 4.2.1 Reference sensitivity level 37
        - 4.2.2 Maximum input level 38
        - 4.2.3 Adjacent Channel Selectivity (ACS) 38
        - 4.2.4 In-band blocking 39
- 5 RF MEASUREMENTS 41
    - 5.1 Measurement environment 41
    - 5.2 Automatic RF measurement system 46
    - 5.3 Measurement results 49
- 6 CONCLUSION 54
- REFERENCES 56
- APPENDICES 60

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5G	5th generation mobile networks
ACS	Adjacent Channel Selectivity
BPSK	Binary Phase Shift Keying, modulation scheme
BW	Bandwidth
D-BPSK	Differential Binary Phase Shift Keying, modulation scheme
dBm	Decibels referenced to milliwatts, unit of power
DL	Downlink
E-UTRA	Evolved Universal Terrestrial Radio Access, air interface of LTE
EARFCN	E-UTRA Absolute Radio Frequency Channel Number
eDRX	Enhanced Discontinuous Reception
eMTC	Enhanced Machine Type Communication, LTE-M
EVM	Error Vector Magnitude
F_{DL_low}	The lowest frequency of the downlink operating band
F_{DL_high}	The highest frequency of the downlink operating band
F_{UL_low}	The lowest frequency of the uplink operating band
F_{UL_high}	The highest frequency of the uplink operating band
FDD	Frequency Division Duplex
FM	Frequency Modulation, modulation scheme
GPRS	General Packet Radio Service

GSM	Global System for Mobile Communications, 2G
HARQ	Hybrid Automatic Repeat Request
Hz	Hertz, unit of frequency
IBB	In Band Blocking
IoT	Internet of Things
kbps	kilobits per second
LPWAN	Low Power Wide Area Networks
LTE	Long Term Evolution, 4G
LTE-M	Long Term Evolution for Machines
MCL	Maximum Coupling Loss
MCU	Microcontroller
MPR	Maximum Power Reduction
ms	millisecond
MTC	Machine Type Communications
N_{RB}	Transmission bandwidth configuration, expressed in units of resource blocks
N_{tone}	Transmission bandwidth configuration for category NB, expressed in units of tones.
$N_{tone\ 3.75kHz}$	Transmission bandwidth configuration for category NB with 3.75 kHz sub-carrier spacing, expressed in units of tones.
$N_{tone\ 15kHz}$	Transmission bandwidth configuration for category NB with 15 kHz sub-carrier spacing, expressed in units of tones.
NB-IoT	Narrowband IoT

NPRACH	Narrowband Physical Random Access Channel
OFDMA	Orthogonal Frequency Division Multiple Access
PMU	Power Management Unit
PRB	Physical Resource Block
PSM	Power Saving Mode
PSRAM	Pseudo Static Random Access Memory
QPSK	Quadrature Phase Shift Keying, modulation scheme
RF	Radio Frequency
RU	Resource Unit
RX	Receiver
SC	Subcarrier
SC-FDMA	Single Carrier Frequency Division Multiple Access
SoC	System on Chip
TS	Technical Specification
TX	Transmitter
UE	User Equipment, end-user device
UI	User Interface
UL	Uplink
UNB	Ultra Narrow Band
VoLTE	Voice over LTE

1 INTRODUCTION

The Internet of Things (IoT) has begun to become a reality, and by year 2020 billions of devices and services are forecasted to be connected to the Internet. Smart homes, smart cities, wearables, health care, agriculture, transportation, smart metering, industrial machines and automation are just a few examples of the different areas for applications that are driving the development of new business models. (1, p. 2.)

The Narrowband IoT (NB-IoT) is one of the radio access technologies that has been developed for this emerging demand of industry. NB-IoT is a Low Power Wide Area Network (LPWAN) technology which is standardized by the 3rd Generation Partnership Project (3GPP). 3GPP is a mobile communications industry collaboration that organises and manages the standards and development of mobile communications standards from GSM to LTE and 5G (2).

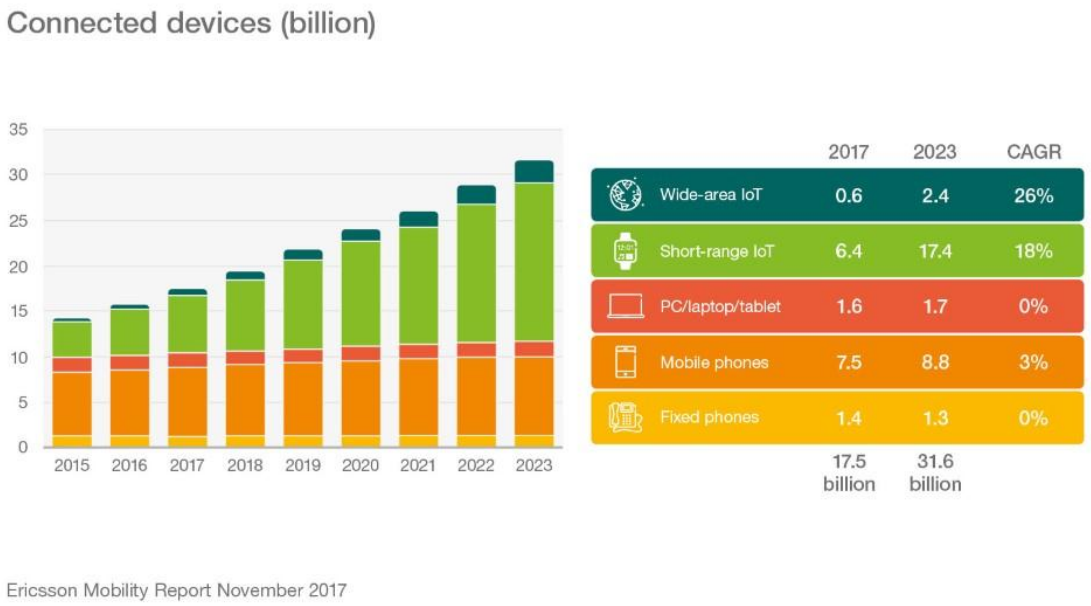
Also, other LPWAN radio technologies are developed for IoT communications. LTE-M and EC-GSM-IoT are the other 3GPP standardized IoT radios and for instance, LoRa and Sigfox are operating on unlicensed frequency bands.

The aim of this thesis was to introduce and compare LPWAN IoT radio technologies. It also aimed to verify the RF performance of the first Mediatek’s NB-IoT chipset. MediaTek is a global fabless semiconductor company which enables more than 1.5 billion consumer products a year. MediaTek is one of the market leaders in developing a tightly integrated, power efficient systems-on-chip (SoC) for mobile devices, home entertainment, network and connectivity, automated driving, and the IoT. (3.)

The RF verification was made by using appropriate measurement equipment to fulfil 3GPP requirements for the RF performance.

2 RADIO TECHNOLOGIES FOR THE IOT

Over 31 billion devices are forecasted to be connected to the Internet by 2023. Around 20 billion of them will be related to the IoT. IoT is divided into short range and wide area segments as can be seen in Figure 1. The short range segment mainly consists of devices connected by unlicensed radio technologies, with a typical range of up to a hundred meters, such as Wi-Fi and Bluetooth. The devices connected over powerline technologies and fixed-line local area networks belong also to this category. NB-IoT, as well other LPWAN radios, belongs to the wide area segment. (4.)



Ericsson Mobility Report November 2017

FIGURE 1. Forecast of connected devices to the Internet. (4)

In this thesis the focus is on NB-IoT and because of that, some major LPWAN radio technologies are presented in this context. Short range radios are not discussed in detail in this thesis although they form the largest part of all radios in the IoT market (Figure 1). IoT radios according to a range are presented in Figure 2.

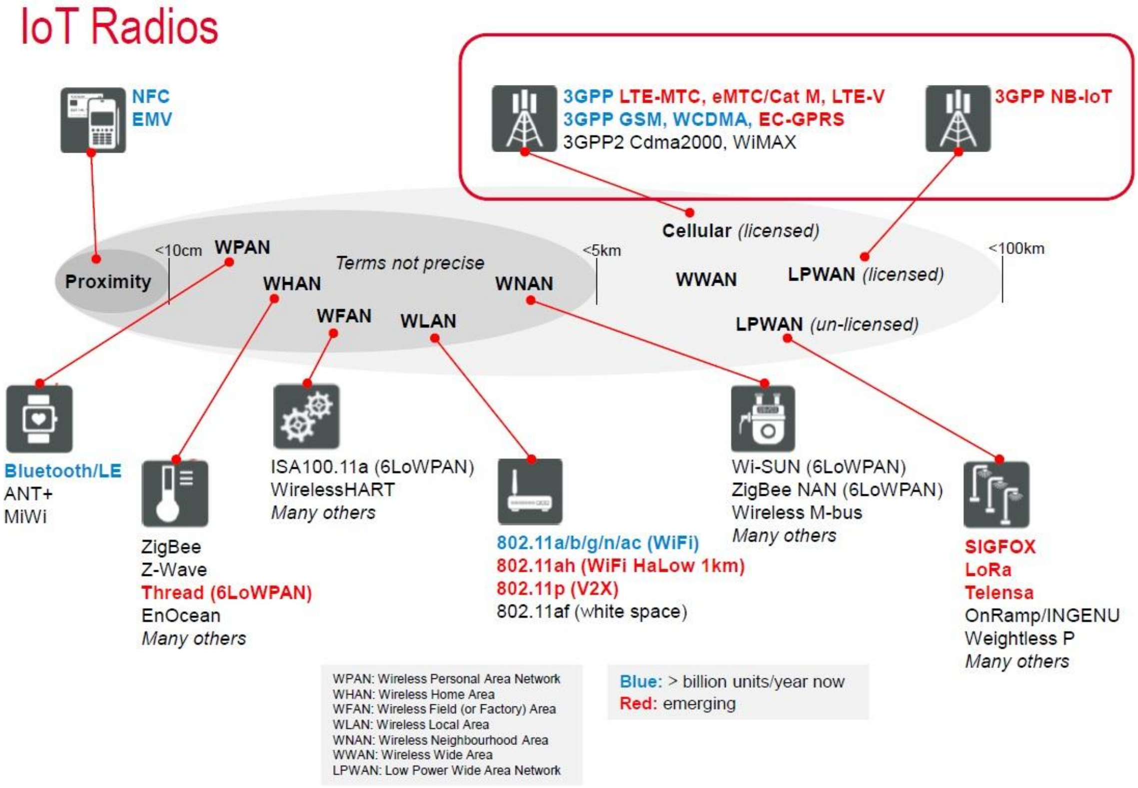


FIGURE 2. IoT radios (5, p. 11)

2.1 Licensed LPWAN radios

2.1.1 NB-IoT

NB-IoT, as well as other LPWAN radio technologies, is developed for machine type communication (MTC). The targets for NB-IoT are a low device cost, an extended coverage, a long battery life and a high network capacity with low data rates. The design targets for NB-IoT are illustrated in Figure 3.

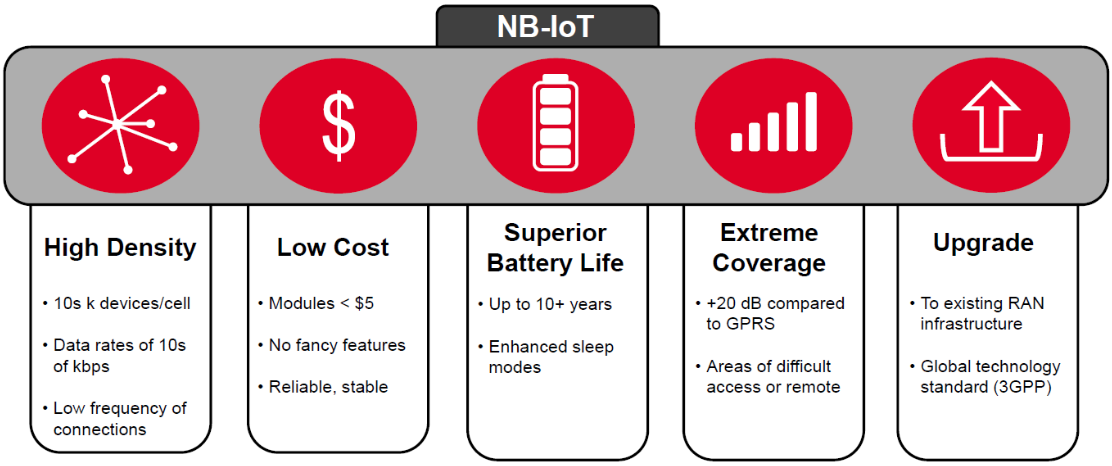


FIGURE 3. NB-IoT design targets (6, p. 10)

From the network point of view NB-IoT deployment could be made in 3 different ways. The NB-IoT may be deployed using any available spectral bandwidth larger than 180 kHz, which is the channel bandwidth of NB-IoT. In standalone mode, NB-IoT is planned to re-use existing GSM frequency bands. A guard-band uses the unused resource blocks within an LTE carrier's guard-band with a guaranteed co-existence. An in-band is the optimal approach for LTE operators, as it has the most efficient spectrum utilization and it is a lower cost approach to support NB-IoT in existing LTE carriers. In this case, the NB-IoT carrier is embedded in the LTE signal by replacing one of the available LTE Physical Resource Blocks (PRB) without causing any disturbance in the LTE operation. (1, p. 6.) Three different NB-IoT deployment options are described in Figure 4.

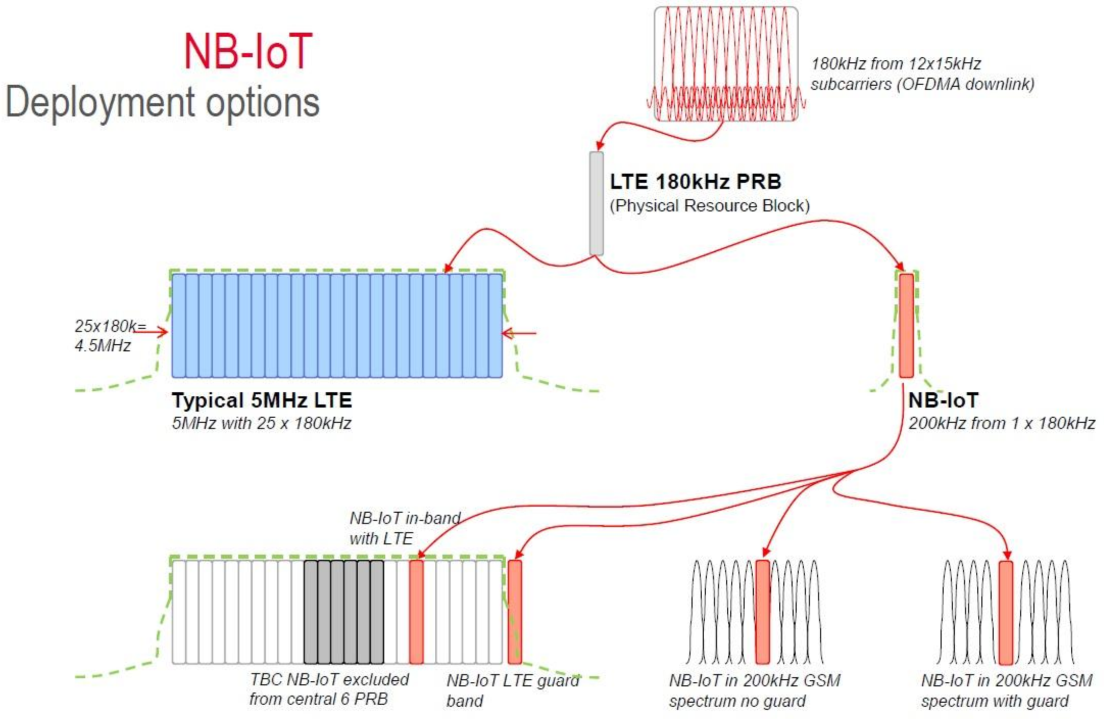


FIGURE 4. Network deployment options for NB-IoT (7, p. 16)

NB-IoT is operating in FDD (Frequency Division Duplex) half duplex mode. That means that the transmitter (TX) and receiver (RX) frequency are separated by a certain frequency offset and they operate in different time slots. The offset between TX and RX frequencies is called a duplex spacing or duplex distance.

NB-IoT uses many of the same techniques as LTE. Orthogonal frequency division multiple access (OFDMA) is in use for a downlink (UE RX) and single carrier frequency division multiple access (SC-FDMA) for an uplink (UE TX). Rate matching, channel coding and interleaving for instance, are inherited from LTE. (8, p. 1.)

In the downlink NB-IoT uses 12 pieces of 15 kHz subcarriers (SC) for a total of 180 kHz which is equivalent to LTE PRB. But in the uplink the case is different. In the uplink there are two different subcarrier spacing modes, 15 kHz and 3.75 kHz. The 15 kHz subcarrier slot duration is 0.5 ms and 3.75 kHz 2 ms. The 15 kHz case is the same as in LTE. (1, p. 10.) The NB-IoT uplink frame structure is illustrated in Figure 5.

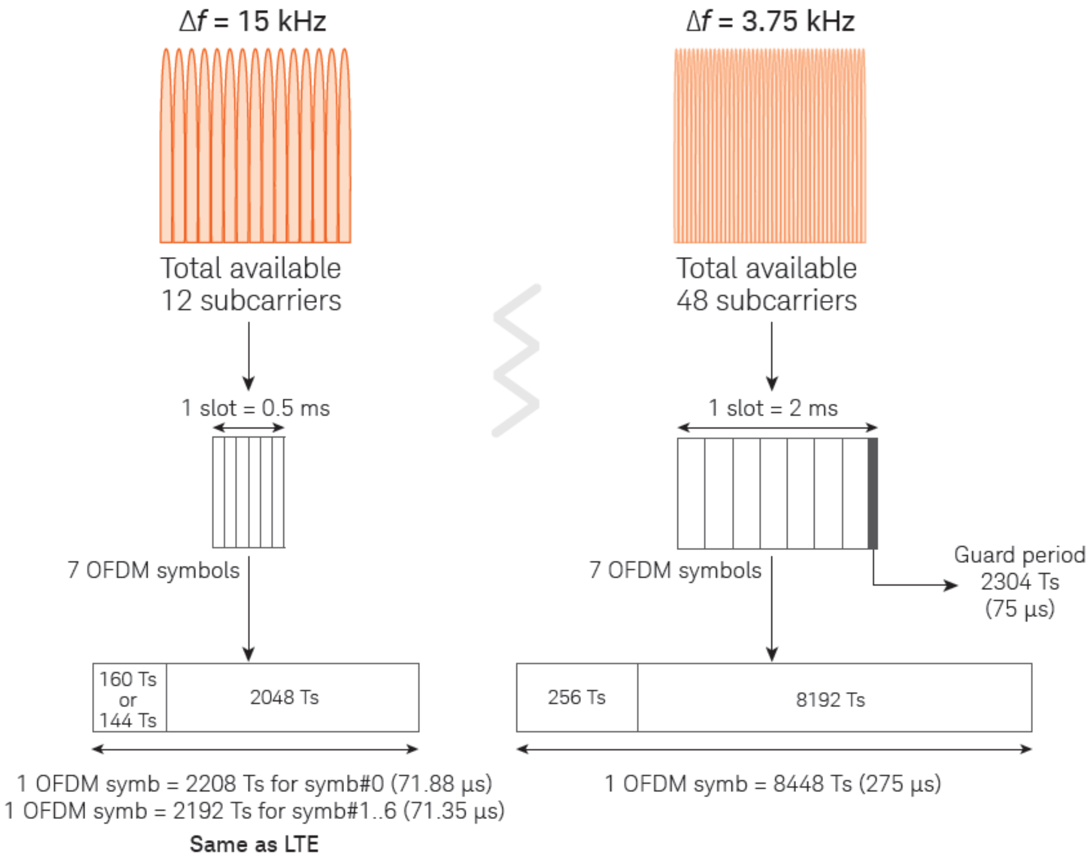


FIGURE 5. NB-IoT uplink frame structure (1, p. 10)

There are also 2 different transmission modes in NB-IoT, a single tone and a multi tone. The single-tone transmission is supported in both 3,75 and 15 kHz subcarrier spacing modes and only one subcarrier can be used. Multi tone transmissions are supported only in 15 kHz mode with 3, 6 or 12 subcarriers. Modulation schemes for the single tone transmission are $\pi/2$-BPSK or $\pi/4$-QPSK and for the multi tone QPSK. (7, p. 32.) Different resource units with various subcarriers for NB-IoT are described in Figure 6.

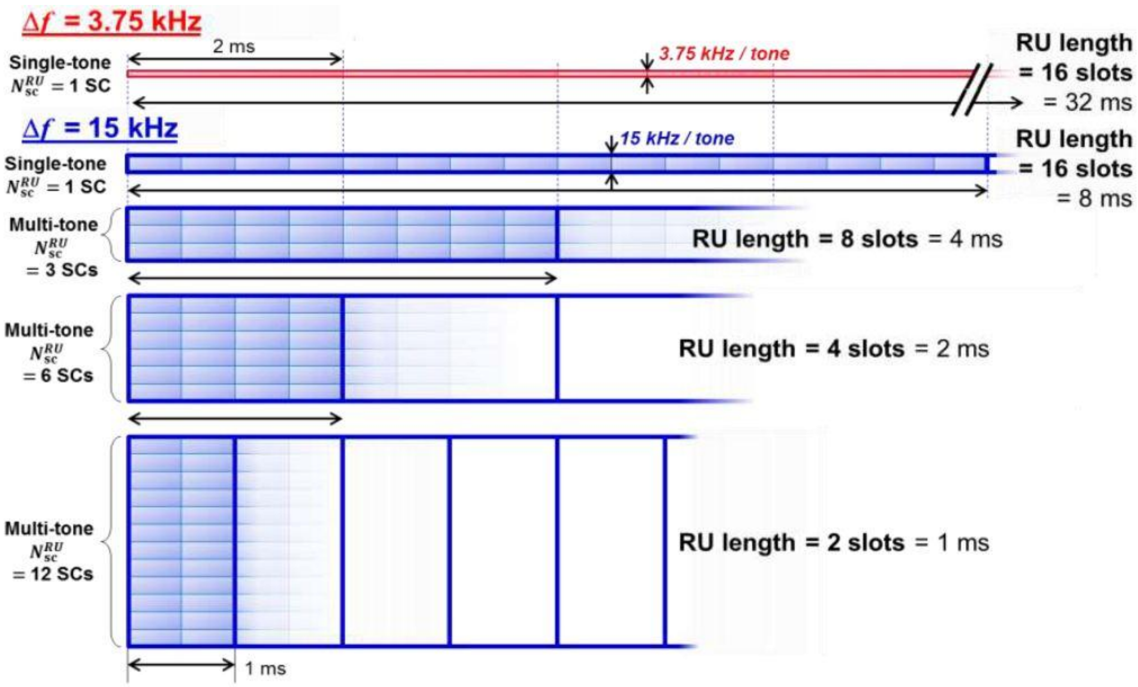


FIGURE 6. NB-IoT uplink resource units (7, p. 33)

2.1.2 LTE-M

LTE-M (Long Term Evaluation for Machines) or LTE Cat M, is another IoT radio technology standardized by 3GPP. As the name says, it is also utilizing the LTE technology. It is also called eMTC (Enhanced Machine Type Communication) in some literature. The channel bandwidth of the LTE-M is 1.4 MHz, equivalent to 6 LTE PRBs (7, p. 17). LTE-M has quite similar design targets as NB-IoT (Figure 3). The biggest differences compared to NB-IoT consist of support of voice functionality via VoLTE (Voice over LTE), full mobility and a higher data rate due to a larger bandwidth (9). The key features of LTE-M are illustrated in Figure 7.

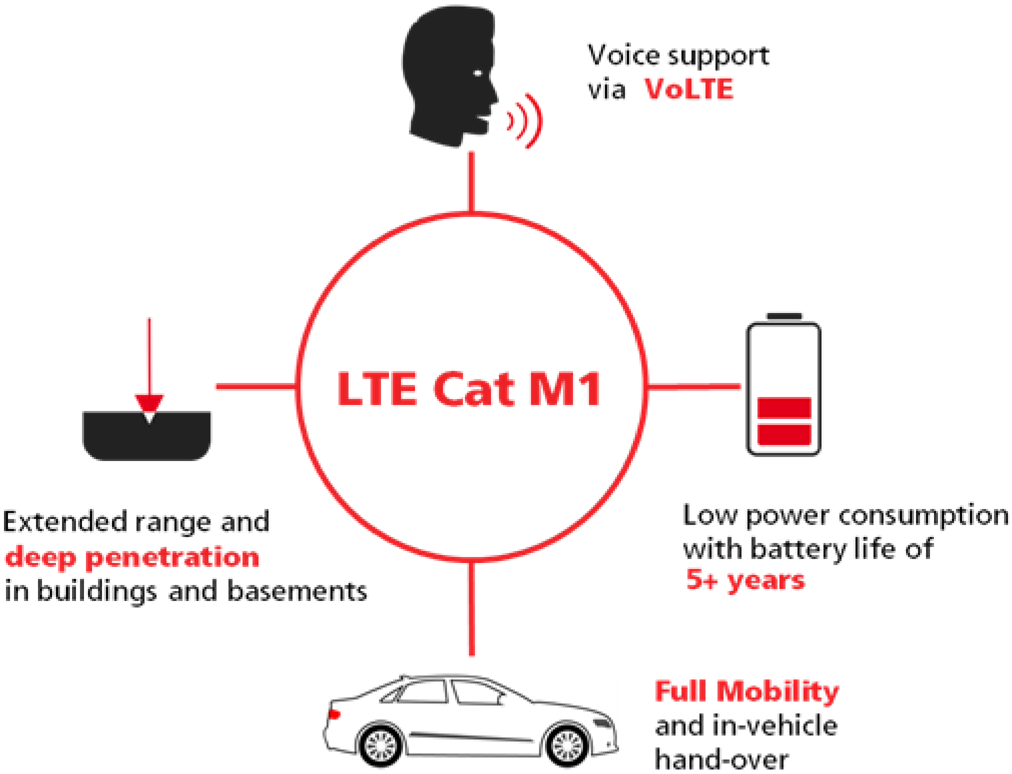


FIGURE 7. Key features of LTE-M (9)

2.1.3 EC-GSM-IoT

The extended coverage GSM IoT (EC-GSM-IoT) is based on the EGPRS (Enhanced GPRS) standard. Changes needed by EC-GSM-IoT can be implemented as a software upgrade to existing GSM networks. It has the same design targets as NB-IoT and LTE-M for IoT communications. EC-GSM-IoT networks will co-exist with 2G, 3G, and 4G mobile networks, but it can only use existing GSM frequency bands (850-900/1800-1900 MHz). Channel bandwidth is 200 kHz, the same as in GSM and NB-IoT. It will also benefit from all the security and privacy mobile network features, such as support for user identity confidentiality, entity authentication, confidentiality, data integrity, and mobile equipment identification. (10.)

2.2 Unlicensed LPWAN radios

Unlicensed LPWAN radios have similar targets for IoT communications as 3GPP radio standards. A long communication range, a battery lifetime, low cost of end-devices and high network capacity are the most important factors. In this thesis two most significant unlicensed technologies in the IoT market, LoRa and Sigfox, are presented.

2.2.1 LoRa

The LoRa technology and LoRaWAN protocol development are managed by LoRa Alliance, which was founded in 2015. Lora Alliance has hundreds of members including technology companies, such as IBM, Cisco, HP, Foxconn and Semtech. (11.) Also, some of the largest mobile network operators belong to alliance members, for instance Orange and SK Telecom. Digita is offering the LoRaWAN network in Finland (12). Figure 8 shows the LoRaWAN global network coverage in February 2018.

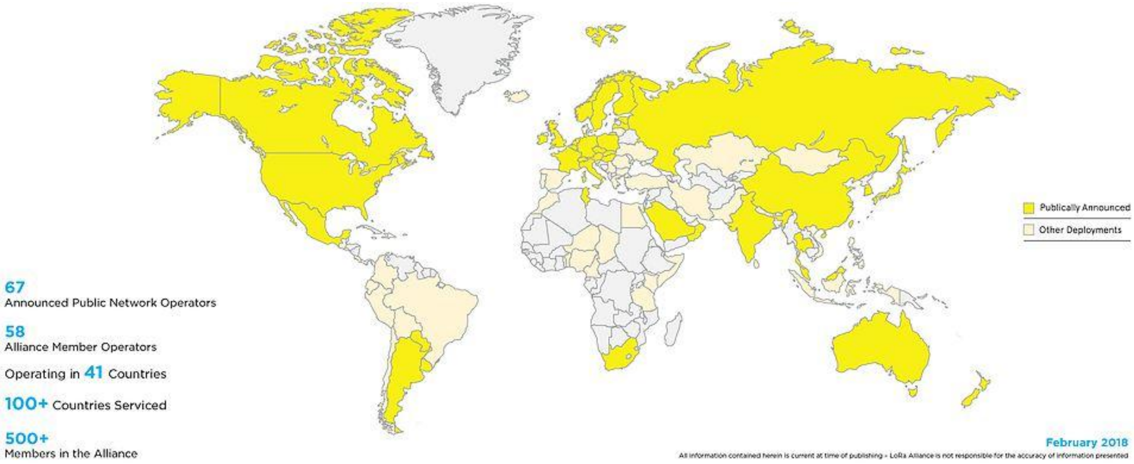


FIGURE 8. LoraWAN networks (13)

LoRaWAN operates below 1-GHz-frequency bands, for instance in Europe 868-MHz band and in North America 915-MHz band. Typical channel bandwidth values are 125, 250 and 500 kHz on those bands. (14, p. 3.) The LoRa technology uses a spread spectrum technology and chirped FM modulation (15, p. 5).

2.2.2 Sigfox

Sigfox was founded in France in 2009 and has its own LPWAN radio technology. Sigfox is deployed in 36 countries and it has a coverage of 803 million people in their networks globally. Connected Finland is a Sigfox operator in Finland and their network covers 85% of the Finnish population. (16.) Sigfox global networks are illustrated in Figure 9.

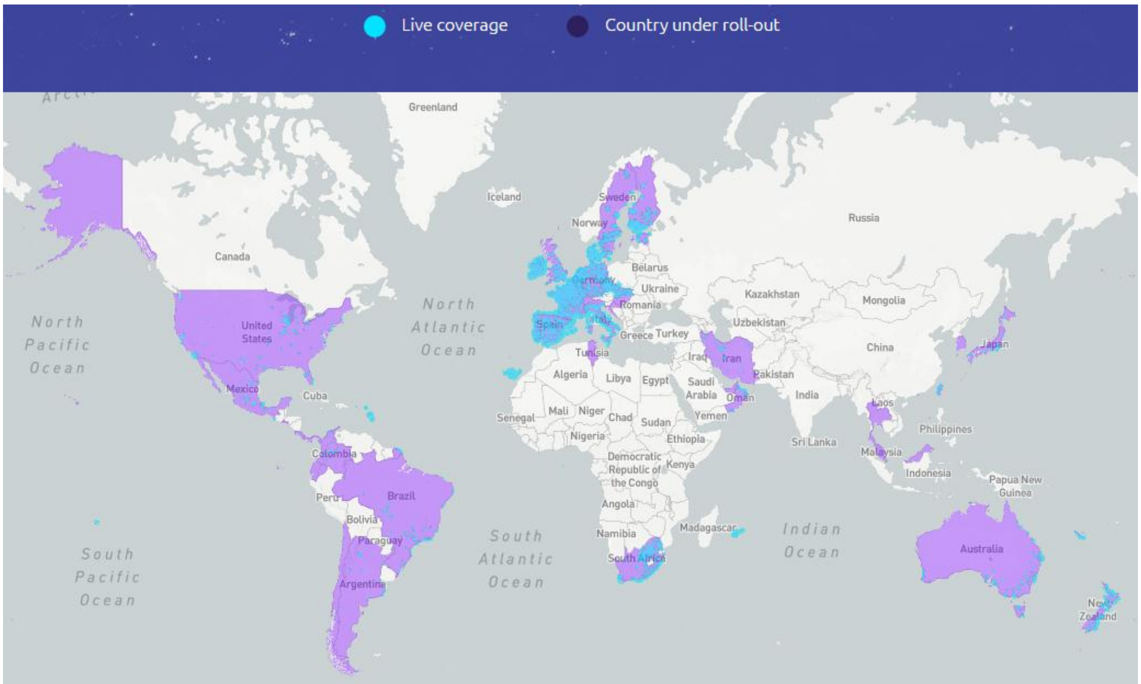


FIGURE 9. Sigfox networks (17)

Sigfox uses the Ultra Narrow Band (UNB) technology. The channel bandwidth of Sigfox is only 100 Hz and it uses the D-BPSK (Differential binary phase shift keying) and GFSK (Gaussian frequency shift keying) modulation. (18.) It operates worldwide in frequency bands from 862 to 928 MHz. (Europe 862 - 876 MHZ and Americas 902 – 928 MHz) (19).

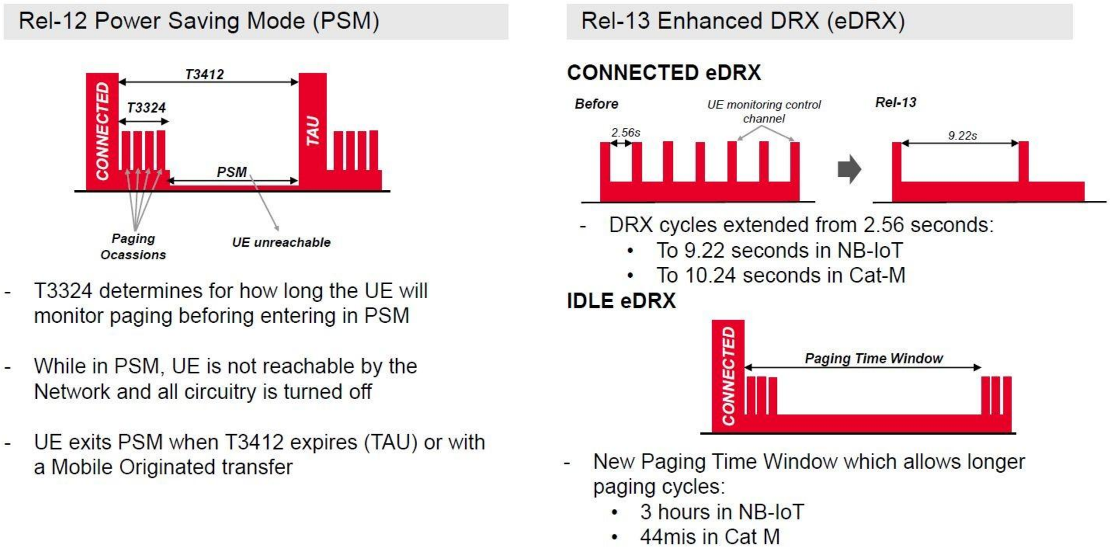
3 IOT RADIO TECHNOLOGIES SUMMARY AND MEDIATEK IOT SOLUTION

The comparison between different IoT radio technologies is made based on most significant requirements that are demanded by massive IoT communications. A long communication range, a long battery lifetime, a low cost of end-devices and a high network capacity are the key factors for IoT devices.

An operating range could be expressed as a Maximum Coupling Loss (MCL) or a link budget. They both mean the same and describe how much a transmitted signal could be attenuated over the air interface in dBs so that the signal could be still detected by the receiver. The bigger the MCL value, the longer the operating range. NB-IoT together with EC-GSM-IoT have the best MCL value (Table 1).

A battery lifetime is inversely proportional to the power consumption of the device. A transmitter output power is typically the most critical parameter that affects to power consumption. In LPWAN radios, the case is not so simple. They are supposed to transmit only very short bursts at a time and a quite small amount of data. Moreover, they are meant to be in deep sleep mode for most of the time. Thus, sleep mode current consumption is even more critical for LPWAN radios than active state power consumption.

3GPP has been specified PSM (Power Saving Mode) and eDRX (Enhanced Discontinuous Reception) for NB-IoT and LTE-M, as illustrated in Figure 10. The maximum duration of PSM could be as long as 12.1 days (7. p, 22). These specifications are made to get an extended duration of sleep modes and in that way to get battery lifetimes longer in IoT devices. NB-IoT has one of the lowest power consumption of LPWAN technologies (Table 1).



- T3324 determines for how long the UE will monitor paging beforing entering in PSM
- While in PSM, UE is not reachable by the Network and all circuitry is turned off
- UE exits PSM when T3412 expires (TAU) or with a Mobile Originated transfer

- DRX cycles extended from 2.56 seconds:
  - To 9.22 seconds in NB-IoT
  - To 10.24 seconds in Cat-M

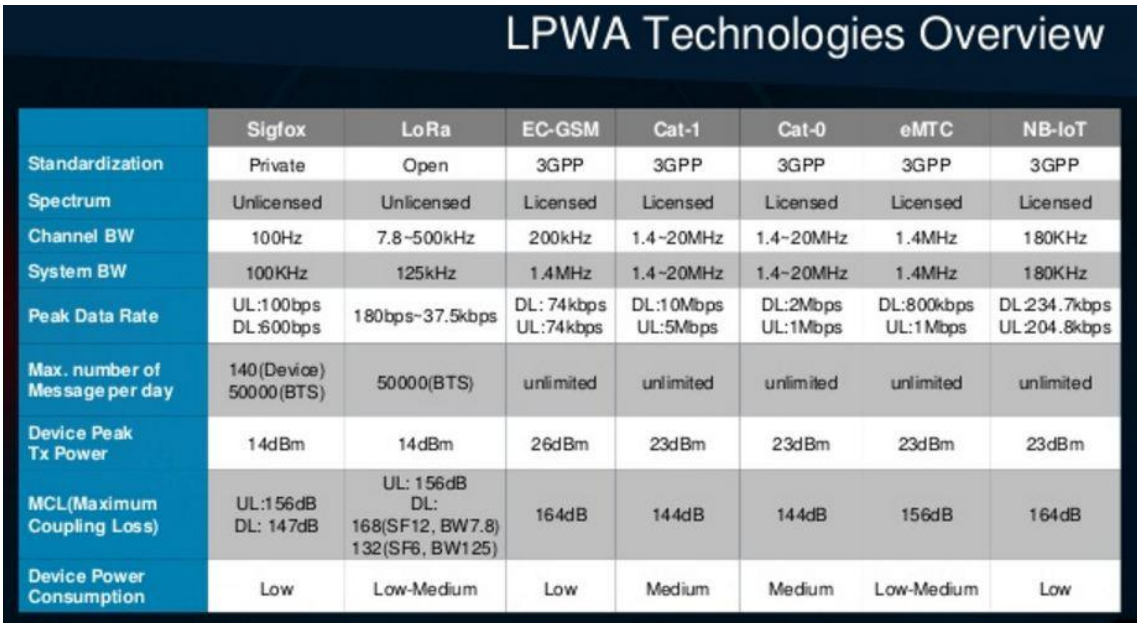
- New Paging Time Window which allows longer paging cycles:
  - 3 hours in NB-IoT
  - 44mis in Cat M

FIGURE 10. Power saving mode and eDRX for NB-IoT and LTE Cat M (7. p, 25)

The support of the massive number of devices is one of the key features of Sigfox, LoRa, and NB-IoT. These technologies work well with the increasing number and density of connected devices. Several techniques are considered to cope with this scalability feature, such as the efficient exploitation of diversity in a channel, as well as in time and space. However, NB-IoT offers the advantage of a very high scalability compared to Sigfox and LoRa. NB-IoT allows a connectivity of up to 100,000 end devices per cell compared to 50,000 per cell for Sigfox and LoRa. (20.)

An NB-IoT end device is operating in half duplex mode, which means that it is not transmitting and receiving simultaneously. Therefore, expensive duplex filters could be avoided at the RF hardware front end design. Also, receiver blocking requirements are not as tight as for instance in a GSM system. This enables to leave out also band filters of the receiver. Typically, only one receiver path is used unlike in an LTE mobile where there is an additional diversity receiver path. Even an integrated on-chip power amplifier on the transmitter path could be considered. These facts make it possible to decrease costs. (21.)

TABLE1. LPWAN technologies overview (22, p. 24)



LPWA Technologies Overview

	Sigfox	LoRa	EC-GSM	Cat-1	Cat-0	eMTC	NB-IoT
Standardization	Private	Open	3GPP	3GPP	3GPP	3GPP	3GPP
Spectrum	Unlicensed	Unlicensed	Licensed	Licensed	Licensed	Licensed	Licensed
Channel BW	100Hz	7.8~500kHz	200kHz	1.4~20MHz	1.4~20MHz	1.4MHz	180KHz
System BW	100KHz	125kHz	1.4MHz	1.4~20MHz	1.4~20MHz	1.4MHz	180KHz
Peak Data Rate	UL:100bps DL:600bps	180bps~37.5kbps	DL: 74kbps UL:74kbps	DL:10Mbps UL:5Mbps	DL:2Mbps UL:1Mbps	DL:800kbps UL:1Mbps	DL:234.7kbps UL:204.8kbps
Max. number of Message per day	140(Device) 50000(BTS)	50000(BTS)	unlimited	unlimited	unlimited	unlimited	unlimited
Device Peak Tx Power	14dBm	14dBm	26dBm	23dBm	23dBm	23dBm	23dBm
MCL(Maximum Coupling Loss)	UL:156dB DL: 147dB	UL: 156dB DL: 168(SF12, BW7.8) 132(SF6, BW125)	164dB	144dB	144dB	156dB	164dB
Device Power Consumption	Low	Low-Medium	Low	Medium	Medium	Low-Medium	Low

MT2625 is MediaTek's first NB-IoT chipset built to meet the requirements of cost efficiency and small IoT devices. The highly integrated MT2625 combines an ARM Cortex-M microcontroller (MCU), a pseudo-static RAM (PSRAM), a flash memory and a power management unit (PMU) into a small package to lower the production costs while also speeding up time-to-market. The chip leverages MediaTek's advanced power consumption technology to enable IoT devices to work with chargeable batteries for years. MT2625 supports a full frequency band, from 450 MHz to 2.1GHz, of 3GPP Release 13 (NB1) and Release 14 (NB2) standards for a wide range of IoT applications. (23.)

The uplink and downlink peak rates of the Release 13 standard can no longer meet the increasing demand for more and more IoT applications on the market. The NB-IoT Release 14 (NB2) specification can achieve over 100-kbps (kilobits per second) uplink and downlink peak data rates by using larger transport blocks and the 2 HARQ process. Moreover, the NB-IoT Release 14 has also been enhanced in terms of mobility, positioning, multicasting, and multi-carrier technologies to further provide better standards and technical support for the development of the IoT in a mature industry. MediaTek believes that NB-IoT will be a key radio technology in the IoT era. MediaTek’s IoT solution includes only the NB-IoT radio. It is also fully Release 14 compliant solution. (24.)

4 3GPP REQUIREMENTS FOR THE NB-IOT RF PERFORMANCE

The NB-IoT, or a UE category NB as it is defined in 3GPP, standardization work was started in the 3GPP Release 13 in 2015 and it was completed in June 2016 and it has still continued in the Release 14 (25). In this chapter some of the 3GPP Release 14, TS 36.101 V14.6.0 (26) and TS 36.521-1 V14.5.0 (27), specifications categories NB1 and NB2 UE (User Equipment), are introduced. Only those RF specification items are presented that are needed in the RF measurement part in chapter 5. The specification TS 36.101 establishes the minimum RF performance requirements and TS 36.521-1 specifies the measurement procedures for the conformance tests of the UE. TS 36.521-1 also takes measurement uncertainties and tolerances into account in performance requirements giving some relief to the test limits specified in TS 36.101.

NB-IoT operating bands are on the same frequencies as LTE bands, and NB-IoT operates in half duplex FDD mode. NB-IoT has a global network coverage due to the LTE coverage. (28.) Table 2 shows the frequency bands and corresponding uplink and downlink frequencies.

TABLE 2. Operating bands for UE (26, p. 40, 53)

E-UTRA Operating Band	**Uplink (UL) operating band BS receive UE transmit**			**Downlink (DL) operating band BS transmit UE receive**			**Duplex Mode**
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
11	1427.9 MHz	–	1447.9MHz	1475.9MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9MHz	–	1510.9 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz	FDD
70	1695 MHz	–	1710 MHz	1995 MHz	–	2020 MHz	FDD

Channel bandwidth is 200 kHz. Requirements are specified for the channel bandwidth listed in Table 3.

TABLE 3. Transmission bandwidth configuration N_{RB}, $N_{tone\ 15kHz}$ and $N_{tone\ 3.75kHz}$ in NB channel bandwidth (26, p. 108)

Channel bandwidth $BW_{Channel}$ [kHz]	**200**
Transmission bandwidth configuration N_{RB}	1
Transmission bandwidth configuration $N_{tone\ 15kHz}$	12
Transmission bandwidth configuration $N_{tone\ 3.75kHz}$	48

Figure 11 illustrates the relation between the channel bandwidth and the transmission bandwidth configuration (N_{tone}). The channel edges are defined as the lowest and highest frequencies of the carrier separated by the channel bandwidth. (26, p. 108.)

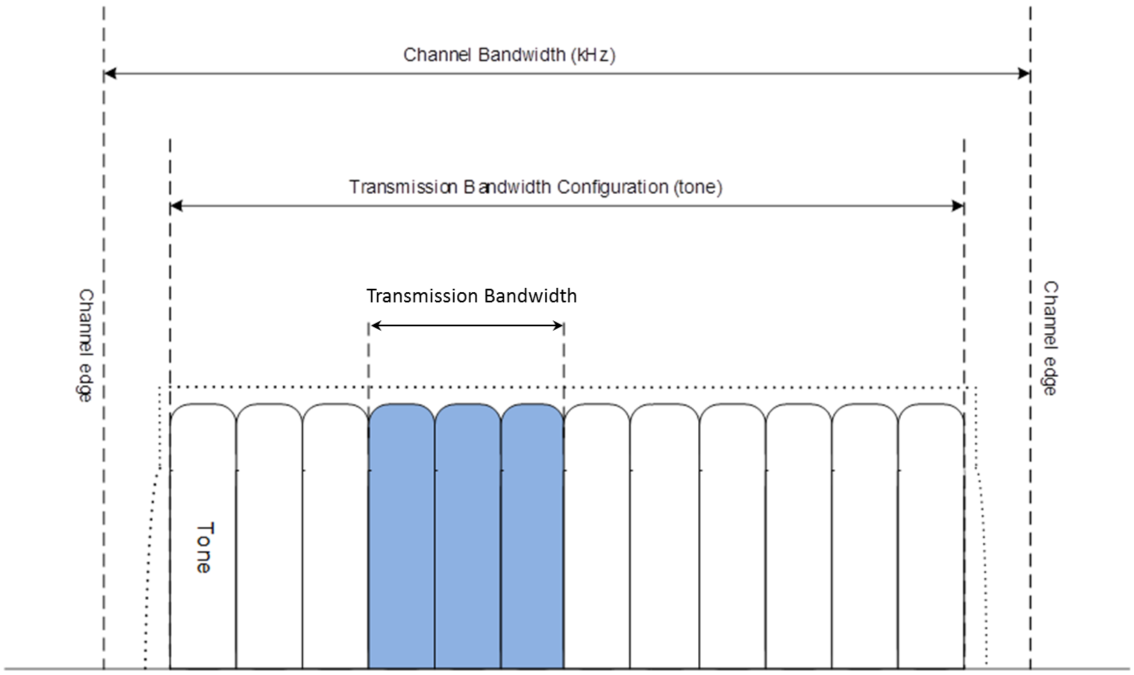


FIGURE 11. Definition of channel bandwidth and transmission bandwidth configuration (26, p. 109)

4.1 Transmitter characteristics

4.1.1 Maximum output power

UE could have 3 different power classes. It defines the maximum output power for any transmission bandwidth (26, p. 122). The maximum output power of the power class is the same on all supported bands, for instance 23 dBm in Class 3. (Table 4.)

TABLE 4. UE Power Class (26, p. 123)

EUTRA band	**Class 3 (dBm)**	**Tolerance (dB)**	**Class 5 (dBm)**	**Tolerance (dB)**	**Class 6 (dBm)**	**Tolerance (dB)**
1	23	±2	20	±2	14	±2.5
2	23	±2	20	±2	14	±2.5
3	23	±2	20	±2	14	±2.5
5	23	±2	20	±2	14	±2.5
8	23	±2	20	±2	14	±2.5
11	23	±2	20	±2	14	±2.5
12	23	±2	20	±2	14	±2.5
13	23	±2	20	±2	14	±2.5
17	23	±2	20	±2	14	±2.5
18	23	±2	20	±2	14	±2.5
19	23	±2	20	±2	14	±2.5
20	23	±2	20	±2	14	±2.5
21	23	±2	20	±2	14	±2.5
25	23	±2	20	±2	14	±2.5
26	23	±2	20	±2	14	±2.5
28	23	±2	20	±2	14	±2.5
31	23	±2	20	±2	14	±2.5
66	23	±2	20	±2	14	±2.5
70	23	±2	20	±2	14	±2.5

4.1.2 Maximum Power Reduction (MPR)

Maximum power reductions are allowed in multi tone transmission modes as specified in Table 5.

TABLE 5. Maximum Power Reduction (MPR) for Power Class 3 and 5 (26, p. 130)

Modulation	**QPSK**		
Tone positions for 3 Tones allocation	0-2	3-5 and 6-8	9-11
MPR	≤ 0.5 dB	0 dB	≤ 0.5 dB
Tone positions for 6 Tones allocation	0-5 and 6-11		
MPR	≤ 1 dB	≤ 1 dB	
Tone positions for 12 Tones allocation	0-11		
MPR	≤ 2 dB		

4.1.3 Configured UE transmitted output power

UE is allowed to set its configured maximum output power P_{CMAX} (26, p. 197). The P_{CMAX} tolerance as a function of the P_{CMAX} level is described in Table 6.

TABLE 6. P_{CMAX} tolerance for power class 3 (26, p. 197)

P_{CMAX} (dBm)	**Tolerance T(P_{CMAX}) (dB)**
$21 \le P_{CMAX} \le 23$	2.0
$20 \le P_{CMAX} < 21$	2.5
$19 \le P_{CMAX} < 20$	3.5
$18 \le P_{CMAX} < 19$	4.0
$13 \le P_{CMAX} < 18$	5.0
$8 \le P_{CMAX} < 13$	6.0
$-40 \le P_{CMAX} < 8$	7.0

4.1.4 Minimum output power

For both single and multi tone transmission, the minimum output power requirement is -40 dBm (26, p. 202).

4.1.5 Transmit ON/OFF time mask

The OFF power measurement period is defined in a duration of at least one sub-frame excluding any transient periods. The ON power is defined as the mean power over one sub-frame excluding any transient period. (26, p. 205.) The time mask for transmitting ON/OFF power defines the ramping time allowed for the UE between transmitting of the OFF power and transmitting of the ON power as illustrated in Figure 12 (27, p. 706).

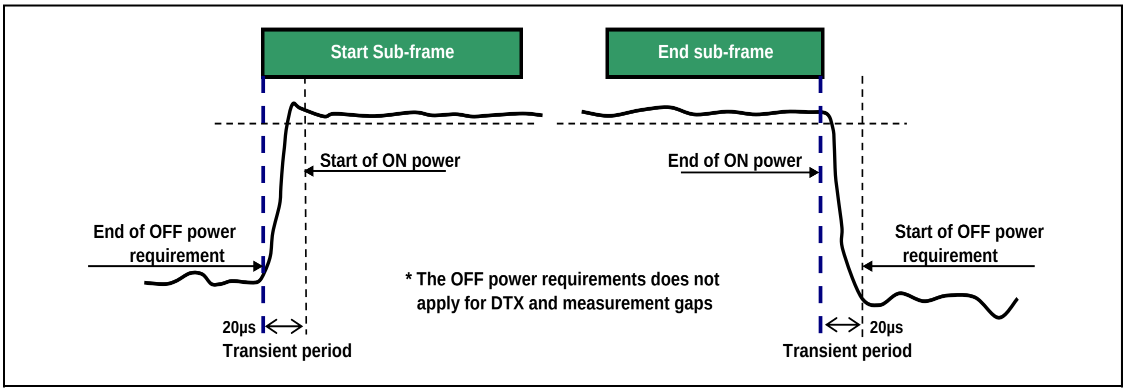


FIGURE 12. General ON/OFF time mask (26, p. 205)

4.1.6 NPRACH time mask

The NPRACH ON power is specified as the mean power over the NPRACH (Narrowband Physical Random Access Channel) measurement period excluding any transient periods as shown in Figure 13. The measurement period for a different NPRACH preamble format is specified in Table 7. (26, p. 213.)

TABLE 7. NPRACH ON power measurement period (26, p. 214)

NPRACH preamble format	Measurement period (ms)
0	5.6
1	6.4

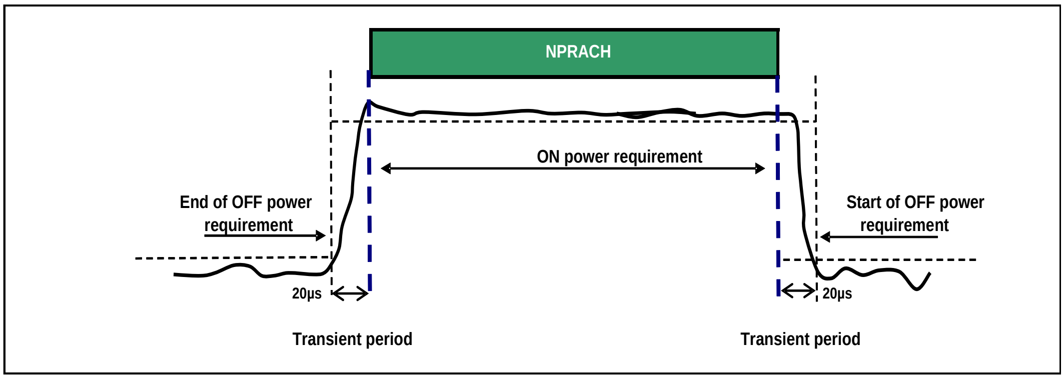


FIGURE 13. NPRACH ON/OFF time mask (26, p. 214)

4.1.7 Power control absolute power tolerance

An absolute power tolerance is the ability of the UE transmitter to set its initial output power to a specific value at the start of a contiguous transmission or non-contiguous transmission with a transmission gap larger than 20 ms. The minimum requirement for the absolute power tolerance is given in Table 8 over the power range bounded by the maximum and the minimum output power. (27, p. 899.)

TABLE 8. Absolute power tolerance (27, p. 899)

Conditions	**Tolerance**
Normal	± 9.0 dB
Extreme	± 12.0 dB

The requirement for the power measured should not exceed the values specified in Tables 9 and 10 (27, p. 902).

TABLE 9. Absolute power tolerance: test point 1 (27, p. 902)

	Channel bandwidth / expected output power (dBm)		
	Configuration ID 1 3.75 kHz (1 tone)	**Configuration ID 2 15 kHz (1 tone)**	**Configuration ID 3 15 kHz (12 tones)**
Expected Measured power Normal conditions	-25 dBm	-19 dBm	-8.2 dBm
Power tolerance f ≤ 3.0GHz	± 10.0dB	± 10.0dB	± 10.0dB
Expected Measured power Extreme conditions	-25 dBm	-19 dBm	-8.2 dBm
Power tolerance f ≤ 3.0GHz	± 13.0dB	± 13.0dB	± 13.0dB
Note 1: The lower power limit shall not exceed the minimum output power requirements			

TABLE 10. Absolute power tolerance: test point 2 (27, p. 902)

	Channel bandwidth / expected output power (dBm)		
	Configuration ID 1 3.75 kHz (1 tone)	**Configuration ID 2 15 kHz (1 tone)**	**Configuration ID 3 15 kHz (12 tones)**
Expected Measured power Normal conditions	-12 dBm	-6 dBm	4.8 dBm
Power tolerance f ≤ 3.0GHz	± 10.0dB	± 10.0dB	± 10.0dB
Expected Measured power Extreme conditions	-12 dBm	-6 dBm	4.8 dBm
Power tolerance f ≤ 3.0GHz	± 13.0dB	± 13.0dB	± 13.0dB
Note 1: The upper power limit shall not exceed the maximum output power requirements			

4.1.8 Power control relative power tolerance

The category NB UE relative power control requirement is defined for NPRACH power step values of 0, 2, 4 and 6 dB. For the NPRACH transmission, the relative tolerance is the ability of the UE transmitter to set its output power relatively to the power of the most recently transmitted preamble. The measurement period for the NPRACH preamble is specified in Table 7. (27, p. 903.)

The requirements specified in Table 11 apply when the power of the target and reference sub-frames are within the power range bounded by the minimum and the maximum output power (27, p. 903).

TABLE 11. Relative power tolerance for NPRACH transmission (27, p. 903)

Power step ΔP [dB]	**NPRACH [dB]**
ΔP = 0	±1.5
ΔP = 2	±2.0
ΔP = 4	±3.5
ΔP = 6	±4.0
NOTE: For extreme conditions an additional ± 2.0 dB relaxation is allowed.	

Each UE output power step measured should meet the test requirements specified in Table 12 (27, p. 905).

TABLE 12. Relative power tolerance NPRACH transmission (normal conditions – Note 1) (27, p. 905)

Expected power step size (up) ΔP [dB]	**NPRACH [dB]**
ΔP = 2	2 ± (2.7)
ΔP = 6	6 ± (4.7)
Note 1: For extreme conditions an additional ± 2.0 dB relaxation is allowed. Note 2: Only UE output power measurements within the range -39.3 to 20.3 dBm for Power Class 3, or -39.3 to 16.8 dBm for Power Class 5 shall be considered in the pass/fail criteria.	

4.1.9 Aggregate power control tolerance

The category NB aggregate power control tolerance is the ability of a UE to maintain its output power in non-contiguous transmission with respect to the first UE transmission. The UE must meet the requirements specified in Table 13 for the aggregate power control over the power range bounded by the minimum and the maximum output power. (26, p. 221.)

TABLE 13. Aggregate power control tolerance (26, p. 221)

UL channel	**Aggregate power tolerance**	
	15 kHz / 12 tones within 53 ms	**15 kHz / 1 tone within 104 ms**
NPUSCH	±3.5 dB	
NOTE: For five consecutive UE transmissions the transmission gaps are 12 ms for 12 tone and 16 ms for single tone transmissions.		

4.1.10 Frequency error

For the UE category NB, the UE modulated carrier frequency should be accurate within the limits specified in Table 14.

TABLE 14. Frequency error requirement (27, p. 936)

Carrier frequency [GHz]	**Frequency error [ppm]**
≤1	±0.2
>1	±0.1

The carrier frequency is observed over a period of one time slot and averaged over $72/L_{Ctone}$ slots, where $L_{Ctone} = \{1, 3, 6, 12\}$ is the number of sub-carriers used for the transmission. (27, p. 936.)

4.1.11 Error Vector Magnitude (EVM)

The Error Vector Magnitude (EVM) means the RMS average of the basic EVM measurements for $240/L_{Ctone}$ slots excluding any transient period for the average EVM case, where $L_{Ctone} = \{1, 3, 6, 12\}$ is the number of subcarriers for the transmission. Different modulation schemes should not exceed the values specified in Table 15 for the parameters defined in Table 16. For EVM evaluation purposes, both NPRACH formats are considered to have the same EVM requirement as the modulated QPSK. (27, p. 961.)

TABLE 15. Minimum requirements for Error Vector Magnitude (27, p. 961)

Parameter	Unit	Average EVM Level	Reference Signal EVM Level
BPSK or QPSK	%	17.5	17.5

TABLE 16. Parameters for Error Vector Magnitude (27, p. 961)

Parameter	Unit	Level
UE Output Power	dBm	≥ -40
Operating conditions		Normal conditions

4.1.12 Carrier leakage

A carrier leakage is an additive sinusoid waveform which has the same frequency as a modulated waveform carrier frequency. The measurement interval is one slot in the time domain. The relative carrier leakage power is a power ratio of the additive sinusoid waveform and the modulated waveform. The relative carrier leakage power of UE should not exceed the values specified in Table 17. (26, p. 232.)

TABLE 17. Minimum requirements for relative carrier leakage power (26, p. 232)

Parameters	Relative limit (dBc)
0 dBm ≤ Output power	-25
-30 dBm ≤ Output power ≤ 0 dBm	-20
-40 dBm ≤ Output power < -30 dBm	-10

4.1.13 In-band emissions for non-allocated tone

The in-band emissions are a measure of the interference falling into the non-allocated tones. The in-band emission is defined as a function of the tone offset from the edge of the allocated UL transmission tone within the transmission bandwidth configuration. The in-band emission is measured as the ratio of the UE output power in a non–allocated tone to the UE output power in an allocated tone. The basic in-band emissions measurement interval is defined over one slot in the time domain. The relative in-band emission must not exceed the values specified in Table 18. (27, p. 986.)

TABLE 18. Minimum requirements for in-band emissions (27, p. 987)

<table>
<tr><th>Parameter description</th><th>Unit</th><th colspan="2">Limit (NOTE 1)</th><th>Applicable Frequencies</th></tr>
<tr><td>General</td><td>dB</td><td colspan="2">$\max\{ -15 - 10 \cdot \log_{10}(N_{tone} / L_{Ctone}),$
$-18 - 5 \cdot (|\Delta_{tone}| - 1) / L_{Ctone},$
$-57\,dBm/(3.75kHz\,or\,15kHz) - P_{tone}\}$</td><td>Any non-allocated (NOTE 2)</td></tr>
<tr><td>IQ Image</td><td>dB</td><td colspan="2">-25</td><td>Image frequencies (NOTES 2, 3)</td></tr>
<tr><td rowspan="3">Carrier leakage</td><td rowspan="3">dBc</td><td>-25</td><td>0 dBm ≤ Output power</td><td rowspan="3">Carrier frequency (NOTES 4, 5)</td></tr>
<tr><td>-20</td><td>-30 dBm ≤ Output power ≤ 0 dBm</td></tr>
<tr><td>-10</td><td>-40 dBm ≤ Output power < -30 dBm</td></tr>
<tr><td colspan="5">NOTE 1: An in-band emissions combined limit is evaluated in each non-allocated tone. For each such tone, the minimum requirement is calculated as the higher of P_{tone} - 30 dB and the power sum of all limit values (General, IQ Image or Carrier leakage) that apply. P_{tone} is defined in NOTE 9.
NOTE 2: The measurement bandwidth is 1 tone and the limit is expressed as a ratio of measured power in one non-allocated tone to the measured average power per allocated tone, where the averaging is done across all allocated tones.
NOTE 3: The applicable frequencies for this limit are those that are enclosed in the reflection of the allocated bandwidth, based on symmetry with respect to the centre carrier frequency, but excluding any allocated tones.
NOTE 4: The measurement bandwidth is 1 tone and the limit is expressed as a ratio of measured power in one non-allocated tone to the measured total power in all allocated tones.
NOTE 5: The applicable frequencies for this limit are those that are enclosed in the tones containing the DC frequency if N_{tone} is odd, or in the two tones immediately adjacent to the DC frequency if N_{tone} is even, but excluding any allocated tone.
NOTE 6: L_{Ctone} is the Transmission Bandwidth (tones).
NOTE 7: N_{tone} is the Transmission Bandwidth Configuration (tones).
NOTE 8: Δ_{tone} is the starting frequency offset between the allocated tone and the measured non-allocated tone. (e.g. $\Delta_{tone} = 1$ or $\Delta_{tone} = -1$ for the first adjacent tone outside of the allocated bandwidth.
NOTE 9: P_{tone} is the transmitted power per 3.75 kHz or 15 kHz in allocated tones, measured in dBm.</td></tr>
</table>

4.1.14 Occupied bandwidth

The occupied bandwidth is defined as the bandwidth containing 99 % of the total integrated mean power of the transmitted spectrum on the assigned channel at the transmit antenna connector. The occupied bandwidth must be less than the channel bandwidth that is 200 kHz. (27, p. 1099.)

4.2 Receiver characteristics

Receiver performance measurements are measured as a function of throughput. The requirement for the throughput is ≥ 95% of the maximum throughput of the reference measurement channel as specified in Table 19 in all cases.

TABLE 19. Fixed Reference Channel for Receiver Requirements (26, p. 1296)

Parameter	Unit	Value
Channel bandwidth	MHz	0.2
Number of subcarriers		12
Modulation		QPSK
Target Coding Rate		1/3
Number of HARQ Processes	Processes	1
Maximum number of HARQ transmissions		1
Transport block size	Bits	88
Number of Sub-Frames per transport block		1
Transport block CRC	Bits	24
Binary Channel Bits Per Sub-Frame	Bits	320
LTE CRS port		N/A
Number of NRS ports		1
Number of NPDSCH repetitions		0
UE DL Category		NB1

4.2.1 Reference sensitivity level

The receiver sensitivity means the lowest power level that a receiver can detect. The better sensitivity, the longer operating range could be achieved by the radio.

The UE throughput must be ≥ 95% of the maximum throughput of the reference measurement channel with a received signal level as specified in Table 20 (26, p. 398).

TABLE 20. Reference sensitivity (26, p. 398)

Operating band	REFSENS [dBm]
1, 2, 3, 5, 8, 11, 12, 13, 17, 18, 19, 20, 21, 25, 26, 28, 31, 66, 70	- 108.2

4.2.2 Maximum input level

The UE maximum input level requirement is -25 dBm. For this input level, the throughput must be ≥ 95% of the maximum throughput of the reference measurement channel. (26, p. 402.)

4.2.3 Adjacent Channel Selectivity (ACS)

The Adjacent Channel Selectivity (ACS) is a measure of a receiver's ability to receive a signal at its assigned channel frequency in the presence of an adjacent channel signal at a given frequency offset from the center frequency of the assigned channel. ACS is the ratio of the receive filter attenuation on the assigned channel frequency to the receive filter attenuation on the adjacent channel. (27, p. 2070.)

UE must fulfil the minimum requirement specified in Table 21 for all values of an adjacent channel interferer up to -25 dBm. However, it is not possible to directly measure the ACS, therefore the lower and upper range of test parameters are chosen in Table 21. (26, p. 409.)

TABLE 21. Adjacent channel selectivity parameters (26, p. 410)

ACS1 test Parameters		
Interferer	**GSM (GMSK)**	**E-UTRA**
Category NB1 or NB2 signal power (P_{wanted}) / dBm	REFSENS + 14 dB	
Interferer signal power ($P_{Interferer}$) / dBm	REFSENS + 42 dB	REFSENS + 47 dB
Interferer bandwidth	200 kHz	5 MHz
Interferer offset from category NB1 or NB2 channel edge	±200 kHz	±2.5 MHz
ACS2 test Parameters		
Interferer	**GSM (GMSK)**	**E-UTRA**
Category NB1 or NB2 signal power (P_{wanted}) / dBm	-53 dBm	-58 dBm
Interferer signal power ($P_{Interferer}$) / dBm	-25 dBm	
Interferer bandwidth	200 kHz	5 MHz
Interferer offset from category NB1 or NB2 channel edge	±200 kHz	±2.5 MHz

Figure 14 illustrates the signal power levels that are calculated from the reference sensitivity requirement in Table 20 for the ACS1 GSM interferer case.

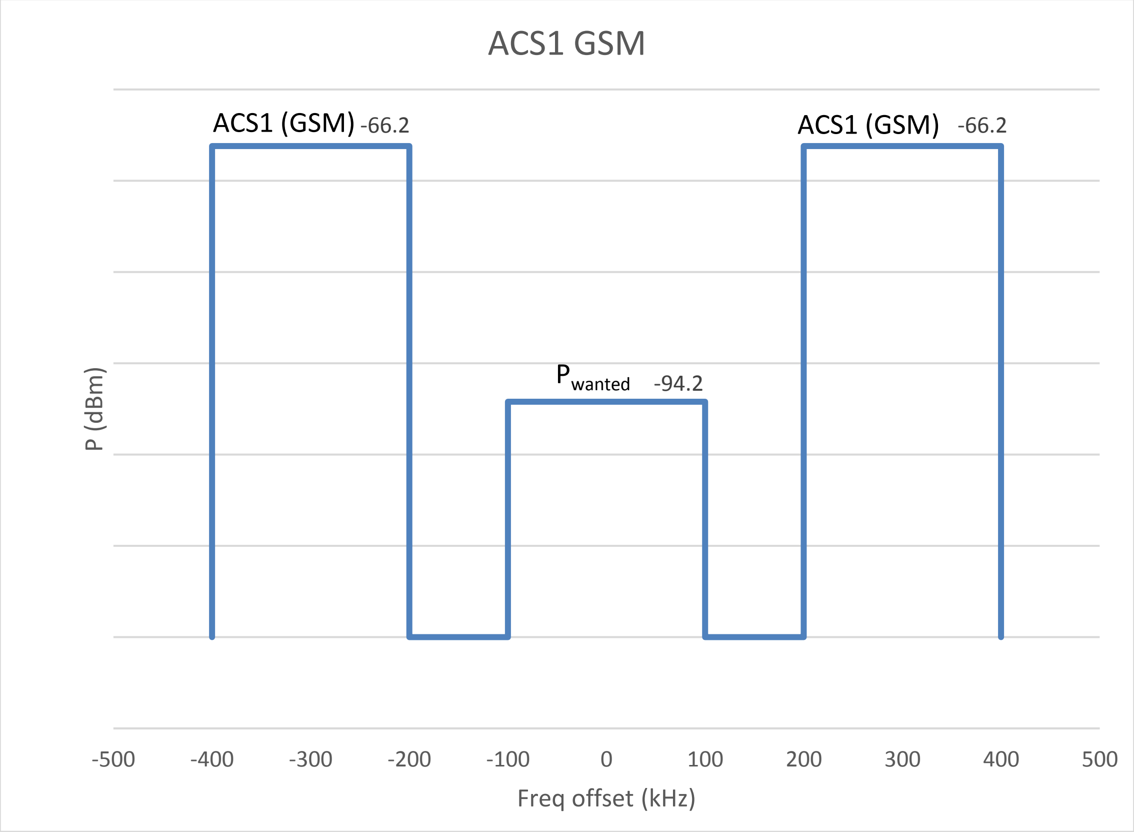


FIGURE 14. ACS1 test case for GMSK modulated interferer signal

4.2.4 In-band blocking

The In-band blocking is defined for an unwanted interfering signal falling into the range from 15 MHz below to 15 MHz above the UE receive band, at which the relative throughput must meet or exceed the requirement with the parameters specified in Table 22. (27, p. 2149.)

TABLE 22. In-band blocking parameters (26, p. 419)

IBB1 test Parameters	
Category NB1 signal power (P_{wanted}) / dBm	REFSENS + 6 dB
Interferer	E-UTRA
Interferer signal power ($P_{\text{Interferer}}$) / dBm	- 56 dBm
Interferer bandwidth	5 MHz
Interferer offset from category NB1 channel edge	+7.5 MHz + 0.005 MHz and -7.5 MHz - 0.005 MHz
IBB2 test Parameters	
Category NB1 or NB2 signal power (P_{wanted}) / dBm	REFSENS + 6 dB
Interferer	E-UTRA
Interferer signal power ($P_{\text{Interferer}}$) / dBm	- 44 dBm
Interferer bandwidth	5 MHz
Interferer offset range from category NB1 channel edge	From +12.5 MHz to F_{DL_high} + 15 MHz and From -12.5 MHz to F_{DL_low} - 15 MHz

The frequency offsets of interfering signals to the wanted signal frequency and signal power levels that are calculated from the reference sensitivity requirement in Table 20 are illustrated in Figure 15.

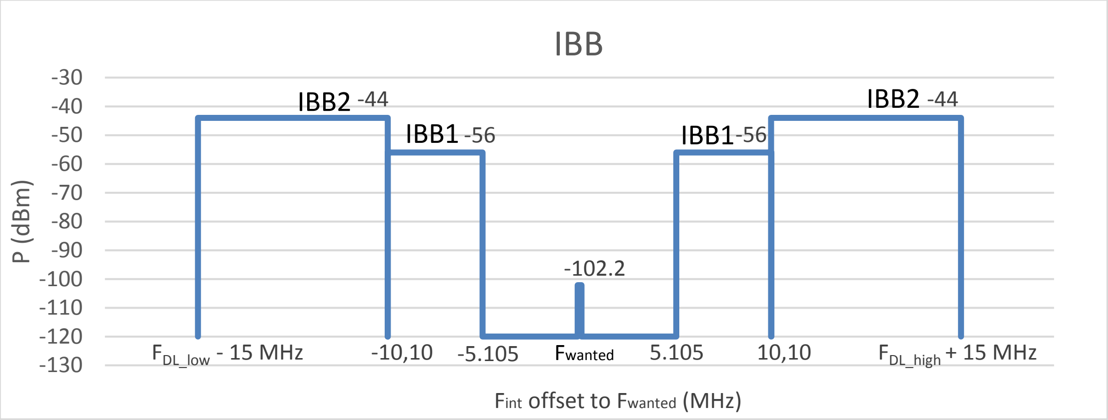


FIGURE 15. In-band blocking limits

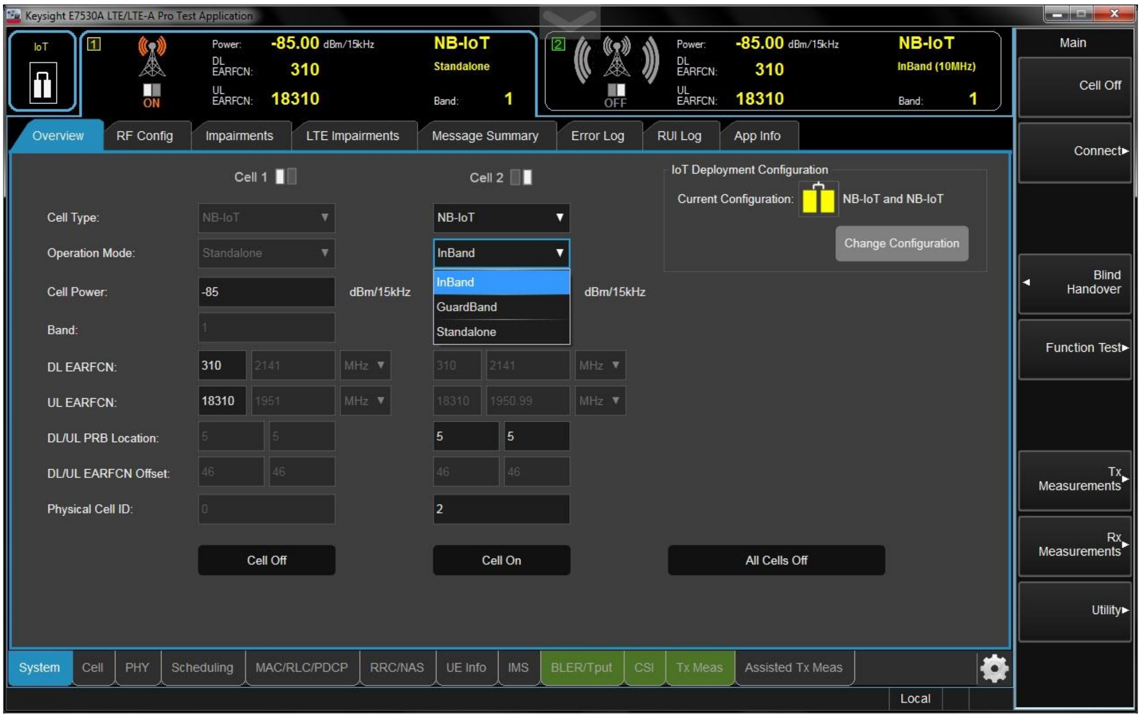
All 3GPP specification 36.521-1 RF requirements that are needed for RF measurements in this thesis are summarized in Appendix 1.

5 RF MEASUREMENTS

5.1 Measurement environment

The measurement instrument used in the RF verification was Keysight's E7515A UXM Wireless Test Set. It is a signalling tester which emulates radio base station, for instance in LTE and NB-IoT radio networks. The UXM has been created for a functional and RF design validation for 4G UEs and beyond. (29.)

Keysight's E7515A UXM Wireless Test Set has an E7530A LTE/LTE-A Pro Test Application, which also contains an NB-IoT RF measurement option. On the system overview tab of the UI (User Interface), basic parameters could be chosen. First of all, there is a possibility to use two NB-IoT cells. In these measurements only Cell 1 was used and standalone was used as the operation mode. Frequency band and channel numbers (DL/UL EARFCN) are other parameters to be chosen in standalone mode. (Figure 16.)



Power: -85.00 dBm/15kHz
DL EARFCN: 310
UL EARFCN: 18310
NB-IoT
Standalone
Band: 1

Power: -85.00 dBm/15kHz
DL EARFCN: 310
UL EARFCN: 18310
NB-IoT
InBand (10MHz)
Band: 1

	Cell 1		Cell 2	
Cell Type:	NB-IoT		NB-IoT	
Operation Mode:	Standalone		InBand	
Cell Power:	-85	dBm/15kHz		dBm/15kHz
Band:	1			
DL EARFCN:	310 2141 MHz		310 2141 MHz	
UL EARFCN:	18310 1951 MHz		18310 1950.99 MHz	
DL/UL PRB Location:	5 5		5 5	
DL/UL EARFCN Offset:	46 46		46 46	
Physical Cell ID:	0		2	

IoT Deployment Configuration
Current Configuration: NB-IoT and NB-IoT

FIGURE 16. System overview window of NB-IoT measurement option.

The Scheduling settings window includes other relevant parameters for RF measurements, for instance the UL subcarrier spacing (3,75 kHz/15 kHz) and the number of subcarriers (1, 3, 6, 12) selections. (Figure 17.)

Cell 1: Power: -85.00 dBm/15kHz; DL EARFCN: 310; UL EARFCN: 18310; NB-IoT Standalone; Band: 1

Cell 2: Power: -85.00 dBm/15kHz; DL EARFCN: 310; UL EARFCN: 18310; NB-IoT InBand (10MHz); Band: 1

DL Bitmap state and period: Off
DL Bitmap: 0
UL Subcarrier Spacing: 15 KHz
☐ Automatic RLC Allocation

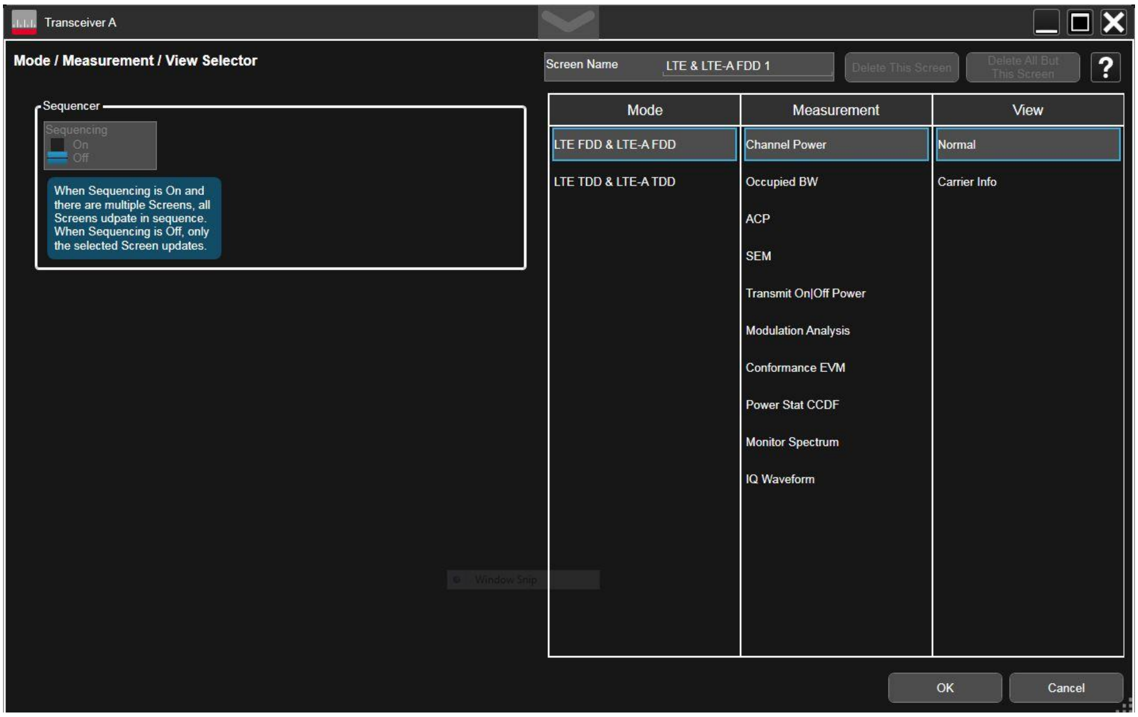
☑ DL Scheduling
MCS (I_{MCS}/Q_m): 4 / QPSK
TBS: 552
Scheduling Delay (I_{delay}/k_0): 0 / 0
NPDSCH Duration: 1
DCI Subframe Repetitions (R): 8
Code Rate: 0.225
NPDSCH Repetitions (I_{rep}/N_{rep}): 0 / 1
Off Duration (DL Subframes): 0
Resource Assignment (I_{SF}/N_{SF}): 6 / 8
HARQ-ACK Resource Index: 0

☑ UL Scheduling
MCS (I_{MCS}/Q_m): 4 / QPSK
TBS: 552
Scheduling Delay (I_{delay}/k_0): 0 / 8
NPUSCH Duration: 1
DCI Subframe Repetitions (R): 8
Code Rate: 0.375
NPUSCH Repetitions (I_{rep}/N_{rep}): 0 / 1
Off Duration (DL Subframes): 0
Resource Assignment (I_{RU}/N_{RU}): 6 / 8
Number of Subcarriers: 1 (1, 3, 6, 12)
Subcarrier Indication (I_{SC}): 0
Subcarrier Start Position:

☐ DL Gap
Threshold: 32
Periodicity: 64
Duration Coefficient: 0.125

FIGURE 17. Scheduling settings window of NB-IoT measurement option.

NB-IoT TX measurements could be found under the LTE & LTE-A FDD option. (Figure 18.)



Screen Name LTE & LTE-A FDD 1

When Sequencing is On and there are multiple Screens, all Screens udpate in sequence. When Sequencing is Off, only the selected Screen updates.

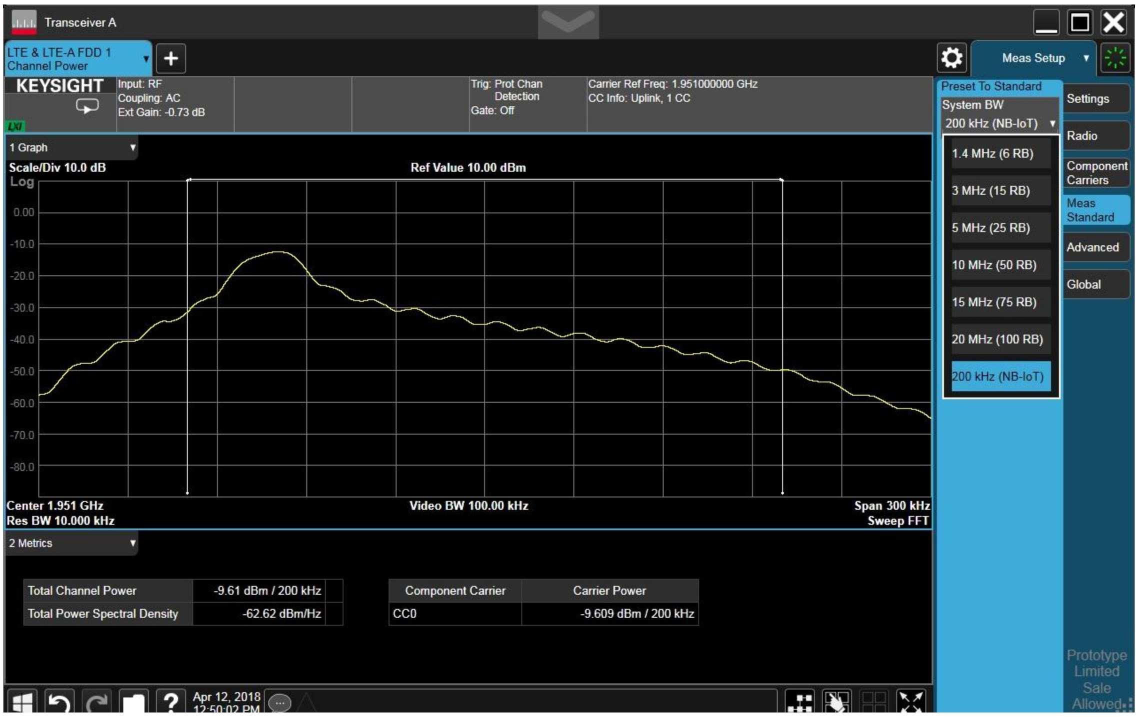
Mode: LTE FDD & LTE-A FDD

Measurement: Channel Power

View: Normal

FIGURE 18. TX measurements in LTE & LTE-A FDD option.

The System BW from Meas Standard should be selected 200 kHz (NB-IoT) to get NB-IoT specific settings into use. There is an example of channel power measurement in Figure 19. The subcarrier spacing is 15 kHz and subcarrier is 1@0 which means that the transmission bandwidth configuration is 1 subcarrier in the subcarrier start position 0. (Figure 19.)



Input: RF
Coupling: AC
Ext Gain: -0.73 dB
Trig: Prot Chan Detection
Gate: Off
Carrier Ref Freq: 1.951000000 GHz
CC Info: Uplink, 1 CC
System BW: 200 kHz (NB-IoT)
Scale/Div 10.0 dB
Ref Value 10.00 dBm
Center 1.951 GHz
Res BW 10.000 kHz
Video BW 100.00 kHz
Span 300 kHz
Sweep FFT

Total Channel Power	-9.61 dBm / 200 kHz
Total Power Spectral Density	-62.62 dBm/Hz

Component Carrier	Carrier Power
CC0	-9.609 dBm / 200 kHz

FIGURE 19. Channel Power measurement window under TX measurements.

UXM receiver performance measurements are based on BLER (Block Error Ratio). 3GPP standards specify that the UE throughput in receiver measurements should be ≥ 95% of the maximum throughput or in other words DL BLER ≤ 5%. (Figure 20.)


Keysight E7530A LTE/LTE-A Pro Test Application

IoT

1 CP CONNECTED

Power: dBm

DL Freq: 2141.00 MHz

UL Freq: 1951.00 MHz

NB-IoT Standalone

Band: 1

2 OFF

Power: -85.00 dBm/15kHz

DL EARFCN: 310

UL EARFCN: 18310

NB-IoT InBand (10MHz)

Band: 1

Trace Selection: UL, DL

414 / 360000

Overall OTA Throughput		
	Uplink	Downlink
Current	1.04 kbps	440.00 bps
Peak	1.04 kbps	440.00 bps
Average	812.38 bps	326.26 bps
Transferred	86.11 kbits	34.58 kbits

Overall BLER	
DL BLER %	5.07 %
UL BLER %	0.00 %

FIGURE 20. BLER/Tput, DL/UL OTA Graph window.

The physical measurement arrangement consists of Keysight's UXM wireless test set: RF combiner, which combines UXM RF ports to the antenna interface of the DUT, which in this case is MediaTek's MT2625 evaluation board. The supply voltage is supplied from the DC voltage power supply to the DC plug of the DUT.

Two RF ports of UXM are needed in 2 receiver measurement test cases, adjacent channel selectivity and in band blocking, because they also require an interfering signal. All other measurements are conducted by one RF port of the UXM (RF Input/Output). (Figure 21.) RF cable losses between the RF Input/Output port and the interfering signal port of UXM and the antenna interface of DUT are presented in Appendix 2.

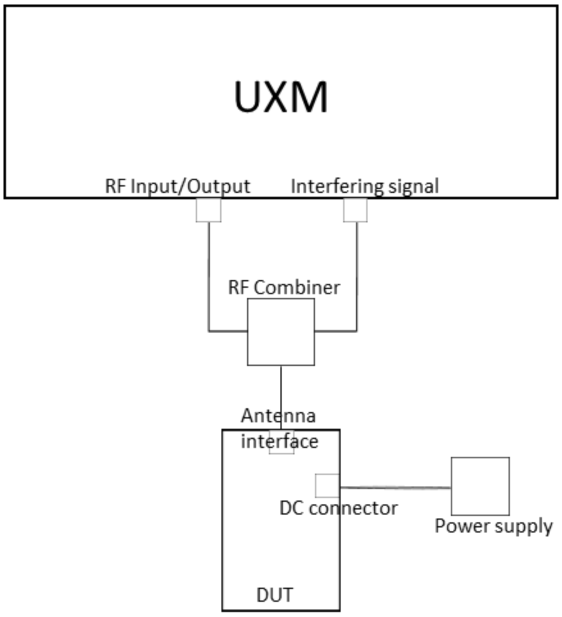
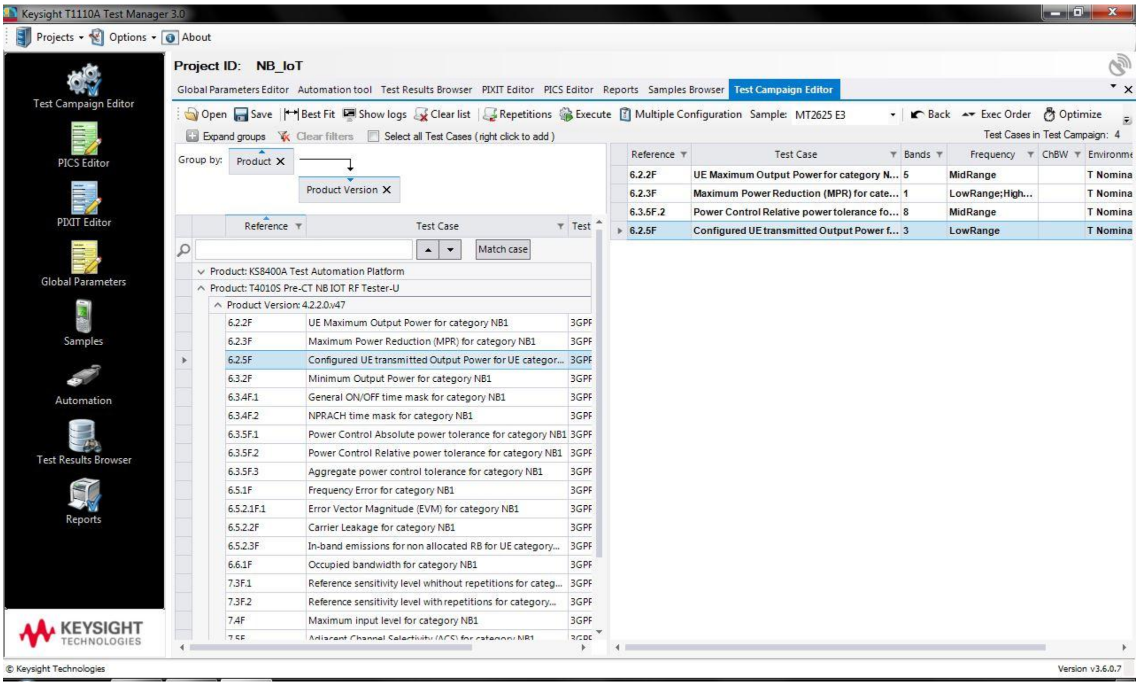


FIGURE 21. Measurement arrangement for DUT (Device Under Test)

5.2 Automatic RF measurement system

The T4010S conformance test system provides a proper set of test cases following the 3GPPP 36.521-1 test specifications for NB-IoT RF UE (30). Test cases could be managed and run with the Keysight T1110A Test Manager application. With the Test campaign editor, test cases can be selected for the test set to be executed. (Figure 22.)



Project ID: NB_IoT

☐ Select all Test Cases (right click to add)

Group by: Product → Product Version

Sample: MT2625 E3

Test Cases in Test Campaign: 4

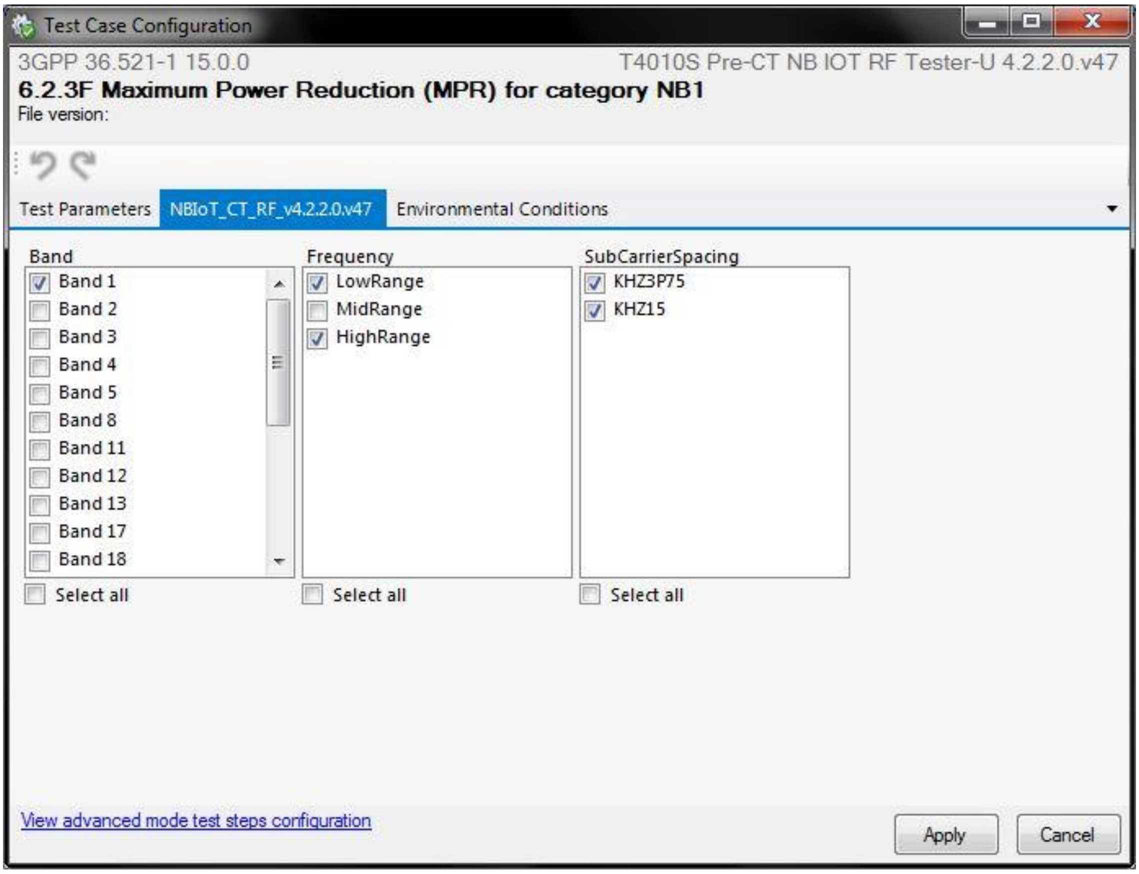
Reference	Test Case	Test
Product: KS8400A Test Automation Platform		
Product: T4010S Pre-CT NB IOT RF Tester-U		
Product Version: 4.2.2.0.v47		
6.2.2F	UE Maximum Output Power for category NB1	3GPF
6.2.3F	Maximum Power Reduction (MPR) for category NB1	3GPF
6.2.5F	Configured UE transmitted Output Power for UE categor...	3GPF
6.3.2F	Minimum Output Power for category NB1	3GPF
6.3.4F.1	General ON/OFF time mask for category NB1	3GPF
6.3.4F.2	NPRACH time mask for category NB1	3GPF
6.3.5F.1	Power Control Absolute power tolerance for category NB1	3GPF
6.3.5F.2	Power Control Relative power tolerance for category NB1	3GPF
6.3.5F.3	Aggregate power control tolerance for category NB1	3GPF
6.5.1F	Frequency Error for category NB1	3GPF
6.5.2.1F.1	Error Vector Magnitude (EVM) for category NB1	3GPF
6.5.2.2F	Carrier Leakage for category NB1	3GPF
6.5.2.3F	In-band emissions for non allocated RB for UE category...	3GPF
6.6.1F	Occupied bandwidth for category NB1	3GPF
7.3F.1	Reference sensitivity level whithout repetitions for categ...	3GPF
7.3F.2	Reference sensitivity level with repetitions for category...	3GPF
7.4F	Maximum input level for category NB1	3GPF

Reference	Test Case	Bands	Frequency	ChBW	Environme
6.2.2F	UE Maximum Output Power for category N...	5	MidRange		T Nomina
6.2.3F	Maximum Power Reduction (MPR) for cate...	1	LowRange;High...		T Nomina
6.3.5F.2	Power Control Relative power tolerance fo...	8	MidRange		T Nomina
6.2.5F	Configured UE transmitted Output Power f...	3	LowRange		T Nomina

FIGURE 22. Test manager, Test campaign editor

In the test case configuration window e.g. bands, frequency areas inside a band and subcarrier spacings used in test cases can be selected. (Figure 23.) A more detailed test step configuration, for instance a channel definition for a low, mid or high range, could be done in an advanced mode test step configuration window. (Figure 24.)

Once the executable test case set has been selected, the test run can be started by clicking an execute button in test campaign editor window (Figure 22.) After that, the E7530A LTE/LTE-A Pro Test Application will be started and a connection will be made between UXM and DUT first and after that, according to the test case either an RX or TX measurement window opens as described in chapter 5.1.



3GPP 36.521-1 15.0.0

T4010S Pre-CT NB IOT RF Tester-U 4.2.2.0.v47

6.2.3F Maximum Power Reduction (MPR) for category NB1

File version:

Band
- ☑ Band 1
- ☐ Band 2
- ☐ Band 3
- ☐ Band 4
- ☐ Band 5
- ☐ Band 8
- ☐ Band 11
- ☐ Band 12
- ☐ Band 13
- ☐ Band 17
- ☐ Band 18

☐ Select all

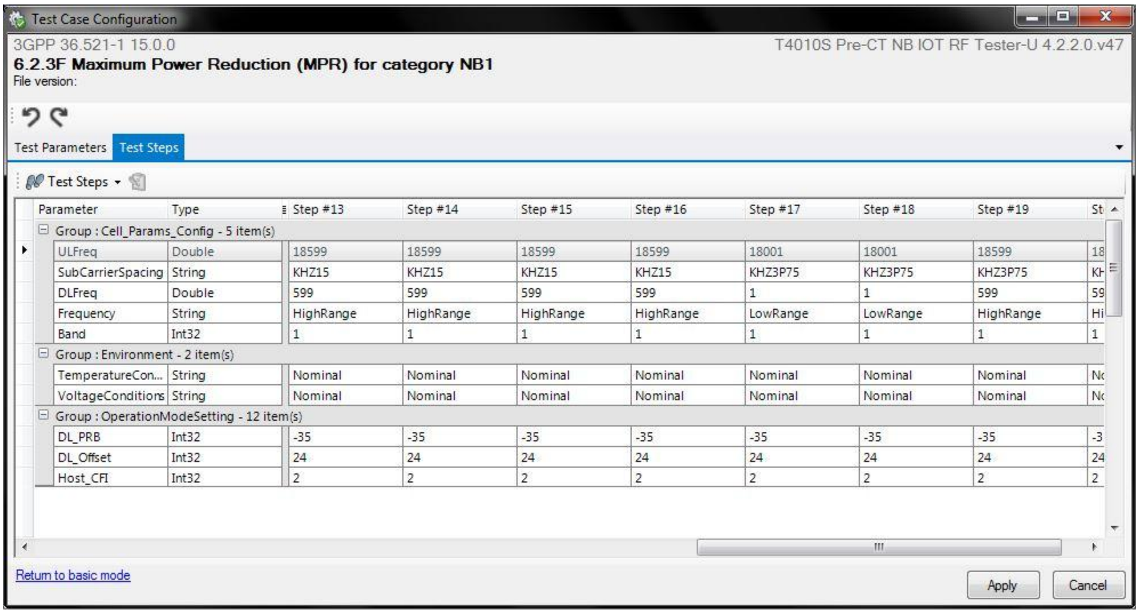
Frequency
- ☑ LowRange
- ☐ MidRange
- ☑ HighRange

☐ Select all

SubCarrierSpacing
- ☑ KHZ3P75
- ☑ KHZ15

☐ Select all

FIGURE 23. Test case configuration, basic mode



3GPP 36.521-1 15.0.0

T4010S Pre-CT NB IOT RF Tester-U 4.2.2.0.v47

6.2.3F Maximum Power Reduction (MPR) for category NB1

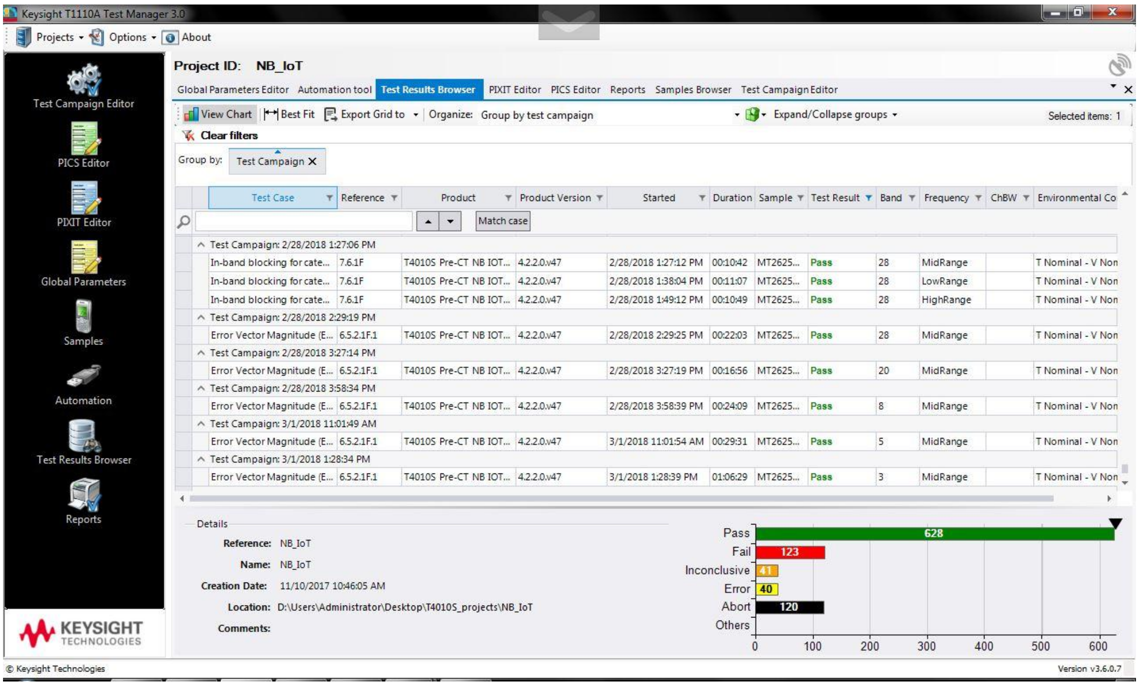
File version:

Parameter	Type	Step #13	Step #14	Step #15	Step #16	Step #17	Step #18	Step #19	St
Group : Cell_Params_Config - 5 item(s)									
ULFreq	Double	18599	18599	18599	18599	18001	18001	18599	18
SubCarrierSpacing	String	KHZ15	KHZ15	KHZ15	KHZ15	KHZ3P75	KHZ3P75	KHZ3P75	KH
DLFreq	Double	599	599	599	599	1	1	599	59
Frequency	String	HighRange	HighRange	HighRange	HighRange	LowRange	LowRange	HighRange	Hi
Band	Int32	1	1	1	1	1	1	1	1
Group : Environment - 2 item(s)									
TemperatureCon...	String	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	No
VoltageConditions	String	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	Nominal	No
Group : OperationModeSetting - 12 item(s)									
DL_PRB	Int32	-35	-35	-35	-35	-35	-35	-35	-3
DL_Offset	Int32	24	24	24	24	24	24	24	24
Host_CFI	Int32	2	2	2	2	2	2	2	2

FIGURE 24. Test case configuration, advanced mode

Test results can be seen in the test results browser window. In that window there is, for instance pass or fail verdict, band and environmental conditions. (Figure 25.)

By clicking the test case result row, a more detailed information window will open. That contains, for instance, test results and test parameters used in the test case.



Project ID: NB_IoT

Organize: Group by test campaign

Selected items: 1

Group by: Test Campaign

Test Case	Reference	Product	Product Version	Started	Duration	Sample	Test Result	Band	Frequency	ChBW	Environmental Co
Test Campaign: 2/28/2018 1:27:06 PM											
In-band blocking for cate...	7.6.1F	T4010S Pre-CT NB IOT...	4.2.2.0.v47	2/28/2018 1:27:12 PM	00:10:42	MT2625...	Pass	28	MidRange		T Nominal - V Non
In-band blocking for cate...	7.6.1F	T4010S Pre-CT NB IOT...	4.2.2.0.v47	2/28/2018 1:38:04 PM	00:11:07	MT2625...	Pass	28	LowRange		T Nominal - V Non
In-band blocking for cate...	7.6.1F	T4010S Pre-CT NB IOT...	4.2.2.0.v47	2/28/2018 1:49:12 PM	00:10:49	MT2625...	Pass	28	HighRange		T Nominal - V Non
Test Campaign: 2/28/2018 2:29:19 PM											
Error Vector Magnitude (E...	6.5.2.1F.1	T4010S Pre-CT NB IOT...	4.2.2.0.v47	2/28/2018 2:29:25 PM	00:22:03	MT2625...	Pass	28	MidRange		T Nominal - V Non
Test Campaign: 2/28/2018 3:27:14 PM											
Error Vector Magnitude (E...	6.5.2.1F.1	T4010S Pre-CT NB IOT...	4.2.2.0.v47	2/28/2018 3:27:19 PM	00:16:56	MT2625...	Pass	20	MidRange		T Nominal - V Non
Test Campaign: 2/28/2018 3:58:34 PM											
Error Vector Magnitude (E...	6.5.2.1F.1	T4010S Pre-CT NB IOT...	4.2.2.0.v47	2/28/2018 3:58:39 PM	00:24:09	MT2625...	Pass	8	MidRange		T Nominal - V Non
Test Campaign: 3/1/2018 11:01:49 AM											
Error Vector Magnitude (E...	6.5.2.1F.1	T4010S Pre-CT NB IOT...	4.2.2.0.v47	3/1/2018 11:01:54 AM	00:29:31	MT2625...	Pass	5	MidRange		T Nominal - V Non
Test Campaign: 3/1/2018 1:28:34 PM											
Error Vector Magnitude (E...	6.5.2.1F.1	T4010S Pre-CT NB IOT...	4.2.2.0.v47	3/1/2018 1:28:39 PM	01:06:29	MT2625...	Pass	3	MidRange		T Nominal - V Non

Reference: NB_IoT
Name: NB_IoT
Creation Date: 11/10/2017 10:46:05 AM
Location: D:\Users\Administrator\Desktop\T4010S_projects\NB_IoT
Comments:

FIGURE 25. Test results browser

Test results could be also converted into an html format. Two examples of those html test result files are attached in Appendices 3 and 4.

More detailed instructions of the whole NB-IoT testing with the UXM and conformance test system can be seen in the NB-IoT tutorial video made by Keysight (31).

5.3 Measurement results

Measurement results are based on 3GPP TS 36.521-1 specifications, as described in chapter 4. These tests do not cover all RF test cases that are in the specification, some cases are executed on other MediaTek sites. For instance, transmitter spurious cases and out of band blocking cases of the receiver are left out from this thesis work. Also, not all supported bands are included and tests are only run in normal conditions and standalone mode. Test results are listed in Table 23.

TABLE 23. Test results

NB-IoT 3GPP TS 36.521-1 Specifications						Standalone			
	Modulation	Channel Bandwidth/ Sub-carrier	SC_Start						
				Band1	Band3	Band5	Band8	Band20	Band28
TX									
Maximum Output Power									
Clause 6.2.2F Maximum Output Power	BPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
			1@47	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
			1@11	Passed	Passed	Passed	Passed	Passed	Passed
Maximum Power Reduction (MPR)									
Clause 6.2.3F Maximum Power Reduction	QPSK	0.2MHz/15K	3@0	Passed	Passed	Passed	Passed	Passed	Passed
			3@3	Passed	Passed	Passed	Passed	Passed	Passed
			3@9	Passed	Passed	Passed	Passed	Passed	Passed
			6@0	Passed	Passed	Passed	Passed	Passed	Passed
			6@6	Passed	Passed	Passed	Passed	Passed	Passed
			12@0	Passed	Passed	Passed	Passed	Passed	Passed
Configured UE transmitted Output Power									
Clause 6.2.5F Configured UE transmitted Output Power 1	QPSK	0.2MHz/3.75	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@47	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@11	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		12@0	Passed	Passed	Passed	Passed	Passed	Passed
Clause 6.2.5F Configured UE transmitted Output Power 2	QPSK	0.2MHz/3.75	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@47	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@11	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		12@0	Passed	Passed	Passed	Passed	Passed	Passed
Clause 6.2.5F Configured UE transmitted Output Power 3	QPSK	0.2MHz/3.75	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@47	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@11	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		12@0	Passed	Passed	Passed	Passed	Passed	Passed
Minimum Output Power									
Clause 6.3.2F Minimum Output Power	BPSK	0.2MHz/3.75	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	BPSK		1@47	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		1@11	Passed	Passed	Passed	Passed	Passed	Passed
	QPSK		12@0	Passed	Passed	Passed	Passed	Passed	Passed
Transmit OFF Power									
Clause 6.3.3F Transmit OFF Power	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed

Transmit ON/OFF Time Mask									
Clause 6.3.4F.1 General ON/OFF time mask	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
Clause 6.3.4F.2 NPRACH time mask	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
Transmit Power Control (absolute)									
Clause 6.3.5F.1 Transmit Power Control (absolute)	QPSK	0.2MHz/3.75	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	12@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	12@0	Passed	Passed	Passed	Passed	Passed	Passed
Transmit Power Control (relative)									
Clause 6.3.5F.2 Transmit Power Cntrol (relative)	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	12@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	12@0	Passed	Passed	Passed	Passed	Passed	Passed
Aggregate power control tolerance									
Clause 6.3.5F.3 Aggregate power control tolerance	QPSK	0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
			1@11	Passed	Passed	Passed	Passed	Passed	Passed
			12@0	Passed	Passed	Passed	Passed	Passed	Passed
Frequency Error									
Clause 6.5.1F Frequency Error	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
			3@0	Passed	Passed	Passed	Passed	Passed	Passed
			6@0	Passed	Passed	Passed	Passed	Passed	Passed
			12@0	Passed	Passed	Passed	Passed	Passed	Passed
Error Vector Magnitude									
Clause 6.5.2.1F Error vector Magnitude(EVM)	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@47	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@11	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	12@0	Passed	Passed	Passed	Passed	Passed	Passed
Carrier Leakage									
Clause 6.5.2.2F Carrier leakage	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@47	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@11	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@47	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@11	Passed	Passed	Passed	Passed	Passed	Passed

IQ Image									
Clause 6.5.2.3F IQ Image,	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@47	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@11	Passed	Passed	Passed	Passed	Passed	Passed
In-band emission									
Clause 6.5.2.3F In-band emissions for non allocated RB	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@47	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@11	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/3.75K	1@47	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@11	Passed	Passed	Passed	Passed	Passed	Passed
Occupied bandwidth									
Clause 6.6.1F Occupied bandwidth	QPSK	0.2MHz/3.75K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	1@0	Passed	Passed	Passed	Passed	Passed	Passed
		0.2MHz/15K	12@0	Passed	Passed	Passed	Passed	Passed	Passed
RX									
Reference sensitivity									
Clause 7.3F.1 Reference Sensitivity Power Level	QPSK	12 SC's	1@0	Passed	Passed	Passed	Passed	Passed	Passed
Max Input Level									
Clause 7.4.F Max Input Level	QPSK	12 SC's	1@0	Passed	Passed	Passed	Passed	Passed	Passed
Adjacent Channel Selectivity									
Clause 7.5F Adjacent Channel Selectivity	QPSK	12 SC's	1@0	Passed	Passed	Passed	Passed	Passed	Passed
In-band blocking									
Clause 7.6.1F In-band blocking	QPSK	12 SC's	1@0	Passed	Passed	Passed	Passed	Passed	Passed

6 CONCLUSION

In the beginning of this thesis work, the rapidly growing IoT business was overviewed. Over 31 billion devices are forecasted to be connected to the internet by 2023 and approximately 20 billion of them will be related to the IoT industry.

Moreover, various IoT radio technologies were introduced. The main focus in this thesis was on the NB-IoT radio technology and it was discussed quite precisely. NB-IoT could be considered as an LPWAN radio. Because of that, also some other LPWAN radios were introduced. Licensed 3GPP radios, LTE-M and EC-GSM-IoT, and unlicensed radios LoRa and Sigfox were introduced.

A comparison between different LPWAN radio technologies were made based on the communication range, battery lifetime, low cost of end devices and high network capacity because these factors could be considered the most significant ones for the massive IoT communication. NB-IoT proved to be a considerable option according to these criterions set to the LPWAN radio technology.

MediaTek believes that NB-IoT will be a key radio technology in the IoT industry. MediaTek's first NB-IoT chipset MT2625 combines an ARM Cortex-M MCU, pseudo-static RAM, flash memory and power management unit into a small package. MT2625 supports a full frequency band, from 450 MHz to 2.1GHz, which is defined in 3GPP Release 13 and Release 14 standards.

Necessary 3GPP specification items were presented in detail for TX and RX measurements. Test cases and limits based on specification items are tabled in appendix 1. The measurement environment and automatic RF measurement system are introduced after that. Finally, test result verdicts are introduced in a table. All measured cases were passed.

It should be noted that these RF measurements do not cover all RF test cases. For instance, TX spurious emission and RX out of band blocking cases were left out of the scope of this thesis. Also, extreme temperature and voltage test cases were not dealt with in this context. Only few frequency bands of all supported bands were tested and tests were executed only in standalone mode. All other relevant RF test cases were executed on the other MediaTek sites.

The objectives set to this thesis were very well achieved as RF measurement results prove. In addition, the maturity of MediaTek’s NB-IoT chipset was achieved at a very satisfactory level and it was well prepared for mass production during the project.

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APPENDICES

Appendix 1	A summary of 3GPP TS 36.521-1 RF requirements
Appendix 2	RF cable losses in measurement arrangement
Appendix 3	In-band emissions for non-allocated tone
Appendix 4	Adjacent channel selectivity (ACS)

NB-IoT Specifications in normal conditions
3GPP TS 36.521-1 (27.)

Transmitter	Modulation	Channel Bandwidth/SC	SC_Start	Upper limit	P_{CMAX}	Lower limit	Tolerance	Units
Clause 6.2.2F Maximum Output Power	BPSK	0.2MHz/3.75K	1@0	25.7	23	20.3	±2.7	dBm
			1@47	25.7	23	20.3		
	QPSK	0.2MHz/15K	1@0	25.7	23	20.3		
			1@11	25.7	23	20.3		
Maximum Power Reduction (MPR)								
Clause 6.2.3F Maximum Power Reduction	QPSK	0.2MHz/15K	3@0	25.7	22.5	19.8	-0.5	dBm
			3@3	25.7	23	20.3	0	
			3@9	25.7	22.5	19.8	-0.5	
			6@0	25.7	22	19.3	-1	
			6@6	25.7	22	19.3		
			12@0	25.7	21	18.3	-2	
Configured UE transmitted Output Power				Power Tolerance				
Clause 6.2.5F Configured UE transmitted Output Power 1	QPSK	0.2MHz/3.75K	1@0	-17.7	-10	-2.3	±7.7	dBm
	QPSK		1@47	-17.7	-10	-2.3		
	QPSK	0.2MHz/15K	1@0	-17.7	-10	-2.3		
	QPSK		1@11	-17.7	-10	-2.3		
	QPSK		12@0	-17.7	-10	-2.3		

Clause 6.2.5F Configured UE transmitted Output Power 2	QPSK	0.2MHz/3.75K	1@0	3.3	10	16.7	±6.7	dBm
	QPSK		1@47	3.3	10	16.7		
	QPSK	0.2MHz/15K	1@0	3.3	10	16.7		
	QPSK		1@11	3.3	10	16.7		
	QPSK		12@0	3.3	10	16.7		
Clause 6.2.5F Configured UE transmitted Output Power 3	QPSK	0.2MHz/3.75K	1@0	9.3	15	20.7	±5.7	dBm
	QPSK		1@47	9.3	15	20.7		
	QPSK	0.2MHz/15K	1@0	9.3	15	20.7		
	QPSK		1@11	9.3	15	20.7		
	QPSK		12@0	9.3	15	20.7		
Minimum Output Power				Pmin (dBm)				
Clause 6.3.2F Minimum Output Power	BPSK	0.2MHz/3.75K	1@0	-39			0	dBm
	BPSK		1@47	-39				
	QPSK	0.2MHz/15K	1@0	-39				
	QPSK		1@11	-39				
	QPSK		12@0	-39				
Transmit OFF Power				Poff (dBm)				
Clause 6.3.3F Transmit OFF Power	QPSK	0.2MHz/15K	1@0		-50			dBm
Transmit ON/OFF Time Mask				Power Change Time				
Clause 6.3.4F.1 General ON/OFF time mask	QPSK	0.2MHz/15K	1@0					

Transmit Power Change Time Mask				Power Change Time				
Clause 6.3.4F.1 slot/sub-frame boundary	QPSK	0.2MHz/15K	1@0	-20		20	-/+20	us
Clause 6.3.4F.2 NPRACH time mask	QPSK	0.2MHz/15K	1@0	-20		20	-/+20	us
Transmit Power Control (absolute)				Power				
Clause 6.3.5F.1 Transmit Power Control (absolute)	QPSK	0.2MHz/3.75K	1@0		-25		±10	dB
		0.2MHz/15K	1@0		-19			
		0.2MHz/15K	12@0		-8.2			
		0.2MHz/3.75K	1@0		-12		±10	
		0.2MHz/15K	1@0		-6			
		0.2MHz/15K	12@0		4.8			
Transmit Power Control (relative)								
Clause 6.3.5F.2 Transmit Power Control (relative)	QPSK	0.2MHz/3.75K	1@0				ΔP = 2 2 ± (2.7)	dB
		0.2MHz/15K	1@0					
		0.2MHz/15K	12@0					
		0.2MHz/3.75K	1@0				ΔP =6 6 ± (4.7)	
		0.2MHz/15K	1@0					
		0.2MHz/15K	12@0					

Aggregate power control tolerance								
Clause 6.3.5F.3 Aggregate power control tolerance	QPSK	0.2MHz/15K	1@0				Given 5 power measurements in the pattern, the 2nd, 3rd, 4th, and 5th measurements shall be within ± 4.2 dB of the 1st measurement	
			1@11					
			12@0					
Frequency Error								
Clause 6.5.1F Frequency Error	QPSK	0.2MHz/3.75K	1@0				|Δf| ≤ 0.1 PPM |Δf| ≤ 0.2 PPM	ppm
		0.2MHz/15K	1@0					
			3@0					
			6@0					
			12@0					

Error Vector Magnitude								
Clause 6.5.2.1F Error vector Magnitude(EVM)	QPSK	0.2MHz/3.75K	1@0				< 17.5 %	
		0.2MHz/3.75K	1@47					
		0.2MHz/15K	1@0					
		0.2MHz/15K	1@11					
		0.2MHz/15K	12@0					
Carrier Leakage								
Clause 6.5.2.2F Carrier leakage	QPSK	0.2MHz/3.75K	1@0				-24.2	dBc
		0.2MHz/3.75K	1@47					
		0.2MHz/15K	1@0					
		0.2MHz/15K	1@11					
		0.2MHz/3.75K	1@0				-19.2	dBc
		0.2MHz/3.75K	1@47					
		0.2MHz/15K	1@0					
		0.2MHz/15K	1@11					
IQ Image								
Clause 6.5.2.3F IQ Image,	QPSK	0.2MHz/3.75K	1@0				-24.2	dB
		0.2MHz/3.75K	1@47					
		0.2MHz/15K	1@0					
		0.2MHz/15K	1@11					
In-band emission								
Clause 6.5.2.3F In-band emissions for non allocated RB	QPSK	0.2MHz/3.75K	1@0					dB
		0.2MHz/3.75K	1@47					
		0.2MHz/15K	1@0					
		0.2MHz/15K	1@11					

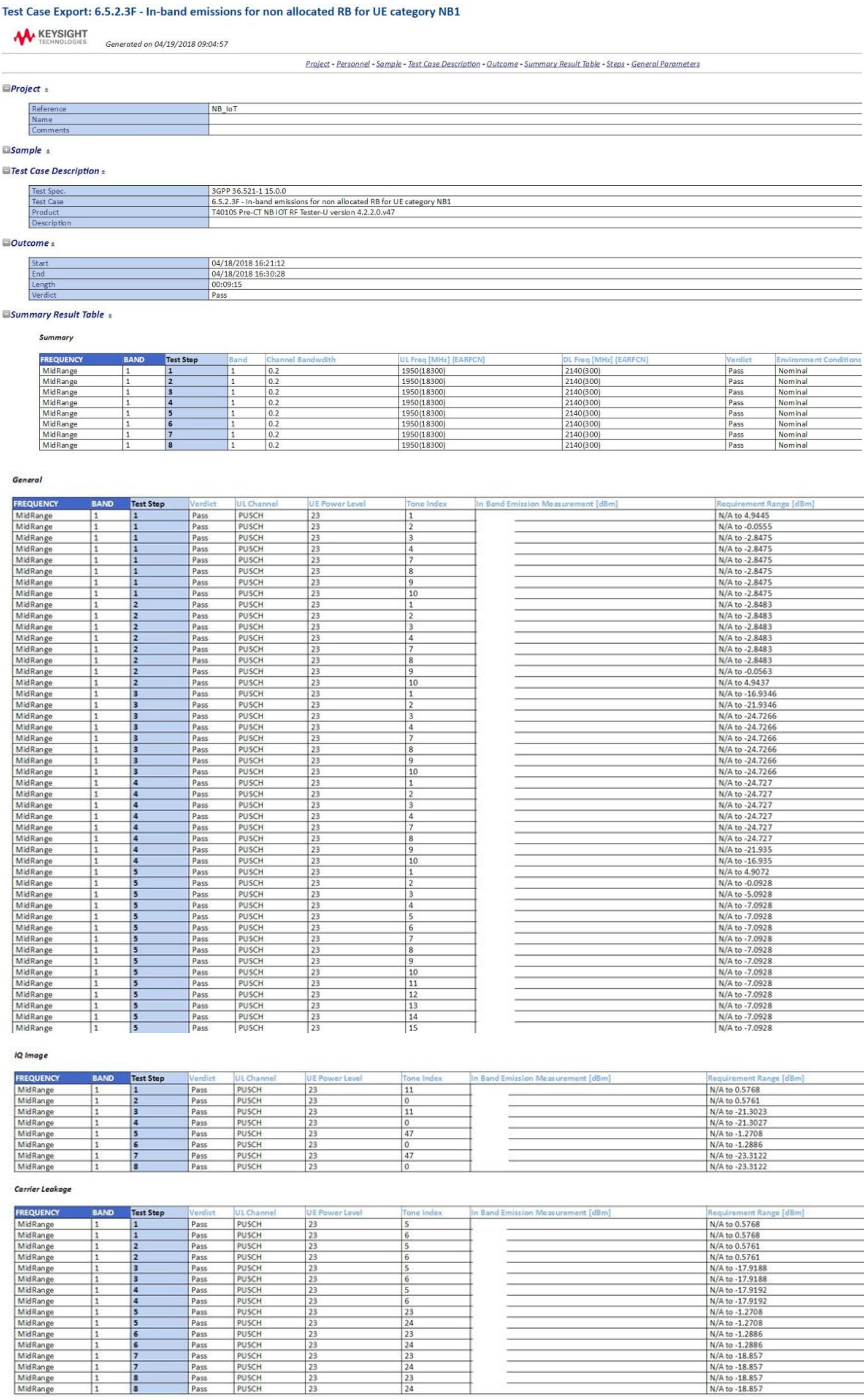
Occupied bandwidth								
Clause 6.6.1F Occupied bandwidth	QPSK	0.2MHz/3.75K	1@0				<200	KHz
		0.2MHz/15K	1@0					
		0.2MHz/15K	12@0					
Receiver								
Test Case:	**Dlink**		**Ulink**			**P_{wanted}**		
	Modulation	Subcarriers	Modulation	SC_Start	Subcarriers			
Reference Sensitivity								
Clause 7.3F.1 Reference Sensitivity Power Level	QPSK	12	BPSK	1@0	15kHz	<-107.5		dBm
Max Input Level								
Clause 7.4.F Max Input Level	QPSK	12	BPSK	1@0	15kHz	-25.7		dBm
Adjacent Channel Selectivity								
Clause 7.5F Adjacent Channel Selectivity	QPSK	12	BPSK	1@0	15kHz	REF-SENS + 14dB		dBm
						-53		dBm
						REF-SENS + 14dB		dBm
						-58		dBm
In-band blocking								
Clause 7.6.1F In-band blocking	QPSK	12	BPSK	1@0	15kHz	REF-SENS + 6		dBm
						REF-SENS + 6		dBm

RF CABLE LOSSES IN MEASUREMENT ARRANGEMENT APPENDIX 2

RF Cable losses

RF Input/Output <-> DUT		Interferer <-> DUT	
Freq. (MHz)	Loss (dB)	Freq. (MHz)	Loss (dB)
400	4,3	400	4,3
450	4,3	450	4,3
500	4,0	500	4,0
700	3,9	700	3,9
800	3,9	800	3,9
850	3,8	850	3,8
900	3,8	900	3,8
950	3,9	950	3,9
1000	3,9	1000	3,9
1400	4,1	1400	4,1
1600	4,1	1600	4,1
1700	4,2	1700	4,2
1800	4,2	1800	4,2
1850	4,3	1850	4,3
1950	4,3	1950	4,3
2000	4,4	2000	4,4
2200	4,4	2200	4,4
2300	4,7	2300	4,7
2400	4,7	2400	4,7

IN BAND EMISSIONS FOR NON ALLOCATED TONE APPENDIX 3/1



Test Case Export: 6.5.2.3F - In-band emissions for non allocated RB for UE category NB1

KEYSIGHT TECHNOLOGIES *Generated on 04/19/2018 09:04:57*

Project - Personnel - Sample - Test Case Description - Outcome - Summary Result Table - Steps - General Parameters

Project ±

Reference	NB_IoT
Name	
Comments	

Sample ±

Test Case Description ±

Test Spec.	3GPP 36.521-1 15.0.0
Test Case	6.5.2.3F - In-band emissions for non allocated RB for UE category NB1
Product	T4010S Pre-CT NB IOT RF Tester-U version 4.2.2.0.v47
Description	

Outcome ±

Start	04/18/2018 16:21:12
End	04/18/2018 16:30:28
Length	00:09:15
Verdict	Pass

Summary Result Table ±

Summary

FREQUENCY	BAND	Test Step	Band	Channel Bandwdith	UL Freq [MHz] (EARFCN)	DL Freq [MHz] (EARFCN)	Verdict	Environment Conditions
MidRange	1	**1**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**2**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**3**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**4**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**5**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**6**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**7**	1	0.2	1950(18300)	2140(300)	Pass	Nominal
MidRange	1	**8**	1	0.2	1950(18300)	2140(300)	Pass	Nominal

General

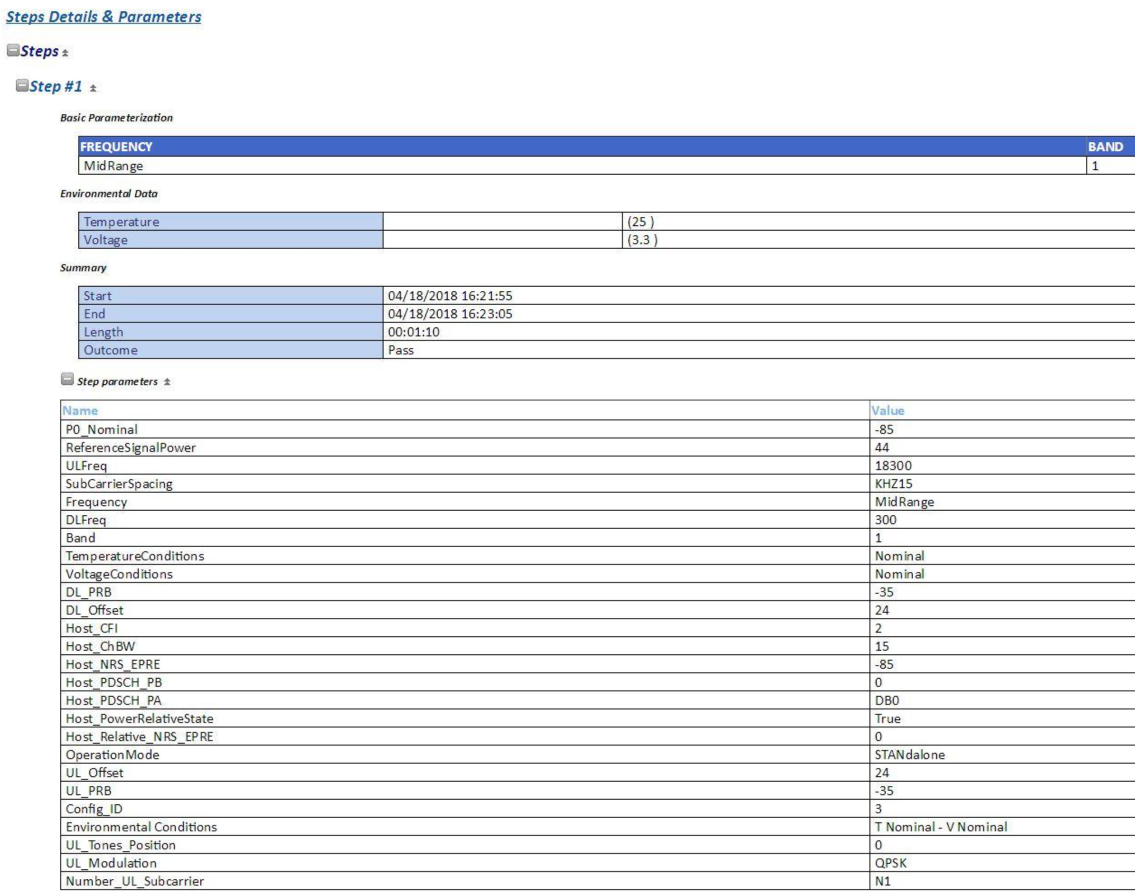
FREQUENCY	BAND	Test Step	Verdict	UL Channel	UE Power Level	Tone Index	In Band Emission Measurement [dBm]	Requirement Range [dBm]
MidRange	1	**1**	Pass	PUSCH	23	1		N/A to 4.9445
MidRange	1	**1**	Pass	PUSCH	23	2		N/A to -0.0555
MidRange	1	**1**	Pass	PUSCH	23	3		N/A to -2.8475
MidRange	1	**1**	Pass	PUSCH	23	4		N/A to -2.8475
MidRange	1	**1**	Pass	PUSCH	23	7		N/A to -2.8475
MidRange	1	**1**	Pass	PUSCH	23	8		N/A to -2.8475
MidRange	1	**1**	Pass	PUSCH	23	9		N/A to -2.8475
MidRange	1	**1**	Pass	PUSCH	23	10		N/A to -2.8475
MidRange	1	**2**	Pass	PUSCH	23	1		N/A to -2.8483
MidRange	1	**2**	Pass	PUSCH	23	2		N/A to -2.8483
MidRange	1	**2**	Pass	PUSCH	23	3		N/A to -2.8483
MidRange	1	**2**	Pass	PUSCH	23	4		N/A to -2.8483
MidRange	1	**2**	Pass	PUSCH	23	7		N/A to -2.8483
MidRange	1	**2**	Pass	PUSCH	23	8		N/A to -2.8483
MidRange	1	**2**	Pass	PUSCH	23	9		N/A to -0.0563
MidRange	1	**2**	Pass	PUSCH	23	10		N/A to 4.9437
MidRange	1	**3**	Pass	PUSCH	23	1		N/A to -16.9346
MidRange	1	**3**	Pass	PUSCH	23	2		N/A to -21.9346
MidRange	1	**3**	Pass	PUSCH	23	3		N/A to -24.7266
MidRange	1	**3**	Pass	PUSCH	23	4		N/A to -24.7266
MidRange	1	**3**	Pass	PUSCH	23	7		N/A to -24.7266
MidRange	1	**3**	Pass	PUSCH	23	8		N/A to -24.7266
MidRange	1	**3**	Pass	PUSCH	23	9		N/A to -24.7266
MidRange	1	**3**	Pass	PUSCH	23	10		N/A to -24.7266
MidRange	1	**4**	Pass	PUSCH	23	1		N/A to -24.727
MidRange	1	**4**	Pass	PUSCH	23	2		N/A to -24.727
MidRange	1	**4**	Pass	PUSCH	23	3		N/A to -24.727
MidRange	1	**4**	Pass	PUSCH	23	4		N/A to -24.727
MidRange	1	**4**	Pass	PUSCH	23	7		N/A to -24.727
MidRange	1	**4**	Pass	PUSCH	23	8		N/A to -24.727
MidRange	1	**4**	Pass	PUSCH	23	9		N/A to -21.935
MidRange	1	**4**	Pass	PUSCH	23	10		N/A to -16.935
MidRange	1	**5**	Pass	PUSCH	23	1		N/A to 4.9072
MidRange	1	**5**	Pass	PUSCH	23	2		N/A to -0.0928
MidRange	1	**5**	Pass	PUSCH	23	3		N/A to -5.0928
MidRange	1	**5**	Pass	PUSCH	23	4		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	5		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	6		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	7		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	8		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	9		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	10		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	11		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	12		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	13		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	14		N/A to -7.0928
MidRange	1	**5**	Pass	PUSCH	23	15		N/A to -7.0928

IQ Image

FREQUENCY	BAND	Test Step	Verdict	UL Channel	UE Power Level	Tone Index	In Band Emission Measurement [dBm]	Requirement Range [dBm]
MidRange	1	**1**	Pass	PUSCH	23	11		N/A to 0.5768
MidRange	1	**2**	Pass	PUSCH	23	0		N/A to 0.5761
MidRange	1	**3**	Pass	PUSCH	23	11		N/A to -21.3023
MidRange	1	**4**	Pass	PUSCH	23	0		N/A to -21.3027
MidRange	1	**5**	Pass	PUSCH	23	47		N/A to -1.2708
MidRange	1	**6**	Pass	PUSCH	23	0		N/A to -1.2886
MidRange	1	**7**	Pass	PUSCH	23	47		N/A to -23.3122
MidRange	1	**8**	Pass	PUSCH	23	0		N/A to -23.3122

Carrier Leakage

FREQUENCY	BAND	Test Step	Verdict	UL Channel	UE Power Level	Tone Index	In Band Emission Measurement [dBm]	Requirement Range [dBm]
MidRange	1	**1**	Pass	PUSCH	23	5		N/A to 0.5768
MidRange	1	**1**	Pass	PUSCH	23	6		N/A to 0.5768
MidRange	1	**2**	Pass	PUSCH	23	5		N/A to 0.5761
MidRange	1	**2**	Pass	PUSCH	23	6		N/A to 0.5761
MidRange	1	**3**	Pass	PUSCH	23	5		N/A to -17.9188
MidRange	1	**3**	Pass	PUSCH	23	6		N/A to -17.9188
MidRange	1	**4**	Pass	PUSCH	23	5		N/A to -17.9192
MidRange	1	**4**	Pass	PUSCH	23	6		N/A to -17.9192
MidRange	1	**5**	Pass	PUSCH	23	23		N/A to -1.2708
MidRange	1	**5**	Pass	PUSCH	23	24		N/A to -1.2708
MidRange	1	**6**	Pass	PUSCH	23	23		N/A to -1.2886
MidRange	1	**6**	Pass	PUSCH	23	24		N/A to -1.2886
MidRange	1	**7**	Pass	PUSCH	23	23		N/A to -18.857
MidRange	1	**7**	Pass	PUSCH	23	24		N/A to -18.857
MidRange	1	**8**	Pass	PUSCH	23	23		N/A to -18.857
MidRange	1	**8**	Pass	PUSCH	23	24		N/A to -18.857



Steps Details & Parameters

Steps

Step #1

Basic Parameterization

FREQUENCY	BAND
MidRange	1

Environmental Data

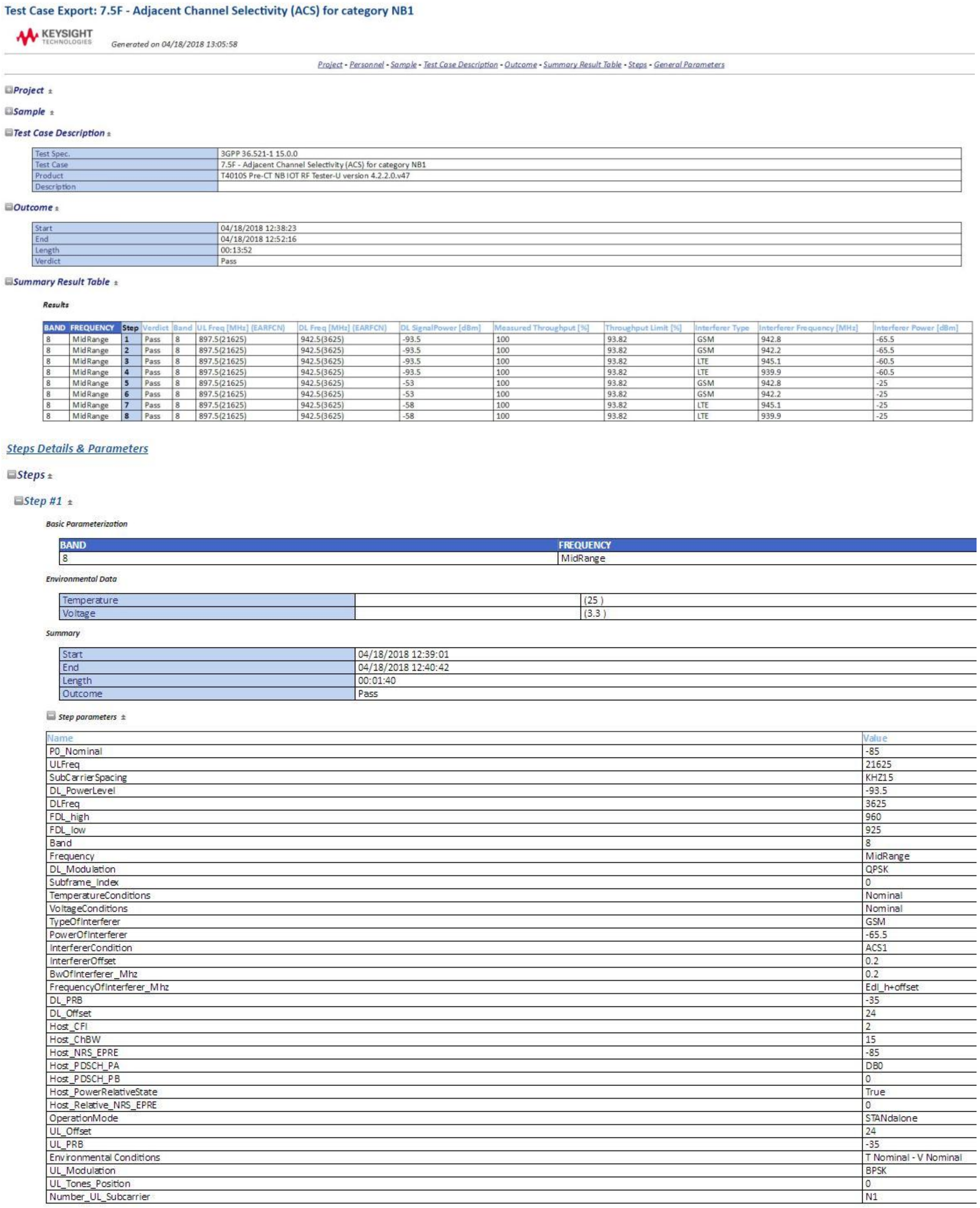
Temperature		(25)
Voltage		(3.3)

Summary

Start	04/18/2018 16:21:55
End	04/18/2018 16:23:05
Length	00:01:10
Outcome	Pass

Step parameters

Name	Value
P0_Nominal	-85
ReferenceSignalPower	44
ULFreq	18300
SubCarrierSpacing	KHZ15
Frequency	MidRange
DLFreq	300
Band	1
TemperatureConditions	Nominal
VoltageConditions	Nominal
DL_PRB	-35
DL_Offset	24
Host_CFI	2
Host_ChBW	15
Host_NRS_EPRE	-85
Host_PDSCH_PB	0
Host_PDSCH_PA	DB0
Host_PowerRelativeState	True
Host_Relative_NRS_EPRE	0
OperationMode	STANdalone
UL_Offset	24
UL_PRB	-35
Config_ID	3
Environmental Conditions	T Nominal - V Nominal
UL_Tones_Position	0
UL_Modulation	QPSK
Number_UL_Subcarrier	N1



Test Case Export: 7.5F - Adjacent Channel Selectivity (ACS) for category NB1

KEYSIGHT TECHNOLOGIES *Generated on 04/18/2018 13:05:58*

Project - *Personnel* - *Sample* - *Test Case Description* - *Outcome* - *Summary Result Table* - *Steps* - *General Parameters*

Project ±

Sample ±

Test Case Description ±

Test Spec.	3GPP 36.521-1 15.0.0
Test Case	7.5F - Adjacent Channel Selectivity (ACS) for category NB1
Product	T4010S Pre-CT NB IOT RF Tester-U version 4.2.2.0.v47
Description	

Outcome ±

Start	04/18/2018 12:38:23
End	04/18/2018 12:52:16
Length	00:13:52
Verdict	Pass

Summary Result Table ±

Results

BAND	FREQUENCY	Step	Verdict	Band	UL Freq [MHz] (EARFCN)	DL Freq [MHz] (EARFCN)	DL SignalPower [dBm]	Measured Throughput [%]	Throughput Limit [%]	Interferer Type	Interferer Frequency [MHz]	Interferer Power [dBm]
8	MidRange	1	Pass	8	897.5(21625)	942.5(3625)	-93.5	100	93.82	GSM	942.8	-65.5
8	MidRange	2	Pass	8	897.5(21625)	942.5(3625)	-93.5	100	93.82	GSM	942.2	-65.5
8	MidRange	3	Pass	8	897.5(21625)	942.5(3625)	-93.5	100	93.82	LTE	945.1	-60.5
8	MidRange	4	Pass	8	897.5(21625)	942.5(3625)	-93.5	100	93.82	LTE	939.9	-60.5
8	MidRange	5	Pass	8	897.5(21625)	942.5(3625)	-53	100	93.82	GSM	942.8	-25
8	MidRange	6	Pass	8	897.5(21625)	942.5(3625)	-53	100	93.82	GSM	942.2	-25
8	MidRange	7	Pass	8	897.5(21625)	942.5(3625)	-58	100	93.82	LTE	945.1	-25
8	MidRange	8	Pass	8	897.5(21625)	942.5(3625)	-58	100	93.82	LTE	939.9	-25

Steps Details & Parameters

Steps ±

Step #1 ±

Basic Parameterization

BAND	FREQUENCY
8	MidRange

Environmental Data

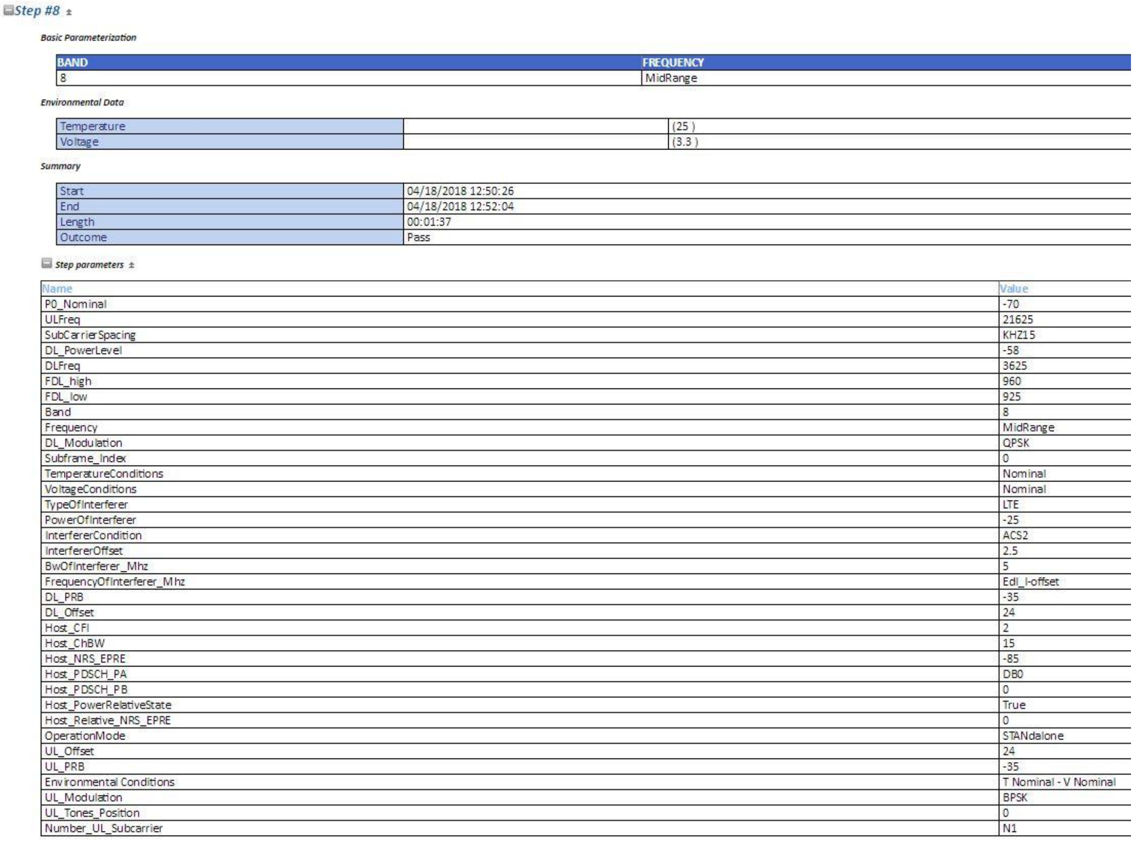
Temperature		(25)
Voltage		(3.3)

Summary

Start	04/18/2018 12:39:01
End	04/18/2018 12:40:42
Length	00:01:40
Outcome	Pass

Step parameters ±

Name	Value
P0_Nominal	-85
ULFreq	21625
SubCarrierSpacing	KHZ15
DL_PowerLevel	-93.5
DLFreq	3625
FDL_high	960
FDL_low	925
Band	8
Frequency	MidRange
DL_Modulation	QPSK
Subframe_Index	0
TemperatureConditions	Nominal
VoltageConditions	Nominal
TypeOfInterferer	GSM
PowerOfInterferer	-65.5
InterfererCondition	ACS1
InterfererOffset	0.2
BwOfInterferer_Mhz	0.2
FrequencyOfInterferer_Mhz	Edl_h+offset
DL_PRB	-35
DL_Offset	24
Host_CFI	2
Host_ChBW	15
Host_NRS_EPRE	-85
Host_PDSCH_PA	DB0
Host_PDSCH_PB	0
Host_PowerRelativeState	True
Host_Relative_NRS_EPRE	0
OperationMode	STANdalone
UL_Offset	24
UL_PRB	-35
Environmental Conditions	T Nominal - V Nominal
UL_Modulation	BPSK
UL_Tones_Position	0
Number_UL_Subcarrier	N1



Step #8 ±

Basic Parameterization

BAND	FREQUENCY
8	MidRange

Environmental Data

Temperature		(25)
Voltage		(3.3)

Summary

Start	04/18/2018 12:50:26
End	04/18/2018 12:52:04
Length	00:01:37
Outcome	Pass

Step parameters ±

Name	Value
P0_Nominal	-70
ULFreq	21625
SubCarrierSpacing	KHZ15
DL_PowerLevel	-58
DLFreq	3625
FDL_high	960
FDL_low	925
Band	8
Frequency	MidRange
DL_Modulation	QPSK
Subframe_Index	0
TemperatureConditions	Nominal
VoltageConditions	Nominal
TypeOfInterferer	LTE
PowerOfInterferer	-25
InterfererCondition	ACS2
InterfererOffset	2.5
BwOfInterferer_Mhz	5
FrequencyOfInterferer_Mhz	Edl_I-offset
DL_PRB	-35
DL_Offset	24
Host_CFI	2
Host_ChBW	15
Host_NRS_EPRE	-85
Host_PDSCH_PA	DB0
Host_PDSCH_PB	0
Host_PowerRelativeState	True
Host_Relative_NRS_EPRE	0
OperationMode	STANdalone
UL_Offset	24
UL_PRB	-35
Environmental Conditions	T Nominal - V Nominal
UL_Modulation	BPSK
UL_Tones_Position	0
Number_UL_Subcarrier	N1