



BSI Standards Publication

Validation of dynamic power control and exposure time-averaging algorithms

Part 1: Cellular network implementations for SAR at frequencies up to 6 GHz

National foreword

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Validation of dynamic power control and exposure time-averaging algorithms – Part 1: Cellular network implementations for SAR at frequencies up to 6 GHz

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**VALIDATION OF DYNAMIC POWER CONTROL
AND EXPOSURE TIME-AVERAGING ALGORITHMS –****Part 1: Cellular network implementations
for SAR at frequencies up to 6 GHz**

FOREWORD

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Full information on the voting for its approval can be found in the report on voting indicated in the above table.

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A list of all parts in the IEC 63424 series, published under the general title *Validation of dynamic power control and exposure time-averaging algorithms*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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INTRODUCTION

The concept of dynamic power control and exposure time-averaging (DPC-ETA) has been introduced recently to enable wireless devices to maintain SAR compliance in real-time. DPC-ETA enables a SAR assessment that is more representative of the user exposure. The procedures in IEC/IEEE 62209-1528:2020 require device under test (DUT) to maintain a fixed output power and transmission duty factor during SAR measurement to establish the correct SAR distribution to determine SAR compliance. When devices are tested at a fixed maximum output power and transmission duty factor for worst-case exposure and continuous use, a reduction in maximum power is often necessary to satisfy SAR compliance. This can result in undesirable device performance with poor link budget and low data throughput.

In DPC-ETA, SAR compliance is determined according to power recorded by the RF modem and time-averaged over a specified window duration. Device output power control is based on the linear SAR to power relationship established for a wireless operating mode and specific exposure condition to maintain SAR compliance during actual use. When the maximum time-averaged power is ensured by DPC-ETA, brief durations of higher instantaneous power can be applied while the maximum time-averaged power is not exceeded.

NOTE 1 The time-averaging windows required by national regulations can be the same as those established for SAR limits or can differ and vary with frequency.

The DPC-ETA algorithms are validated using power control test sequences with conducted and radiated power measurement methods described in Annex A and Annex B. The criteria for correlating power measurement results with expected DPC-ETA behaviour of the test sequences are also described. The measurement system validation and system check considerations are discussed in Annex C. The correlation of radiated power and single-point SAR measurement is illustrated in Annex D. The SAR methods that can be applied instead of radiated power measurement are described in Annex F. Guidance for validation of capacitive proximity sensor triggering with time-averaged detection are provided in Annex E.

NOTE 2 For the purposes of this document, test laboratories and users are referred to as user(s). This document provides recent information for users to address specific testing needs. It is possible that it is not able to provide solutions to all issues that are being identified or explored. The improvements realized from experiences in applying this document for DPC-ETA algorithm validation, including any adjustments needed to validate devices or comprehensive uncertainty analyses, that need further considerations, can be addressed in a subsequent revision of this document.

VALIDATION OF DYNAMIC POWER CONTROL AND EXPOSURE TIME-AVERAGING ALGORITHMS –

Part 1: Cellular network implementations for SAR at frequencies up to 6 GHz

1 Scope

This part of IEC 63424 describes the methods for validating dynamic power control and (dynamic) exposure time-averaging (DPC-ETA) algorithms used in RF modem chipsets of wireless devices. The DPC-ETA implementations are exposure-based, where SAR is time-averaged according to power recorded by the RF modem. Time-averaging windows up to six minutes consistent with applicable SAR limits and regulatory policies are considered for frequencies up to 6 GHz. The DPC-ETA power control parameters are established based on SAR compliance results with all relevant design and operating tolerances taken into consideration. The device output power is controlled by DPC-ETA to maintain SAR compliance in real-time. While SAR compliance is evaluated independently by applying IEC/IEEE 62209-1528:2020 [1]¹, this document contains information for algorithm validation.

Quasi-static and dynamic power control test sequences are described in this document for algorithm validation. The test sequences are sent from a radio communication tester (RCT) and DPC-ETA responses are measured with conducted and radiated power measurement methods to confirm algorithm functionality. Test sequences for wireless configurations that need validation, including wireless mode transitions, call drop, handover, discontinuous transmission, and simultaneous transmission are described. Considerations for measurement automation to acquire time-aligned results for correlation with power changes in the test sequences are provided. DPC-ETA algorithms are validated by correlating the normalized power measurement results with the expected behaviours of an implementation for the applied test sequences. The procedures in this document also support algorithm validation of modular transmitters using an appropriate test platform. Guidance for using SAR methods in place of radiated power measurements and capacitive proximity sensor triggering with time-averaged detection are also included.

NOTE 1 A separate document will be considered to validate DPC-ETA implementations above 6 GHz, according to near-field millimetre-wave band power density exposure requirements. Substantially shorter time-averaging window durations, on the order of a few seconds, can be required to satisfy some national regulatory requirements.

NOTE 2 The scope of this document is limited to cellular network technologies that have RF modem transmission power dictated by a base station and therefore can be tested using RCT test sequences. Cellular network technologies (also referred to as wireless wide area networks (WWAN)) include Global System for Mobile Communications (GSM), Universal Mobile Telecommunication System (UMTS), Long-Term Evolution (LTE) and 5G New Radio (NR), including other related 2G, 3G, 4G, and 5G specifications, respectively. A separate document will be considered for validating DPC-ETA implementations for wireless local area network (WLAN) technologies, such as those based on the IEEE 802.11 standards series. With WLAN technologies, the transmit power is dictated independently by the RF modem and can be specific to each power control implementation, requiring different testing approaches.

NOTE 3 The procedures in this document can also be considered for 3GPP [2] 5G NR FR1 bands above 6 GHz.

NOTE 4 This document does not address algorithm validation for simultaneous transmission configurations involving transmitters that are not controlled by DPC-ETA operations in the RF modem. These are evaluated according to regulatory requirements.

¹ Numbers in square brackets refer to the Bibliography.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

dynamic power control

DPC

power control algorithm used in RF modem chipset of wireless devices according to descriptions in this document

Note 1 to entry: Transmitter power control is based on power measured and recorded by the RF modem according to the linear SAR and power relationship of individual wireless mode configurations and exposure conditions to maintain time-averaged power below a specified threshold for continuous exposure and SAR compliance.

3.2

exposure time-averaging

ETA

time-averaging algorithm used in RF modem chipset of wireless devices for calculating time-averaged exposure according to measured and recorded power

Note 1 to entry: The recorded power is time-averaged over a specified time window according to the SAR limit or regulatory requirements. The calculated time-averaged power is used in DPC-ETA implementations as feedback to adjust transmitter power dynamically in real-time. For the purposes of algorithm validation, simple arithmetic averaging, or other suitable types of averaging accepted by the regulator, are covered by the procedures in this document.

3.3

dynamic power control and exposure time-averaging

DPC-ETA

algorithms used in RF modem chipset of wireless devices according to 3.1 and 3.2 to ensure SAR compliance for continuous exposure based on time-averaged power over a specified time window duration

3.4

RF modem

wireless transceiver incorporated in the chipset of wireless devices that supports the wireless protocol and operations

Note 1 to entry: RF modems include, for example, GSM, UMTS, LTE, and 5G NR to support the wireless modes specified by 3GPP protocols.

3.5

wireless operating mode

wireless operating configurations used in RF modems, according to parameters defined by wireless protocols (e.g. 3GPP), for transmission within the wireless network and infrastructure

Note 1 to entry: The parameters include the RF channel frequency, channel bandwidth, signal modulation and other transmission protocol specifications (e.g. power requirements, carrier aggregation, etc.) for communication with other devices in the network.

3.6**proximity sensor**

capacitive sensor or multiple capacitive sensors for detection of user proximity from the DUT, for the purpose of limiting transmitter power in order to ensure conformity with RF exposure limits

3.7**specific absorption rate****SAR**

measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency electromagnetic field

3.8**output power**

power at the output of the RF transmitter when the antenna, or a load with the same input impedance as the antenna, is connected to it

3.9**conducted power**

power delivered by the power amplifier of the device to 50 Ω matched load

Note 1 to entry: For the purposes of this document, conducted power is measured at the antenna port using equipment with 50 Ω input impedance.

3.10**power control algorithm**

DPC-ETA protocol used in a DUT to set and adjust the output power of the transmitter to satisfy SAR compliance

3.11**radiated power**

power measured with the DUT transmitting using its built-in antenna while operating in an anechoic chamber, according to the DPC-ETA algorithm validation procedures described in this document

3.12**time-averaging**

averaging of power recorded by the RF modem or measured by test equipment over a specified time window

Note 1 to entry: The calculated time-averaged power is used by the RF modem for power control to ensure a maximum time-averaged power is not exceeded for continuous exposure.

3.13**maximum time-averaged output power**

P_{limit}

maximum time-averaged power allowed for continuous exposure

Note 1 to entry: For the purposes of this document, a specified P_{limit} includes all tolerances that are relevant to DPC-ETA operations, which corresponds to a not-to-exceed value. The P_{limit} stored in the DUT is typically a nominal value without including the tolerance. The measured P_{limit} can be higher or lower than the nominal value, but within the specified DPC-ETA tolerance and does not exceed the specified P_{limit} .

3.14

time-averaging window time window

$T_{w\text{avg}}$

time interval used to calculate time-averaged power and determine time-averaged exposure

Note 1 to entry: For the purposes of this document, time-averaged exposure is determined according to the time-averaging requirements specified by SAR limits and regulatory policies. A frequency-dependent time-averaging window can be required by some national regulations.

3.15

maximum instantaneous output power

P_{max}

maximum output power a transmitter supports for the intended operations

Note 1 to entry: For algorithm validation, a specified P_{max} includes all tolerances relevant to DPC-ETA operations; i.e. it is a not-to-exceed value. The P_{max} stored in a DUT is typically the nominal value without including the tolerance. The measured P_{max} can be higher or lower than the nominal value, but within the specified DPC-ETA tolerance and does not exceed the specified P_{max} .

Note 2 to entry: Compare with IEC 60050-192:2015, 192-13-05: "instantaneous value: value of a time dependent variable at a given instant".

3.16

SAR target SAR_{target}

peak spatial-average SAR value corresponding to the measured P_{limit} of a wireless operating mode and exposure condition

Note 1 to entry: The tolerances for a measured P_{limit} also apply to the SAR_{target} .

3.17

SAR reported SAR_{reported}

peak spatial-average SAR value corresponding to the minimum (specified P_{limit} , specified P_{max}) obtained by scaling measured SAR_{target} associated with measured P_{limit} of a wireless operating mode and exposure condition.

3.18

optional output power threshold P_{ctrl}

DPC-ETA power control parameter, in addition to P_{max} and P_{limit}

Note 1 to entry: Depending on the DPC-ETA implementation, it can be used to specify a low power threshold for power control or a minimum power level for power adjustment. This can be an internal parameter with no OEM access or not required at all for some implementations.

3.19

power control test sequence

test sequence described in this document for DPC-ETA algorithm validation

Note 1 to entry: Quasi-static and dynamic test sequences are used to validate algorithm functionality and power control continuity in steady-state and dynamic operating conditions. The test sequences are sent by the RCT under program control of the automated measurement setup to enable time-aligned recording of measured responses and power requests in the test sequences.

3.20

dynamic test sequence

test cycle where the requested power levels consist of many changes

3.21**quasi-static test sequence**

test cycle where the requested power levels consist of one or two changes

EXAMPLE Request a power level of 0 dBm for a given period, followed by $P_{\max}$ for a given period.

3.22**random test sequence**

test cycle where there are hundreds of pseudo-random independent power level and radio access technology (RAT) change requests, designed to stress test and validate the dynamic response of the dynamic power control and exposure time-averaging algorithm

3.23**frequency band**

<radio access technology> transmitting frequency range associated with a radio access technology (RAT)

3.24**channel**

<frequency> specific sub-division of the transmit frequency range defined for a radio access technology (RAT) according to the operating parameters of a particular wireless technology, such as signal characteristics and channel bandwidth

3.25**normalized time-averaged output power**

measured power normalized by the measured P_{limit}

Note 1 to entry: The purpose is to enable measured responses to be compared and correlated across test configurations with different power control parameters, time-averaging windows, or DPC-ETA, and wireless operating characteristics, such as during a call drop, handover, discontinuous transmission, or simultaneous transmission conditions.

3.26**host device**

final product or equipment with DPC-ETA algorithm operating in the RF modem of its transmitter

Note 1 to entry: For modular transmitters with built-in DPC-ETA, a representative test platform is necessary for algorithm validation testing with conducted and radiated power measurements. When DPC-ETA is triggered by proximity sensors through immediate triggering, the triggering is controlled by the host device and is confirmed according to IEC/IEEE 62209-1528:2020 [1] procedures.

3.27**duty factor****pulse duty factor**

ratio of the average pulse duration to the reciprocal of the pulse repetition frequency in a pulse sequence

Note 1 to entry: For DPC-ETA algorithm validation, this is determined by the transmission scheme corresponding to the TDMA time slots in GSM/GPRS, or DL:UL configurations used in TDD for LTE and NR. When these duty factors apply, slot-based burst power is used to set specific TDMA and TDD power request levels in the test sequence according to RCT and wireless protocol requirements, and frame-based averaged power is measured according to the power measurement equipment configurations.

[SOURCE: IEC 60050-702:1992 [3], 702-03-09, modified – Note to entry has been added.]

3.28**test configuration**

combination of wireless operating mode and associated exposure condition (SAR test position or distance)

Note 1 to entry: Algorithm validation is performed using the test configurations defined by the DPC-ETA power control parameters.

3.28.1

default test configuration

test configurations that are tested for algorithm validation according to the selection criteria described in this document

Note 1 to entry: Other test configurations that need testing according to regulatory policies or other device operating requirements can be selected using the "additional test configuration" criteria described in this document.

3.29

device under test

DUT

device containing one or more wireless transmitters or transceivers that is tested according to the methods of this document

3.30

DPC-ETA tolerance

T_c

aggregate of all tolerances that are relevant for DPC-ETA operations

Note 1 to entry: For algorithm validation, all tolerances that are relevant for DPC-ETA operations are considered. The tolerance for maximum output power is normally considered for SAR compliance by scaling the measured SAR to the maximum output power allowed by the tune-up specifications. This tolerance for SAR compliance includes all DPC-ETA tolerances and other relevant tolerances, such as algorithm performance, TxAGC (transmitter automatic gain control), and device-to-device and production variations. These tolerances can be specified and established differently for products from different manufacturers. The tolerances of interest can vary with regulatory policies. The power control parameters used by the algorithm validation procedures in this document are considered with respect to the specified, nominal, and measured values, according to tolerances allowed by the P_{limit} and SAR_{target} of a test configuration.

4 Symbols and abbreviated terms

4.1 Physical quantities

The International System of Units (SI) is used throughout this document.

Symbol	Quantity	Unit	Dimensions
P	power	watt	W
SAR	specific absorption rate	watt per kilogram	W/kg

4.2 Abbreviated terms

3GPP	3rd Generation Partnership Project
5G	fifth generation
CA	carrier aggregation
CC	component carrier
CDMA	code division multiple access
DL	downlink
DUT	device under test
EDGE	Enhanced Data rates for GSM Evolution
EN-DC	E-UTRA New Radio Dual Connectivity
E-UTRA	Evolved UMTS Terrestrial Radio Access (3GPP)
FDD	frequency division duplexing
FR1	Frequency Range 1 (3GPP 5G NR) ²
GPIO	general purpose interface bus
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
LTE	Long Term Evolution
MIMO	multiple input multiple output
NR	New Radio (3GPP)
NR DPS	New Radio Dynamic Power Sharing
NR EPS	New Radio Equal Power Sharing
NR NSA	New Radio Non-standalone
NR SA	New Radio Standalone
OEM	original equipment manufacturer
OTA	over the air
PC	personal computer
psSAR	peak spatial-average SAR
RAT	radio access technology
RCT	radio communication tester
RF	radio frequency
SAR	specific absorption rate
TDD	time division duplexing
TDMA	time division multiple access
TER	total exposure ratio
TxAGC	transmitter automatic gain control
UMTS	Universal Mobile Telecommunications System
UL	uplink
WCDMA	wideband code division multiple access
WLAN	wireless local area network

² 3GPP 5G NR FR1 presently spans 410 MHz to 7 125 MHz; before 2019 FR1 was 450 MHz to 6 000 MHz, sometimes informally called "5G sub-6 GHz."

5 Dynamic power control and exposure time-averaging implementation operation descriptions

5.1 General

RF modem chipset-based DPC-ETA implementations are used by wireless devices to mitigate the conservative SAR measured with existing methods. It enables a device to dynamically manage the output power of one or more transmitters. The power recorded by the RF modem is applied according to the linear SAR to power relationship of a specific wireless configuration and exposure condition to ensure SAR compliance in real-time for a time-averaging window specified by the applicable SAR limit or regulatory policies. Either a fixed or frequency dependent time-averaging window, up to six minutes, can be used. An overview of the DPC-ETA operating characteristics and configurable parameters supported by this document are described in 5.2 and 5.3.

5.2 General algorithm operation overview

The implementations considered in this document are based on 3GPP technologies, including simultaneous transmissions with multiple transmitters and antennas. Output power is managed by DPC-ETA in a controlled manner, over time, according to both instantaneous and time-averaged power to determine actual user exposure. Regardless of how the wireless network requests a transmitter to change output power, a DPC-ETA enabled device has built-in capabilities to accept network power change requests or limit power increases at the device level to ensure the maximum time-averaged power is not exceeded to ensure SAR compliance.

DPC-ETA is designed to operate seamlessly across transmission schemes, such as TDMA, TDD or FDD. For most implementations, other than the power control parameter and time-averaging window values, the same DPC-ETA algorithms are applied across all wireless modes, frequency bands and transmission configurations controlled by the RF modem chipset. When identical hardware and firmware are used, the configurations that need validation can be reduced.

The power control parameters in 5.3 are established according to the SAR and power relationship of wireless operating modes and exposure conditions. It is typical for DUTs to operate at power levels based on nominal specifications according to a defined tune-up tolerance. The measured SAR is scaled to the tune-up tolerance limit to determine compliance. The DPC-ETA power control parameters stored in DUTs are based on nominal values. The actual parameters used by the device can deviate from the stored nominal values, but within the DPC-ETA tolerance (T_c). SAR compliance is ensured if reported SAR ($SAR_{reported}$) is less than the RF exposure limit specified by the regulator. The power measured during algorithm validation is normalized to the measured P_{limit} ($P_{limit,m}$) (see 5.3.2 b)) to correlate measured responses with the expected DPC-ETA behaviour of the implementation. The tolerances generally include both power independent and power dependent components, where the power independent tolerances are expected to be mostly cancelled out in the normalization process. The remaining tolerances can result in the normalized ratios exceeding 1,0. To ensure DPC-ETA operates within the tolerances supported by the $P_{limit,m}$, the procedures described in 6.10 are applied to ensure the normalized ratios calculated from the measured nominal values remain within the tolerance range for the P_{limit} and corresponding SAR_{target} used for the wireless mode.

NOTE Tune-up tolerance is the range of variations allowed for the maximum nominal output power in a wireless operating mode.

5.3 Configurable parameters

5.3.1 General

DPC-ETA parameters vary with each combination of wireless operating mode, frequency band, exposure condition or test distance, and antenna configuration; they are instantaneous maximum power ($P_{\max}$), maximum time-averaged power (P_{limit}), intermediate or optional output power threshold (P_{ctrl}), SAR target (SAR_{target}) and time-averaging window ($T_{w_{\text{avg}}}$). All relevant tolerances that can influence DPC-ETA operations are considered in DPC-ETA tolerance (T_c) and they are included in the power control parameters to determine the specified values. For example, if there is no tolerance for $P_{\max}$, P_{limit} , and P_{ctrl} , etc., the exact values would be used as the specified and measured parameters for algorithm validation. When tolerances are applied to the parameters, the nominal values would be lower than the specified values by the DPC-ETA tolerance T_c ; therefore, for the purposes of algorithm validation, specified values correspond to the maximum values including tolerances. In this document, the specified parameters with all relevant tolerances included are used to determine the power levels in test sequences sent by the RCT to ensure the power control restrictions, e.g. associated with P_{limit} , can be triggered for algorithm validation. The nominal parameters stored in the device during production are applied by DPC-ETA for power control according to the allowed tolerances. The power measured for the parameters used by a device is expected to remain within the DPC-ETA tolerance of nominal values. The measured SAR associated with measured P_{limit} is scaled to the minimum of specified P_{limit} and specified $P_{\max}$ (minimum ($P_{\text{limit,specified}}$, $P_{\max,\text{specified}}$)) to determine SAR_{reported} . SAR compliance is demonstrated if the SAR_{reported} is less than the RF exposure limit specified by the regulator. The measured power is normalized by the $P_{\text{limit,m}}$, based on nominal values, to compare and correlate DPC-ETA responses. The normalization tolerance is determined according to the tolerances allowed by the SAR_{target} associated with the $P_{\text{limit,m}}$ (see 6.10). Since the values of specified parameters with tolerance included are higher than the nominal values and DPC-ETA operates according to nominal parameters stored in the device, normalizing measured results by the $P_{\text{limit,specified}}$ can lead to lower ratios due to unintended offsets in the normalization.

In general, the tolerances applicable to the power control parameters include both power independent and power dependent components. For example, TxAGC tolerance generally varies with power and can be specified either separately or included in the tune-up tolerance by the manufacturer. When SAR is measured at a fixed power level, TxAGC tolerance is generally not of significant concern. For DPC-ETA algorithm validation, varying power levels are used in the test sequences. When the measured power is normalized by the $P_{\text{limit,m}}$, the power independent tolerance components are expected to mostly cancel out in the ratio. However, the power dependent components, such as TxAGC tolerance, are expected to influence the calculated ratios. When the time-averaged power is near P_{limit} , the power dependent tolerances can result in normalized ratios $> 1,0$. For lower normalization ratio values, the tolerance can also introduce discrepancies for correlating measured responses with the expected algorithm behaviour. Therefore, the worst-case TxAGC tolerance across all relevant power levels is applied. The procedures in 6.10 are applied to ensure the highest value of the normalized ratio in a test configuration is within the tolerance range supported by the $P_{\text{limit,m}}$ and associated SAR_{target} .

NOTE 1 The relevant device tolerances that can influence algorithm validation (for example, tune-up, TxAGC, algorithm design and operation, device-to-device or production tolerances, and measurement tolerances) would need consideration. Comprehensive uncertainty analyses are not addressed in this document due to DPC-ETA implementation specifics that are typically unavailable to the users (test laboratories), and because device manufacturers can use different tolerance criteria. The relevant algorithm validation and measurement tolerances ($k = 1$) described in this document are applied directly to the measured results in accordance with regulatory requirements.

All parameters ($P_{\max}$, P_{limit} and P_{ctrl}) measured for a DUT cannot exceed the specified values for the algorithm validation results to be valid. When the measured results are normalized by an unstable or incorrect P_{limit} value due to DUT or measurement tolerance concerns, it can also introduce unintended biases and inconsistent results (e.g. normalized ratio $> 1,0$). It is important to ensure that all values of $P_{\text{limit},m}$ are accurate and reliable (see A.2.9 for P_{limit} measurement requirements).

NOTE 2 Depending on the DPC-ETA implementation, regulatory policies can require specific tolerance considerations for algorithm validation.

5.3.2 DPC-ETA power control parameters applicable to existing implementations

The DPC-ETA power control parameters applicable to existing implementations are described in the following list. These configurable parameters can be initiated by network conditions or be triggered by host device operating requirements.

- a) $P_{\max}$ is the maximum instantaneous output power; it is the maximum output power a transmitter can sustain at any instant. The measured $P_{\max}$ ($P_{\max,m}$) cannot exceed the specified $P_{\max}$ ($P_{\max,\text{specified}}$) while remaining within the tolerance range of SAR_{target} .
- b) P_{limit} is the maximum time-averaged output power across the time-averaging window ($T_{w,\text{avg}}$). The $P_{\text{limit},m}$ is based on the nominal value and a specified tolerance range established by the SAR_{target} for devices (i.e. $\leq SAR_{\text{reported}}$) to ensure all operations remain SAR compliant. The $P_{\text{limit},m}$ cannot exceed the $P_{\text{limit},\text{specified}}$, which is the highest time-averaged power level allowed for continuous use when DPC-ETA is active.

NOTE 1 With items a) and b), for TDMA and TDD configurations, consistent use of slot-burst power and frame-average power for both $P_{\max}$ and P_{limit} avoids unintended duty factor offsets and incorrect normalization of measured responses due to mixing of power types used (see 6.10 and 7.5).

NOTE 2 With items a) and b), when the $P_{\text{limit},\text{specified}}$ is higher than $P_{\max,\text{specified}}$ for a wireless mode, DPC-ETA can become transparent and inactive because a transmitter is unable to operate above $P_{\max}$. Under such circumstances, the higher P_{limit} cannot be measured; therefore, $P_{\max}$ is used instead. Thus, SAR compliance is based on the $P_{\max,\text{specified}}$ (see 6.10 and A.2.6 for exceptions due to tolerances) as demonstrated using SAR_{reported} , obtained by scaling SAR_{target} to the corresponding minimum ($P_{\text{limit},\text{specified}}$, $P_{\max,\text{specified}}$). Because of tolerances associated with the nominal parameters ($P_{\max}$ and P_{limit}), the P_{limit} used by the device can become lower than the corresponding $P_{\max}$ and DPC-ETA can become active. Testing of such configurations can require additional guidance from the manufacturer, and in accordance with regulatory policies, to adjust the procedures of this document for algorithm validation.

- c) SAR_{target} is the 1 g or 10 g psSAR corresponding to the $P_{\text{limit},m}$ of a wireless operating mode and exposure condition. The SAR compliance results can be subject to further scaling to include all relevant tolerances for DPC-ETA operations. For algorithm validation, when P_{limit} is less than $P_{\max}$, SAR_{target} corresponds to the $P_{\text{limit},m}$; otherwise, SAR_{target} corresponds to the $P_{\max,m}$ (see 6.10 for normalization tolerance considerations). The SAR compliance is demonstrated using SAR_{reported} , obtained by scaling SAR_{target} to the corresponding minimum ($P_{\text{limit},\text{specified}}$, $P_{\max,\text{specified}}$).
- d) P_{ctrl} is an optional parameter in certain DPC-ETA implementations. It typically specifies the nominal power level for maintaining a sustained connection according to instantaneous or time-averaged power, or both, and DPC-ETA power control conditions. In some cases, multiple parameters can be used, for example, an optional threshold value (P_{ctrl}) and a fixed minimum power setting (P_{low}). These power levels need confirmation to ensure they are enforced by the algorithm according to the functionality of the implementation.

NOTE 3 When P_{ctrl} is not used at all, for the purposes of applying the DPC-ETA algorithm validation test sequences in Annex A, a value of $P_{\text{ctrl}} = P_{\text{limit}} - n \times (P_{\max} - P_{\text{limit}})$, with all values in dBm, is considered to configure the test sequences, with $n \leq 1$ and consistent with regulatory policies; for example, $n = 0,5$.

The preceding parameters can be named differently in individual implementations. The functionalities of each parameter are confirmed to be equivalent to those described above before applying this document for algorithm validation. The nominal parameters are generally stored in non-volatile memory of the device or RF modem, with no user access under normal use conditions, and used for algorithm validation measurements. The measured DPC-ETA parameters are reviewed and confirmed to remain within the tolerance range supported by the nominal values. Illustration of the output power characteristics of a simple DPC-ETA implementation is depicted in Figure 1.

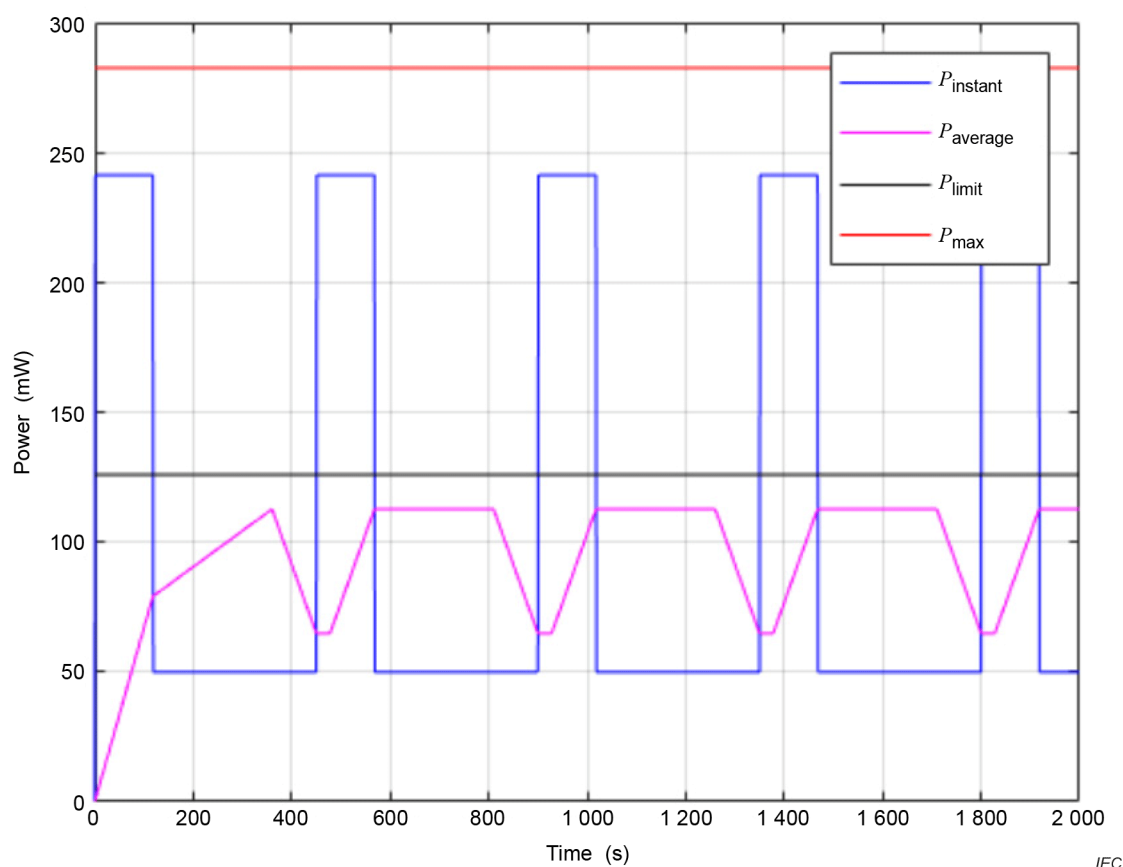


Figure 1 – Illustration of the output power characteristics of a simple DPC-ETA implementation

6 Algorithm validation considerations

6.1 General

SAR compliance and algorithm validation are evaluated independently to simplify the measurement requirements. The algorithm validation approach used in this document enables the SAR measurement procedures in IEC/IEEE 62209-1528:2020 [1] to be applied for compliance testing. SAR is measured at a fixed maximum time-averaged output power (see P_{limit} in 5.3) for continuous use and scaled to include all DPC-ETA tolerances and other relevant tolerances to determine compliance. For algorithm validation, the relevant tolerances, such as algorithm performance, design, device-to-device or production variations, and certain power dependent tolerances that are included in the SAR measurement, also need consideration according to regulatory requirements to determine the specified power control parameter values. The measured DPC-ETA parameters that are based on nominal values stored in the DUT cannot exceed the specified parameters while remaining within the range of tolerance for the nominal values in the wireless mode configurations. DPC-ETA enables a device to operate for short durations with instantaneous power higher than P_{limit} , up to P_{max} , while continuously ensuring compliance with time-averaged SAR over a specified time-averaging window ($T_{w_{\text{avg}}}$) and remains within the tolerance allowed by the SAR_{target} (i.e. $\leq SAR_{\text{reported}}$) and P_{limit} (i.e. $\leq P_{\text{limit,specified}}$).

6.2 DPC-ETA algorithm validation criteria

While the algorithms can differ among chipset vendors, applying the procedures outlined within this document requires that operating characteristics are based on the power control parameters described in this document. The range of values used for the parameters are expected to vary according to the SAR and power relationship of the wireless modes, exposure conditions, frequency bands, and antenna locations.

A practical approach for algorithm validation is to identify the combinations of test configurations, according to the range of power control parameters in 5.3, to validate algorithm functionality in the wireless modes, exposure conditions and network operating configurations with power control test sequences. The DPC-ETA parameters are established according to SAR compliance measurement results and DPC-ETA tolerances for the applicable wireless operating modes and exposure conditions. SAR is determined in real-time based on power measured by the RF modem to adjust device output power and ensure compliance. Closed loop power control is applied by DPC-ETA according to the established power control parameters, where power control functionality is influenced by the range (spread) and offset of these parameters among the wireless modes. When the same identical algorithm is used across all wireless configurations and radio access technologies (RATs), selecting the more conservative combinations of power control parameters used among the wireless configurations and exposure conditions for algorithm validation would optimize the testing requirements. When variations or exceptions are applied to certain wireless configurations, these are identified to determine if additional validation would be necessary.

6.3 SAR linearity

The measured SAR is associated with a specific power level in a separate process that is independent of the SAR measurement. This requires the same output power condition to be maintained for both SAR and power measurements. The measured SAR with a device coupled to a phantom at maximum output power condition is associated with the conducted power measured at the antenna port, also at maximum output conditions. It has been demonstrated and accepted that a linear relationship applies between SAR and power for a specific wireless operating configuration and exposure condition. Linearity is important for SAR compliance results to be scalable with power and for DPC-ETA power control. The tolerances of power dependent parameters, such as transmitter automatic gain control (TxAGC), can be fully accounted for according to the worst-case value across all relevant power levels to establish power control parameters for ensuring the tolerances for SAR and P_{limit} are always maintained. The measurement equipment non-linearity associated with signal modulation is accounted for in SAR probe calibration and therefore mitigated, and device output compression is addressed by 3GPP conformity testing requirements; therefore, the impact from these is expected to be insignificant.

6.4 Test sequences

Two types of test sequences are used for algorithm validation. Quasi-static test sequences are applied to verify fundamental algorithm operations and transitions across wireless modes, frequency bands and conditions with different P_{max} and P_{limit} or $T_{w\text{avg}}$. Dynamic test sequences with varying output power and time intervals in the power requests are used to confirm DPC-ETA operation in a dynamic manner. Both types of test sequences are applicable and relevant for algorithm validation. Quasi-static test sequences are used to validate all test configurations. Dynamic test sequences are more complex, which can require certain interpretations to correlate measured results with expected algorithm behaviour; therefore, these are mainly used in selected test configurations. The test sequences described in Annex A are considered for algorithm validation.

NOTE 1 When other test sequences are required by national regulations, algorithm validation is performed according to those regulatory requirements.

A test sequence can include multiple wireless modes and test configurations to verify similar or related DPC-ETA operating conditions, sequentially in a single test to streamline the algorithm validation testing process. For transitional operations across wireless modes or frequency bands, different P_{max} , P_{limit} , P_{ctrl} and $T_{w\text{avg}}$ values can apply. The power control parameters before and after each transition are both verified by the measured power. The DPC-ETA parameters are typically triggered by normal network operating conditions, similar to those in test sequences sent from the RCT for algorithm validation. However, a device can support host-managed triggering, such as sensing mechanisms or other host-controlled conditions, for the device to initiate DPC-ETA power control parameter changes for different exposure conditions (e.g. distance or position) or requirements imposed by transmitters not controlled by DPC-ETA. When a configuration has already been considered for validation, the DPC-ETA parameters in host-managed configurations can be confirmed by power measurement or other suitable means to minimize further testing. Other than identifying the relevant testing concerns and providing general recommendations, specific test sequences are not considered for the following:

- a) DPC-ETA transitions triggered by changes in antenna configurations; for example, transmit diversity (see 7.8) or dynamic antenna tuning implementations;
- b) DPC-ETA transitions triggered by conditions managed by the host device; for example, changes in exposure conditions detected by sensors (see 7.7);

NOTE 2 The dynamics of DPC-ETA do not apply to semi-static or duty factor-based power control with proximity sensor or similar mechanisms where the procedures in IEC/IEEE 62209-1528:2020 [1] are applicable.

- c) power-up, fail-safe and malfunctioning (see 6.13).

NOTE 3 As DPC-ETA responses at power-up and during fail safe/malfunctioning or other device specific conditions are generally design dependent, additional validation can be required by national regulations.

6.5 Power measurement

DPC-ETA responses to power control test sequences are recorded by conducted power, radiated power or SAR measurements. Conducted power is measured at the DUT antenna port, radiated power is measured with the device operating in a suitable size anechoic chamber (see B.9.2) and SAR is measured with the device operating beside the phantom (see Annex F). The same measurement equipment can be used for conducted and radiated power measurements. The test setup also applies to the transitional and simultaneous transmission configurations.

All algorithm validation configurations are tested with quasi-static test sequences using conducted power measurement. Conducted power measured at the antenna port is not influenced by the host device or antenna. Provided the same RF hardware is used between the RF modem and antenna port, conducted power is independent of host device configurations or antenna. Introducing the host device, antenna, and path loss (free space in radiated setup, tissue simulating liquid in SAR measurement setup) possibly does not impact the dynamic power control at the antenna port. Host device and antenna influence the relationship between SAR_{target} and P_{limit} , which is fixed for a given host configuration, antenna, transmitting frequency, exposure condition and separation distance. Therefore, DPC-ETA functionality can be validated in any one setup, i.e. either in conducted power measurement setup (time-averaged conducted power $\leq P_{limit,specified}$), or in radiated power measurement setup (time-averaged radiated power $\leq$ radiated power corresponding to $P_{limit,specified}$), or in SAR measurement setup (time-averaged SAR $\leq SAR_{reported}$). These measurement setups are validated using a known source prior to performing DPC-ETA validation. Equivalency between these setups and correlation between radiated measurement setup and SAR measurement setup is described in Annex D. The general configurations of measurement equipment, test setup and power measurement accessories, such as directional couplers, combiner/splitters, circulators, and filters are described in Annex B. The SAR measurement methods are described in Annex F.

NOTE National regulations can require confirming DPC-ETA functionality in more than one setup.

6.6 Measurement rate

The power change requests in real networks can be up to 1 500 updates per second for UMTS and 1 000 updates per second for LTE. Because of test setup constraints it would be impractical to apply power-change requests more often than once every few seconds for algorithm validation. Coordination of the test equipment, such as power meters, RCTs and associated automation process, is important to record time-aligned power requests and measured responses. An appropriate power measurement rate for DPC-ETA algorithm validation, Tp_{avg} , is applied to record the expected DPC-ETA behaviour before, during and after each power transition in the test sequences. Instead of the power update rates used by the network, the external power measurement sampling rate (Tp_{avg}) of the power meter or spectrum analyser would only need to be sufficient for recording the transitions in the test sequences with an accepted time resolution for correlating DPC-ETA behaviour with measured responses and power requests. The measurement rate is determined by the shortest transitions in the dynamic power control test sequences. It has been determined that $Tp_{avg} \leq 0,1$ s is applicable for measurements with the quasi-static and dynamic test sequences described in this document. This is less than 0,2 % of the 50 s to 360 s time-averaging window durations currently specified by SAR limits and regulatory policies. When multiple Tw_{avg} values are used in test configurations involving multiple frequency bands during simultaneous transmission, the value of Tp_{avg} used in the measurements is set to a multiple of the corresponding Tw_{avg} values to synchronize time-averaging calculations across Tw_{avg} windows; for example, 0,1 s is a multiple of 50 s, 60 s, 100 s, or 360 s time windows. For the purposes of the procedures in this document, a periodic and fixed power measurement rate is applied throughout a measurement, to ensure consistency in calculating time-averaged power by simple summation and averaging. Otherwise, each measured power is time integrated over the corresponding Tp_{avg} before summing over Tw_{avg} and then divided by Tw_{avg} to determine time-averaged power (i.e. $\sum (P_i \times Tp_{avg,i}) = P_{avg} \times Tw_{avg}$). This applies when a consistent Tp_{avg} is not maintained due to equipment coordination in the measurement automation. The time-averaging of measured power according

to a periodic or fixed $T_{p_{avg}}$ in the measurement implies that simple averaging is applied to correlate results and maintain consistency in applying acceptance criteria.

NOTE In the determination of $T_{p_{avg}} \leq 0,1$ s, the 0,1 s is an example and longer measurement intervals can be applied according to regulatory policies and system validation results, with typical recommendation for much less than 1 s. Also, SAR methods described in Annex F can require longer measurement intervals depending on the SAR system (for example, scanning probe or sensor array systems).

The time-averaging scheme used in the RF modem can differ from regulatory requirements. Depending on regulatory policies, independent post-processing can be applied to calculate time-averaged power using a specific averaging scheme, instead of the variant used in the RF modem. Since post-processing of measured results does not change the power control behaviour, this would not be equivalent to using values recorded and applied by the device for feedback and power adjustments. When applicable, regulatory guidance can also allow correction factors to be applied for using specific averaging schemes.

6.7 Measurement automation

Time alignment between power requests initiated by the RCT and measured power samples is done for correlating power change requests and DPC-ETA responses. Operating the tests manually can be difficult and is not supported by the procedures in this document. Test automation enables all operations to be recorded with accurate time alignment. After program control of the test equipment and accuracy of the power recording and time-averaging process are validated to ensure the automation has been implemented correctly, a simple verification test or procedure with known results can be used to confirm the automated test setup, before validating a DUT.

6.8 DPC-ETA power control and time-averaging calculations during transitions

Quasi-static test sequences and conducted power measurement are used to verify transitional operations. Continuity of power control during transitions across wireless operating modes, frequency bands with the same or different $T_{w_{avg}}$, exposure/use conditions, and any other conditions where different P_{max} or P_{limit} , or both are specified, is demonstrated during algorithm validation. Besides RF modem-initiated transitions, DPC-ETA implementations that support host device-initiated transitions triggered by sensors, or other conditions determined by the host, are also considered for algorithm validation. During periods of discontinuous transmissions or conditions initiated by host device triggered DPC-ETA transitions, both instantaneous and time-averaged power are verified before and after the transition, according to the corresponding power control parameters and time-averaging window.

For transitional operations that involve different time-averaging windows, the time-averaging procedures applied are verified during algorithm validation. Regardless of how time-averaging is performed by the DPC-ETA algorithm in the DUT, for algorithm validation the same criteria are used to calculate time-averaged power from measured responses across transitions with different $T_{w_{avg}}$. This ensures results are processed consistently according to the same time-averaging criteria, to avoid validation acceptance discrepancies due to post-processing variations across measurement systems used by test laboratories.

When transitioning across test configurations, such as during handover, discontinuous transmission, call drop or frequency bands with different $T_{w_{avg}}$, the following are applied to ensure time-averaging is calculated consistently across a transition. For handover or frequency band switching, a connection to the next wireless mode is established before the previous configuration is disconnected. This allows a seamless transition without a transmission gap. However, a short transmission gap can be introduced for call drops and discontinuous transmissions or due to RCT configuration requirements. These are considered according to the correct $T_{w_{avg}}$ values.

Time-averaged power is calculated at the power measurement rate of $T_{p_{avg}}$. Each time power is measured, time-averaged power is calculated according to $T_{w_{avg}}$. For example, with $T_{p_{avg}} = 0,1$ s and $T_{w_{avg}} = 100$ s, 1 000 power measurement samples are time-averaged at 0,1 s intervals. Each measurement sample is scaled by 1/1 000 and then summed to determine the time-averaged power. For $T_{w_{avg}} = 60$ s, the measurement samples are scaled by 1/600. If there is a transmission gap, it is considered as part of the initial segment before the next segment is applied. When different $T_{w_{avg}}$ apply, time-averaged power across the transmission gap is calculated using the initial $T_{w_{avg}}$ until the next connection is established. For example, when transitioning from $T_{w_{avg}} = 100$ s to $T_{w_{avg}} = 60$ s, with a transmission gap in between, the gap is time-averaged according to a 100 s window. When transitioning from one $T_{w_{avg}}$ to a different $T_{w_{avg}}$, power measurement is separated into two segments of power measurements:

- first power measurement versus time corresponds to the first $T_{w_{avg}}$ where the measured power is zero after the transition (i.e. in Formula (1): $P_{tx1}(t) = 0$ or $t >$ transition time);
- second power measurement versus time corresponds to the second $T_{w_{avg}}$, where the measured power is zero before the transition (i.e. in Formula (1): $P_{tx2}(t) = 0$ or $t >$ transition time).

The integral in Formula (1) is converted in summation in Formula (2) for discrete power measurement rate of $T_{p_{avg}}$. These two power measurement samples are scaled by corresponding $T_{p_{avg}}/T_{w_{avg}}$ (e.g. $1/N1 = 1/1\ 000$ for 100 s $T_{w_{avg}}$, $1/N2 = 1/600$ for 60 s $T_{w_{avg}}$), then power measurement samples are summed, and normalized to the applicable P_{limit} in each segment of the transition to obtain time-averaged normalization ratio versus time for each segment. Then, both segments are summed versus time to verify that the aggregate time-averaged normalization ratio (i.e. $\max(R)$ in Formula (1) and Formula (2)) is within the tolerance.

$$R(t) = \frac{1}{T_{w1_{avg}}} \int_{t-T_{w1_{avg}}}^t \left[\frac{P_{tx1}(t)}{P_{limit1,m}} \right] dt + \frac{1}{T_{w2_{avg}}} \int_{t-T_{w2_{avg}}}^t \left[\frac{P_{tx2}(t)}{P_{limit2,m}} \right] dt \quad (1)$$

where

- $R(t)$ is the exposure ratio as function of time;
- $T_{w1_{avg}}$ is the time-averaging window for transmission 1, expressed in seconds;
- $T_{w2_{avg}}$ is the time-averaging window for transmission 2, expressed in seconds;
- $P_{tx1}(t)$ is the (conducted) power for transmission 1, expressed in watts;
- $P_{tx2}(t)$ is the (conducted power for transmission 2, expressed in watts;
- $P_{limit1,m}$ is the measured maximum time-averaged power for transmission 1, expressed in watts;
- $P_{limit2,m}$ is the measured maximum time-averaged power for transmission 2, expressed in watts.

$$R(i) = \frac{1}{N1} \sum_{i-N1+1}^i \left[\frac{P_{tx1}(i)}{P_{limit1,m}} \right] + \frac{1}{N2} \sum_{i-N2+1}^i \left[\frac{P_{tx2}(i)}{P_{limit2,m}} \right] \quad (2)$$

Since the measured SAR_{target} can be different between transmitters before and after transition, the normalization ratio in Formula (2) can be scaled by $SAR_{\text{target}}/SAR_{\text{limit}}$ to determine time-averaged SAR normalized to the SAR_{limit} ($SAR_{\text{avg,norm}}$) as shown in Formula (3). Formula (3) can be used for any transitional cases (see Clause 7), including when Tw_{avg} is the same before and after transition (i.e. $N1 = N2$) and for simultaneous transmission configurations.

$$SAR_{\text{avg,norm}}(i) = \frac{1}{N1} \sum_{i=N1+1}^i \left[\frac{P_{\text{tx1}}(i)}{P_{\text{limit1,m}}} \times \frac{SAR_{\text{target1,m}}}{SAR_{\text{limit1}}} \right] + \frac{1}{N2} \sum_{i=N2+1}^i \left[\frac{P_{\text{tx2}}(i)}{P_{\text{limit2,m}}} \times \frac{SAR_{\text{target2,m}}}{SAR_{\text{limit2}}} \right] \quad (3)$$

SAR compliance can be verified using Formula (4).

$$\max(SAR_{\text{avg,norm}}(i)) \leq \max \left(\frac{SAR1_{\text{reported}}}{SAR_{\text{limit1}}}, \frac{SAR2_{\text{reported}}}{SAR_{\text{limit2}}} \right) \quad (4)$$

When algorithm validation for simultaneous transmission involves adding and removing wireless configurations with different Tw_{avg} , each transmission is considered separately according to criteria described above (also see 7.6). The different P_{max} and P_{limit} values used in the wireless modes are applied to satisfy maximum aggregate power requirements for DPC-ETA power control and SAR compliance; for example, transitioning from LTE to 5G NR NSA (see 7.6.2).

For simultaneous transmission analysis with radios not controlled by the DPC-ETA algorithm (for example, WLAN+WWAN compliance where only WWAN operations use DPC-ETA power control), additional consideration for simultaneous transmission SAR compliance is generally unnecessary during algorithm validation. The measured SAR values of simultaneous transmission configurations are scaled, either separately or as an aggregate (in a volume scan), with tolerances included, and the DPC-ETA power control parameters are established based on the SAR compliance results. Ensuring power control and time-averaging calculations across transitions are within the tolerance allowed by the measured P_{limit} and corresponding SAR_{target} is sufficient for algorithm validation.

6.9 Test reduction

Depending on the DPC-ETA implementation, when the same power control algorithm is used for all wireless operating modes and frequency bands, validation can be performed only for a subset of these configurations, upon demonstration or justification of algorithm operation independence across wireless configurations and frequency bands. In addition, validation of algorithm continuity across discontinuous transmissions, transitions due to host device triggered power control changes or other similar configurations can be streamlined when such operations are also independent across wireless modes and frequency bands.

6.10 Normalization of measured power

All power measurement results are normalized to the maximum measured time-averaged power ($P_{\text{limit,m}}$) as shown in Formula (5), for continuous operation, according to the time-averaging window (Tw_{avg}) to correlate measured responses across wireless modes, frequency bands and transitional configurations. Normalized power $P_{\text{norm}}(t)$ in Formula (5) is time-averaged over Tw_{avg} as shown in Formula (6), and the highest of this ratio R_{max} (see Formula (7)) is verified to be within the DPC-ETA tolerance Tc as part of algorithm validation.

$$P_{\text{norm}}(t) = \frac{P_{\text{tx}}(t)}{P_{\text{limit,m}}} \quad (5)$$

$$R(t) = \frac{1}{Tw_{\text{avg}}} \int_{t-Tw_{\text{avg}}}^t P_{\text{norm}}(t) dt \quad (6)$$

$$R_{\text{max}} = \max(R(t)) \quad (7)$$

$$P_{\text{tx}}(Tw_{\text{avg}}) = R_{\text{max}} \times P_{\text{limit,m}} \leq P_{\text{limit,specified}} \quad (8)$$

The measured power for test sequences cannot exceed the $P_{\text{max,specified}}$ and the time-averaged power cannot exceed the $P_{\text{limit,specified}}$ for the Tw_{avg} used as shown in Formula (8). However, because of certain power dependent tolerance components that can cancel out in the normalization process, tolerance of the calculated ratios needs consideration, especially when ratios become higher than 1,0 or outside the tolerance range allowed by the SAR_{target} . When the measured instantaneous power is higher than P_{limit} , the number of such occurrences, in conjunction with the power dependent tolerances, can result in somewhat higher calculated ratios. Since the power level of P_{limit} is used in all test sequences for this document, the highest of the ratios (see Formula (7) for R_{max}) in a test configuration is used to ensure all ratios are within the tolerance range allowed by P_{limit} (i.e. $\leq P_{\text{limit,specified}}$) and SAR_{target} (i.e. $\leq SAR_{\text{reported}}$).

The power dependent tolerances (e.g. TxAGC) for the test device and, if applicable, power measurement equipment (range and calibration) possibly do not fully cancel out in the normalization process. In addition, certain tolerances, such as device-to-device variations or other production variations, can be addressed or characterized differently across manufacturers and regulatory requirements. All tolerances that are relevant to DPC-ETA algorithm validation need consideration. After the tolerances for algorithm validation are identified, according to manufacturer and regulatory requirements, these are aggregated into the single parameter Tc , and applied to ensure the normalized ratios are within the tolerance range allowed by the SAR_{target} (i.e. $\leq SAR_{\text{reported}}$) of a test configuration.

NOTE 1 The tolerances included in Tc are determined according to both the $P_{\text{max,specified}}$ and $P_{\text{limit,m}}$ of the wireless test configurations.

To avoid potential confusion in simultaneous transmission configurations where both the normalization ratio and total exposure ratio (TER) are used, where tolerance is generally not applicable to TER, RF modem manufacturers have recommended that the normalization ratio is scaled by $SAR_{\text{target}}/SAR_{\text{limit}}$, to further distinguish this from TER and to minimize potential misinterpretation of test results. Formulas (5), (6) and (8) scaled by $SAR_{\text{target}}/SAR_{\text{limit}}$ are represented by Formulas (9), (10) and (11), respectively.

$$SAR_{\text{norm}}(t) = \frac{P_{\text{tx}}(t)}{P_{\text{limit,m}}} \times \frac{SAR_{\text{target,m}}}{SAR_{\text{limit}}} \quad (9)$$

$$SAR_{avg,norm}(t) = \frac{1}{Tw_{avg}} \int_{t-Tw_{avg}}^t SAR_{norm}(t) dt \quad (10)$$

$$\max(SAR_{avg,norm}(t)) = \max\left(R_{max} \times \frac{SAR_{target,m}}{SAR_{limit}}\right) \leq \frac{SAR_{reported}}{SAR_{limit}} \quad (11)$$

The use of 1,0 as a nominal ratio or a scaled ratio to determine the tolerance range allowed by SAR_{target} are equivalent and can be applied in accordance with regulatory policies. In the following, consistent use of nominal (stored) and measured values of P_{max} and P_{limit} is determined by regulatory requirements. $SAR_{target,norm}$ is the corresponding SAR_{target}/SAR_{limit} , and R_{max} is the highest ratio calculated from the measured time-averaged power and $P_{limit,m}$ of a test configuration.

- a) Regardless of whether the nominal (stored) or measured values of P_{max} and P_{limit} are used, T_c represents the aggregate of all DPC-ETA relevant tolerances. For ratios scaled by normalized SAR target, $SAR_{target,norm} = SAR_{target}/SAR_{limit}$, the following conditions apply.

- 1) When $P_{limit} < P_{max}$:

$SAR_{target,norm} \times (1,0 - T_c) < (R_{max} \times SAR_{target,norm}) < \text{minimum}(SAR_{target,norm} \times (1,0 + T_c), SAR_{reported}/SAR_{limit})$ applies.

This situation generally corresponds to the normal DPC-ETA operating conditions.

For example, if $SAR_{target} = 1,2$ W/kg, $SAR_{limit} = 1,6$ W/kg, $SAR_{reported} = 1,52$ W/kg, $T_c = 26$ %, with $P_{limit} < P_{max}$ and $R_{max} = 1,07$, the adjusted ratio is $1,07 \times 0,75 = 0,8025$, which is within the range of $0,75 \pm 26$ % or $[0,56, 0,945]$. In this case, $T_c = 26$ % is approximately 1,0 dB ($k = 2$ standard deviations uncertainty); typical values of 0,9 dB ($k = 2$ std. dev. uncertainty) for TxAGC tolerance and 0,5 dB ($k = 2$ std. dev. uncertainty) for power independent and algorithm tolerances (root sum square of 23 % and 12 % = 26 %) are assumed. Device-to-device or production tolerances are not considered.

Alternatively, if $SAR_{target} = 0,8$ W/kg (e.g. to allow SAR margins for Wi-Fi), $SAR_{reported} = 1,04$ W/kg, for the same SAR_{limit} and T_c , but with $R_{max} = 0,70$; the adjusted ratio is $0,7 \times 0,5 = 0,35$, which is outside the range of $0,5 \pm 26$ % or $[0,37, 0,63]$. Thus, this is not within the tolerance range (T_c) allowed by the SAR_{target} .

- 2) When $P_{max} < P_{limit} \leq P_{max} \times (1,0 + T_c)$:

$SAR_{target,norm} \times (1,0 - T_c) < (R_{max} \times SAR_{target,norm}) < \text{minimum}(SAR_{target,norm} \times (1,0 + T_c), SAR_{reported}/SAR_{limit})$ applies, as $SAR_{reported}$ corresponds to minimum ($P_{limit,specified}, P_{max,specified}$). This is the condition when $P_{limit} > P_{max}$ by less than T_c , where DPC-ETA can become active due to tolerances. It is applied when algorithm validation testing is performed for this condition according to regulatory policies.

- 3) When $P_{limit} \geq P_{max} \times (1,0 + T_c)$:

$(R_{max} \times SAR_{target,norm}) \leq SAR_{reported}/SAR_{limit}$ applies. This is the condition when $P_{limit} > P_{max}$ by more than T_c , where DPC-ETA is expected to be inactive. It is applied when algorithm validation testing is performed according to regulatory policies to address specific algorithm implementation concerns.

NOTE 2 Power cannot be measured when $P_{limit} \geq P_{max}$. Manufacturer and regulatory guidance are used to determine the algorithm validation measurement requirements.

b) For ratios not scaled by $SAR_{\text{target,norm}}$, the following conditions apply.

1) When $P_{\text{limit}} < P_{\text{max}}$:

$(1 - T_c) < R_{\text{max}} < \text{minimum} \{(1, 0 + T_c), P_{\text{limit,specified}}/P_{\text{limit,m}}\}$ applies.

For example, if $T_c = 26\%$ and $P_{\text{limit}} < P_{\text{max}}$, with $R_{\text{max}} = 1,07$, this is within the range of $1,0 \pm 26\%$ or $[0,74, 1,26]$.

Alternatively, if $R_{\text{max}} = 0,70$, this is outside the range of $[0,74, 1,26]$. Thus, this is not within the tolerance range (T_c) allowed by the SAR_{target} .

2) When $P_{\text{max}} < P_{\text{limit}} \leq P_{\text{max}} \times (1, 0 + T_c)$:

$(1 - T_c) < R_{\text{max}} < \text{minimum} \{(1 + T_c), \text{minimum} (P_{\text{limit,specified}}, P_{\text{max,specified}})/P_{\text{limit,m}}\}$ applies.

3) When $P_{\text{limit}} \geq (P_{\text{max}} + T_c)$:

$R_{\text{max}} \leq P_{\text{max,specified}}/P_{\text{limit,m}}$ applies.

During transition test cases, there is a configuration before the transition and a configuration after the transition that can have different DPC-ETA parameters (P_{limit} , P_{max} , SAR_{target} , etc.). Before the transition, the above criteria are confirmed using the parameters of the initial configuration. Immediately after the transition and while still within $T_{w_{\text{avg}}}$ of the initial configuration, the above criteria are assessed with both configurations. R_{max} is calculated as shown in Formula (1). The maximum while considering both configurations is used as the acceptance criteria. After the transition and beyond $T_{w_{\text{avg}}}$ of the first configuration, the criteria are confirmed using the parameters of the second configuration.

Mixing of specified and measured parameters can introduce unintended offsets that can result in incorrect normalization ratios and render the algorithm validation invalid. In the procedures of this document, all measured results are normalized by the $P_{\text{limit,m}}$. In addition, the measured responses and the corresponding P_{limit} can be subject to power measurement tolerances, where the normalized ratios can be affected by small variations in measured results, especially P_{limit} (see A.2.9 for P_{limit} measurement considerations). In applying the measurement check procedures of Annex C, it is ensured that the $P_{\text{max,m}}$, $P_{\text{limit,m}}$, $P_{\text{ctrl,m}}$, $P_{\text{min,m}}$ are within the tolerance range allowed by P_{limit} . Taking power measurement tolerances into consideration, the calculated ratios of $P_{\text{max,m}}/P_{\text{limit,m}}$, $P_{\text{ctrl,m}}/P_{\text{limit,m}}$, and $P_{\text{min,m}}/P_{\text{limit,m}}$ can provide some indications of the power dependent tolerances when compared to ratios calculated from specified parameters. In addition, and if applicable, P_{ctrl} is also verified according to expected behaviour of the DPC-ETA implementation.

NOTE 3 When P_{max} and P_{limit} are measured with the same measurement setup used for the algorithm validation test configuration (wireless mode, conducted or radiated method, test sequence, and DPC-ETA parameters), where all attenuations in the measurement chain are the same for both P_{max} and P_{limit} , except for certain power dependent measurement tolerances, the attenuations are expected to mostly cancel out in the normalization.

For TDMA and TDD configurations, the P_{max} and P_{limit} used in the test sequences are based on slot-based burst power to match wireless protocol used in the RCT. However, to be consistent with power measurement equipment and the measurement rate ($T_{p_{\text{avg}}}$) used, frame-averaged power is measured. Provided burst-averaged and frame-averaged power are applied consistently on the network/RCT side and the measurement equipment (response) side, the duty factor cancels out and becomes transparent in the normalization process. Otherwise, erroneous results, due to unintended offsets from mixing frame-averaged and burst power in the normalization, would render the measurement results invalid.

6.11 Simultaneous transmission with other transmitters in host device

Simultaneous transmission of transmitters and antennas controlled by the RF modem is also managed by DPC-ETA. For devices with other transmitters that are not controlled by DPC-ETA and not addressed by this document, such as Wi-Fi and Bluetooth, simultaneous transmission is managed by the host device, according to the sum of the exposure ratios of the transmitters or other time-averaging and power control criteria. For such devices, the DPC-ETA controlled SAR levels are typically lowered, to provide a sufficient margin for the host device to ensure SAR compliance for simultaneous transmission.

NOTE Simultaneous transmissions are typically transmitted using separate antennas, therefore the SAR distributions possibly do not overlap and in this case they do not add up in the local sum of exposure ratios. In some cases, the SAR maximum is not co-located with the antenna; this is especially the case when the DUT chassis acts as radiator, typically at frequencies lower than 1 GHz.

6.12 Modular transmitter test platform

The power measurement methods described in this document can be applied to both standalone host products and modular transmitters incorporating DPC-ETA in the RF modem. A test platform representative of a typical host device is used to interface with a modular transmitter to perform DPC-ETA algorithm validation. A wide range of power control parameters, with varying offsets between the parameters, can be considered for conducted power measurement using a modular test platform. Conducted power measured at the antenna port is not influenced by the host device or antenna. Provided the same RF hardware is used between the RF modem and antenna port, conducted power is independent of host device configurations and, as appropriate, the results can be used to support multiple host devices that operate within the subset of conducted power measured for the DPC-ETA configurations. A representative antenna is used in a modular test platform to correlate radiated power and conducted power measurements according to normalized results. Regulatory policies can require independent radiated power measurements for individual host platforms or devices.

6.13 Power-up and fail-safe considerations

6.13.1 General

Power-up and fail-safe concerns can be addressed differently according to the design of an individual product, and regulatory requirements. Examples of how these can be addressed are provided in 6.13.2 and 6.13.3.

6.13.2 Power-up and reboot

When power records for the previous $T_{w_{avg}}$ are unavailable during power-up, reset, or reboot, conservativeness of DPC-ETA response and behaviour can need consideration. Under circumstances where multiple reboots can be applied in close succession, depending on the applicable $T_{w_{avg}}$, there can be a slight potential that time-averaged power would not be calculated correctly for brief moments. This is different than emerging from a prolonged period of discontinuous transmission, e.g. idle or sleep for longer than $T_{w_{avg}}$, where the power record of the previous $T_{w_{avg}}$ is possibly unavailable but is known to be zero.

During reboot, wireless protocols generally allow a higher than normally used output power, to ensure the initial connection can be reliably established with the network. Limiting device output power would be generally counter-productive, and can potentially result in longer and higher exposure, especially for a low P_{limit} . Therefore, it would be desirable to initiate any device-imposed power restriction immediately after a connection has been established during reboot, and DPC-ETA can assume P_{limit} has been reached before the reconnection; or according to other assumptions accepted by regulatory policies, to apply subsequent power control. If feasible, the ability of a device to record shutdown time can enable DPC-ETA to determine the last power off duration, to maintain DPC-ETA control continuity when the device is initialized at reboot.

6.13.3 Fail-safe and malfunctioning

Under circumstances when a device can malfunction and DPC-ETA functionality can be impacted, a conservative default power setting can be applied to ensure SAR compliance regardless of DPC-ETA conditions. Instead of prohibiting a device from operating, a default power setting based on the power level necessary to maintain SAR compliance for all relevant exposure conditions in the corresponding wireless modes can be considered for some non-critical malfunctions or failure conditions.

NOTE It would be helpful to report the conservative default power setting's power level in the test report, as well as implement in the compliance test DUT the possibility to enable and disable this power level.

7 Test sequence considerations

7.1 Basic algorithm validation with quasi-static test sequences

The basic DPC-ETA operations are verified in steady state with quasi-static power control test sequences. After it has been confirmed that each power step change has reached steady state for $0,2 \times T_{w_{avg}}$ or 20 s, whichever is smaller, the next power change is initiated. DPC-ETA responses are measured with conducted power for quasi-static test sequences. Radiated power measurement is applied only to selected test configurations. Correct test setup and measurement configurations are confirmed by correlated DPC-ETA responses, based on normalized results of the same test configuration and test sequence, for conducted power measured at the antenna port and radiated power measured in an anechoic chamber.

Depending on the intended power control functionality of the implementation, steady-state conditions are determined according to the operating characteristics of the algorithm. For example, if the output power can continue to oscillate within a narrow range when reaching steady state, it would require a longer duration to observe such conditions to establish an average value to determine the steady-state condition. In allowing the power control to reach steady state, the DPC-ETA responses are well defined with little to no ambiguity to correlate power requests with responses recorded by the power measurements. The quasi-static test sequence and test procedures are described in Clause A.3. The power levels in the test sequence are specified relative to P_{max} , P_{limit} , and P_{ctrl} to enable the same test sequence specification to be applied to wireless operating modes and frequency bands with different power control parameter values.

7.2 Dynamic test sequences for validation of rapid power changes

Under normal network conditions, a device can receive power control requests to increase or decrease power according to propagation characteristics and environmental conditions. In deeply faded conditions, the network can request a device to operate at maximum power (P_{max}). These power changes are often rapid and unpredictable. Depending on the time-averaged power calculated from power recorded by the RF modem, DPC-ETA can limit device output power to ensure P_{limit} and the allowed tolerances are not exceeded. The power adjustments made by DPC-ETA can be highly dependent on both instantaneous and time-averaged power over the time-averaging window. The power control is not expected to reach steady state.

An appropriately configured power control test sequence, with a sufficiently wide range of power step changes and varying time intervals, is applied to verify DPC-ETA behaviour in rapid power change conditions. In addition to using pre-configured power control test sequences, random test sequences with both the power amplitude and request interval modulated by random numbers are also considered to alleviate testing bias. The measured power is normalized, reviewed, and correlated with the expected behaviour of the DPC-ETA implementation according to power requests in the test sequence. The recommended dynamic test sequence and test procedures are described in Clause A.5.