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TECHNICAL REPORT

colour inside

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

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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

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IEC TR 63424-1 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
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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.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

- reconfirmed,
- withdrawn, or
- revised.

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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.

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[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
Tw_{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
Tc
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]
GPIB	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 (Tc). 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} ($P_{\text{limit,m}}$) (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 $P_{\text{limit,m}}$, 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 (Tw_{avg}). All relevant tolerances that can influence DPC-ETA operations are considered in DPC-ETA tolerance (Tc) 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 Tc; 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 ($P_{limit,specified}$, $P_{max,specified}$)) 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 $P_{limit,m}$, 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 $P_{limit,m}$ (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 $P_{limit,specified}$ 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 $P_{limit,m}$, 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 $P_{limit,m}$ 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 $P_{limit,m}$ 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} ($P_{max,specified}$) while remaining within the tolerance range of SAR_{target}.

b) P_{limit} is the maximum time-averaged output power across the time-averaging window (Tw_{avg}). The $P_{limit,m}$ is based on the nominal value and a specified tolerance range established by the SAR_{target} for devices (i.e. ≤ $SAR_{reported}$) to ensure all operations remain SAR compliant. The $P_{limit,m}$ cannot exceed the $P_{limit,specified}$, 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 $P_{limit,specified}$ is higher than $P_{max,specified}$ 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 $P_{max,specified}$ (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 ($P_{limit,specified}$, $P_{max,specified}$). 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 $P_{limit,m}$ 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 $P_{limit,m}$; 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 ($P_{limit,specified}$, $P_{max,specified}$).

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 $P_{ctrl} = P_{limit} - n \times (P_{max} - P_{limit})$, 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.

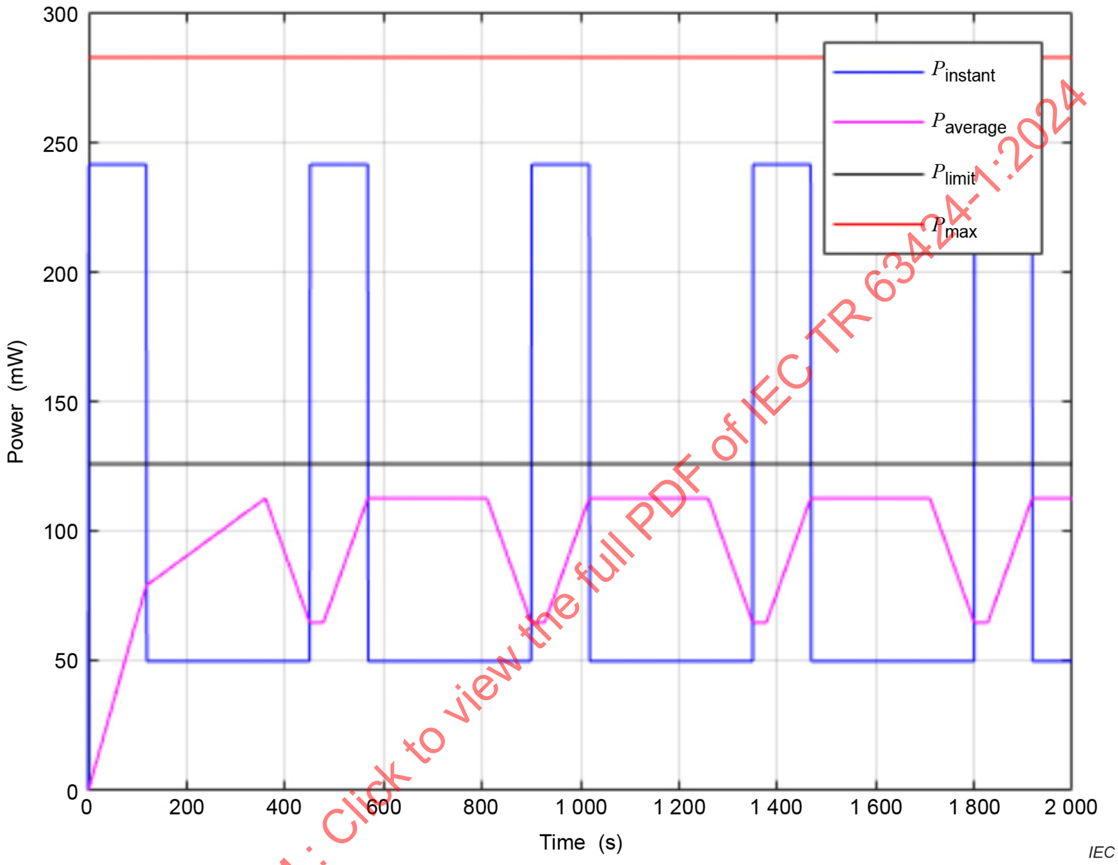

Figure 1 – Illustration of the output power characteristics of a simple DPC-ETA implementation

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 (Tw_{avg}) and remains within the tolerance allowed by the SAR_{target} (i.e. ≤ SAR_{reported}) and P_{limit} (i.e. ≤ $P_{\text{limit,specified}}$).

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 Tw_{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 Tw_{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 ≤ $P_{\text{limit,specified}}$), or in radiated power measurement setup (time-averaged radiated power ≤ radiated power corresponding to $P_{\text{limit,specified}}$), or in SAR measurement setup (time-averaged SAR ≤ 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} ≤ 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. $\sum (P_i \times Tp_{\text{avg},i}) = P_{\text{avg}} \times Tw_{\text{avg}}$). 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 Tp_{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 Tp_{avg} ≤ 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 Tw_{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 Tw_{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 Tw_{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 Tw_{avg} values.

Time-averaged power is calculated at the power measurement rate of Tp_{avg}. Each time power is measured, time-averaged power is calculated according to Tw_{avg}. For example, with Tp_{avg} = 0,1 s and Tw_{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 Tw_{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 Tw_{avg} apply, time-averaged power across the transmission gap is calculated using the initial Tw_{avg} until the next connection is established. For example, when transitioning from Tw_{avg} = 100 s to Tw_{avg} = 60 s, with a transmission gap in between, the gap is time-averaged according to a 100 s window. When transitioning from one Tw_{avg} to a different Tw_{avg}, power measurement is separated into two segments of power measurements:

– first power measurement versus time corresponds to the first Tw_{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 Tw_{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 Tp_{avg}. These two power measurement samples are scaled by corresponding Tp_{avg}/Tw_{avg} (e.g. 1/$N$1 = 1/1 000 for 100 s Tw_{avg}, 1/$N$2 = 1/600 for 60 s Tw_{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.

$$R(t) = \frac{1}{Tw1_{avg}} \int_{t-Tw1_{avg}}^{t} \left[\frac{P_{tx1}(t)}{P_{limit1,m}} \right] dt + \frac{1}{Tw2_{avg}} \int_{t-Tw2_{avg}}^{t} \left[\frac{P_{tx2}(t)}{P_{limit2,m}} \right] dt \qquad (1)$$

where

$R(t)$ is the exposure ratio as function of time;

$Tw1_{avg}$ is the time-averaging window for transmission 1, expressed in seconds;

$Tw2_{avg}$ 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.

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

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.

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

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

$$R_{\text{max}} = \max\left(R(t)\right) \tag{7}$$

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

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. ≤ $P_{\text{limit,specified}}$) and SAR_{target} (i.e. ≤ SAR_{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. ≤ SAR_{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.

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

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

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

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, Tc 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 $P_{limit} < P_{max}$:

      $SAR_{target,norm} \times (1,0 - Tc) < (R_{max} \times SAR_{target,norm}) <$ minimum $(SAR_{target,norm} \times (1,0 + Tc), SAR_{reported}/SAR_{limit})$ 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, Tc = 26 %, with $P_{limit} < P_{max}$ and R_{max} = 1,07, the adjusted ratio is 1,07 × 0,75 = 0,802 5, which is within the range of 0,75 ± 26 % or [0,56, 0,945]. In this case, Tc = 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 Tc, but with R_{max} = 0,70; the adjusted ratio is 0,7 × 0,5 = 0,35, which is outside the range of 0,5 ± 26 % or [0,37, 0,63]. Thus, this is not within the tolerance range (Tc) allowed by the SAR_{target}.

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

      $SAR_{target,norm} \times (1,0 - Tc) < (R_{max} \times SAR_{target,norm}) <$ minimum $(SAR_{target,norm} \times (1,0 + Tc), SAR_{reported}/SAR_{limit})$ 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 Tc, 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 $P_{limit} \geq P_{max} \times (1,0 + Tc)$:

      $(R_{max} \times SAR_{target,norm}) \leq SAR_{reported}/SAR_{limit}$ applies. This is the condition when $P_{limit} > P_{max}$ by more than Tc, 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 $SAR_{target,norm}$, the following conditions apply.

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

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

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

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

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

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

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

$R_{max} \leq P_{max,specified}/P_{limit,m}$ 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 Tw_{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 Tw_{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 $P_{limit,m}$. 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 $P_{max,m}$, $P_{limit,m}$, $P_{ctrl,m}$, $P_{min,m}$ are within the tolerance range allowed by P_{limit}. Taking power measurement tolerances into consideration, the calculated ratios of $P_{max,m}/P_{limit,m}$, $P_{ctrl,m}/P_{limit,m}$, and $P_{min,m}/P_{limit,m}$ 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 (Tp_{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 Tw_{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 Tw_{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 Tw_{avg}, where the power record of the previous Tw_{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 × Tw_{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.

7.3 Transition between wireless operating modes

As a device transitions across wireless modes and frequency bands (e.g. in a handover), different DPC-ETA parameters are applied for power control according to the SAR and power relationships of the operating configurations. Depending on regulatory requirements, different time-averaging windows can be used before and after the transition. Algorithm validation for transitional operations are tested with quasi-static test sequences and conducted power measurements. The applied test sequences are configured to enable DPC-ETA to establish a steady-state time-averaged power close to P_{limit}, for 0,2 × Tw_{avg} or 20 s, both before and after the transition. This is confirmed by monitoring or displaying both the measured (instantaneous) conducted power and calculated time-averaged power through the measurement automation process. Upon reaching steady state, the transition is initiated by the user, with power measured continuously through the transition, until steady state is reached again.

When the measurements are completed, the measured power is normalized to the corresponding $P_{limit,m}$ of the wireless modes (see 5.3, 6.10, and A.2.9) before and after the transition. The instantaneous power requested in the test sequence and the calculated time-averaged power for the time-averaging window(s) used are all normalized to the corresponding $P_{limit,m}$ and plotted. The instantaneous and time-averaged power are both correlated to the expected behaviour of the DPC-ETA implementation for the applied test sequence. The P_{max}, P_{limit}, and Tw_{avg} applied before and after the transition are verified by the plot. When different Tw_{avg} values are used, the time-averaging schemes used by the device can vary in calculating time-averaged power across the transition, for example, simple versus weighted averaging. To maintain validation acceptance consistency, time-averagings of the measured responses are post-processed according to criteria described in 6.8. Guidance for wireless mode selection of transitional operations is included in Clause A.5.

7.4 Transition between discontinuous transmission conditions

The procedures in 7.3 for algorithm validation of transitional operations can be applied to conditions with sporadic and discontinuous transmissions or a dropped call. A quasi-static test sequence with the desired discontinuous transmission intervals and durations is applied. When there is no transition between wireless modes or frequency bands, only one set of DPC-ETA parameters and time-averaging window is involved. The measurement results are normalized and plotted to confirm power control continuity according to the transmission and idling intervals in the test sequence. The measured instantaneous power and calculated time-averaged power are verified against the power control parameters (all normalized) before correlating with the expected behaviour of the DPC-ETA implementation for the applied test sequence.

7.5 Transition between TDMA, TDD, and FDD transmission conditions

When TDMA or TDD applies to a wireless mode, the inherent duty factor included in the transmission needs verification to ensure it is correctly accounted for in the power control and time-averaging operations. The power control parameters, especially P_{max} and P_{limit}, can be specified with or without the duty factor, whereas the measured SAR usually includes duty factor. For the purposes of algorithm validation, slot-burst averaged power is applied to test sequences and frame-averaged power is measured for TDMA and TDD configurations. The duty factor would cancel out and become transparent in the normalization process provided burst and frame-based duty factors are applied consistently. The power measurement equipment is configured with the proper triggering for the specific wireless mode to measure frame-averaged power at a rate of $Tp_{avg} \leq 0,1$ s. The measured and time-averaged power are normalized to the $P_{limit,m}$, for plotting and correlation with the expected behaviour of the implementation for the applied test sequence.

When multiple transmission duty factors are supported by a wireless technology or RAT, the highest and lowest duty factor are used in the test sequences for algorithm validation. In addition to continuous transmission at a fixed duty factor, transitional operations for TDMA and TDD are also verified; for example, handover, dropped call or discontinuous transmissions are verified according to 7.3 and 7.4. Power control continuity for transitions between TDMA/TDD and FDD can be confirmed according to this subclause 7.5 and 7.3.

For transition between GSM and LTE, manual intervention can be done for the RCT to establish the connections, e.g. a reset or manual initiation. Therefore, transition between GSM/TDMA and LTE FDD/TDD for 2G/3G to 4G is confirmed indirectly through validation of transition between GSM/UMTS and UMTS/LTE. The procedures for quasi-static and dynamic test sequences in 7.1 and 7.2 are applied to standalone TDMA and TDD modes. A quasi-static test sequence is applied to transitional operations according to 7.3 and 7.4.

7.6 Transition between simultaneous transmitters and antennas

7.6.1 General

The combination of transmitters and antennas supported by DPC-ETA and the corresponding simultaneous transmission configurations are considered to determine algorithm validation requirements. The DPC-ETA power control parameters used for the wireless modes and exposure conditions in standalone and simultaneous transmission configurations can be different. Depending on the frequency bands and regulatory requirements, different time-averaging windows can apply to individual signals in the simultaneous transmission combination.

The consideration for algorithm validation of simultaneous transmission is limited to the transmitters and antennas that are under direct control of DPC-ETA in the RF modem. Power control continuity and algorithm functionality are verified by sequentially adding transmitters/antennas to the applicable simultaneous transmission combination and then removing the transmitter/antennas from the combination in the same order (first added first removed). When transmitters/antennas are added or removed from the combination, the maximum power allowed for each transmitter/antenna and DPC-ETA power control requirements can change to satisfy aggregate power specification for the combination. Depending on the SAR_{target} and P_{limit} established for the transmitters and antennas in the simultaneous transmission combinations, DPC-ETA power control parameters can be specified conservatively for all configurations in the combination or separately for sub-groups in the combination. The configurable parameters need review to determine how to apply test sequences for algorithm validation.

The criteria for validating simultaneous transmission power control continuity are described in Clause A.7. A quasi-static test sequence is used to – one at a time – add transmitters to and remove transmitters from the simultaneous transmission combination. The normalized instantaneous and time-averaged output power are both observed through the measurement automation process to ensure steady state is reached, for 0,2 × Tw_{avg} or 20 s, before initiating the transition to add or remove the next transmitter in the combination. The P_{max} and P_{limit} of individual transmitters/antennas can change as transmitters/antennas are added or removed. The RCT is configured to request the applicable P_{max} for all the transmitters/antennas.

Different DPC-ETA power control parameters and time-averaging windows can apply to each transmitter/antenna in the combination. In order to analyse the power measurement results to verify algorithm functionality and power control continuity, power is measured independently for each transmitter/antenna and normalized to the corresponding $P_{\text{limit,m}}$. This would require multiple sets of power meters or spectrum analysers, directional couplers, or multiple RCTs to support multiple wireless technologies. Synchronization of the RCTs and power meters is done to ensure the power change requests and power measurements are time aligned to correlate results with the expected behaviour of the implementation for the applied test sequence.

7.6.2 5G NR NSA EN-DC

For 5G NR operating in non-standalone (NSA) mode with E-UTRA NR – Dual Connectivity (EN-DC) in FR1 (e.g. [4]), an LTE anchor is used to coordinate network control traffic for the NR data transmission. Provided the aggregate power is not exceeded, either LTE or NR can transmit at maximum output power according to the Dynamic Power Sharing or at half the maximum power for Equal Power Sharing schemes specified by 3GPP. The power control parameters established for LTE and NR are based on separate SAR to power relationships; however, LTE is the primary carrier with preference over NR in network power control. In applying the quasi-static test sequence, different power level combinations are considered for LTE and NR, within the range of allowed aggregate power to validate power control continuity according to the expected behaviour of the implementation for the applied test sequence. When different time-averaging windows are used for the frequency bands (see 6.8), the normalized time-averaged power for LTE and NR are considered separately to satisfy the normalization tolerance described in 6.10 and in accordance with regulatory policies.

7.6.3 Carrier aggregation

For carrier aggregation (CA) in LTE and NR, the power allowed for the component carriers (CC) is determined by the network (primary versus secondary), the number of CCs and headroom available from the maximum aggregate power. Depending on whether intra-band or inter-band CA and contiguous or non-contiguous CCs are used and how these are managed by DPC-ETA, additional considerations are done if algorithm validation is executed. When P_{max} and P_{limit} are based on the aggregate power allowed for the CCs, for intra-band CA the power of all CCs can be easily accounted for by the RF modem to calculate time-averaged power. For inter-band CA with CCs in multiple frequency bands, different P_{max}, P_{limit} and time-averaging window values can be used for the CCs and how each is controlled by DPC-ETA can be implementation dependent.

7.7 Transitions initiated by host triggered conditions

Host device triggered conditions, such as proximity sensors or other mechanisms, can be used to initiate DPC-ETA transitions. The triggering is independently controlled by the host device to inform DPC-ETA to switch to a new set of power control parameters, usually due to changes in exposure conditions. The triggering conditions are validated independently according to regulatory policies or suitable procedures. When the DPC-ETA functionality and power control continuity of host triggered configurations are the same as other transitional operations, additional algorithm validation can be avoided provided it is confirmed that the DPC-ETA parameters are correctly applied by the RF modem. This can be verified in conjunction with other transitional operations with a quasi-static test sequence.

NOTE The DPC-ETA procedures in this document are applicable when the power control and sensor triggering functionalities are operating independently within the corresponding assemblies.

7.8 Transition between diversity antennas

The SAR to power relationship is different for diversity antennas due to antenna locations and types. A separate set of power control parameters is established for each antenna. This is equivalent to a transition in operating configuration, where the wireless mode remains the same, but the exposure condition is different. DPC-ETA algorithm functionality can be validated by applying the transitional test sequence and procedures in 7.3.

8 Validation test setup and procedures

8.1 General

Conducted and radiated power measurements are used to measure instantaneous responses from power requests in the test sequences and to calculate time-averaged responses. Both conducted and radiated power measurements are performed in a controlled manner, to circumvent propagation path loss and environmental influences associated with closed loop power control conditions using SAR methods. See Annex F for further information on algorithm validations, and Annex D for correlation between single-point SAR and radiated power measurements. The same power measurement test setup, test equipment and measurement automation process can be used for both types of power measurements. The algorithm validation criteria for different DPC-ETA and network operating configurations are described in Clause 7. The test sequences and measurement considerations are described in Annex A.

The insertion losses due to passive components, such as directional couplers, combiner/splitters, filters, cables, etc., in each measurement chain are quantified or calibrated out to ensure the measured results can be properly compensated. For radiated power measurements, the path loss between the DUT and the RCT/measurement antenna is also accounted for along with the passive components to ensure the power levels specified by the test sequences are correctly applied by the RCT and DUT. The measurement automation process and test equipment involved are validated to ensure the recorded power is time-aligned with the power requests in the test sequences. Each of the measurement configurations, including standalone and transitional operations, TDMA/TDD modes, different time-averaging windows, and simultaneous transmission configurations, can be verified using a DUT with known test results before system deployment.

8.2 Conducted power measurement

Conducted power is measured at the antenna port of the DUT. It is measured for the wireless modes and exposure conditions that require algorithm validation according to the quasi-static and dynamic test sequences. Quasi-static test sequences are used to verify basic algorithm functionality in steady-state conditions with easily identifiable DPC-ETA responses. Dynamic test sequences are used to verify DPC-ETA power control continuity for rapid power change conditions in typical network configurations, where steady state is not expected. Quasi-static test sequences are also used with conducted power measurements to verify transitional operations, such as handover, call drop, discontinuous and simultaneous transmission conditions. Dynamic test sequences are only applied to selected test configurations, to minimize certain interpretations requiring details that are unavailable to the user, to correlate measured responses with expected behaviour of a DPC-ETA implementation for the applied test sequence. The test setup for conducted power measurement is described in Clause B.8.

8.3 Radiated power measurement

Radiated power is measured with the device in a miniature or larger size anechoic chamber. Commercially available chambers used for 5G NR OTA tests with the compact antenna test range (CATR) method can generally be used. Instead of the connection at the antenna port of a DUT, it is replaced with a connection to an antenna inside the anechoic chamber for the RCT to transmit test sequences to the DUT. The same antenna is also used to support power measurement with the same or similar setup used (outside the anechoic chamber) for conducted power measurement. The test setup for radiated power measurement is described in Clause B.9.

NOTE Commercially available CATR chambers are intended for 5G NR FR2 (above 24 GHz) measurements and most have shielding and other specifications as low as 500 MHz. For the purposes of DPC-ETA algorithm validation, other than the RF shielding and operating characteristics, many of the 5G NR millimetre-wave band specifications for the chambers are generally irrelevant. Before a chamber is used, its effectiveness is verified with a known device using the actual radiated power measurement algorithm validation test setup.

Before each radiated power measurement, P_{limit} is measured in the same radiated test setup for normalizing the test results. The DUT and RCT/measurement antenna are kept stationary and undisturbed for measurements of both P_{limit} and the test sequence. Any shift or movement would require P_{limit} to be re-measured. The signal level at the RCT is compensated to account for attenuations due to passive components in the measurement chain and propagation or path losses inside the anechoic chamber, to ensure the requested power is transmitted by the DUT.

9 Post-processing and correlation of measurement results

The conducted and radiated (instantaneous) power measurement results are each normalized to the corresponding P_{limit} measured with the respective methods before the test sequence is initiated. The instantaneous power is time-averaged over the applicable Tw_{avg}, at each measurement interval Tp_{avg} (see 6.8). Until a sufficient number of power samples (Tw_{avg}/Tp_{avg}) is available, the time-averaged power in quasi-static test sequences would lag until steady state is reached. Dynamic test sequences are generally initiated at a steady-state condition with time-averaged power between P_{ctrl} and P_{limit}.

The requested power in the test sequence is normalized to the $P_{limit,specified}$ and included in the same plot showing both normalized instantaneous and time-averaged power (measured). Depending on the test configuration (for example, standalone wireless mode, transitions between wireless modes, frequency band or due to call drop, handover, discontinuous transmission, or simultaneous transmission, etc.), both instantaneous and time-averaged power are correlated with the expected DPC-ETA responses of the implementation for the applied test sequence. The instantaneous power is compared with the power requests in the test sequence to confirm algorithm functionality. As the time-averaged power approaches P_{limit}, the measured instantaneous power is managed by DPC-ETA to ensure P_{limit} is not exceeded. If P_{ctrl} is also used for power control, its intended functionality is also verified. When the requested power is noticeably lower than P_{limit}, DPC-ETA would adjust the instantaneous power, according to the intended behaviour of the implementation, to manage a desired time-averaged power level and maintain a sustained connection, or as requested by the test sequence. Within the power measurement tolerance of the test equipment, instantaneous power cannot exceed P_{max}, and time-averaged power cannot exceed P_{limit}. For TDMA and TDD configurations, it is important for both P_{max} and P_{limit} to be consistently specified and measured according to slot-based burst and frame-averaged power, to avoid unintended and incorrect offsets introduced by the duty factor. When multiple frequency bands are involved in transitional test configurations, it needs to be confirmed that the correct time-averaging windows are applied. The transition between time windows, and resulting tightening or relaxation of power control margins, also need confirmation according to the changes in Tw_{avg} values.

The corresponding levels of the normalized P_{max} (P_{max}/P_{limit}), P_{limit}, and P_{ctrl} are identified on each plot, according to regulatory policies on how normalization and measurement tolerances can be applied. The multiple sets of P_{max}, P_{limit}, and P_{ctrl} used in transitional operations are also identified on the plots according to regulatory policies. Any discrepancies are analysed and reviewed (for example, due to possible power control or algorithm implementation tolerances that possibly have not been included), to address algorithm functionality or measurement issues to ensure the results are valid.

NOTE The plots of normalized results for conducted and radiated power measurements are expected to be almost identical; therefore, it would be desirable to use side by side plots instead of putting both on the same plot where one curve can be covered by the other. The number and types of plots included in test reports can vary according to regulatory policies; e.g. only a subset of the plots can be needed for all measured results.

10 Validation and measurement tolerance considerations

In applying this document, all tolerances that can influence DPC-ETA need consideration for the algorithm validation. The DUT related tolerances can include output power (tune-up and TxAGC) tolerances, algorithm operation tolerances, and other product design tolerances (e.g. host device triggered transitions) or device-to-device variations. When the measured power is normalized by the $P_{\text{limit,m}}$, the power dependent tolerances are not expected to cancel out in the normalization process. The normalization tolerance for this is determined based on the highest ratio in each test configuration according to that supported by the SAR_{target} and P_{limit}. When the same equipment and test setup are used for power measurement of both the test sequences and P_{limit}, except for tolerance variations across range settings of power meters, most of the tolerances are expected to cancel out in the normalization process. The tolerances that do not cancel out in the normalization due to the power measurement equipment are typically insignificant. As appropriate, this can be addressed according to regulatory requirements. Provided the instantaneous (measured) and time-averaged power results are time-aligned with the power requests in the test sequence sent from the RCT, the sequence of power control events is compared to the expected DPC-ETA behaviour of the implementation for the applied test sequence. Any delays in power requests and responses recorded by the test equipment and the measurement automation process are expected to be dependent on the specific test equipment and design of the measurement automation. If the power request steps and following recorded responses can not be qualitatively correlated, the tolerances due to the measurement automation and misalignment of recorded events in time can need consideration. The test results are generally correlated in a qualitative manner in time and quantitively in (normalized) amplitude. Algorithm validation tolerances are discussed in Annex C.

11 Acceptance criteria and algorithm validation requirements

11.1 General

The procedures are based on DPC-ETA power control parameters established according to SAR compliance measurement results at the maximum time-averaged power (P_{limit}) for continuous use. In actual use conditions, both instantaneous and time-averaged power according to a specified time-averaging window (Tw_{avg}) are managed by DPC-ETA to enable higher instantaneous power for short durations, up to P_{max}, while maintaining time-averaged power at ≤ P_{limit}. When it is demonstrated that a DPC-ETA implementation operates within the tolerances allowed by the power control parameters for the SAR_{target} established at P_{limit}, SAR compliance is satisfied. The DPC-ETA related tolerances included in the specified power control parameters cannot be higher than the tolerance allowed by the SAR_{target} (i.e. ≤ SAR_{reported}) and P_{limit} (i.e. ≤ $P_{\text{limit,specified}}$) used in each wireless mode.

The following are general acceptance criteria and operating conditions for ensuring that DPC-ETA functions according to the specified and nominal power control parameters, and is maintaining power control continuity within the allowed tolerance range in transitional operations. These are reviewed for both the instantaneous and time-averaged power measurement results, and correlated with requests in test sequences and expected behaviour of the DPC-ETA implementation for the applied quasi-static and dynamic test sequences. The same criteria and requirements are applied to validate results based on conducted and radiated power measurements. The measured values of P_{limit}, according to A.2.9, are used for the normalization. When the same test configuration is measured, including wireless mode, exposure condition (test distance and position, etc.), DPC-ETA power control parameters (P_{max}, P_{limit}, P_{ctrl}), time-averaging window, and test sequence, then similar normalized results can be obtained in different setups, i.e. by normalizing measured conducted power of test sequence to the measured conducted power value of P_{limit} in conducted test setup, or by normalizing measured radiated power of test sequence to the measured radiated power value corresponding to P_{limit} in radiated test setup, or by normalizing measured single-point SAR of test sequence to the measured single-point SAR value corresponding to P_{limit} in SAR measurement setup. The observation points below are checkpoints that can be used to support the confidence in the algorithm validation and test setup.

11.2 Acceptance criteria

a) The measured instantaneous power cannot exceed the $P_{max,specified}$. For TDMA and TDD configurations, slot-based burst power is applied to the test sequences and frame-averaged power is measured for both P_{max} and P_{limit}.

b) When P_{limit} is less than P_{max} or when P_{limit} is greater than P_{max} but within tolerance, the time-averaged power measured for Tw_{avg} cannot exceed the $P_{limit,specified}$, which in turn ensures that the time-averaged SAR cannot exceed the $SAR_{reported}$. The highest normalized measured values R_{max} in each test configuration cannot exceed the minimum of the tolerance allowed by the SAR_{target} associated with the $P_{limit,m}$ and the ratio of the $P_{limit,specified}/P_{limit,m}$.

c) When P_{limit} is greater than P_{max} by more than the associated tolerance, the normalized time-averaged power measured for Tw_{avg} is less than the normalized $SAR_{reported}$, which corresponds to P_{max}. The highest normalized measured value of R_{max} is less than or equal to the ratio of the $P_{max,specified}/P_{limit,m}$.

d) The maximum time-averaged power measured for Tw_{avg} cannot be less than the $SAR_{target,norm}$ by more than the associated tolerance. The maximum normalized values of R_{max} cannot be below the tolerance allowed by SAR_{target} associated with the $P_{limit,m}$.

e) During transitional test cases, the sum of the normalized time-averaged power measured for Tw_{avg} cannot exceed one, that is the normalized time-averaged combined SAR is less than the maximum of the normalized $SAR_{reported}/SAR_{limit}$ for each transmitter.

f) When DPC-ETA algorithms are used to control the simultaneous transmission RF exposure, the sum of the R_{max} values remains within tolerance of the maximum SAR_{target} and P_{limit}.

NOTE 1 For b), c) and d): See 6.10 for normalization tolerance.

NOTE 2 For b): The use of scaled or non-scaled normalization ratios (or both) can be determined according to regulatory policies to clearly explain and illustrate the test results with respect to the allowed tolerance range (Tc); See Figure A.1, Figure A.2, Figure A.3, Figure A.4, and the illustrative example in Clause A.10.

NOTE 3 For e): See 6.8 for transition normalization.

NOTE 4 For f): See Clause B.4 for simultaneous transmission.

NOTE 5 See A.2.9 for P_{limit} measurement requirements.

11.3 Observation points

a) When the time-averaged power is less than P_{limit} by a margin established by the individual DPC-ETA implementation, the measured instantaneous power is expected to track requested power according to network- or technology-specific power control protocols (GSM, UMTS, LTE, NR, etc.). The instantaneous power can be higher than P_{limit} when time-averaged power is ≤ P_{limit} or (P_{limit} minus a margin).

b) Depending on the wireless technologies, network protocols can use different power control step resolutions; for example, GSM uses 2 dB steps. This can result in lower values of $P_{\text{max,m}}$ and $P_{\text{limit,m}}$ than those requested in the test sequences.

c) The measured instantaneous power is expected to be less than the requested power as time-averaged power approaches P_{limit}. The instantaneous power can be reduced or set to a pre-defined lower level (e.g. P_{ctrl} or equivalent) to ensure time-averaged power is ≤ P_{limit} or less than or equal to (P_{limit} minus a margin). The rate at which the instantaneous power is reduced and time-averaged power can approach P_{limit} is DPC-ETA implementation dependent.

d) For quasi-static test sequences, when reaching steady state, the time-averaged power is expected to settle at the desired or requested power (influenced by wireless protocol) in the test sequence with the measured instantaneous power approaching the time-averaged power.

e) When rapid power changes are applied, such as those in the dynamic test sequences, the measured instantaneous power possibly does not track the requested power, i.e. an increase in requested power can result in a decrease in measured instantaneous power or vice versa. DPC-ETA power control is based on time-averaged power, which is determined by the time-averaging window duration, previous recorded power in the window, relative level of the time-averaged power from P_{limit}, and the power control algorithms used in an implementation. These need consideration to review responses from dynamic test sequences.

f) For transitional operations, including transmit diversity and host device triggered transitions, it is verified that the correct DPC-ETA power control parameters and time-averaging window(s) are reflected by the normalized instantaneous and time-averaged power results before and after the transition. It is confirmed that power control continuity is maintained across the transition due to differences in parameters and time-averaging windows, i.e. the instantaneous and time-averaged power measured cannot exceed the corresponding P_{max} and P_{limit} before and after the transition. The power levels within the time gap introduced by a transition are accounted for by the instantaneous and time-averaged power after the transition.

g) When TDMA or TDD applies, it is verified that the transmission duty factors inherent to the wireless modes are accounted for in both continuous and discontinuous transmissions, according to the duty-factor-adjusted P_{max} and P_{limit}. When transitioning between wireless modes with different duty factors (TDMA, TDD, and FDD, etc.), it is verified that the correct duty factors are applied, in conjunction with any changes in P_{max} and P_{limit}.

h) For simultaneous transmission, the power measurement results are analysed to demonstrate DPC-ETA power control continuity according to the different power control parameters used by the simultaneous transmission wireless configurations. When wireless modes are added or removed in a simultaneous transmission combination, the maximum power allowed for each wireless mode can be limited by the maximum aggregate power of the combination. A properly configured quasi-static power control test sequence is applied, according to the DPC-ETA power control parameters used in the wireless configurations in the simultaneous combination. The measured instantaneous and time-averaged power over the time-averaging window used for each wireless mode in the simultaneous transmission combination are verified. The management of power control parameters for each wireless mode, and their contribution to the simultaneous combination, can be DPC-ETA implementation dependent and need consideration to apply the criteria described above.

i) For 5G NR NSA with EN-DC in FR1, sequential and overlapping transmissions between LTE and 5G NR are verified according to the power control parameters used for each, and also during simultaneous transmission. Depending on the frequency bands used for LTE and NR, different time-averaging windows can apply. The criteria described above for the applicable wireless modes and transmission conditions are applied to evaluate power control continuity.

j) When host device triggered transitions are tested, although not a part of this document, the triggering conditions are validated according to regulatory procedures. When the actual transition between wireless modes can be delayed by the host device (conditional triggering), this is also taken into consideration to correlate measured results with expected behaviour of the implementation for the applied test sequences.

k) When algorithm validation is done to demonstrate power-up or fail-safe conditions, these are evaluated according to criteria established for the specific DPC-ETA implementation, according to regulatory requirements.

The measured results can have slight time misalignment with the power requests in the test sequence due to time recording imprecision in the measurement automation. This can require certain interpretations to determine the cause of misalignment. When results cannot be correlated, which can be due to measurement setup and automation issues or algorithm operating characteristics, the measurement can be repeated only after the discrepancies are reviewed and addressed.

12 Reporting of validation results

The reporting requirements for DPC-ETA algorithm validation can vary by regulatory policies; for example, the number and types of plots to include in test reports for the measurements and test configurations. In general, the background information for supporting the test setup and measurement results in test reports is determined by regulatory policies. The DPC-ETA power control parameters, SAR targets, time-averaging window durations, wireless mode operating parameters, and exposure conditions evaluated for SAR compliance are clearly identified. The criteria and test configurations selected for algorithm validation of standalone wireless modes, transitional operations, simultaneous transmission, etc., are explained and listed in the test report. Additional explanation can be done to support the test results for certain transitional operations and simultaneous transmission configurations. The conducted and radiated power measurement test setup, equipment, and measurement automation used are described and illustrated.

The quasi-static and dynamic test sequences used with the power measurement methods for the test configurations are listed in test reports. The normalized results are plotted to show correlation of measured responses with expected behaviour of the implementation for the applied test sequence. The highest of the normalized ratios (R_{max}) in a test configuration is used to demonstrate the tolerance allowed by the SAR_{target} and the P_{limit} is satisfied. Plots with sufficient resolution are used to enable both qualitative (temporal) and quantitative (magnitude) comparisons. The measured DPC-ETA parameters identified on each plot are within the specified tolerances, to demonstrate power control continuity and algorithm functionality. Selected plots of non-normalized results can be included to demonstrate certain specifics of the validations; for example, an oscillatory or fluctuating steady-state condition or unexpected control behaviour. Any inconsistencies between the expected and recorded responses are clearly explained to justify the results.

Annex A
(informative)

Test sequence consideration details

A.1 General

The DPC-ETA algorithm validation test sequences are described in this Annex A. The range of power control parameter values used for the test configurations are also provided. Additional regulatory guidance can be applicable for testing varying implementations. Test sequences are considered to verify the following DPC-ETA functionalities:

a) applying quasi-static power control test sequences to verify basic DPC-ETA operating characteristics and transitional operations in steady-state conditions
   1) for standalone wireless modes and exposure conditions,
   2) when transitioning across frequency bands, wireless modes, or during handover, call drop, and discontinuous transmission conditions, for UMTS, LTE and NR,
   3) standalone GSM/GPRS configurations, and transitions between GSM and UMTS,
   4) simultaneous transmission of UMTS, LTE, and NR configurations supported by the DPC-ETA implementation (excluding GSM/GPRS);

b) applying dynamic and random power control test sequences with varying amplitude and interval to confirm algorithm functionality in typical network conditions with rapid power changes.

Guidance for users to correlate power measurement results with the expected behaviour of a DPC-ETA implementation for the applied test sequences is also included.

A.2 General test sequence configuration and measurement considerations

A.2.1 General

Conducted power measurements, radiated power measurements or SAR tests are used to record DPC-ETA responses of the quasi-static and dynamic power control test sequences sent by the RCT to the DUT. Conducted power is measured at the antenna port of the DUT. Radiated power is measured in a miniature anechoic chamber (see Annex B). The recorded power levels are different for the measurement methods, but the same measurement equipment and similar test setup are used for both methods. SAR is measured with a SAR measurement system (see Annex F). The results are normalized to the $P_{\text{limit,m}}$ of the wireless modes with the highest normalized ratio remaining within the tolerance allowed by the SAR_{target} and P_{limit}. The measurement configurations and test setup are confirmed by correlated conducted and radiated measurement results, for the same wireless configuration and test sequence.

For modular platforms, conducted power can be measured for a range of DPC-ETA parameter values (P_{max}, P_{limit}, P_{ctrl} and Tw_{avg}). The results can be used by host devices incorporating transmitter modules that use DPC-ETA parameters within the tested ranges for the same output hardware configurations. Depending on regulatory policies, except for new configurations, additional algorithm validation with conducted power are unnecessary. This can be considered for products from the same manufacturer using the same design, hardware, and RF components between the RF modem chipset and antenna port. Radiated power or SAR measurements with the host device are generally measured in selected conducted power measurement configurations, to verify that the normalized results are correlated between the antenna port and standalone device.

A.2.2 Quasi-static and dynamic test sequences

Quasi-static test sequences are used to

– allow time-averaged power to reach steady state before subsequent power requests are initiated,

– to verify basic DPC-ETA operating characteristics and transitional operations.

The measured responses at steady state can be correlated with the expected DPC-ETA behaviour in a more predictable and consistent manner for algorithm validation. Dynamic test sequences are used to simulate the rapid power control conditions in typical network conditions, where steady-state power control is not expected for DPC-ETA. This can require certain implementation details for users to correlate measured responses with the expected DPC-ETA behaviour.

A.2.3 Power control parameters

The time needed for DPC-ETA to respond to power request changes in quasi-static test sequences received from the RCT and for time-averaged power to reach steady state is dependent on the time-averaging window duration Tw_{avg}. In general, the range of P_{max} to P_{limit} and P_{limit} to P_{ctrl} are established according to the SAR characteristics of the wireless modes. DPC-ETA power control characteristics would vary with the parameter values used for the wireless modes and the offsets among the parameters (P_{max}, P_{limit}, and P_{ctrl}) in each wireless mode. The power control variations would determine how DPC-ETA arrives at the desired time-averaged steady-state condition. In addition, a larger Tw_{avg} is expected to have a longer lag time for time-averaged power to reach steady state. Power control is also influenced by the relative levels of P_{max}, P_{limit}, and P_{ctrl} in a wireless mode.

A.2.4 Power control segments

The DPC-ETA parameters can generally be associated with three power control segments that are used to configure test sequences and to correlate measured responses with expected behaviour. The initial and final time-averaged power of the power changes in quasi-static test sequences are confirmed at steady-state condition according to the range (amplitude) of RCT power requests and DPC-ETA responses. The responses recorded by the measured power are reviewed for consistency with the expected DPC-ETA behaviour for the applied test sequences. The test sequences in Clause A.3 and Clause A.4 have included a few similar power steps to confirm DPC-ETA operating consistency.

Typical DPC-ETA behaviours of the power control segments are described in the following list items. The power level for sustaining a reliable connection between a DUT and the RCT during power measurement is set to $P_{\mathrm{min}} \leq 0$ dBm. When the SAR of a wireless mode and exposure condition (separation distance or antenna location, etc.) is noticeably lower than the limit, the $P_{\mathrm{limit,specified}}$ can be higher than P_{max}. Since the maximum output power of a transmitter is limited to P_{max}, DPC-ETA would become transparent or inactive for such wireless modes when P_{limit} is larger than P_{max} by at minimum the tolerance allowed for the SAR_{target} (see A.2.6). Thus, SAR compliance is determined at P_{max}, instead of P_{limit}, and algorithm validation is typically not necessary for such configurations. In some cases, P_{ctrl} can be used as an optional internal parameter, with no OEM access, or not used at all in some implementations. This can require the test sequences and algorithm validation procedures to be adjusted for the specific implementation. If P_{ctrl} is an internal parameter, the appropriate values are used. When P_{ctrl} is not used at all, for the purposes of applying the DPC-ETA algorithm validation test sequences, a value of $P_{\mathrm{ctrl}} = P_{\mathrm{limit}} - n \times (P_{\mathrm{max}} - P_{\mathrm{limit}})$ according to the specified parameters, with all values in dBm, are considered to configure the test sequences, with $n \leq 1$ and consistent with regulatory policies; for example, n = 0,5.

a) Active power control: This segment corresponds to conditions when power requests are in the range $P_{max} \leftrightarrow P_{limit}$ or the power control reserve available to the DPC-ETA implementation is insufficient to sustain continuous transmission at P_{limit}. The instantaneous power can be lowered and time-averaged power is actively limited to $\leq P_{limit}$ by DPC-ETA. The power measured and time-averaged over Tw_{avg} cannot exceed the P_{limit} and allowed tolerance. The initial condition, before reaching the active power control segment, can start anywhere between P_{min} and P_{max}. Depending on Tw_{avg} and the range of offsets between $P_{max} \leftrightarrow P_{limit}$, $P_{limit} \leftrightarrow P_{ctrl}$, and $P_{ctrl} \leftrightarrow P_{min}$, etc., the power adjustments and DPC-ETA responses can vary for different implementations.

b) Normal power control: This segment typically corresponds to conditions when power requests are in the range $P_{limit} \leftrightarrow P_{ctrl}$ (or equivalent levels) and continuous transmission can be sustained. When quasi-static test sequences are used, DPC-ETA is expected to maintain a steady-state time-averaged power between P_{limit} and P_{ctrl}. The range of DPC-ETA power control parameters, offsets, and the value of Tw_{avg}, in conjunction with the initial condition, would generally influence the power adjustments applied (increases and decreases) by DPC-ETA to operate in the normal power control segment.

c) Passive or inactive power control: This is the segment when power requests are in the range $P_{ctrl} \leftrightarrow P_{min}$. DPC-ETA is generally not expected or needed to make additional power adjustments other than fulfilling the power change requests from the RCT (network) to maintain time-averaged power at a desired level below P_{ctrl} or its equivalent. This is often the case in good propagation conditions where transmissions can be sustained at low power. The time for power requests in quasi-static sequences to reach steady state in the passive power control segment is expected to vary with Tw_{avg} and the range of DPC-ETA power control parameters and offsets. The power adjustments and DPC-ETA responses can vary with the initial and final power levels of power requests in a test sequence.

A.2.5 Test sequence and measurement coordination

The power requests in test sequences are specified relative to P_{max}, P_{limit}, and P_{ctrl} of the wireless modes to enable the same test sequence to be used for all wireless modes and test configurations. Due to different time lags associated with Tw_{avg}, the condition for time-averaged power to reach steady state is confirmed manually by the user to initiate the next power change in quasi-static test sequences. This also applies to transitional operations, such as handover, call drop, discontinuous transmissions, and simultaneous transmission, etc., that use quasi-static test sequences. As necessary, a test can be aborted if an incorrect test configuration or condition is detected by the user. A manual user-key entry or a mouse-click can be programmed into the measurement automation for the confirmation. This requires the measured power to be available for users to make confirmation before initiating the next step in the test sequence. It can also provide users with some control to overcome certain equipment coordination concerns during handover, call drop, or simultaneous transmission transitions. A duration of 0,2 × Tw_{avg} or 20 s, whichever is less, is allowed after a power request has reached steady state, at the desired time-averaged power level and DPC-ETA condition, before the next power step change or transition is initiated.

A.2.6 Wireless mode test considerations

DPC-ETA parameters are established according to the SAR to power relationship of a wireless mode and the exposure condition evaluated during SAR compliance. The values of P_{max} and P_{limit} are influenced by the SAR of the wireless mode and frequency band in the RAT. P_{limit} is typically set a few dB lower than P_{max} for power control according to time-averaged and instantaneous power. For high SAR configurations, a lower P_{limit} is often used to maintain SAR compliance. When SAR is low, the allowable P_{limit} can be higher than P_{max}. Since output power is limited by P_{max}, depending on tolerances established for the SAR_{target} and P_{limit}, DPC-ETA can become transparent and inactive in single radio transmission scenarios. Algorithm validation is typically unnecessary for standalone wireless modes when SAR compliance is evaluated at P_{max}. However, if there is the possibility for such configurations to become active due to simultaneous transmission scenario or transitional operation like change in Tw_{avg} or tolerance or other interactions within the algorithm or implementation, additional validation can need consideration to verify algorithm operating characteristics for configurations with P_{limit} > P_{max}, in accordance with regulatory policies. In general, additional considerations and regulatory review can be necessary for configurations with P_{limit} > P_{max} where difference is less than the tolerance range supported by the SAR_{target}. These configurations are generally the less desired choices for algorithm validation, although they can be required by regulatory policies because of specific concerns related to algorithm functionality.

The following items are considered to determine test configurations for DPC-ETA algorithm validation according to the specified parameters with all relevant tolerances included. Specified parameters with tolerances included are used to determine power request levels in test sequences, to ensure DPC-ETA power control restrictions are triggered using higher power values sent by the RCT. For the wireless modes in a RAT, when P_{max} [dBm] > P_{limit} [dBm] + Tc [dB], the configuration or configurations with the largest (P_{max} − P_{limit}) value [dBm] are considered for testing. This typically corresponds to a higher SAR or more stringent configuration for algorithm validation within this range of parameters. It is referred to as the "default test configuration" for applying test sequences in this document. When there are no wireless modes in a RAT where P_{limit} [dBm] < P_{max} [dBm] − Tc [dB], whether testing is needed is determined according to regulatory policy or other implementation related specific conditions. For the remaining wireless modes in the RAT, where P_{limit} [dBm] < P_{max}[dBm] − Tc [dB] or where P_{limit} > P_{max}, whether testing is needed is determined according to regulatory policy or other implementation related specific conditions. The wireless mode with the largest (P_{max} − P_{limit}) value [dBm] for these remaining wireless modes is referred to as the "additional test configuration" for applying test sequences. When multiple wireless configurations exist for the default test configuration or additional test configuration, the configurations with the smallest (P_{limit} − P_{ctrl}) value [dBm] (or equivalent, see A.2.4) among the default test configuration or additional test configuration are used.

The wireless mode settings and measurement configurations for the respective RATs are described in the following list. These are applied in accordance with regulatory policies.

a) Conducted and radiated power are measured on the middle channel of a frequency band according to the following wireless configurations:

   1) quadrature phase-shift keying (QPSK) with the largest channel bandwidth and < 25 % or equivalent resource block (RB) allocation with 0 dB maximum power reduction (MPR); centred within the channel for LTE/NR.

      The selection of NR waveform (DFT-s-OFDM versus CP-OFDM) is transparent and is based on the power control parameters used by the wireless modes for determining the default test configuration and additional test configurations.

   2) 12,2 kbit/s RMC (Reference Measurement Channel) for UMTS;

   3) RC3/SO55 or equivalent for CDMA2000;

4) GMSK for GSM/GPRS; with P_{max}, P_{limit}, and P_{ctrl} based on frame-averaged output power across all eight time slots.

b) For test sequences used to verify DPC-ETA operations in simultaneous transmission configurations, as appropriate, P_{min} ≤ 0 dBm can be applied to maintain connectivity with the RCT, to avoid potential disconnect and reconnect issues when switching between different transmission combinations.

A.2.7 Test sequence considerations

When the same power control process and DPC-ETA algorithms are applied to all wireless modes within a RAT, the configurations used for algorithm validation are determined according to the DPC-ETA parameters (P_{max}, P_{limit} P_{ctrl} and Tw_{avg}). When the same algorithms and power control process are applied to all RATs, the test configurations can be further reduced.

At least one test configuration is tested for each RAT and Tw_{avg} using the default test configuration. Both FDD and TDD are considered for each RAT. For example, among the LTE bands, the applicable Tw_{avg} for FDD and TDD are considered separately in the default test configuration(s). The highest transmission duty factor and frame-averaged power configuration are considered for GSM/GPRS (see Clause A.6 for GSM/GPRS testing) and TDD. When additional tests are triggered by regulatory policies or device configuration specifics, these can apply the additional test configuration. When the DPC-ETA algorithm is applied differently in certain wireless modes or RAT configurations, these can need separate testing, independent of the default test configuration and additional test configurations. In general, when many frequency bands or a wide range of DPC-ETA parameters and offsets are used, both default test configuration and additional test configuration can need consideration according to regulatory policies for algorithm validation to demonstrate power control continuity for the range of parameters used.

A.2.8 TDD and TDMA measurement considerations

The measurement equipment records technology specific frame-averaged power to account for TDD and TDMA transmission duty factors, and to satisfy the measurement rate Tp_{avg} specified by the procedures. For TDD, the measurement setup can require uplink-downlink isolation to separate bi-directional transmissions within the frequency channel. When the isolation of directional coupler or combiner/splitter ports are insufficient, separate input and output ports can be used on the RCT to reduce uplink-downlink cross-coupling. A circulator or combiner/splitter combination can also be considered, to redirect signals between the RCT and antenna port on the DUT (see Clause B.8).

A.2.9 Normalization of results

The measured maximum output power of a DUT typically has a fixed offset from the maximum tune-up tolerance value according to the $P_{max,specified}$. When the measured power is normalized to the $P_{limit,m}$ of a wireless mode, both power dependent and power independent tolerance components need consideration to correlate measured responses with expected behaviour of the test sequences. The power independent tolerances are expected to mostly cancel out in the normalization process. The power dependent tolerances, such as TxAGC, can introduce variations in the normalized ratio. In addition, the power measurement equipment can also have power dependent and power independent tolerance components that can affect the normalized ratios. Tolerance of the normalized ratios is considered according to the SAR_{target} and P_{limit} tolerances described in 6.10 and regulatory policies.

Transitional operations with different DPC-ETA parameters are analysed using normalized results. Before a test sequence is initiated, P_{limit} values are measured for all wireless modes used in the sequence, to confirm they are within the allowed tolerance range, i.e. $P_{\text{limit,m}} \leq P_{\text{limit,specified}}$. Since the normalized ratios are quite sensitive to P_{limit}, small variations in $P_{\text{limit,m}}$ can introduce undesirable concerns; for example, a $P_{\text{limit,m}}$ that is lower than its actual value can result in the normalized ratios exceeding 1,0 when a quasi-static test sequence approaches or reaches steady state near P_{limit}. In the procedures, all P_{limit} are measured for at least 30 s both immediately before and after a test sequence measurement, and the average of all values measured for the specific P_{limit} is used to normalize the measured responses in the test sequence, to minimize the effects of both equipment and DUT output drifts. In using normalized values, tolerance of the ratios is expected to be mostly due to the power dependent tolerance components, which is addressed according to tolerance allowed by the SAR_{target} and P_{limit}. If the power dependent tolerances of the power measurement equipment are insignificant, compensation of attenuations in the measurement chain can be optional when normalized results are used (see 6.10). Therefore, further scaling of measured results is avoided. In addition to DUT tolerances, regulatory policies also need consideration to determine how power measurement tolerances are applied. For example, similar to SAR measurement criteria, when a fixed maximum measurement tolerance is applied, compensation is possibly not allowed or necessary.

NOTE 1 Depending on device implementation, the procedures specified by the RF modem or chipset manufacturer are applied for power measurement at P_{limit}. It can be necessary to put DPC-ETA into a dedicated operating mode without disabling the algorithm to ensure the correct P_{limit} is measured. When DPC-ETA is disabled or put into factory test mode to set power levels for measurement, it is important to ensure that the exact same power levels used by the DPC-ETA parameters are measured. In some cases, a device reset can be necessary.

NOTE 2 When the $P_{\text{limit,specified}}$ is greater than the $P_{\text{max,specified}}$, the $P_{\text{limit,m}}$ is possibly not within the allowed tolerance of P_{limit}, since the DUT will not transmit above P_{max}. In this scenario, it is important to confirm that the $P_{\text{limit,m}}$ is within the allowed tolerance of P_{max}.

A.2.10 Measurement automation

The wireless mode and transitional configurations used in a test sequence for handover, call drops, discontinuous transmissions, and simultaneous transmission, etc., can vary for individual devices. The power requests in a test sequence (Clauses A.3 and A.4) are based on the DPC-ETA parameters of wireless modes, which can be easily calculated by the measurement automation for the RCT. The wireless modes, frequency bands and transmission configurations used for algorithm validation cannot be easily pre-configured for the RCT. These are device specific and are determined by the user, including transitional configurations, before testing. If full automation is desired, a user configurable list can be generated for the automation process to configure the wireless mode and parameters of each test sequence at run-time. Alternatively, the wireless operating parameters can be configured manually for the RCT and apply partial automation to each segment of the measurement. Availability of both the measured and time-averaged power through the automated process, during run-time, in a suitable form or format is necessary for the user to confirm steady-state conditions and to initiate subsequent transitions in a test sequence.

Automation is necessary to record time-aligned power measurements and power requests to correlate measured responses with power change in the test sequence and to ensure measurement consistency. When full automation is not feasible, partial automation in conjunction with manual procedures are considered. This can require regulatory coordination to ensure the test results are accepted. The test sequences can be grouped into separate or multiple segments to apply partial automation, to circumvent equipment coordination issues or to reduce difficulties associated with long test sequences and Tw_{avg}.

A.3 Basic algorithm validation

A.3.1 General

Quasi-static test sequences are used to verify basic DPC-ETA functionality according to steady-state time-averaged power. The RCT sends the same power level for each request until power control reaches steady state at the expected time-averaged power level for 0,2 × Tw_{avg} or 20 s before the next power request is initiated by the user. The time lag to reach steady state is a function of the time-averaging window, Tw_{avg}. The power levels in the test sequences sent by the RCT are based on the specified DPC-ETA parameters with tolerances included. All measured results are reviewed and confirmed to be within the tolerances specified for the parameters (see 5.3). The highest normalized ratio in a test configuration is used to ensure the tolerance allowed by SAR_{target} and P_{limit} (see 6.10) is satisfied.

A.3.2 Standalone wireless mode quasi-static test sequence

After an active connection has been established between the RCT and the DUT, a steady-state baseline condition at P_{min} is established for the quasi-static test sequence. The power requests in Table A.1 are executed sequentially after the time-averaged power has settled at P_{min}. Except for the transitioning point (step 6), the same power level is requested by the RCT at each step until the desired time-averaged power has reached steady state. Power is measured throughout the entire process, starting when the connection is established. A user confirmation is applied to trigger the next power request in the test sequence. The transitioning point at step 6 is intended to provide a quick and relatively larger magnitude of power change in the reverse direction to prepare for the next power request. It can also enable certain transitional behaviour to be observed to confirm algorithm functionality. A few steps are repeated in the test sequence, with varying initial conditions, to verify algorithm response consistency (e.g. steps 1 through 4 versus steps 7 through 10). Steps 1 through 10 are applied to the RAT with the most conservative algorithm validation configurations and steps 1 through 4 are applied to the remaining RATs that need testing. Generally, the configuration with the largest difference between P_{limit} and P_{max} (RAT with max(P_{max} − P_{limit})) is the most conservative condition for validation. This reduces the testing time to reach steady state for long Tw_{avg} durations; e.g. 360 s.

Table A.1 – Standalone wireless mode quasi-static test sequence

Step	RCT requested instantaneous power	Tw_{avg} time-averaged steady-state power	Time-averaged power: user observation/response or action
1	Establish connection and maintain P_{min}	P_{min}	Once connected, request P_{min} and wait for time-averaged power to settle at P_{min} in the passive segment to establish baseline; a user key entry is used to initiate the following test sequence
2	P_{max}	P_{limit}	
3	$(P_{limit} + P_{ctrl})/2$	$(P_{limit} + P_{ctrl})/2$	
4	$(P_{max} + P_{limit})/2$	P_{limit}	
5	$(P_{ctrl} + P_{min})/2$	$(P_{ctrl} + P_{min})/2$	
6	P_{max}	transitioning point: execute the next step when instantaneous power reaches approximately $(P_{limit} + P_{ctrl})/2$	
7	P_{min}	P_{min}	
8	$(P_{max} + P_{limit})/2$	P_{limit}	
9	$(P_{limit} + P_{ctrl})/2$	$(P_{limit} + P_{ctrl})/2$	

Step	RCT requested instantaneous power	Tw_{avg} time-averaged steady-state power	Time-averaged power: user observation/response or action
10	P_{max}	P_{limit}	
11	Terminate connection	NA	Disconnected
NOTE Depending on the power control step resolutions used by the wireless technologies, the measured steady-state power can level off with an offset, at a lower power, from that specified in column 3; for example, GSM uses 2 dB power control step resolution. Last column of the table is completed by the user according to test results and observations (see illustrative example in Clause A.10).			

A.3.3 User observations

The following observations require user review to verify the algorithm is operating as expected.

a) When reaching steady state at each step, the time-averaged power is converging to a power level managed by DPC-ETA, according to the power requested by the RCT and instantaneous power applied by the DUT. When the requested (specified) power is higher than measured P_{limit}, the power control adjustments within the device are reflected by the measured instantaneous power. Depending on algorithm implementation, the instantaneous power adjustment can be gradual or abrupt with decreases and increases.

b) The time lag and time taken to approach time-averaged power and reach steady state for each step are reviewed for consistency according to the power control and integration characteristics of Tw_{avg}. Depending on the changes in magnitude of the power requests and algorithm responses, whether it is a power increase or decrease, and the relative power level, it can take less or much longer than Tw_{avg} to reach steady state.

c) DPC-ETA behaviour is confirmed while time-averaged power is approaching steady state. When the desired (DPC-ETA managed versus requested) time-averaged power is sufficiently lower than P_{limit}, the measured power (instantaneous) would track the requested (specified) power from the RCT. Otherwise, the measured power corresponding to the active power control applied by DPC-ETA is reviewed, to ensure time-averaged power remains below the $P_{limit,m}$ and within the tolerance allowed by the SAR_{target}.

   1) When a sufficient power control reserve is available, DPC-ETA is expected to settle at the requested power level, with time-averaged power below P_{limit}, or with instantaneous power at a desired level to support a sustained connection.

   2) When a marginal power control reserve is available, DPC-ETA would settle at a DPC-ETA managed power control level, typically with time-averaged power close to P_{limit} and within the allowed tolerance, or with instantaneous power at a suitable level to support a sustained connection.

   3) When settling at steady-state condition, the oscillatory behaviour (magnitude and periodicity, etc.) is reviewed for consistency with the expected DPC-ETA implementation.

      i) Oscillations can occur near P_{limit} or at a DPC-ETA managed power level when the availability of power control reserve is marginal. This can require additional considerations to determine steady-state conditions, according to algorithm behaviour using an averaged power level.

      ii) With a sufficient power control reserve, little to no oscillation would be expected.

d) When all steps are applied, the consistency of power control behaviour for the equivalent steps in the test sequence is compared, i.e. the behaviours of steps 1 through 4 versus steps 7 through 10, etc.

NOTE As appropriate, similar observations also apply to other algorithm validation tests in this Annex A.

A.4 Dynamic and random power control test sequences, discontinuous transmissions

A.4.1 General

Dynamic test sequences, representative of typical network operating conditions due to environmental and propagation influences, with relatively rapid and asynchronous power requests in both magnitude and time, are used to verify DPC-ETA power control continuity. The time between power requests in the test sequence is substantially shorter than Tw_{avg}, and time-averaged power is not expected to reach steady state.

A.4.2 Test sequence considerations

Each RAT is considered for algorithm validation with dynamic test sequence by applying the default test configuration using the shortest Tw_{avg} configuration (already) measured with a quasi-static test sequence (A.3.2). Both FDD and TDD are considered for testing. The highest transmission duty factor configuration is measured for GSM/GPRS and LTE/NR TDD configurations according to frame-averaged power using dynamic test sequences. When the same DPC-ETA algorithms are not used for all the RATs and wireless modes, such configurations are considered independently to determine if additional testing is necessary.

The time interval between power requests in the dynamic test sequences is limited to 0,01 times to 0,3 times Tw_{avg}, but not less than 3 s or longer than 25 s, to allow coordinated measurement automation and to reduce the impact of time lag due to long Tw_{avg}. DPC-ETA responses are expected to vary with Tw_{avg}, the relative offsets between DPC-ETA parameters and the magnitude, duration, and direction of power changes (increases or decreases). Besides using pre-defined test sequences, a sequence of randomly generated power requests is also considered, to demonstrate the validation is unbiased.

The following are considered to configure dynamic test sequences.

a) The power requests are configured to emulate network operating conditions with rapid and asynchronous power increase and decrease, due to varying propagation characteristics and environmental conditions.

b) The measured and time-averaged power can not exceed the $P_{max,specified}$ and $P_{limit,specified}$, while remaining within the tolerance allowed by the SAR_{target} and P_{limit}.

   1) Conditions with abrupt reversal of power amplitudes and varying durations are included in the power requests.

   2) The random test sequence is configured according to two separate random number generators to adjust the amplitude and time interval of power requests, independently and simultaneously in a dynamic manner. The requested power is within the range of $P_{max} \leftrightarrow P_{min}$ and 0,01 × $Tw_{avg} \leftrightarrow$ 0,3 × Tw_{avg}, but not < 3 s or > 25 s. The random test sequence is ≥ 1,5 × Tw_{avg} with mean power ≥ P_{limit}, excluding non-transmitting segments.

   3) Two transmission gaps of 0,2 × Tw_{avg} and 0,3 × Tw_{avg} are included, respectively, within the first and last one-third of the random test sequence, to verify power control continuity due to discontinuous transmission. Both gaps are initiated by the user with a manual key entry. The durations of the transmission gaps are counted as part of the random sequence (≥ 1,5 × Tw_{avg}).

c) A few power requests with minor variations in amplitude or time duration, or both are included in the pre-configured segment of the dynamic test sequence, to compare algorithm response consistency.

A.4.3 Power measurement considerations

a) Both the pre-configured and random segments of the test sequence, including the discontinuous transmission gaps, are applied to at least one RAT. The remaining RATs can apply either the pre-configured or the random segment, in equal numbers.

b) Except for the two transmission gaps, power is measured continuously throughout the entire process. Power measurement can be paused during the gaps, provided these are correctly reflected by power measurements immediately before and after the gap, and properly accounted for in the time-averaging (see 6.8).

c) When the time-averaged power is sufficiently below the $P_{\text{limit,m}}$ with a sustained connection, the measured (instantaneous) power can track the requested power; otherwise, the measured power is actively controlled by DPC-ETA to keep time-averaged power below the $P_{\text{limit,m}}$.

d) It would be desirable for the measured and time-averaged power of the pre-configured segment to be available, e.g. displayed or plotted by the automation process, for users to confirm measurement progress and identify issues to abort a measurement configuration with long Tw_{avg}.

e) The measured (instantaneous) and time-averaged power are correlated with the expected behaviour of the DPC-ETA implementation for the power requests in the applied test sequence.

A.4.4 Dynamic test sequence

The power request intervals in the dynamic sequence are provided in fractions of Tw_{avg}, within the range 3 s to 25 s. These are identified in Table A.2, where Max is applied to reduce testing time and Min is applied to avoid equipment setup or automation coordination issues. Therefore, either the smaller of Tw_{avg} and Max, or the larger of Tw_{avg} and Min, applies.

Table A.3 describes the power request steps in the test sequence, including the random sequence and discontinuous transmission gaps.

Table A.2 – Power request time intervals calculated as a function of Tw_{avg} and limited to 3 s (Min) to 25 s (Max)

$n \times Tw_{\text{avg}}$ or Max/Min [s][a]	Tw_{avg} [s]		
	60	100	360
0,01 × Tw_{avg} or 3	3	3	3
0,05 × Tw_{avg} or 10	3	5	10
0,1 × Tw_{avg} or 15	6	10	15
0,2 × Tw_{avg} or 20	12	20	20
0,3 × Tw_{avg} or 25	18	25	25

[a] 0,01 × Tw_{avg} is used by the measurement automation to limit the random sequence to ≥ Min.

Table A.3 – Dynamic test sequence

Step	RCT requested instantaneous power	Power request duration [s]		Time-averaged power: user observation/response or action
1	Establish connection, and maintain P_{limit}	Wait until time-averaged power fully settles at P_{limit} for at least 0,2 × Tw_{avg} or 20		Once connected, request P_{limit} and wait until time-averaged power fully settles at P_{limit} to establish a baseline; then initiate rest of the test sequence with a manual user key entry; time to reach P_{limit} can depend on Tw_{avg}
2	P_{max}	0,3 × Tw_{avg} or 25		
3	P_{min}	0,05 × Tw_{avg} or 10		
4	$(P_{limit} + P_{ctrl})/2$	0,01 × Tw_{avg} or 3		
5	P_{max}	0,2 × Tw_{avg} or 20		
6	$(P_{max} + P_{limit})/2$	0,2 × Tw_{avg} or 20		
7	$(P_{limit} + P_{ctrl})/2$	0,2 × Tw_{avg} or 20		
8	P_{ctrl}	0,05 × Tw_{avg} or 10		
9	$(P_{max} + P_{limit})/2$	0,2 × Tw_{avg} or 20		
10	$(P_{ctrl} + P_{min})/2$	0,1 × Tw_{avg} or 15		
11	P_{max}	0,3 × Tw_{avg} or 25		
12	P_{ctrl}	0,05 × Tw_{avg} or 10		
13	P_{limit}	0,2 × Tw_{avg} or 20		
14	P_{max}	0,3 × Tw_{avg} or 25		
15	$(P_{limit} + P_{ctrl})/2$	0,3 × Tw_{avg} or 25		
16	$(P_{limit} + P_{ctrl})$ × 3/4	0,2 × Tw_{avg} or 20		
17	$(P_{limit} + P_{ctrl})/4$	0,05 × Tw_{avg} or 3		
18	$(P_{ctrl} + P_{min})/2$	0,05 × Tw_{avg} or 10		
19	P_{limit}	0,3 × Tw_{avg} or 25		
20	$(P_{max} + P_{limit})/2$	0,2 × Tw_{avg} or 20		
21	P_{max}	0,3 × Tw_{avg} or 25		
22	$(P_{limit} + P_{ctrl})$ × 3/4	0,05 × Tw_{avg} or 3		
23	$(P_{limit} + P_{ctrl})/4$	0,2 × Tw_{avg} or 20		
24	$(P_{limit} + P_{ctrl})$ × 3/4	0,05 × Tw_{avg} or 10		
25	$(P_{max} + P_{limit})/2$	0,3 × Tw_{avg} or 25		
26	P_{limit}	0,1 × Tw_{avg} or 15		
27	P_{ctrl}	0,05 × Tw_{avg} or 10		
28	P_{max}	0,3 × Tw_{avg} or 25		
29	$(P_{ctrl} + P_{min})/2$	0,1 × Tw_{avg} or 15		
30	$(P_{max} + P_{limit})/2$	0,05 × Tw_{avg} or 10		
31	P_{ctrl}	0,2 × Tw_{avg} or 20		

Step	RCT requested instantaneous power	Power request duration [s]		Time-averaged power: user observation/response or action
32	$(P_{limit} + P_{ctrl}) \times 3/4$	0,05 × Tw_{avg} or 10		
33	P_{max}	0,01 × Tw_{avg} or 3		
34	$(P_{limit} + P_{ctrl})/2$	0,2 × Tw_{avg} or 20		
35	P_{min}	0,1 × Tw_{avg} or 15		
36	Random test sequence $P_{max} \leftrightarrow P_{min}$ with mean power of transmitting segments ≥ P_{limit} and max[0,01 × (Tw_{avg}), Min] ↔ min[0,3 × (Tw_{avg}), Max]	≥ 1,5 × Tw_{avg} or 450 with two separate discontinuous transmission gaps within first and last one-third of the random sequence duration for 0,2 × Tw_{avg} and 0,3 × Tw_{avg} each		Can optionally pause power recording during the transmission gaps provided the actual gap time is accounted for by the time records of before and after power samples to show continuity of algorithm responses with respect to the DPC-ETA power control parameters
37	Terminate connection	NA		Disconnected

NOTE 1 Due to time lag introduced by Tw_{avg}, the changes in instantaneous power possibly do not track time-averaged power, which can continue to increase or decrease in opposite direction of the instantaneous power for some duration until much earlier values in the time-averaging buffer are shifted out.

NOTE 2 It is noted that different combinations of power requests (column 2) and intervals (column 3) are expected to result in varying DPC-ETA responses; therefore, such conditions also need consideration to analyse measured responses to correlate with expected behaviour of the implementation for the applied test sequence.

NOTE 3 For example, a random real number between a and b can be generated using RAND() × $(b - a) + a$. Two independent random number sequences are applied to separately modulate the burst power amplitude and duration simultaneously.

A.5 Transition between wireless operating modes and call drop conditions

A.5.1 General

A quasi-static test sequence is used to validate transitions within or across UMTS, CDMA2000, LTE, and NR wireless configurations in FDD and TDD modes, or a call drop within a wireless mode (see Clause A.6 for all GSM/GPRS related configurations).

A.5.2 Test sequence considerations

Depending on the RATs supported by the RCT or RCTs, the transitions considered in a test sequence can be tested in a partially automated manner, one at a time with each initiated separately by the user or as independent tests. Alternatively, a fully automated test sequence can be configured for transitions across multiple wireless modes and RATs. A quasi-static test sequence is used to verify handover across frequency bands and wireless modes for the applicable Tw_{avg}. A simulated call-drop and immediate reconnect, within a few seconds, is tested for each RAT to verify power control continuity. When partially automated procedures are applied, if not kept to the minimum the gaps introduced by transmission pauses from switching RCT configurations can result in undesirable decreases in time-averaged power and can render the validation inapplicable.

A.5.3 Test sequence configuration

The following items are considered to configure test sequences for handover and call drop.

a) DPC-ETA power control at steady state with time-averaged power at or near the $P_{\text{limit,m}}$ (i.e. in active power control) is confirmed, with the RCT requesting $P_{\text{max,specified}}$, before and after each transition. Transitions are avoided at instances that are multiples of Tw_{avg} after requesting P_{max} for robust testing of power control continuity. It is recommended to initiate transition after the time-averaged power settles at P_{limit} (i.e. after at least Tw_{avg}) and immediately after the DPC-ETA adjusts the power from P_{max} to P_{ctrl}. Alternatively, transition can be initiated after the time-averaged power has reached steady state and at an instant that is odd multiples of 0,5 × Tw_{avg} (e.g. 1,5 × Tw_{avg}, 2,5 × Tw_{avg}, etc.) after requesting P_{max}. Power is measured continuously during the transition, until DPC-ETA power control reaches steady state again according to P_{max} and P_{limit} of the next wireless mode.

   Different Tw_{avg} can apply before and after a transition (see 6.8). A wait time of at least 0,2 × Tw_{avg} or 20 s is allowed after the time-averaged power has reached steady state, which can vary with Tw_{avg}.

b) Step a) is applied to all transitions in the test sequences for the wireless modes and RATs supported by DPC-ETA in a device and needing testing, including the following:
   - FDD for UMTS, LTE, and NR;
   - TDD for LTE and NR;
   - NR SA and NR NSA EN-DC;
   - CDMA2000 and UMTS.

   NOTE It is possible that some regulatory policies require only a few transitions to be tested instead of all combinations.

c) The transitions that need testing are determined by the RATs and Tw_{avg} supported by the device according to the following items.

   The transitions included in the test sequence are representative and proportional to the number and complexity of the RATs supported and Tw_{avg} used, taking into consideration the following.

   1) All supported RATs and Tw_{avg}, according to FDD and TDD, are considered.
      i) The highest and lowest transmission duty factors supported by TDD are considered for all RATs; or for each RAT, if different DPC-ETA control algorithms are used.
      ii) The number of transitions tested for the RATs are consistent for covering the range of Tw_{avg} and DPC-ETA parameters used, i.e. the default test configuration and additional test configuration used in A.3.2 for FDD and TDD.
      iii) When multiple antennas are used, for example, high and low band antennas, each antenna is either considered separately or included in already tested configurations, to verify power control continuity for antenna switching (also see diversity antenna in A.9.1).
   2) The default test configurations used for the RATs are considered for each Tw_{avg}; or at least once for each RAT, if different DPC-ETA control algorithms are used.
   3) The additional test configurations for the RATs, if applicable, are considered for each Tw_{avg}; or at least once for each RAT, if different DPC-ETA control algorithms are used.
   4) Transitioning back and forth across all Tw_{avg} are considered in the above test configurations, to confirm power control tightening and relaxation due to Tw_{avg} changes.
   5) When different Tw_{avg} apply, the time-averaged power before, during (if applicable), and after the transition for the applicable Tw_{avg} are clearly illustrated in the test report.

d) The transitions can be tested separately in a partially automated manner or with multiple transitions included in a single test sequence.

   1) Transitions between FDD and TDD (to and from) are included in the test sequences.

   2) The middle channel of the frequency band is used for all transitions, similar to that described in A.2.6.

e) The sequence of wireless modes tested, Wm(n), with the corresponding control parameters and conditions are tabulated similar to Table A.4 (adjust and modify as needed) to identify the configurations considered for testing.

   Depending on the measurement automation, the transitions in the test sequence can be executed according to the wireless modes and RATs determined by the user; for example, from a user-configured list read by the automated process to program the test sequence (see A.2.10).

f) As appropriate, call drops can be included in the handover test sequences. Call drops are initiated by the user, with a separate manual key entry value to distinguish between a handover transition and a call drop. Otherwise, call drops can be tested independently.

   1) Call drops can be included at the end (completion) of a handover. When the time-averaged power has reached steady state after the call drop, the next handover is executed.

   2) Multiple (longest and shortest) Tw_{avg} are considered for call drop testing, which can be included in separate RATs; i.e. these do not need to be tested for each RAT.

   3) Multiple (highest and lowest) TDD duty factors are considered for call drop testing, and can be included in separate RATs; i.e. these do not need to be tested for each RAT.

   4) When applicable and testing is performed, a call drop for 5G NR is executed in NSA EN-DC mode; otherwise, SA mode is considered.

The following parameters and conditions are assumed to determine the wireless modes used in Table A.4. Depending on regulatory policies, it is possible that not all configurations considered in the table need testing.

– RATs supported: UMTS, LTE (FDD/TDD), NR (FDD/TDD) (SA/NSA); no GSM and CDMA2000 support.

– Tw_{avg} = [60, 100] s for above and below 3 GHz (based on U.S. policies).

– Tp_{avg} = 0,1 s.

– The same DPC-ETA control algorithm applies to all RATs, modes, and bands; therefore, transition test configuration reduction applies.

– TDD duty factor range is 21,6 % to 63,3 %, for the supported RATs.

– NR supports both SA and NSA, with different Tw_{avg} for bands transmitting simultaneously in EN-DC.

– NR NSA supports dynamic power sharing (DPS) with aggregate maximum output power of $P_{max,LTE} + P_{max,NR} \leq P_{cmax}$ (LTE/NR aggregate). It is assumed that different sets of P_{max}, P_{limit}, and P_{ctrl} are applicable to LTE and NR NSA; therefore, $P_{max,LTE}$ and $P_{max,NRNSA}$ are independent parameters used for DPC-ETA.

Table A.4 – Example test sequence for handover and call drop

Wireless mode (Wm)	RAT	Band	Tw_{avg} [s]	FDD or TDD duty factor [%]	P_{max} [dBm]	P_{limit} [dBm]	P_{ctrl} [dBm]	Configuration details and conditions; user observation
1	LTE	2	100	FDD	24	20	17	
2	NR (SA)	77	60	63,3	23	20	17	
3	UMTS (RMC)	4	100	FDD	23	19	16	
4	LTE	41	100	21,6	26	22	18	
					call drop			
5	NR (SA)	25	100	FDD	23	21	17	
6	UMTS	22	60	FDD	23	20	17	
					call drop			
7	NR NSA EN-DC	66A / 41A	100	FDD (66A) TDD (41A) 63,3 %	23 24 (DPS P_{max} = 24)	20 21	17 18	
8	NR NSA EN-DC	41A / 77A	100/60	TDD LTE at 43,3 % NR at 63,3 %	24 23 (DPS P_{max} = 24)	20 19	17 16	
					call drop			
…								
n − 1								
n								

NOTE The values of Tw_{avg} used in Table A.4 are representative of U.S. regulatory policies (based on existing experience). A fixed value of 360 s generally applies to other regulatory jurisdictions.

A.6 GSM/GPRS configurations – duty factor, call drop, discontinuous transmission, transition between GSM and UMTS

A.6.1 General

GSM/GPRS operations are verified separately from other RATs. Both single and multiple time-slot configurations are considered to verify DPC-ETA functionality. Power control continuity across RATs, for transitions between GSM/GPRS and UMTS or CDMA2000 for TDMA and FDD only, are considered to avoid manual RCT switching issues and equipment setup concerns. Transition between GSM/GPRS and LTE is not considered, and transition between GSM/GPRS and NR is not currently and not expected to be supported by networks.

A.6.2 Test sequence considerations and configuration

The following items are considered to determine GSM/GPRS test sequences. When multiple transitions and configurations are included in a test sequence, the measurements can be performed with full automation, or separately in a partially automated manner.

a) The lowest GSM duty factor (1/8) and the highest GPRS duty factor (maximum number of slots) supported by the device are both considered for algorithm verification, according to the default test configurations, for the highest and lowest frequency bands supported by the device. For different number of time slots, different values of P_{max} and P_{limit} can be specified for such configurations to satisfy power specifications and SAR requirements; therefore, the correct parameters applied to the test configurations need confirmation.

b) Instead of performing the tests for discontinuous transmission and call drop independently, both can be included in the test sequence. An 0,2 × Tw_{avg} discontinuous transmission gap is used to confirm power control continuity.

c) GSM/GPRS, UMTS, and CDMA2000 all operate below 3 GHz; therefore, the same 100 s or 360 s Tw_{avg} applies according to existing regulatory policies. Depending on RCT support for automated switching between RATs, the following are considered for transitioning between GSM/GPRS and UMTS or CDMA2000.

   1) The default test configurations among the respective frequency bands and modes in each RAT are considered according to the largest GPRS duty factor, to verify transitioning from GSM/GPRS to UMTS or CDMA2000.

   2) The default test configurations among the respective frequency bands and modes in each RAT are considered according to the smallest GSM/GPRS duty factor, to verify transitioning from UMTS or CDMA2000 to GSM/GPRS.

   3) The middle channel of the corresponding frequency band, according to A.2.6, is used.

NOTE Reduced maximum averaged power can be used in some higher duty factor (slot) configurations for GPRS. For DPC-ETA to remain active, the P_{limit} of the largest duty factor configuration used for testing cannot be higher than P_{max}.

A.6.3 Power measurement considerations

a) The TDMA power measurement configurations in A.2.8 are applicable.

b) Before the power change in a transition is initiated, $P_{\text{max,specified}}$ is requested with measured time-averaged power in steady state at or near the $P_{\text{limit,m}}$ (i.e. in active power control). Power is measured continuously during the transition until time-averaged power reaches steady state after the transition.

   1) The time-averaged power has reached steady state before and after each discontinuous transmission, call drop, or transition, for at least 0,2 × Tw_{avg} or 20 s.

   2) Call drop, discontinuous transmission, and transitions are initiated with a manual user key entry, after steady state is confirmed, and power is measured continuously throughout the transition. Transitions are avoided at instances that are multiples of Tw_{avg} after requesting P_{max} for robust testing of power control continuity. It is advisable to initiate transition after the time-averaged power settles at P_{limit} (i.e. after at least Tw_{avg}) and immediately after the DPC-ETA adjusts the power from P_{max} to P_{ctrl}. Alternatively, transition can be initiated after the time-averaged power has reached steady state and at an instant that is at odd multiples of 0,5 × Tw_{avg} (e.g. 1,5 × Tw_{avg}, 2,5 × Tw_{avg}, etc.) after requesting P_{max}.

   3) Power measurement can be paused for the discontinuous transmission gap when the measured power before and after the transition can clearly identify the transmission gap and the time-averaged power is properly accounted for (see 6.8).

c) The configurations included in the test sequence are tabulated, similar to Table A.5, to illustrate the wireless modes and transitions (duty factor changes, call drop, discontinuous transmission (Tx) and GSM/GPRS ↔ UMTS/CDMA2000 transition), and to correlate measured responses with the expected behaviour of the implementation for the applied test sequence.

Table A.5 – Example test sequence for GSM/GPRS and transitional operations

RAT	Band [MHz]	GSM/GPRS time slots	P_{max} [dBm]	P_{limit} [dBm]	P_{ctrl} [dBm]	Configuration details and conditions; (Example) user observation
GSM	1 800/1 900	1/8	21	18	15	highest frequency band: default test configuration with lowest duty factor; when time-averaged power reaches steady state, initiate 0,2 × Tw_{avg} discontinuous Tx and wait for time-averaged power to reach steady state again after transmission resumes before initiating next step
GPRS	800/900	4/8	28	25	22	transition: 1 800/1 900 → 800/900 band, lowest frequency band: default test configuration with highest duty factor; when time-averaged power reaches steady state, initiate call drop, wait for reconnection and time-averaged power to reach steady state again before initiating next step
UMTS	800/900	FDD	23	20	17	transition: GPRS → UMTS according to default test configuration with highest duty factor; wait until time-averaged power reaches steady state before initiating next step
GPRS	1 800/1 900	2/8	25	22	19	transition: UMTS → GPRS according to default test configuration with lowest duty factor; when time-averaged power reaches steady state, initiate 0,3 × Tw_{avg} discontinuous Tx and wait for time-averaged power to reach steady state after transmission resumes before initiating next step or terminate test sequence
NOTE While burst-averaged power according to $P_{max,specified}$, $P_{limit,specified}$, and $P_{ctrl,specified}$ is used in the test sequences, frame-averaged power is measured during algorithm validation measurements.						

A.7 Simultaneous transmission and RAT specific considerations

A.7.1 General

The test sequence for simultaneous transmission starts with the default test configuration with the largest (P_{max} [dBm] − P_{limit} [dBm]) value among the wireless modes that need consideration. A quasi-static test sequence is used with the RCT requesting P_{max} for all transmissions added to the simultaneous combination. After the time-averaged power of the first transmission reaches steady state at P_{limit}, the default test configuration for next to largest (P_{max} [dBm] − P_{limit} [dBm]) value in the list of simultaneous configurations is added. The time-averaged power for both transmissions are allowed to reach steady state before the next configuration is added. The subsequent transmission configurations are added in similar manners to the simultaneous combination.

For 5G NR NSA, EN-DC requires an active LTE anchor to support 5G transmissions. The default test configuration for the primary connection (LTE anchor) is activated first, followed by the default test configuration for the secondary connection (NR). When testing is performed for carrier aggregation, similar conditions are considered to add primary and secondary component carriers.

Testing of simultaneous transmission can be complex and highly dependent on RCT support and test equipment coordination to configure certain test conditions. Depending on device capabilities, the test configurations that need consideration, e.g. inter-band CA, can vary with regulatory policies. Transitional operations, such as call drop or handover, are not considered for simultaneous transmission in this document; if testing is needed to confirm power control continuity, the procedures in this document can be adjusted according to regulatory guidance to perform the measurements.

A.7.2 Aggregate power requirements

When adding simultaneous transmission configurations to a combination, the maximum output power allowed for each existing transmission can change to satisfy maximum aggregate output power allowed by network protocol or DPC-ETA. For example, in NR NSA, equal power sharing (EPS) and dynamic power sharing (DPS) for primary and secondary serving cells, or restrictions imposed by the device, can limit power in a wireless mode. The power of the component carriers (CC) in carrier aggregation (CA) can be limited by the number of CCs. These power restrictions are determined by network protocol and SAR compliance requirements. To sustain the primary connection, a secondary connection can be dropped. Depending on regulatory policies, multiple Tw_{avg} can apply to different frequency bands in the simultaneous transmission combination. When the power requirements are not automatically adjusted by the RCT or RCTs, according to wireless protocol specifications, interventions are necessary to apply the correct power settings for testing. The following guidance can be considered to address individual situations.

A DPC-ETA implementation can use the same or different P_{max} and P_{limit} for simultaneous transmission configurations and standalone transmission. Determination of aggregate power in a simultaneous transmission combination can vary with implementation. For algorithm validation, the steady-state time-averaged power of each simultaneous transmission in the combination is verified, according to the corresponding P_{max} and P_{limit} or conditions supported by the network and device-imposed conditions, to correlate DPC-ETA responses with the expected power control behaviour of the implementation, for the applied simultaneous transmission test sequence. The conditions for both network-based and device-based power adjustments are reviewed to ensure these are correctly reflected in the final results, to correlate measured responses with expected behaviour.

After the last simultaneous transmission configuration is added and the time-averaged power of all transmissions have reached steady state, the simultaneous transmission configurations are removed or terminated one at a time, starting with the first one included in the test sequence. Upon removal of a configuration, the time-averaged power of the remaining transmissions are allowed to reach steady state before the next transmission is removed. At each step, the network-based and device-based power requirements can relax as more configurations are removed; therefore, the corresponding DPC-ETA responses and expected algorithm behaviour are observed and confirmed according to the active connections and Tw_{avg} used in the combination. The time needed for the time-averaged power to reach steady state can vary with power adjustments, the number of transmissions, and Tw_{avg} time lag of the frequency bands in the combination.

A.7.3 Power measurement and automation considerations

Different P_{limit} can apply for different wireless configurations, and Tw_{avg} can vary with frequency bands. Therefore, power is measured independently for the simultaneous transmitting signals to enable each to be normalized by the corresponding P_{limit} for each of the transitional segments (Tx_1 … Tx_n/Tp_1 … Tp_n; see A.7.4), to ensure the highest normalized power ratios of each configuration in the segment is within the tolerance allowed by the SAR_{target} and P_{limit}.

The different RATs and transmitter combinations that are controlled by the same RF modem and DPC-ETA algorithm are generally limited to two or three due to hardware constraints for the number of transmitters in typical devices. Although the algorithm validation procedure for simultaneous transmission has been generalized and independent power measurements are used to acquire simultaneous transmitting signals, this is generally not a practical concern for the test equipment and measurement automation. When more than two or three simultaneous transmitting signals are supported by DPC-ETA, RCT and power measurement equipment considerations can become increasingly complex. More practical approaches to streamline equipment coordination and measurement automation beyond this document, in accordance with regulatory policies, would need consideration.

The measurement automation alternatives in A.2.10 are considered for algorithm validation of simultaneous transmission configurations to add or remove transmissions in a user-assisted or partially automated manner. Availability of measured and time-averaged power of individual transmissions in the simultaneous combination are necessary for users to initiate transitions to the subsequent configurations (add or remove transmissions), according to steady state time-averaged conditions.

A.7.4 Test sequence considerations

Intra-band CA configurations are considered as a single standalone configuration. Inter-band CA configurations are considered as separate simultaneous transmission configurations according to the number of frequency bands and Tw_{avg} involved. NR NSA is considered as two simultaneous transmissions, the LTE anchor and NR traffic. When CA and NR NSA are both applicable, additional guidance according to regulatory policies possibly needs consideration to determine if such conditions would need separate testing. The following approach can be adapted accordingly to consider the applicable simultaneous transmission configurations that need testing. Other factors, such as TDD transmission duty factor, also need consideration to apply normalized duty factor according to frame averaged power, to correlate measured responses with expected DPC-ETA behaviour.

The following are steps to configure simultaneous transmission test sequences for algorithm validation.

a) The maximum output power according to network protocol requirements for simultaneous transmission, as normally expected by the DUT, is used in RCT requests. The network is unaware of the DPC-ETA specifics in a device. Local or device-based restrictions are excluded in determining network power requests.

b) For 5G NR NSA, the maximum and aggregate power for LTE and NR are configured according to EPS and DPS requirements.

   NOTE Simultaneous transmission of UMTS, CDMA2000, or GSM/GPRS with NR is not considered.

c) Starting with the first transmitter (Tx_1) and the default test configuration with the largest difference between P_{max} and P_{limit}, the sequence of power measurements up to the point before the next transmitter (Tx_2) is added is referred to as Segment Tx_1. Segment Tx_2 corresponds to both Tx_1 and Tx_2 transmitting simultaneously and segment Tx_n would correspond to all transmitters (Tx_1 through Tx_n) transmitting simultaneously.

d) After a transmitter is added or removed, the time-averaged powers for all transmitters are each allowed to reach steady state for 0,2 × Tw_{avg} or 20 s before initiating the next addition or removal. Depending on the RCT and equipment coordination requirements, it can be necessary to add or remove transmitters/configurations manually when automation is difficult. In some cases, a secondary connection can be dropped to sustain the primary connection (CA or EN-DC). A compromised approach can be necessary to adjust the power to maintain both connections according to regulatory guidance.

e) After all transmissions are added to the simultaneous combination and the time-averaged power of all transmissions have reached steady state in Segment Tx_n, the output of each transmitter is reduced sequentially to P_{min} (or turned off), starting from Tx_1 until Tx_n; and, the time-averaged power of all remaining transmissions are allowed to reach steady state before power is reduced or removed for the next transmission in the combination.

f) During transmitter removal or power reduction to P_{min}, the first added transmitter (Tx_1) is removed first instead of removed last. The simultaneous transmission configurations for sequences added and removed are different. A different segment naming convention is used to distinguish the transmission removal process; for example, Segment Tp_n would correspond to all transmitters active and Segment Tp_1 with only the last added transmitter active. In this case, Tx_n would be identical to Tp_n. The test configurations and procedures are described in a similar manner in the algorithm validation test report.

g) Transitions are avoided at instances that are multiples of Tw_{avg} after requesting P_{max} for robust testing of power control continuity. It is recommended to initiate transitions after the time-averaged power has reached steady state and having a duration of each segment (i.e. Segment Tx_1 through Segment Tx_n and Segment Tp_1 through Segment Tp_n) that is at odd multiples of 0,5 × Tw_{avg} (e.g. 1,5 × Tw_{avg}, 2,5 × Tw_{avg}, etc.)

A.8 Host device based external triggering transitions

A.8.1 General

External events or conditions controlled by a host device can be used to trigger DPC-ETA transitions. This is typically related to changes in exposure conditions detected by the host, or coordination of transmitters not controlled by DPC-ETA that require a new set of DPC-ETA parameters to be applied for the wireless configuration. The triggered wireless configurations are those already taken into consideration in the algorithm validation process. The DPC-ETA configurations triggered by host-managed conditions are operating in the same manner as network initiated DPC-ETA transitions. A simple power measurement or other suitable means is sufficient to verify the correct DPC-ETA parameters are applied after the transition without further algorithm validation.

A.8.2 DPC-ETA algorithm validation considerations

The following items are considered for DPC-ETA transitions triggered by a host device; i.e. triggering is not an integral part of the DPC-ETA design or directly controlled by the implementation.

a) The host-based triggering mechanism and conditions that are not an integral part of the DPC-ETA implementation are confirmed and validated separately according to regulatory requirements. As necessary, triggering consistency of the sensing mechanisms is verified for both enabling and disabling of the relevant conditions.

b) Coordination of transmitters not controlled by DPC-ETA, such as Wi-Fi, to ensure the aggregate exposure ratio (or TER) of all simultaneous transmissions is < 1,0 is confirmed at the host level according to regulatory policies.

c) The triggered conditions and corresponding DPC-ETA responses, i.e. the $P_{max,specified}$, $P_{limit,specified}$, $P_{ctrl,specified}$, Tw_{avg}, and other associated parameters, are verified for the triggering condition intended for a wireless mode.

   1) A simple power measurement can be applied to avoid further algorithm validation testing. In situations where the triggering can depend on additional conditions to initiate the next DPC-ETA configuration (for example, until the output is close to P_{limit}), other suitable means would be necessary to validate the transition. This type of contingent or conditional triggering can necessitate applying test modes and host device coordination, to perform algorithm validation according to the implementation.

2) If the triggered condition corresponds to a new DPC-ETA operating condition that has not been considered in the wireless modes for algorithm validation, according to Clause 7, independent validation can need consideration. Regulatory guidance is necessary to determine suitable test conditions for sensor triggering and DPC-ETA validation.

A.9 Transmit diversity and simultaneous transmission antenna configurations

A.9.1 Diversity antennas

Diversity antennas can have different SAR to power relationships due to antenna type or installation location differences. Different P_{max} and P_{limit} are typically used for the antennas. The DPC-ETA parameters for the antenna with more conservative SAR characteristics can be used for both antennas, and antenna switching would be transparent for DPC-ETA. When different sets of DPC-ETA parameters are used, confirmation that the proper parameters are applied to the corresponding antennas is needed to ensure power control continuity. It is also determined if rapid switching between diversity antennas is supported or suppressed by the DUT, to ensure such conditions would not introduce unexpected complications for DPC-ETA. In most cases, testing of antenna switching in pre-configured transmission conditions would require factory test mode. It is sufficient to use simple power measurement means to verify the correct DPC-ETA parameters are applied to the antennas, to avoid further algorithm validation for configurations already considered by the wireless modes. If the antenna switching can depend on additional conditions to initiate the next DPC-ETA configuration (for example, until the output is close to P_{limit}), other suitable means would be necessary to validate the transition. This type of contingent or conditional triggering can necessitate applying test modes and host device coordination to perform algorithm validation.

A.9.2 Simultaneous transmission

Simultaneous transmissions can involve single or multiple frequency bands and single or multiple antennas. For devices with multiple antennas operating with separate transmitters according to independent DPC-ETA parameters, transmissions are generally managed by the RF modem for transparent DPC-ETA operations. When multiple frequency bands are transmitted using the same antenna, the DPC-ETA parameters used for each frequency band are considered independently to verify DPC-ETA operations, especially when different Tw_{avg} are used. Unless separate antenna ports are available for multiple frequency bands, case-by-case conducted power measurement test setup with combiner/splitter and filters are necessary to capture the simultaneous signals for algorithm validation (see Clause B.8). The simultaneous transmission procedures in Clause A.7 can be considered and modified accordingly for algorithm validation. The criteria in Clause A.7 also apply to simultaneous transmission of multiple frequency bands through separate independent antennas; for example, 5G NR NSA.

A.10 Illustrative example

A.10.1 General

Until the procedures in this document have been implemented by a user with the proper measurement automation and post-processing requirements for actual use, it is not feasible to acquire algorithm validation test results based on DPC-ETA algorithms operating within an actual DUT. An illustrative example is described in the following according to simplistic power control procedures, to demonstrate how DPC-ETA responses are generally reviewed and analysed with respect to the power control parameters and expected behaviour of the test sequence. The responses and results are simulated, i.e. generated using a spreadsheet by applying basic power control criteria according to the quasi-static test sequence of A.3.2. To further illustrate the procedures, a 20 s discontinuous transmission segment (segment A), segments transitioning from Tw_{avg} = 100 s to 60 s (segment B), and then back to 100 s (segment C) time windows, and a TDMA segment (segment D) with $P_{limit} > P_{max}$, are also included after the quasi-static sequence. Since the intelligent power control algorithms used in realistic devices cannot be easily applied interactively in a dynamic manner using a spreadsheet, the DPC-ETA responses (i.e. simulated measured power) have been generated separately for each power request step in the test sequences, one segment at a time, for the purposes of this illustrative example.

A.10.2 DPC-ETA power control and operating parameters

The power control, time-averaging windows and other associated parameters used to determine power control and time-averaging operations in the spreadsheet are shown in Table A.6. A measurement interval (Tp_{avg}) of 0,1 s is used to generate the measured data, which are time-averaged with a 100 s or 60 s time window. A tolerance of 1,5 dB (k = 1) has been assumed, with TxAGC, algorithm, and certain other device tolerances included, i.e. the equivalent of Tc. The SAR_{target}, SAR_{limit}, and corresponding normalization ratio scaling factor ($SAR_{target,norm} = SAR_{target}/SAR_{limit}$) are also shown in Table A.6. Table A.6 also includes the power control parameters and power levels used in the quasi-static test sequence and additional segments (A through D), with respect to specified power levels (including tolerances), nominal values stored in a DUT, and measured values assumed for the device. These serve to illustrate how the parameters in the test sequence (RCT in Table A.7), DUT, and measured (instantaneous) values are related according to the tolerance allowed for SAR_{target} and P_{limit}. In this example, except for segment D (TDMA), it is assumed that the device operates at a level of 0,5 dB above the nominal value, which is within the 1,5 dB tolerance (Tc) allowed by the SAR_{target} and P_{limit}.

Table A.6 – Power control and operating parameters used in the illustrative example

Parameters		Power control [dBm]	Specified	Nominal	Measured
Tw_{avg} = 100 s: Quasi-static test sequence, segments A and C parameters					
Tp_{avg} [s]	0,1	P_{max}	24,0	22,5	23,0
Tw_{avg} [s]	100	P_{limit}	21,0	19,5	20,0
Tc, k = 1 [dB]	1,5	P_{ctrl}	18,0	16,5	17,0
		P_{min}		0,00	
SAR_{target} [W/kg]	1,12	$(P_{max} + P_{limit})/2$	22,75		
SAR_{limit} [W/kg]	1,6	$(P_{limit} + P_{ctrl})/2$	19,75		
$SAR_{target,norm}$	0,70	$(P_{ctrl} + P_{min})/2$	15,06		
Tw_{avg} = 60 s: segment B parameters					
Tp_{avg} [s]	0,1	P_{max}	20,5	19,0	19,5
Tw_{avg} [s]	60	P_{limit}	17,5	16,0	16,5
Tc, k = 1 [dB]	1,5	P_{ctrl}	14,5	13,0	13,5
SAR_{target} [W/kg]	1,02				
SAR_{limit} [W/kg]	1,6				
$SAR_{target,norm}$	0,64				
TDMA: segment D parameters					
Tp_{avg} [s]	0,1	P_{max}	30,0	28,5	20,1
Tw_{avg} [s]	100	P_{limit}	31,0	29,5	19,9
Tc, k = 1 [dB]	1,5	P_{ctrl}	28,0	26,5	18,0
SAR_{target} [W/kg]	1,10				
SAR_{limit} [W/kg]	1,6				
$SAR_{target,norm}$	0,69				
Duty factor [%]	8,3				

A.10.3 Correlating measured responses with expected DPC-ETA behaviour

The power step change conditions for the quasi-static test sequence and the additional segments are shown in Table A.7. The power level at each step in the test sequence, sent by the RCT to the DUT, and the expected time-averaged power of DUT at steady state, are also listed. While the instantaneous power requested by the RCT can be as high as P_{max} (including tolerance), the time-averaged power calculated from simulated measured instantaneous power is limited to P_{limit} (without tolerance), according to the parameters used for the corresponding segments in Table A.6. The measured instantaneous power can be highly dependent on the power control characteristics of the DPC-ETA algorithm implementation; therefore, no specific or expected values of instantaneous power are shown in Table A.6 and Table A.7. For this illustrative example, a rather simplistic power control mechanism is applied to generate relevant (simulated) measurement samples to satisfy the power control and time-averaging conditions.

The illustrative example consists of 13 999 simulated power measurement samples at 0,1 s interval. A small amount of random variation has been added to each measurement sample to simulate typical measurement fluctuations. The power control is allowed to reach steady state for 20 s or longer before the next power step in the test sequence or segment is initiated. The conditions of the parameters, along with the measured and calculated values, for the first and last occurrences over the duration of each step in the test sequence or segments, are shown in Table A.8. While the measured instantaneous power can exceed P_{limit}, the maximum time-averaged power is limited to the $P_{\text{limit,m}}$, and remains within the tolerance range allowed by SAR_{target} and P_{limit} regardless of power requested by the RCT or test sequence. The time needed for each power request in the test sequence to reach steady state is dependent on the simplistic algorithm used in the example. The settling time also depends on the initial and final power levels, where larger power differences can take longer to reach steady state. The piecewise simplistic power control simulated in this example is unimportant provided the power levels required by the power control parameters are satisfied.

The requested (RCT) and measured power (instantaneous), along with the calculated time-averaged power (DUT), are shown in Figure A.1. The normalized results, with respect to $SAR_{\text{target,norm}}$ and the tolerance range, are shown in Figure A.3, and the non-scaled version is shown in Figure A.2, where additional details are revealed because of the normalization process on a linearly scaled plot. The changes introduced by the different P_{limit} of the segments have become more obvious. The lagging of time-averaged and instantaneous power due to power samples in the previous segment included in the current time windows, and its impact on time-averaged power, can also be observed. When transitioning from a higher P_{limit} configuration to a lower P_{limit} configuration, depending on the algorithms and time windows used, the previous samples before the transition can have noticeable influences after the transition. The highest ratio of the measured power (see R_{max} in 6.10) normalized by the corresponding P_{limit} in each segment, before and after being scaled by $SAR_{\text{target,norm}}$, are shown in Table A.9, along with the tolerance range allowed by the assumed 1,5 dB tolerance (Tc) applied to the SAR_{target} and P_{limit}. The tolerance range shown by the dotted and dash lines in Figure A.2 and Figure A.3 are different. This is because when time-averaged power is scaled by $SAR_{\text{target,norm}}$, the tolerance range is also scaled by $SAR_{\text{target,norm}}$. The TDMA duty factor in segment D resulted in a different tolerance range than the other segments, for both non-scaled and scaled results in Figure A.2 and Figure A.3. The equivalence of the normalization schemes, with and without $SAR_{\text{target,norm}}$ scaling, can be observed in Figure A.2 and Figure A.3, which is illustrated separately in Figure A.4.

Each power change step in the quasi-static test sequence and the additional segments can be identified by the power request changes from the RCT, according to the blue line in the Figure A.1, Figure A.2, and Figure A.3. The measured instantaneous power and calculated time-averaged power for the corresponding Tw_{avg} are shown, respectively, by the orange and red curves. The 10 steps in the quasi-static test sequence are followed by the four additional segments: (A) 20 s discontinuous transmission, (B) transition from 100 s Tw_{avg} to 60 s Tw_{avg}, (C) transition from 60 s Tw_{avg} back to 100 s Tw_{avg}, and (D) a GSM/TDMA segment with $P_{\text{limit}} > P_{\text{max}}$ but less than the allowed 1,5 dB tolerance for Tw_{avg} = 100 s. Except for step 6 (transition point) in the quasi-static sequence, and the fixed duration discontinuous Tx segment, each power step change or segment is allowed to reach steady state and remains in that condition for at least 20 s before the next transition is initiated.

In transitioning from the quasi-static sequence to segment A (33 s of discontinuous Tx at −30 dBm), due to the much higher power applied before the transition, the reduction in time-averaged power over segment A is relatively small. When transitioning from segment A to segment B (Tw_{avg} = 60 s), the higher power from the quasi-static sequence continues to influence the first 270 time-averaged samples in segment B (600 samples minus 330 samples from segment A). The first 1 000 time-averaged samples in segment C, with Tw_{avg} = 100 s, are influenced by the last 999 samples in segment B. For segment D, as indicated in Table A.6, $P_{limit} > P_{max}$ but within the 1,5 dB tolerance range (Tc). The second tolerance condition in 6.10 requires a reduced upper tolerance range to be applied. Under this condition, P_{limit} cannot be measured, and is limited by the $P_{max,m}$; therefore, the algorithm can become active when P_{limit} becomes slightly less than P_{max}. The normalized RCT power shown in Figure A.2 and Figure A.3 for segment D are lower because $P_{limit} > P_{max}$, which are distinguished from other conditions where $P_{limit} < P_{max}$. In addition, single slot GSM/TDMA is assumed for segment D, where slot-burst power (with tolerance) is sent from the RCT, and frame-averaged power is measured (simulated) by the power measurement equipment. Because of the simplistic algorithm used in this simulated example and the noticeable small difference between P_{limit} and P_{max}, it has taken 30 s for segment D to reach steady state (see normalized curves).

Table A.7 – Power request of test sequence from RCT (specified) and expected steady-state power of DUT (measured)

Steps	Power [dBm]	RCT	DUT
1	P_{min}	0,00	0,00
2	P_{max} (P_{limit})	24,00	20,00
3	(P_{limit} + P_{ctrl})/2	19,75	19,75
4	(P_{max} + P_{limit})/2	22,75	20,00
5	(P_{ctrl} + P_{min})/2	15,06	15,06
6	P_{max}; (P_{limit} + P_{ctrl})/2	24,00	19,75
7	P_{min}	0,00	0,00
8	(P_{max} + P_{limit})/2	22,75	20,00
9	(P_{limit} + P_{ctrl})/2	19,75	19,75
10	P_{max}	24,00	20,00
A	Discontinuous Tx	−30,00	−30,00
B	Tw_{avg} = 60 s	20,50	16,50
C	Tw_{avg} = 100 s	24,00	20,00
D	TDMA; Tw_{avg} = 100 s	30,00	19,90

Table A.8 – First and last instance of power levels in each step of test sequence or segments

Test seq. step	Time [s]	RCT power [dBm]	Measured power [mW] simulated	Measured power [dBm] simulated	Tw_{avg} averaged power [mW]	Tw_{avg} averaged power [dBm]	Ratio	Ratio × SAR_{norm}
1	0,0	0,00	0,935	−0,290	1,000 0	0,000 0	0,01	0,01
	20,0	0,00	0,955	−0,201	1,000 3	0,001 5	0,01	0,01
2	20,1	24,00	199,617	23,002	1,199 0	0,788 0	0,01	0,01
	140,0	24,00	200,078	23,012	99,841 9	19,993 1	1,00	0,70
3	140,1	19,75	31,594	14,996	99,673 9	19,985 8	1,00	0,70
	195,4	19,75	31,597	14,996	94,412 3	19,750 3	0,94	0,66
4	195,5	22,75	199,436	22,998	94,411 7	19,750 3	0,94	0,66
	239,8	22,75	199,523	23,000	99,951 0	19,997 9	1,00	0,70
5	239,9	15,06	32,086	15,063	99,783 2	19,990 6	1,00	0,70
	359,8	15,06	31,982	15,049	32,081 1	15,062 5	0,32	0,22
6	359,9	24,00	199,615	23,002	32,248 6	15,085 1	0,32	0,23
	388,8	24,00	199,432	22,998	80,650 1	19,066 1	0,81	0,56
7	388,9	0,00	1,031	0,133	80,619 2	19,064 4	0,81	0,56
	508,9	0,00	0,984	−0,069	1,000 7	0,003 3	0,01	0,01
8	509,0	22,75	199,609	23,002	1,199 3	0,789 1	0,01	0,01
	579,8	22,75	4,938	6,936	100,905 7	20,039 2	1,01	0,71
9	579,9	19,75	1,073	0,306	100,905 8	20,039 2	1,01	0,71
	699,8	19,75	0,920	−0,361	94,573 5	19,757 7	0,95	0,66
10	699,9	24,00	199,489	22,999	94,772 0	19,766 8	0,95	0,66
	821,8	24,00	199,481	22,999	100,134 8	20,005 8	1,00	0,70
A	821,9	−30,00	0,001	−30,387	99,735 4	19,997 2	1,00	0,70
	851,8	−30,00	0,001	−29,601	55,059 8	17,408 3	0,55	0,39
B	851,9	20,50	2,170	3,365	55,055 4	17,408 0	1,23	0,79
	971,8	20,50	2,280	3,597	44,674 2	16,500 6	1,00	0,64
C	971,9	24,00	199,559	23,001	44,868 8	16,519 4	0,45	0,31
	1 091,8	24,00	199,619	23,002	99,067	19,995 9	1,00	0,70
D	1 091,9	30,00	63,155	18,004	99,770 4	19,990	1,00	0,69
	1 399,8	30,00	63,031	17,996	99,069 7	19,959 4	0,99	0,68

NOTE Ratio (column 8) is the normalization ratio at the time-step; i.e. time-averaged power divided by P_{limit}. SAR_{norm} in column 9 is the $SAR_{target,norm}$. Measured power in columns 4 and 5 correspond to the DUT power in Table A.7.

Table A.9 – Highest normalized ratio with respect to $SAR_{target,norm}$ and SAR_{target}

	Quasi-static and segment A		Segment B		Segment C		Segment D	
Highest calculated ratio R_{max}	1,01		1,23		1,01		1,08	
Normalization references	SAR	SAR_{norm}	SAR	SAR_{norm}	SAR	SAR_{norm}	SAR	SAR_{norm}
(SAR_{target} or $SAR_{target,norm}$)	1,12	0,70	1,02	0,64	1,12	0,70	1,10	0,69
(SAR_{target} or $SAR_{target,norm}$) × (1,0 + Tc)	1,58	0,99	1,44	0,90	1,58	0,99	1,23	0,77
R_{max} × (SAR_{target} or $SAR_{target,norm}$)	1,13	0,71	1,25	0,79	1,13	0,71	1,19	0,74
(SAR_{target} or $SAR_{target,norm}$) × (1,0 − Tc)	0,79	0,50	0,72	0,45	0,79	0,50	0,78	0,49

NOTE SAR_{norm} columns correspond to SAR columns normalized to SAR limit. Numbers in table represent either Tc or R_{max} multiplied by the scaled or non-scaled normalization ratio.

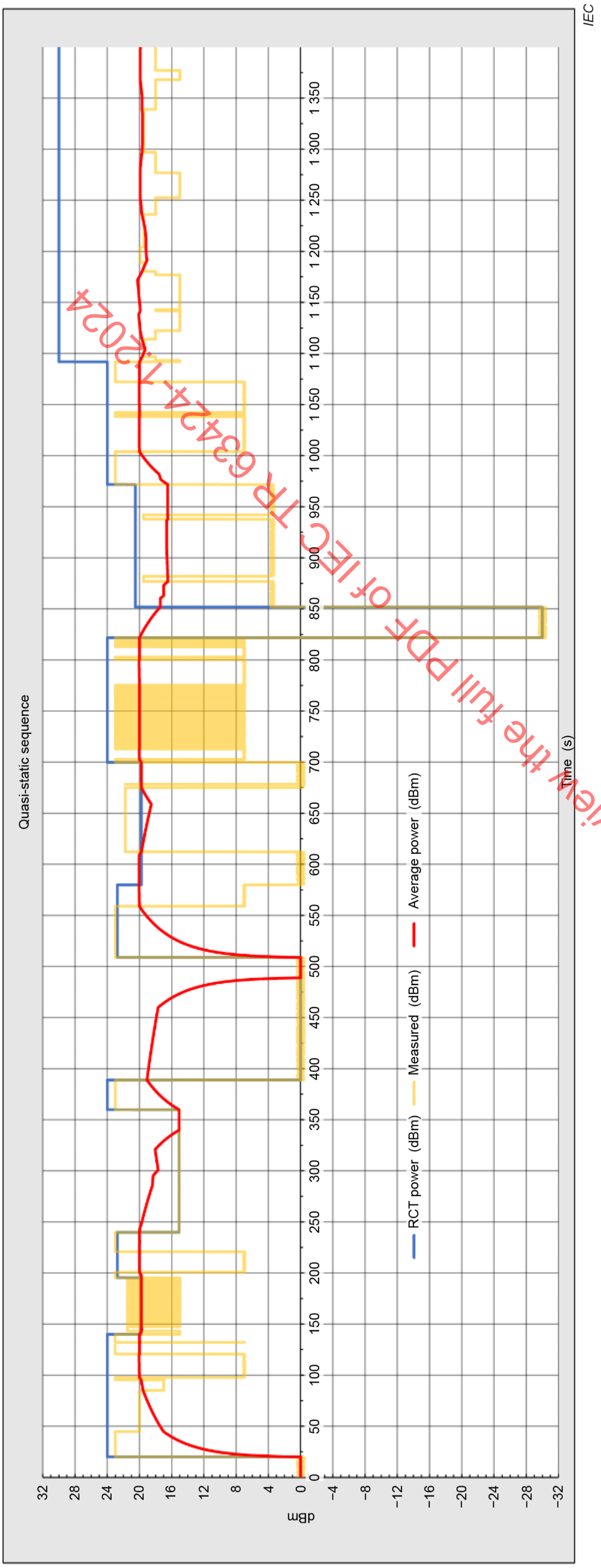

Figure A.1 – Plot of simulated power control of quasi-static test sequence and segments A through D

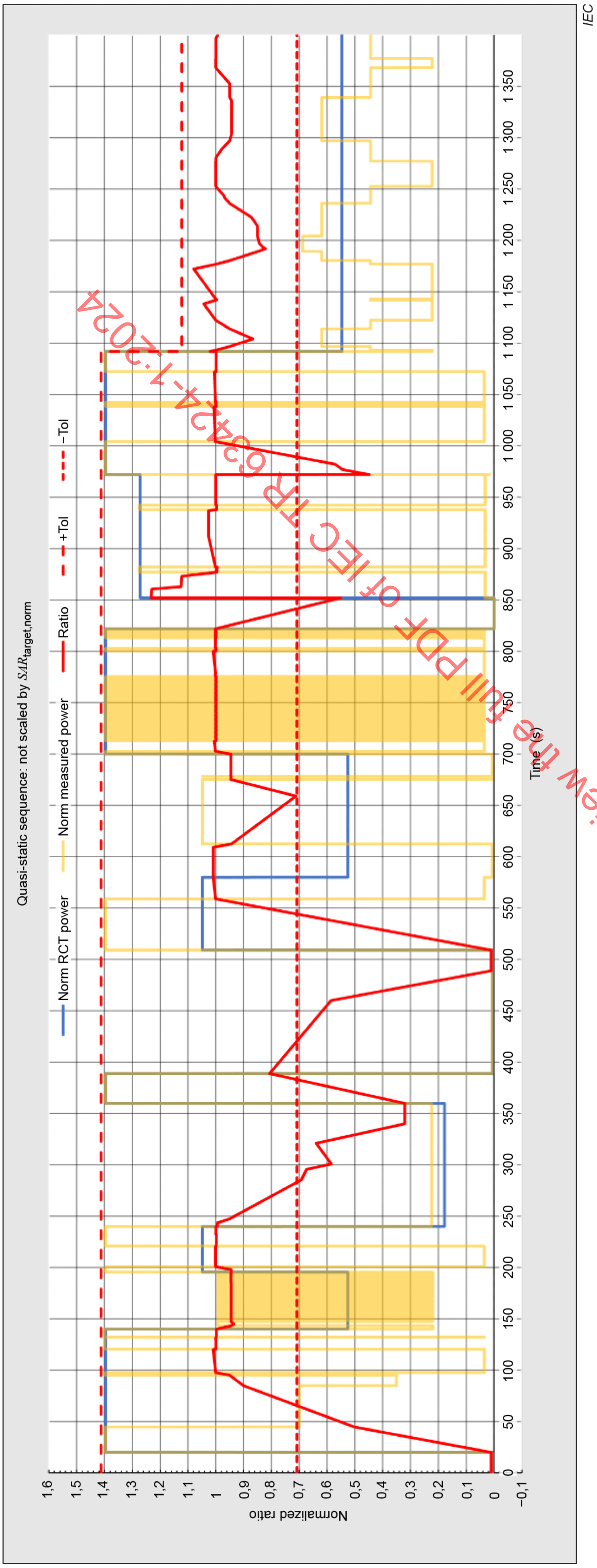

Figure A.2 – Results of Figure A.1 normalized relative to SAR_{target} (not scaled by $SAR_{target,norm}$)

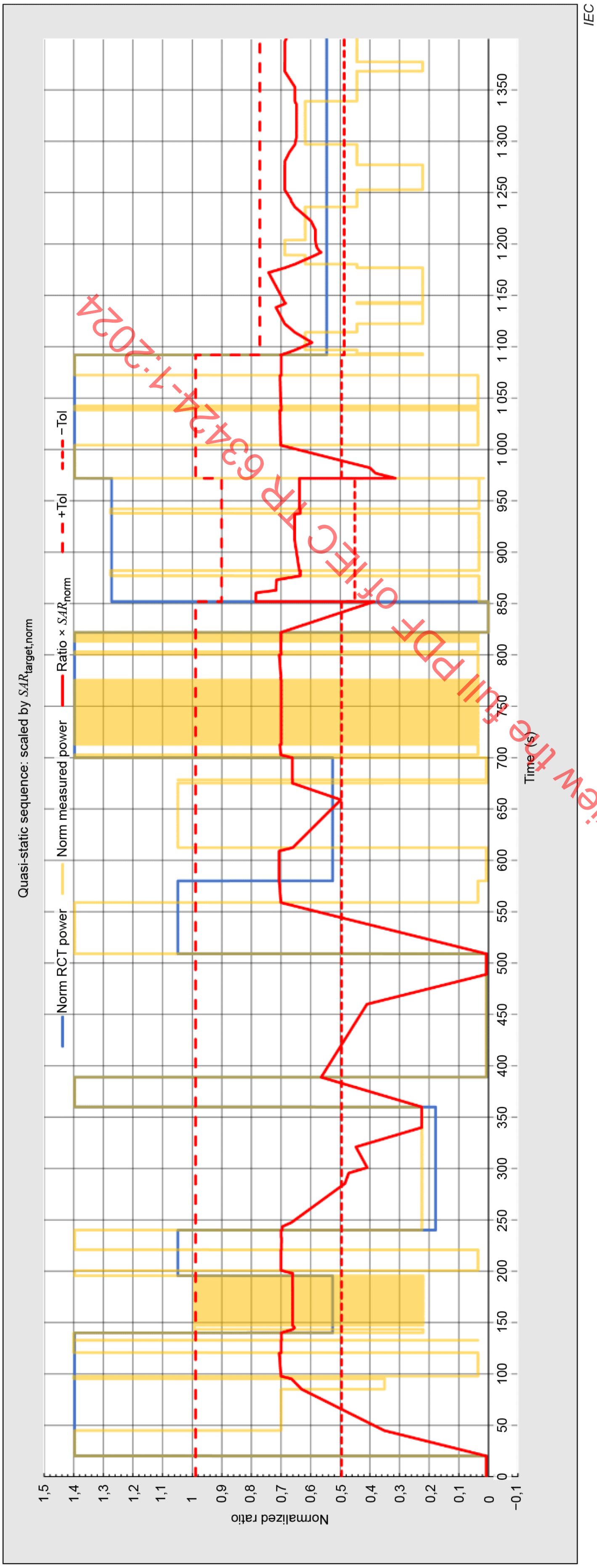

Figure A.3 – Results of Figure A.1 normalized with respect to SAR limit

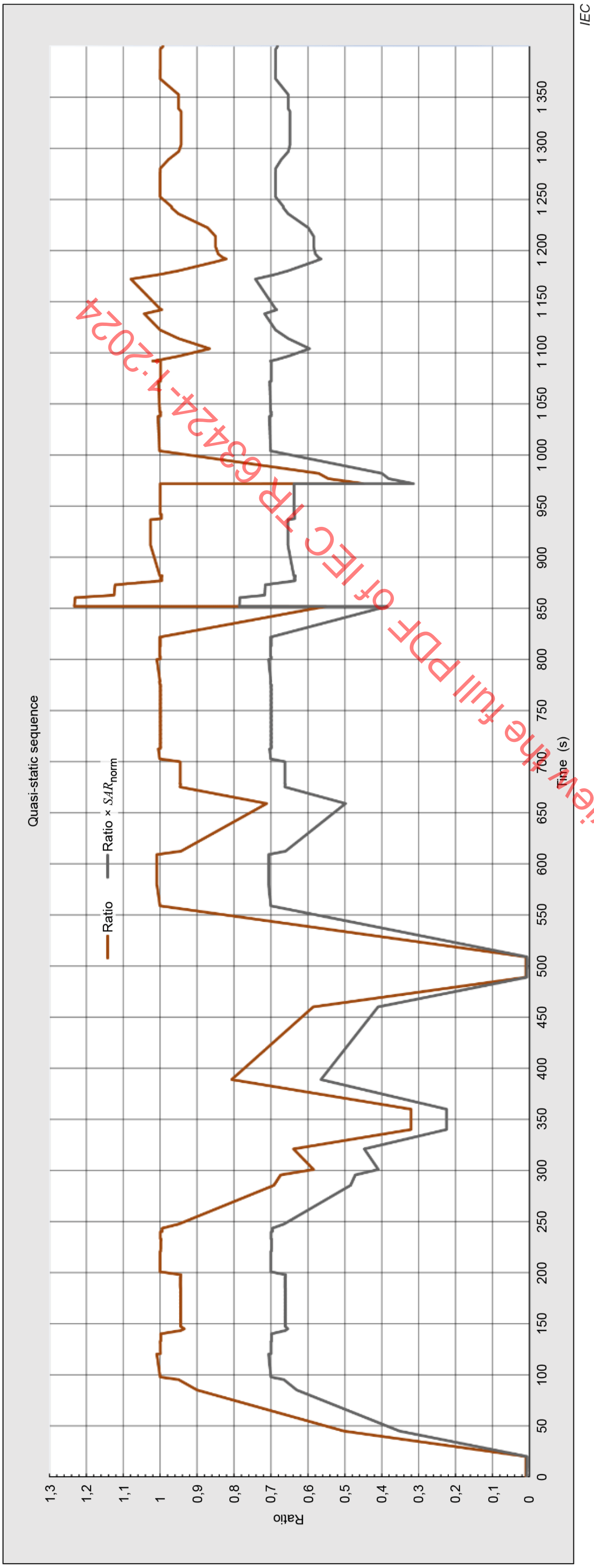

Figure A.4 – Plot of normalized ratios relative to SAR_{target} and SAR limit of Figure A.2 and Figure A.3, respectively

Annex B
(informative)

Power measurement test setup considerations

B.1 General measurement considerations

The test equipment, including cables and passive components, used for DPC-ETA algorithm validation with power measurements is expected to vary with wireless configurations and test conditions. When multiple RATs or frequency bands are involved in the validation, for example handovers, simultaneous transmission or 5G NR NSA, separate RF ports or, as necessary, RCTs can be needed. When all the RATs in a test sequence are not supported by the RCT, multiple RCTs would become necessary, which can introduce equipment coordination difficulties in the measurement automation. Depending on the test equipment needed to support simultaneous transmission, multi-band signals in the same RAT, such as inter-band CA, can use single or multiple RF ports on the RCT. For different RATs, multiple RF ports can be necessary for the RCT to support simultaneous transmission. The power is measured independently and normalized to the corresponding $P_{\text{limit,m}}$ of the wireless modes in the simultaneous transmitting RATs or frequency bands. The normalized ratio (R) for each transmitting RAT is calculated independently from the ratio of corresponding measured time-averaged power and corresponding $P_{\text{limit,m}}$. The highest aggregate of normalized ratios of active transmitters (max(R_1 + R_2 + …) of each configuration in the simultaneous transmission combination are confirmed to satisfy the tolerance allowed by the corresponding SAR_{target} and P_{limit}. When the same antenna is used for the RATs or frequency bands on the DUT, splitters/combiners, and band pass filters are necessary to separate the multi-band uplink and downlink signals to enable independent uplink power measurement and routing of downlink signals from the RF ports on the RCT to the antenna port on the DUT.

In the simplest configuration, a directional coupler or splitter/combiner is typically used to enable coupling of the uplink signal for power measurement. Depending on the downlink signal level, if the uplink-downlink cross-coupling isolation of the directional coupler or splitter/combiner is insufficient, a band pass filter can be used at the coupling port to provide additional isolation for FDD configurations. TDD configurations can use higher quality couplers, splitter/combiner, or separate RF ports at the RCT, along with a circulator to decouple uplink and downlink signals to minimize cross-coupling (see associated figures in Clause B.8 for example connections).

Based on the antenna and RF port configurations on the DUT and RCT or RCTs, placement of directional couplers, combiner/splitter, and filters or circulator are adjusted according to the power measurement configurations. All attenuations, and cable and path losses, are correctly accounted for at the measurement frequencies, according to calibrated or properly assessed values for the components. To ensure the correct signal levels specified by the test sequences or wireless protocol are transmitted and received at both the DUT and RCT, the attenuations along each signal path are properly compensated for at the corresponding RF ports on the RCT. Depending on the types of splitter/combiner used, the path attenuations through the ports, and transmissions in opposite directions, can be influenced by the signal types and imbalance or mismatch, etc.; therefore, each port is characterized separately in the actual test setup configurations, to ensure the correct path loss is used. Therefore, each test setup is independently verified along all connection paths before algorithm validation measurements are performed. Depending on the test sequences and types of transitions used for validation, the power recording process in the measurement automation is also verified, to avoid unexpected issues.

B.2 Single technology test setup

To validate an individual technology, i.e. configurations within a specific RAT such as UMTS or LTE, only one RF port or channel is generally used to connect the DUT to the RCT. This is the simplest and most fundamental test configuration that uses a directional coupler or splitter/combiner for uplink power measurement. The downlink signal level can generally be kept to a sufficiently low, but satisfactory, level to minimize cross-coupling of downlink signal in the uplink power measurement. If additional isolation becomes necessary, separate RF ports can be used on the RCT. The downlink is connected to a circulator, and the uplink signal from the DUT is connected through the circulator to a directional coupler for power measurement; see Figure B.2.

The same measurement setup for conducted and radiated power measurement with test sequences are used to measure P_{limit} for normalization of power measured in the test sequence (see A.2.9). The power sensor of the meter can be connected directly to the antenna port on the DUT, without a directional coupler, to confirm component attenuation and other path losses. Most DUTs possibly need to operate in specific DPC-ETA configurations for P_{limit} measurement. In other situations, factory test mode or equivalent conditions with DPC-ETA suspended or disabled can be necessary for the device to transmit at a fixed power level for P_{max} and P_{limit} measurements. For the power measurements, when the power level is set manually, instead of retrieved automatically by the device, additional considerations can be necessary to ensure the correct levels actually used by the device are measured, to avoid normalization errors.

For uplink inter-band carrier aggregation or handover between frequency bands within the same RAT, the component carriers, or signals from different frequency bands, can be transmitted through one or more antennas on a DUT. Test configurations with different DPC-ETA parameters (P_{max}, P_{limit}, Tw_{avg}, SAR_{target}, etc.) are generally used for algorithm validation. For test configurations with the same DPC-ETA parameters, transmitting through the same antenna, the aggregate power for both frequency bands can be measured using appropriate power meter or spectrum analyser settings. When different DPC-ETA parameters are used for the wireless configurations, additional directional couplers, splitters/combiners, and band pass filters are necessary at the DUT antenna port, to support separate power recording and enable subsequent processing according to the respective DPC-ETA parameters. When separate antenna ports are used on the DUT, the signal paths are each configured independently for uplink power measurement (see Figure B.3).

B.3 Multiple or mixed technology test setup

When transitioning across RATs during handover, multiple RF ports can be used on the RCT to support the wireless technologies. The transition from one wireless configuration to another is usually a sequential process, where one service or connection is terminated before the device is reconnected to the next service or RAT. The use of separate RCTs for different RATs can be difficult to coordinate in the measurement automation; therefore, this is not desired. The different RATs or frequency bands can use the same or different antennas on the DUT, with the same or different DPC-ETA control parameters. Other than the possibility of using separate RF ports (or multiple RCTs) for the RATs or frequency bands, the configurations described in Clause B.2 for handover can be applied. As appropriate, splitter/combiner and band pass filters can be used to support uplink power measurement for DUTs with the RATs or frequency bands transmitted on the same antenna.

B.4 Simultaneous transmission

Simultaneous transmission can involve the same or different RATs; for example, inter-band CA, or 5G NR NSA in EN-DC mode. The signals are expected to be in different frequency bands. Simultaneous transmission in the same frequency band for multiple RATs is less likely and is not considered. Intra-band CA are transparent to DPC-ETA; thus, separate algorithm validation is not necessary.

Power is measured separately for each transmission in a simultaneous transmission combination. When individual transmissions are added to or removed from the combination, the independently measured power is normalized to the corresponding $P_{\text{limit,m}}$ of the individual transmission to verify power control continuity. For segments of the test (see A.7.4) where only one transmitter is active, the highest normalized ratio (R_{max}) of transmitting RAT is confirmed to remain within the tolerance allowed by the SAR_{target} and P_{limit}. For each segment of the test sequence (see A.7.4) where multiple transmitters are active, the highest aggregate of normalized ratios of active transmitters (TER = max(R_1 + R_2 + … R_k) out of the duration of the segment with k transmitters) is confirmed to remain within the tolerance allowed by the SAR_{target} and P_{limit}.

The procedures and measurement setup described in Clauses B.2 and B.3, for power measurement in single and multiple technology configurations, can be adapted accordingly to determine the proper test setup requirements for simultaneous transmission. Additional considerations can be necessary to ensure the RCT(s) and power meters are properly coordinated in the measurement automation. The measurement system possibly needs separate verification to ensure certain variations of a test setup used for specific test conditions have been correctly configured, according to regulatory policies for the validation measurements.

B.5 Automation considerations

While the measurement process needs automation to precisely record time-aligned power measurements and RCT power requests, partial automation in a user-assisted manner can be desired or necessary for certain transitional test configurations. Full automation can be quite complex when all wireless modes and RATs are considered. For example, transitions, handover, or simultaneous transmission across multiple RATs can need separate RF ports (or RCTs) and different combinations of passive components that can need independent compensation. Even if the RCT supports multiple RATs, the differences in wireless protocols and separate RF port configurations can introduce certain programming complexity for measurement automation. However, automation generally provides increased measurement consistency with reduced testing time.

For the purposes of test equipment automation, dedicated control programming languages that can support a common set of control commands and semantics are typically available in the latest generation test equipment, especially from the same vendor. The commands enable remote programming of specific classes or categories of equipment operating over either GPIB or RJ-45 types of interfaces. In most cases, only minor programming changes can be needed to support similar equipment used in different test setups.

There are also commercially available control and automation software packages that enable users to generate control programs with a drag-and-drop modular graphical interface. The burden of low-level programming is avoided, and users are typically not expected to have detailed understanding of the underlying programming and control process to interface with the controller. In addition, these software application packages are generally available with support for real-time display of measurement results and certain complex post-processing tools. There is also the consideration for SAR system vendors to implement automated DPC-ETA power measurement for algorithm validation.

B.6 Equipment settings and calibration considerations

The power measurement equipment is confirmed to have valid calibrations at the operating frequencies of the wireless modes. The attenuations and insertion losses of passive accessories and components are measured and confirmed either regularly or before the measurement. For radiated power measurements, the path loss inside the anechoic chamber also needs consideration to ensure the proper power levels in the test sequence are applied by the RCT and DUT. Since measured responses with varying power level and with constant power at P_{limit} have the same path loss, the losses are expected to cancel out in the normalization. However, if significant, power dependent tolerances of the power measurement equipment can need consideration to minimize the impact of P_{limit}. Regulatory policies are applied to identify and list all equipment and components used, in test setup block diagrams, and test setup photos to illustrate the equipment and measurement configurations.

Power meters are typically used for DPC-ETA algorithm validation. However, spectrum analysers can be considered to achieve equivalent results. When the measured power is normalized to $P_{\text{limit,m}}$, according to A.2.9, if the power meter switches range or resolution during the measurement, any offsets in measured values for the range of measurement resolutions are noted and compensated, to ensure the normalized results are consistent with measured responses. These types of range/resolution offsets can be associated with the digitization process of the meter or calibration of the power sensors. It would be desirable to disable resolution or range switching in the power measurement equipment by selecting a fixed and optimized range for the intended measurements. Even within a fixed measurement range, the power dependent tolerances of the equipment are not expected to fully cancel out in the normalization process and, if significant, can need consideration. The cable losses and accessory attenuations such as directional couplers, combiners/splitters, filters, or attenuators, etc., can be included in the power meter offset compensation, to avoid further adjustments to the recorded results. It is also important to ensure that the measured power levels, before compensating for attenuations and insertion or path losses, are sufficiently above the noise level, to ensure results can be compensated with the desired accuracy and precision. As appropriate, power measurement tolerances are considered according to regulatory policies.

B.7 Measurement system verification

A system check or validation is performed, according to procedures that are equivalent to those described in Annex C, before the system and corresponding automation are deployed for algorithm validation measurements. The results are used to confirm that the system is applicable for the intended algorithm validation measurement configurations, and also satisfies any regulatory policies for demonstrating the measurement system can be used to validate the intended DPC-ETA implementation. The procedures used to process measurement results, to show the measured instantaneous power is time-aligned and consistent with the power requested by the RCT for calculating time-averaged power, according to Tw_{avg}, are confirmed for all features and test parameters supported by the measurement system. Besides periodic system verification (e.g. annually), additional verifications are necessary when changes are made to the measurement system, automation, or test protocol.

B.8 Conducted power measurement setup options

Depending on the test configurations and RCT or RCTs used, and the number of RATs or RF ports needed by the wireless test configurations for the intended algorithm validation measurements (single technology, call drop, handover, or simultaneous transmission, etc.), the passive components used in the power measurement configurations can vary. Directional couplers, attenuators, combiners/splitters, band pass filters or circulators can be used along different uplink paths or downlink paths, or both, which can be associated with a single or multiple RF ports on the RCT or RCTs or DUT antenna port or ports. Whether FDD or TDD configurations are tested can require adjustments to the connected components. If uplink and downlink cross-coupling isolation is an issue, separate RF ports on the RCT with a circulator can be used. In order to measure at the rate of Tp_{avg} for TDMA, or TDD using DL:UL transmission ratios, the power meter or spectrum analyser is configured to acquire frame-averaged power. The attenuations introduced by passive components to support the power measurement can reduce the signal level to an undesirable level then noise can become an issue. Uplink and downlink path losses are both compensated for at the RF ports on the RCT or RCTs to ensure the desired and intended power levels are transmitted and received at the RCT and DUT.

Examples of typical RCT configurations and associated passive components are illustrated in the following figures. A combination of scenarios for applying passive components to support the power measurement setup are also illustrated, for both single and multiple RAT connections with single or multiple RCT RF ports or DUT antenna ports, or both.

In Figure B.1, RCT and power meter are connected to a PC with GPIB or RJ-45 for program control. The DUT can be under PC control through a USB connection, to enable/disable DPC-ETA or test mode operations. As appropriate, a splitter/combiner can be used to connect the DUT with the RCT and power sensor, in place of the directional coupler. Figure B.2 is described in Clause B.2.

In Figure B.3, alternative connections with multiple RAT or frequency band signals using the same RF port on the RCT or antenna port of the DUT are illustrated in separate subfigures.

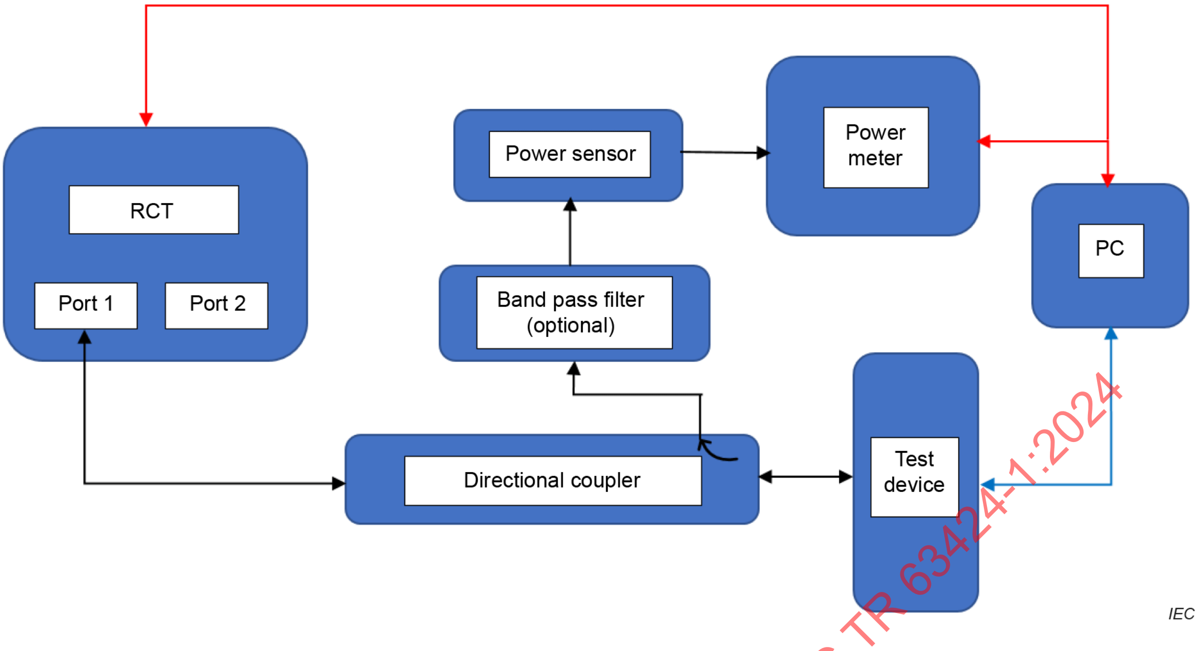

Figure B.1 – Typical single RAT power measurement configuration with optional band pass filter for directional coupler cross-coupling isolation

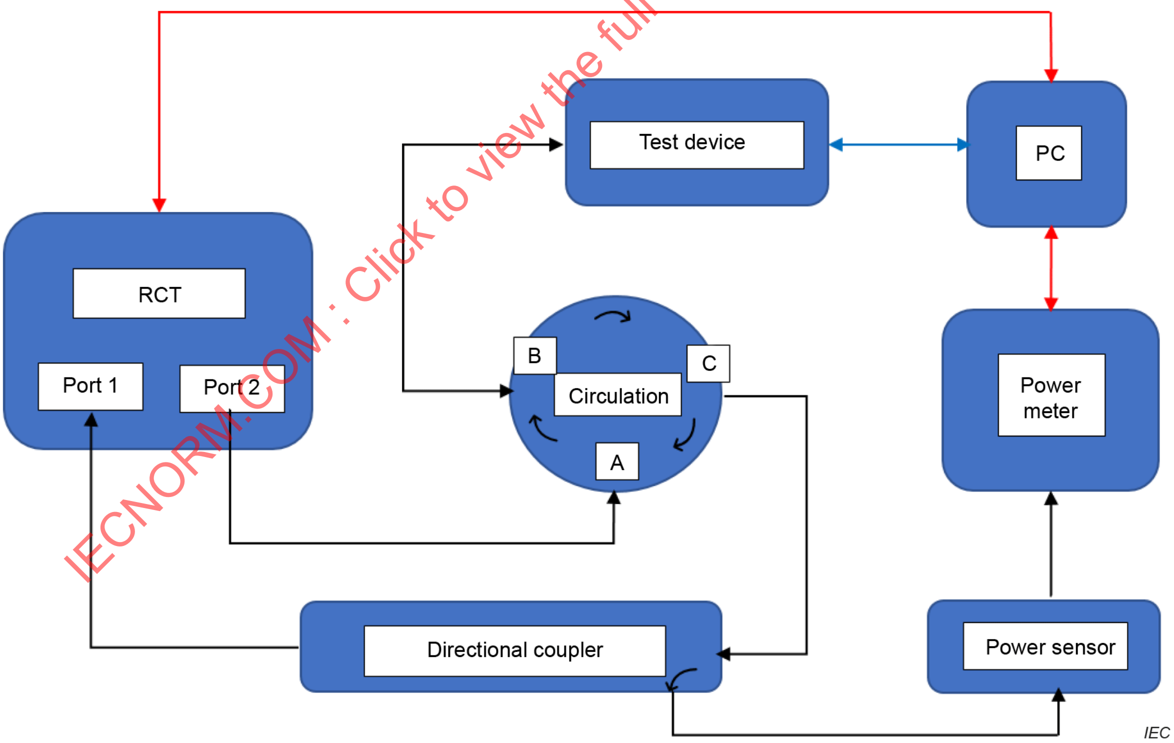

Figure B.2 – Typical single RAT power measurement configuration with separate RF ports on the RCT for uplink-downlink isolation to reduce directional coupler cross-coupling

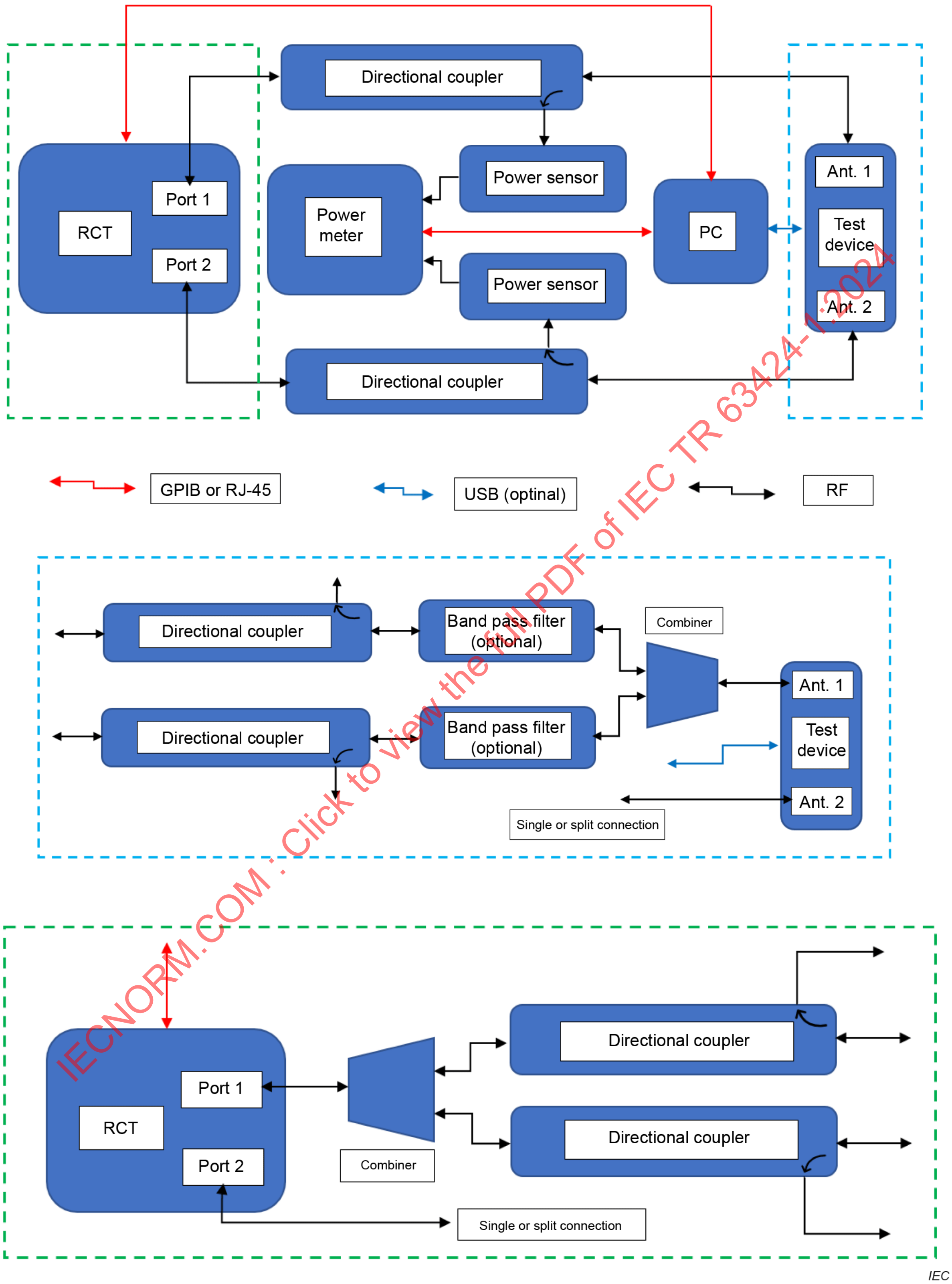

Figure B.3 – Typical multiple RAT or frequency band power measurement configuration with separate RF ports on the RCT and antenna ports on DUT for independent power measurements

B.9 Radiated power measurement setup options

B.9.1 General

Conducted power is measured at the antenna port or ports (50 Ω configurations) of the DUT. Radiated power is measured in an anechoic chamber with the DUT operating standalone using the built-in antenna or antennas. Instead of connecting directly to the antenna port or ports on the DUT, the RF port or ports on the RCT or RCTs are connected to an appropriate antenna or antennas to communicate directly with the DUT.

Radiated power is measured in a miniature (or larger) anechoic chamber to exclude external influences. The same or similar measurement setup are used for both conducted and radiated power measurements by including the path loss inside the anechoic chamber, i.e. between the DUT antenna and the RCT or measurement antenna.

When multiple RATs or frequency bands are considered, e.g. 5G NR EN-DC, it would be possible to measure radiated power for NR and conducted power for LTE, as illustrated in Figure B.4.

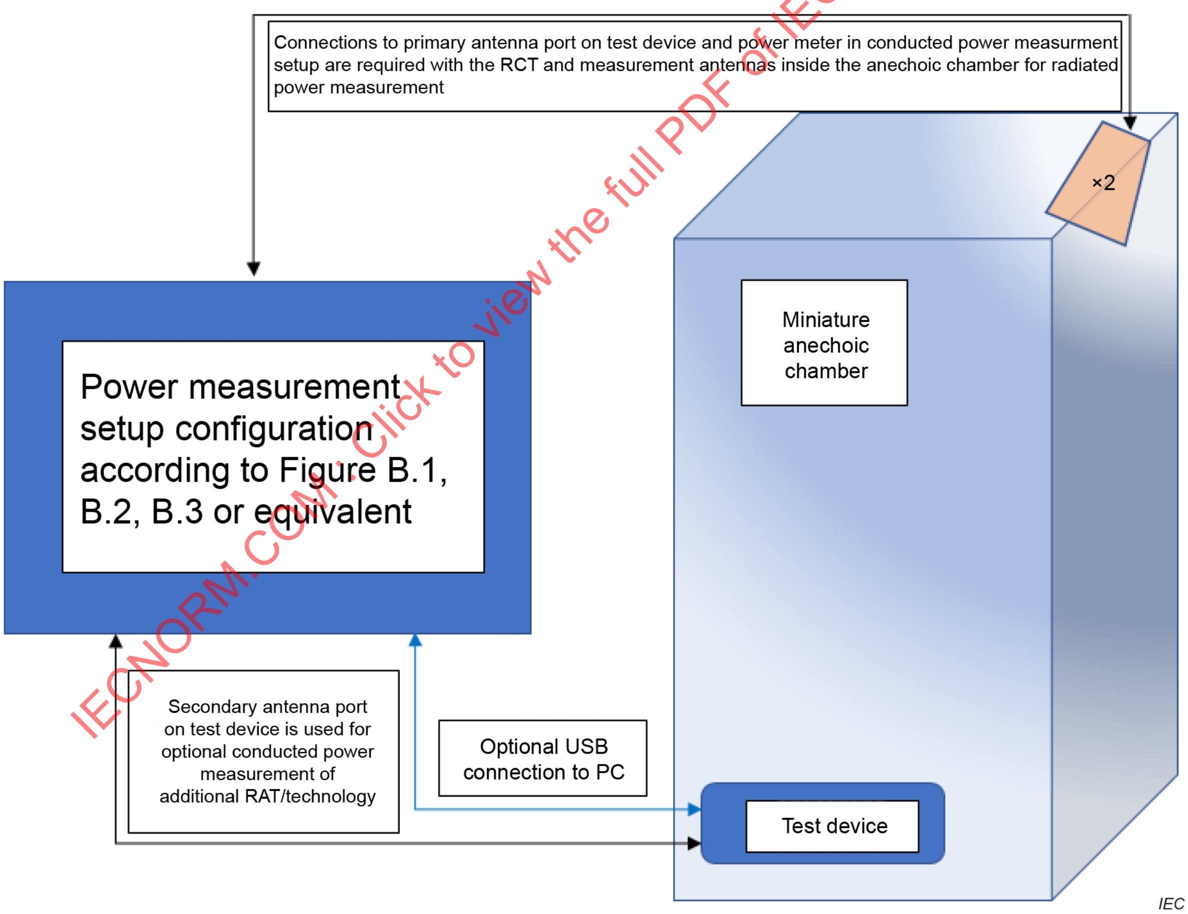

Figure B.4 – Typical radiated power measurement configuration for RAT with optional conducted power connection for a second or additional RAT

B.9.2 Anechoic chamber considerations

The commercially available miniature anechoic chamber typically used for 5G NR OTA tests with the CATR method is used for DPC-ETA algorithm validation of small devices (smart phones). Since the specific 3GPP OTA measurement characteristics of 5G NR for FR2 are not relevant for the validation measurements in this document, only the shielding and operating characteristics for the intended radiated measurement setup are considered. When necessary, a larger or full-size anechoic chamber can be considered for tablets and laptop computers.

Annex C
(informative)

Measurement system verification and tolerance considerations

C.1 General

The measurement system is verified before deployment to ensure it is suitable for capturing the intended power change variations to derive DPC-ETA responses for comparison with the expected algorithm behaviour of the intended algorithm validation tests. Additional verifications are performed when changes are made to the measurement system or when new DPC-ETA implementations are considered. Since the power measurements are normalized to the measured P_{limit} and relative results are used to determine DPC-ETA responses for comparison with expected behaviour, most of the power independent tolerances are expected to cancel out in the normalization process. The remaining power dependent tolerances of the DUT are addressed according to 6.10. The power dependent tolerances of the measurement equipment are expected to be insignificant and, as necessary, this can be addressed according to regulatory policies. A relatively simple procedure has been considered to estimate the tolerances involved in the normalization of measured results to the measured P_{limit}. Correlation of measured responses and expected behaviour is typically qualitative and implementation dependent. Correlation uncertainty is not addressed in this document and, as necessary, it can be considered according to regulatory policies.

NOTE Details of validation of the automation and post-processing procedures are not addressed in this document due to anticipated implementation variations. The user is responsible for ensuring that these have been properly validated before system deployment for results to be credible. Regulatory requirements can exist.

C.2 Measurement system verification procedures

Power control requests can occur at a rather rapid rate in wireless networks; for example, up to 1 500 times per second. To avoid test equipment and measurement automation coordination issues, the minimum time interval of the power requests in test sequences is limited 3 s for algorithm validation. This applies to all test sequences used in this document, i.e. quasi-static, dynamic, and random sequences.

To ensure the relevant DPC-ETA responses are captured by the measured power at the minimum power request time interval, a measurement rate of $Tp_{\text{avg}} \leq 0{,}1$ s is used for the test system. This is verified by applying a programmed pulse train from a signal generator, with a varying pulse duration corresponding to the range of durations and transition times (rise time and fall time) used in the dynamic test sequences, at an amplitude ≥ P_{max} (largest). The results are reviewed to confirm that all transitions in the pulse train are correctly captured by the power measurement with a time delay ≤ 0,05 s (i.e. 0.5 × Tp_{avg}) and ≤ 0,2 dB of amplitude differences for all transitions. A total test duration ≥ 30 s is sufficient for this demonstration.

C.3 Power measurement normalization tolerance

When the measured power is normalized to the $P_{\text{limit,m}}$, confirmation of power measurement linearity at Tp_{avg} is necessary. Power is measured in a selected wireless mode for each RAT and frequency band used for algorithm validation, at P_{max}, P_{limit} and P_{ctrl}, to ensure both the test equipment and DUT are operating as expected. Power is measured continuously at each of these power levels, at ≤ Tp_{avg}, for at least 30 s to ensure the measured values are correct and stable. The measured values of P_{max}, P_{limit} and P_{ctrl} cannot exceed the specified values. To estimate the range of power dependent tolerances, the following can be considered. P_{limit} is measured immediately before P_{max} and P_{ctrl} are each measured, with all $P_{\text{limit,m}}$ values within 0,2 dB of the averaged value. The average of the $P_{\text{limit,m}}$ is used to compute ratios of P_{max} and P_{ctrl} to P_{limit}. The ratios can be compared to ratios calculated from the specified values, i.e. measured ratios scale proportionally with specified ratios. The difference between the measured and specified ratios cannot be higher than the power dependent tolerances of the device and measurement equipment, in accordance with regulatory guidance.

The power independent tolerances of the DPC-ETA parameters (P_{max}, P_{limit}, P_{ctrl}) and associated offsets between measured and specified values are expected to be synchronized (systematic) and have minimal contribution to the normalized ratios. When P_{limit} is measured according to A.2.9, the deviations between the measured and specified ratios are expected to be mostly due to the power dependent tolerances associated with calibration linearity of DUT output power and measurement equipment. The test can be performed before the validation measurements of a DUT according to regulatory policies.

When the same power measurement setup is used for both conducted and radiated power measurements, except for a difference in power level (range), the same normalization procedure is applied. Unless it is needed according to regulatory policies, additional confirmation in the radiated configuration is not necessary.