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TECHNICAL REPORT

Use of measurement detectors in radio measurement methods

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

At the ETSI TC ERM meeting #62 in June 2017 the issue of measurement detectors was discussed and it was indicated by ERM WGRM chairman that the Quasi Peak (QP) detector may be no longer appropriate in radio standards and should possibly be avoided in future. Concerns were raised that before ETSI will take any decision in this regard ETSI should carefully consider the issue of measurement detectors. Measurement results not only with QP also with RMS and Average detector vary with signal shape and measurement receiver setting, which is not the intention of typical radio measurements. Harmonised standards covering the essential requirements of article 3.2 of the Radio Equipment Directive (RED) [i.23] should contain reproducible measurements. But common measurement procedures and settings for the different detectors are currently not available in ETSI.

1 Scope

The present document provides to ETSI technical group's information on the use of measurement detectors (e.g. quasi peak, RMS, average, peak) in radio measurement methods.

The focus in the present document is on measurement detectors used in spectrum analysers and EMI receivers. Various other technologies to measure RF signals do exist, like specific true RMS sensors and selective voltmeters. They are not further studied in the present document but could be of specific use in some cases.

EMI measurement methods and audio measurements/detectors (e.g. SINAD) are not in the scope of the present document.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] CENELEC EN 55016-1-1:2010 + A1:2010 + A2:2014: "Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus".

[i.2] CENELEC EN 55016-1-1: 2004: "Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus".

[i.3] Application note by Dipl. -Ing. Dieter Schwarzbeck: "The EMI-Receiver according to CISPR 16-1-1".

NOTE: Available at http://www.schwarzbeck.de/appnotes/EMIRcvrCISPR16.pdf.

[i.4] Commission implementing Decision (EU) 2017/1483 of 8 August 2017 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2006/804/EC.

[i.5] ERC Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)", 13 October 2017.

[i.6] ETSI EN 300 330 (V2.1.1): "Short Range Devices (SRD); Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.7] ETSI EN 300 220-2 (V3.1.1): "Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 2: Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU for non specific radio equipment".

[i.8] ETSI EN 300 328 (V2.1.1): "Wideband transmission systems; Data transmission equipment operating in the 2,4 GHz ISM band and using wide band modulation techniques; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.9] ECC/DEC(04)03: "ECC Decision of 19 March 2004 on the frequency band 77 - 81 GHz to be designated for the use of Automotive Short Range Radars".

[i.10] ECC/DEC(06)04: "ECC Decision of 24 March 2006 amended 9 December 2011 on the harmonised conditions for devices using UWB technology in bands below 10.6 GHz".

[i.11] ECC/DEC(06)08: "ECC Decision of 1 December 2006 on the conditions for use of the radio spectrum by Ground- and Wall- Probing Radar (GPR/WPR) imaging systems".

[i.12] ECC/DEC(11)02: "ECC Decision of 11 March 2011 on industrial Level Probing Radars (LPR) operating in frequency bands 6-8.5 GHz, 24.05-26.5 GHz, 57-64 GHz and 75-85 GHz".

[i.13] ERC Recommendation 74-01: "Unwanted emissions in the spurious domain", Cardiff 2011.

[i.14] ITU Radio Regulations, Edition of 2016.

[i.15] ANSI 63.10-2013: "American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices".

[i.16] FCC Part 15: "Electronic Code of Federal Regulations, Title 47: Telecommunication, Part 15: Radio frequency devices", May 15, 2018.

[i.17] FCC Knowledge Database (KDB).

NOTE: Available at https://apps.fcc.gov/oetcf/kdb/index.cfm.

[i.18] SEAMCAT, Spectrum Engineering Advanced Monte Carlo Analysis Tool.

NOTE: Available at www.seamcat.org.

[i.19] CENELEC EN 55016-2-3: 2010 + A1:2010 + AC:2013 + A2:2014: "Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-3: Methods of measurement of disturbances and immunity - Radiated disturbance measurements".

[i.20] RAUSCHER, C.: "Fundamentals of Spectrum Analysis", 7th edition, 2011, ISBN 978-3-939837-01-5.

[i.21] LIEBL, DETLEV: "Measuring with modern spectrum analysers", 02/2013.

NOTE: Available at https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_application/application_notes/1ma201_1/1MA201_9e_spectrum_analyzers_meas.pdf.

[i.22] CENELEC EN 55013: "Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement".

[i.23] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC.

[i.24] ETSI EN 302 264 (V2.1.1): "Short Range Devices; Transport and Traffic Telematics (TTT); Short Range Radar equipment operating in the 77 GHz to 81 GHz band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.25] ETSI EN 302 065-1 (V2.1.1): "Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU; Part 1: Requirements for Generic UWB applications".

[i.26] ETSI EN 302 066 (V2.1.1): "Short Range Devices (SRD); Ground- and Wall- Probing Radar applications (GPR/WPR) imaging systems; Harmonised Standard covering the essential requirements of article 3.2 of the Directive 2014/53/EU".

[i.27] ECC Report 64 (February 2005): "The protection requirements of radiocommunications systems below 10.6 GHz from generic UWB applications".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, following terms apply:

CISPR-detector: measurement detector as defined in CENELEC EN 55016-1-1 [i.1] and as used in an EMI receiver

EMI receiver: measurement instrument as defined in CENELEC EN 55016-1-1 [i.1]

measurement instrument: EMI receiver or spectrum analyser, both with or without FFT-based functions

Occupied Bandwidth (OBW) (according to [i.14] Article 1.153): "The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage 0.5% of the total mean power of a given emission."

Spectrum Analyser (SA): measurement instrument to assess the spectrum's shape and energy content of the signal at its input

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADC	Analog-to-Digital Converter
AM	Amplitude Modulation
AV	Average
BW	Bandwidth
CEPT	European Conference of Postal and Telecommunications Administrations
CISPR	Comité International Spécial des Perturbations Radioélectriques (International Special Committee on Radio Interference)
CR	Trace mode clear write
CW	Continuous Wave
DC	Duty Cycle
DUT	Device Under Test
e.i.r.p.	equivalent isotropic radiated power
EC	European Commission
ECC	Electronic Communications Committee of CEPT
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EU	European Union
EUT	Equipment Under Test
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
IF	Intermediate Frequency
ISM	Industrial, Scientific and Medical
KDB	Knowledge Database
LO	Local Oscillator
LPR	Level Probing Radar
MH	Maxhold
OBW	Occupied Bandwidth
OFDM	Orthogonal Frequency-Division Multiplexing

PEP	Peak Envelope Power
PK	Peak
PRF	Pulse Repetition Frequency
QAM	Quadrature Amplitude Modulation
QP	Quasi Peak
RBW	Resolution BandWidth
RC	Resistor-Capacitor
REC	Recommendation
RF	Radio Frequency
RMS	Root Mean Square
RMS-AV	RMS-Average
RTA	RealTime spectrum Analyser (FFT based)
SA	Spectrum Analyser
SINAD	Signal-to-Interference ratio including Noise And Distortion
SRD	Short Range Devices
SRdoc	System Reference document
SRR	Short Range Radar
SWT	Sweeptime
SZ	Spectrum analyser Zero span
TGSRR	Tasks Group Short Range Radar
Ton	Time period when the signal is switched on
Toff	Time period when the signal is switched off
UWB	Ultra-WideBand
VBW	Video Bandwidth
WGFM	Working Group Frequency Management
WGRM	Working Group Radio Matters
WGSE	Working Group Spectrum Engineering

4 Regulatory requirements

4.0 General

Clause 4 provides an overview on the current practice on the consideration of the measurement detectors in ETSI and CEPT, before an in-depth analysis of measurement detectors and measurement instruments is offered in clauses 5, 6 and 7.

4.1 Overview

A common European process from the idea of a new radio system to the harmonised standard with measurement procedures (ETSI, CEPT, EC) is shortly summarized in Table 1. Table 1 also includes some indication on the importance of a measurement detector in the different steps.

Table 1: The importance of a measurement detector

ETSI SRdoc	A new radio systems is described in a System Reference Document (SRdoc) by ETSI to trigger the rule-making in CEPT.	The measurement detector is usually not considered in the SRdoc
CEPT Compatibility studies	CEPT considers the SRdoc in Working Group Frequency Management (WGFM) and will typically first request the Working Group Spectrum Engineering (WGSE) to conduct compatibility studies. WGSE analyses then if the new radio systems can coexist with existing systems and will publish their results in an ECC Report; these studies are considering more and more the probability of interference by using Monte Carlo simulations (e.g. with the open source software SEAMCAT [i.18]), by observing the time-, frequency- and spatial domain.	The compatibility studies do seldom contain information on the measurement detectors
CEPT rule making	WGFM creates a new regulation based on the WGSE studies.	The regulatory limits do seldom contain information on the measurement detectors
ETSI harmonised standard	ETSI may then create a harmonised standard including measurement procedures for the regulatory requirements, that leads to reproducible and stable measurement results.	The measurement detector is an essential part for each requirement

4.2 Examples of regulations without requirements on detectors

Many frequency regulations only mention the frequency band and the radiated power limit in this band and there is no information about the measurement detector (and also mostly no details on the measurement bandwidth).

A few popular examples for SRDs from EC Decision 2017/1483/EU [i.4] and ERC Recommendation 70-03 [i.5] are provided in Table 2.

Table 2: Examples of frequency assignments without information on measurement detectors from [i.4] and [i.5]

Frequency range	Category of short-range devices	Transmit power/field strength/power density limit
13 553 kHz - 13 567 kHz	Inductive devices	42 dBμA/m at 10 metres
868 MHz - 868,6 MHz	Non-specific short-range devices	25 mW e.r.p.
2 400 MHz - 2 483,5 MHz	Wideband data transmission devices	100 mW e.i.r.p. and 100 mW/100 kHz e.i.r.p. density applies when frequency hopping modulation is used, 10 mW/MHz e.i.r.p. density applies when other types of modulation are used

No requirements on the measurement detector are requested in these cases. What does that mean for the measurement standard? It is completely up to the ETSI technical bodies to develop appropriate requirements for the measurement detectors, since there is not common guidance available. The harmonised standards for the equipment in the above frequency bands are containing for example the following requirements regarding measurement detectors:

- ETSI EN 300 330 [i.6] for 13,56 MHz: Quasi Peak
- ETSI EN 300 220-2 [i.7] for 868 MHz:
  - *"Unless stated otherwise, an RMS detector shall be used.*
  - *The RBW of the spectrum analyser shall be wide enough to cover the complete power envelope of the signal of the EUT.*
  - *In the case of non-constant envelope modulation, a peak detector shall be used."*

- ETSI EN 300 328 [i.8] for 2,4 GHz:
    - *"The RF output power is defined as the mean equivalent isotropically radiated power (e.i.r.p.) of the equipment during a transmission burst.*
    - *Use a fast power sensor suitable for 2,4 GHz and capable of minimum 1 MS/s.*
    - *Sample speed 1 MS/s or faster.*
    - *The samples shall represent the RMS power of the signal.*
    - *Between the start and stop times of each individual burst calculate the RMS power over the burst…."*

4.3 Examples of regulations with requirements on detectors

4.3.1 Definitions from Radio Regulations

The mean power is defined in Article 1.158 of the ITU Radio Regulations [i.14] as "*The average power supplied to the antenna transmission line by a transmitter during an interval of time sufficiently long compared with the lowest frequency encountered in the modulation taken under normal operating conditions.*"

4.3.2 UWB regulations

- The first UWB regulation published was **ECC/DEC(04)03** [i.9] for car radars in the band 77-81 GHz. Decides 2 of ECC/DEC(04)03 says "*that the 79 GHz frequency range (77-81 GHz) is designated for Short Range Radar (SRR) equipment on a non-interference and non-protected basis with a maximum mean power density of -3 dBm/MHz e.i.r.p. associated with an peak limit of 55 dBm e.i.r.p.;*". The limitation here is not such clear as in ECC/DEC(06)04 (see below), but the harmonised standard ETSI EN 302 264 [i.24] being developed by ETSI ERM TGSRR has adopted later the same procedures as the ETSI EN 302 065-1 [i.25] is doing according to ECC/DEC(06)04 [i.10].
- **ECC/DEC(06)04** [i.10] contains in decides 2 clear information on the measurement detector to be used: *"that, for the purpose of the Decision, the following definitions apply: a) Maximum mean e.i.r.p. spectral density: the highest signal strength measured in any direction at any frequency within the defined range. The mean e.i.r.p. spectral density is measured with a 1 MHz resolution bandwidth, an RMS detector and an averaging time of 1 ms or less. b) Maximum peak e.i.r.p.: the highest signal strength measured in any direction at any frequency within the defined range. The peak e.i.r.p. is defined within a 50 MHz bandwidth".*
- The following requirements are provided in **ECC/DEC(06)08** [i.11]: *"Maximum mean and peak power densities of any undesired emission emanating from GPR/WPR imaging systems are defined below. For pragmatic reasons and for taking the mitigation factors into account, the mean power density shall be determined by formula (1) or (2) below and the peak values shall be measured according to ETSI EN 302 066".*
- **ECC/DEC(11)02** [i.12] contains in Annex 1 the following information on the measurement detector to be used: "*(1) Mean e.i.r.p. spectral density within LPR antenna mainbeam is the average power per unit bandwidth radiated in the direction of the maximum level;(2) Peak e.i.r.p. within mainbeam is the power contained within a 50 MHz bandwidth at the frequency at which the highest mean radiated power occurs. If measured in a bandwidth of x MHz, this level is to be scaled down by a factor of 20log(50/x) dB".*

The requirement for such a detailed prescription of the limits including the measurements detectors in the UWB regulation comes from the large possible occupied bandwidth of these systems (e.g. pulsed systems with a pulse width of 1 ps, MB-OFDM with a bandwidth of 500 MHz each OFDM symbol) resulting in a large peak/average ratio. In addition the large frequency ranges of the UWB systems are overlapping with many primary and secondary radio services which explains the need for a careful description of the limits.

Considering p) of ECC/DEC(06)04 [i.10] provides further background information: "*that ECC Report 64 has considered interference potential resulting from mean power and only limited consideration has been given to peak power interference, time gating and frequency hopping. ECC may review this Decision in the light of these possible implications*".

4.3.3 ERC Recommendation 74-01

ERC Recommendation 74-01 [i.13] contains in recommendation 6 some guidance on how to measure the spurious emissions:

"… Unless the Peak Envelope Power (PEP) is explicitly quoted, the spurious domain emission limits specified in this Recommendation from the transmitter into the antenna port are in terms of mean power. The mean power (P) of any spurious domain transmission from a burst transmitter is the mean power averaged over the burst duration."

4.3.4 FCC Part 15

In FCC part 15 "radio frequency devices" [i.16] describes in clause 15.35 the "Measurement detector functions and bandwidths". FCC part 15 applies to "intentional, unintentional, or incidental radiators which may be operated without an individual license", and thus it also applies to SRDs. The typical detector in FCC part 15 below 1 GHz is the quasi peak (15.35.a) and above 1 GHz average and peak (15.35.b). FCC applies different limits for different detectors.

For the fundamental emission special measurement methods are defined in ANSI 63.10 [i.15] and FCC documents (see FCC knowledge database -KDB [i.17], e.g. guidance for compliance measurements according section 15.247).

4.4 Summary and consequences for the present document

More or less clear prescriptions on measurement detectors are available in frequency regulation where a high potential peak/average ratio (UWB) and where a frequency overlap with primary and secondary radio users (co-channel) is expected (UWB, spurious emissions).

No requirements on measurement detectors in frequency regulations are usually requested in pure SRD and ISM frequency bands, where the frequency assignment is based on non-interference and non-protection, and where usually no primary or secondary radio users are expected at the same frequency as the radio user (co-channel).

Guidance on the use of measurement detectors would be beneficial, especially for cases without any requirements from the frequency regulation.

Time has come to evaluate how the existing detectors behave in combination with radio signals used by current radio systems. In particular, to prevent the development of artificial test scenarios to demonstrate compliance with the essential requirements stated in article 3.2 of the Radio Equipment Directive [i.23].

Clause 5 will explain the measurement detectors as parts of measurement instruments, clause 6 will summarize the relevant measurement detectors and clause 7 will practically show the impact of different measurement detectors when measuring different signals.

5 Detectors as parts of measurement instruments

5.0 Introduction

This clause gives a rough description of spectrum analysers and measurement receivers (measurement instruments). Detectors are parts of these instruments. The choice of measurement parameters, including the detector, influences other parameters. Thus, certain knowledge as pointed out in this clause is required when choosing how to measure with those instruments.

The main focus is on the instrument's overall architecture, the way how results are presented to the user and the different settings the user has to choose.

A more in-depth description of measurement instruments can be found in [i.20].

5.1 General

Measurement detectors are integral parts of measurement instruments. Their purpose is to assess the signal's envelope (see Figure 1) with a weighting function. This weighting influences the measured value shown by the instrument. The type of detector defines what weighting function is applied. Every detector has its own behaviour.

These detectors can be implemented by analog or digital circuits.

A description of the available weighting detectors is provided in clause 6.

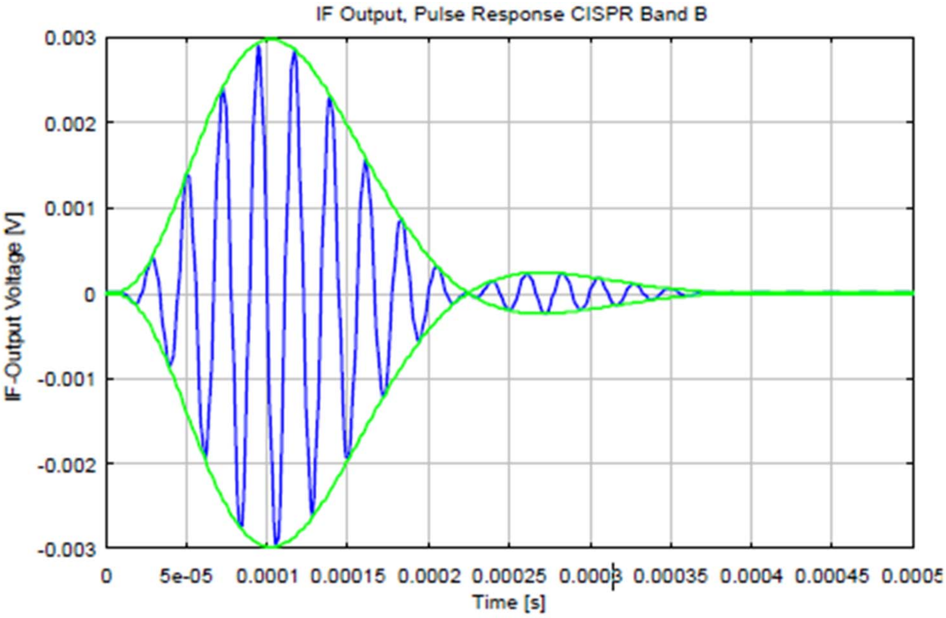

Figure 1: Signal plotted as voltage vs. time (blue) and its envelope (green)

5.2 Basic function of measurement instruments

5.2.0 Generic

The measurement instruments in the present document are either spectrum analysers or EMI-receivers. Both instrument types can either be conventional (sweeping a frequency range by continuously tuning the local oscillator) or FFT-based.

For spectrum analysers - suited as an all-purpose measurement instrument - no normative definitions exist. For EMI-receivers, certain minimum requirements regarding hardware parameters and measurement functions are found in CENELEC EN 55016-1-1 [i.1].

5.2.1 Conventional measurement instrument (without FFT- based functions)

An exemplary block diagram of a conventional measurement instrument is shown in Figure 2.

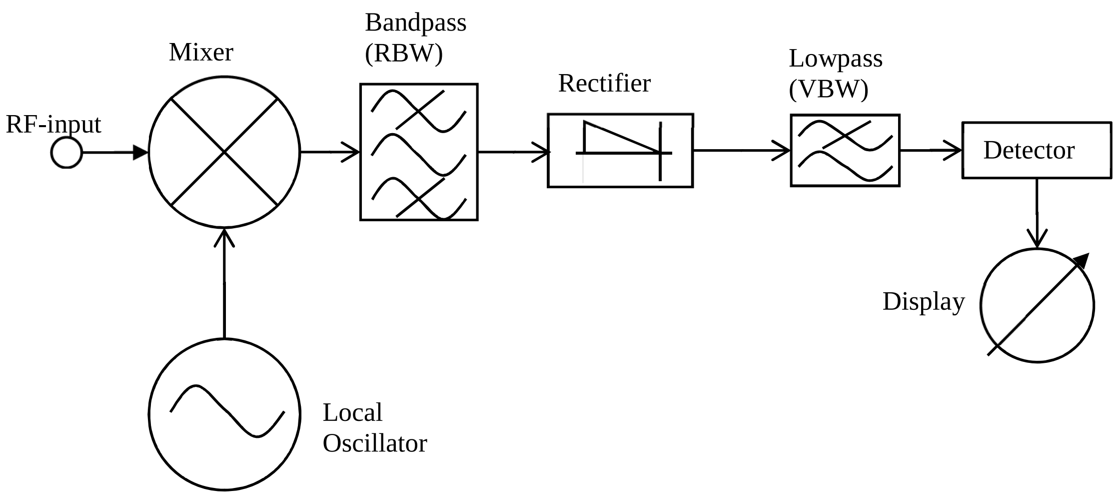

Figure 2: Simplified block diagram of a conventional measurement instrument signal path from the RF-input through the detector to the level meter

Measurement instruments offer many options to influence the measuring process. The instrument can either sweep across a frequency range (spectrum mode) or is tuned to a specific frequency (zero-span mode).

In spectrum mode, the instrument steps through the frequency list. Each trace point represents the voltage on that certain frequency as seen through the chosen resolution bandwidth, detector and measurement time.

In zero-span-mode the frequency is fixed and the voltage is shown as a function of time. The settings for resolution bandwidth, detector, etc. still apply as above in spectrum mode.

Simplified, a conventional spectrum analyser works as follows: the input signal is shifted to an intermediate frequency (short: IF) by the means of a local oscillator (short: LO) using a mixer. The resulting IF-signal is passed through a bandpass filter whose bandwidth is termed resolution bandwidth (short: RBW, sometimes referred to as receiver bandwidth). The filtered signal is fed to a rectifier, where the envelope of the IF-signal is extracted. The envelope's voltage is passed through the video filter which is a lowpass with an adjustable bandwidth (video-bandwidth, VBW). The video filters output is passed to the detector, whose output voltage is shown as the measurement result to the user.

After that, the LO is tuned to the next frequency. When all frequencies in the desired frequency range (defined by a start and stop frequency) have been stepped through, the analyser starts over again to sweep across the frequency range. The time required for one complete sweep is called sweep time. The time the analysers LO is locked to one frequency is the time where the detector is fed with voltage. The detector is reset any time the LO's frequency is changed. This means that the time for the measurement on one specific frequency is given by the sweep time divided by the number of the display's trace points. If the analyser is operated in zero span mode, then the sweep time defines the range of the time axis.

Advanced conventional measurement instruments, by contrast, digitize the IF. The IF filters, rectifiers and detectors - formerly analog parts of the circuitry are fully digital. However, even with this technology, the instrument can only perform measurements within the measurement bandwidth, and measuring a spectrum takes long time.

5.2.2 FFT-based measurement instrument

A FFT-based measurement instrument digitizes the signal mixed onto the intermediate frequency before the signal is limited to the chosen IF bandwidth. The availability of analog-to-digital converters (ADC) with a high sampling rate and a wide dynamic range makes this possible. Two different types of FFT-based measurement instruments are available:

- Instruments that digitize the input signal with an ADC in the baseband.
- Instruments that digitize the signal with an ADC at the output of the wideband IF filter.

Baseband systems are limited by the currently available ADCs, e.g. for a 1 GHz measuring receiver an ADC is necessary with 2 GS/s sampling rate to meet the Nyquist criterion and high resolution, e.g. 16-bit for an FFT-bandwidth of 30 MHz to meet the CENELEC EN 55016-1-1 [i.1] overload requirements for quasi-peak detection. Such ADCs are simply not available today. A good compromise is to combine both types in one instrument, e.g. baseband system up to 30 MHz and with FFT applied to the wideband IF signal above 30 MHz. Exemplary block diagrams of the two types of FFT-based EMI receivers are shown in Figure 3.

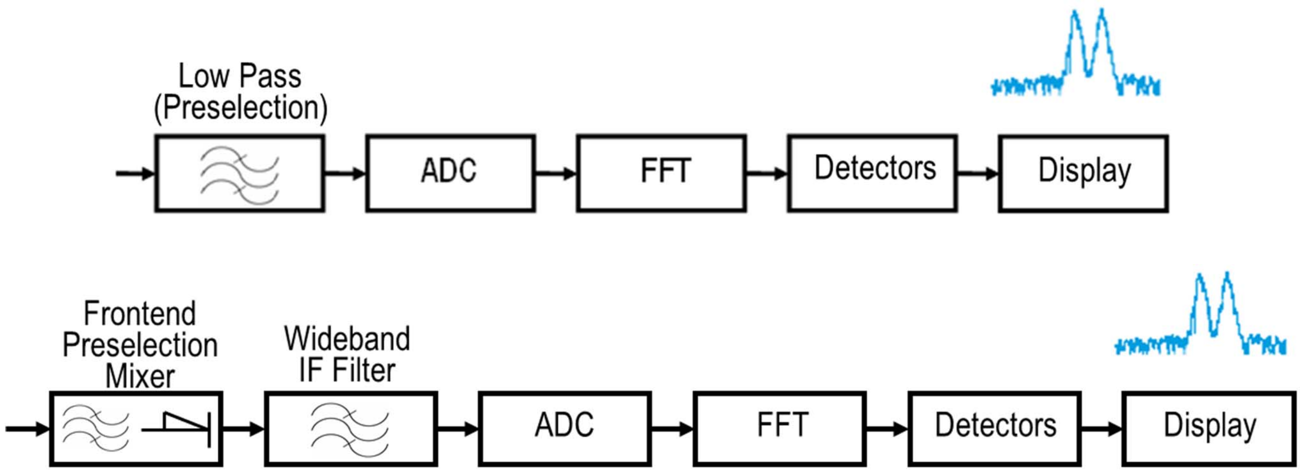

Figure 3: Simplified block diagrams of a FFT-based EMI receiver baseband system (above) and a heterodyne EMI receiver with FFT applied to the wideband IF signals (below)

The heterodyne EMI receiver uses fast Fourier transform (FFT) to compute the relevant spectrum from the time domain signal of the digitized IF. The IF contains the spectrum to be measured in the time domain - hence the term "time domain scan". The FFT parameters and the time domain signal window are set in such a way that the resolution bandwidth and filter characteristics match the IF bandwidths stipulated in CENELEC EN 55016-1-1 [i.1]. In this way, the receiver implements a filter bank with, say, several thousand parallel filters. After each of these filters there are a rectifier and detectors. Instead of a single measured value representing the frequency range of each measurement bandwidth (e.g. 9 kHz), this approach delivers a large number of parallel measured values covering the frequency range of several thousand measurement bandwidths at the same time. This reduces the measurement time by a factor that corresponds to the number of parallel measurement bandwidths. The purpose of preselection is to reduce the peak pulse voltage through band limitation and so avoid overloading any mixers, IF amplifiers or the ADC.

5.3 Detector influence to trace display and trace functions

Modern measurement instruments use digital displays for the recorded spectra. Accordingly, the resolution of both the level and the frequency display is limited. Particular when large frequency spans are displayed, one pixel contains spectral information of a larger subrange. Therefore, several measured values, referred to as samples, fall onto one pixel. The selected detector determines the sample to be represented by the pixel. The principles of the selection of samples to be displayed as a function of detectors are shown in [i.20] and [i.21].

During the display process previous values can be considered by the measurement instrument via the means of trace functions like e.g. storing the maximum/minimum of the displayed values. With that in mind, trace functions can be seen as kind of a "history"-function related to previous traces.

In case of using trace average, some things have to be considered:

- Linear or logarithmic averaging
- Use of average detector with trace averaging
- Use of RMS/RMS-Av detector with trace averaging

It has to be agreed onto what is to be averaged: the logarithmic values (on decibel-scale) or the linear values (before converting them back to the logarithmic scale). Often, measurement instruments offer the choice between the intended averaging mode. Although averaging on the decibel-scale is nice to quickly smooth the display, it has no meaningful equivalent meaning in terms of measuring a physical quantity.

The Average-detector calculates the linear average for each displayed trace from the samples allocated to a pixel. For this calculation the samples of the envelope are required on a linear level scale. Basically, the Average-detector calculates its output values from a one-dimensional vector of incoming voltage-samples $\vec{u}$ with N elements as follows:

$$U_{Av} = \frac{1}{N}\sum_{i=1}^{N} u_i$$

The trace function "linear averaging" applies an averaging over the pixels in subsequent traces, with the total number of traces to be averaged and the trace index s this means (independent from the detector):

$$\overline{U} = \frac{1}{S}\sum_{s=1}^{S} U_s$$

For trace mode "linear averaging" and an Average-detector, this becomes:

$$\overline{U_{Av}} = \frac{1}{S}\sum_{s=1}^{S} U_{Av,s}$$

A common question is if trace averaging with an Average detector leads systematically to different results than to increase the measurement time. For this, consider a vector of samples $\vec{u}$ and $\vec{v}$ with N elements each. Let $\vec{w}$ be the concatenation of $\vec{u}$ and $\vec{v}$ in time, so $\vec{w}$ has $2N$ Elements. So one gets:

$$U_{Av,u} = \frac{1}{N}\sum_{i=1}^{N} u_i \qquad \text{and} \qquad U_{Av,v} = \frac{1}{N}\sum_{i=1}^{N} v_i$$

$$\overline{U_{Av,uv}} = \frac{1}{2}\left(\frac{1}{N}\sum_{i=1}^{N} u_i + \frac{1}{N}\sum_{i=1}^{N} v_i\right) = \frac{1}{2N}\left(\sum_{i=1}^{N} u_i + \sum_{i=1}^{N} v_i\right)$$

This is the same as if the average detector would have been applied to the sample set $\vec{w}$ (without trace averaging):

$$U_{Av,w} = \frac{1}{2N}\sum_{i=1}^{2N} w_i = \overline{U_{Av,uv}}$$

This means, that the same operations have been applied to the sample sets, and thus the results are identical. Obviously, this example can be prolonged to an arbitrary number of sample sets. Neglecting the time-/frequency behaviour of the signal, this means: it does not matter if one applies linear trace averaging or increases the measurement time accordingly, if an Average-detector is used.
Nonetheless, one has to regard that the averaging process itself acts as a first order lowpass filter, cascaded with the video filter (VBW). This leads to the side requirement that a large VBW (VBW ≥ 3 × RBW) is used when trace averaging is applied.

For the RMS-detector trace averaging is not valid. The trace averaging process will lead to a result that is larger than the actual value. The reason for that is the way the RMS-detector works, which is shown below. This also applies to values measured using the RMS-Av-Detector, since the same effects occur.

Assume an instrument that has recorded the rectified IF-voltage in discrete time steps. By definition, the corresponding RMS-value is then given as:

$$U_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} u_i^2}$$

where N is the number of voltage samples u taken during the measurement time. As one can see from the definition, the detector rates the power (across a resistor of 1 Ω) in a defined interval of time. From a different point of view, one can see the similarity to the absolute value of vector $\vec{u}$ with dimension N.

Now it is considered what happens when trace averaging is applied. Let $\overline{U_{RMS}}$ be the average of two RMS-values resulting from the two vectors $\vec{u}$ and $\vec{v}$ with the same dimension. This means:

$$\overline{U_{RMS}} = \frac{1}{2}\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N} u_i^2} + \sqrt{\frac{1}{N}\sum_{i=1}^{N} v_i^2}\right) = \frac{1}{2\sqrt{N}}\left(\sqrt{\sum_{i=1}^{N} u_i^2} + \sqrt{\sum_{i=1}^{N} v_i^2}\right)$$

The alternative to that is to double the measurement time and take a single reading from the instrument. This means that one records the sample set w with $2N$ samples, where w is the concatenation of u and v in terms of time ($w = u + v$ with $u_i = 0\ \forall i > N$ and $v_i = 0\ \forall\ i < N$). The corresponding RMS-value is:

$$U_{RMS,uv} = \sqrt{\frac{1}{2N}\sum_{i=1}^{2N} w_i^2} = \sqrt{\frac{1}{2N}\sum_{i=1}^{2N} (u_i + v_i)^2}$$

This term can be expanded to:

$$U_{RMS,uv} = \frac{1}{\sqrt{2N}}\sqrt{\sum_{i=1}^{2N} (u_i^2 + 2u_i v_i + v_i^2)} \xrightarrow[u_i v_i = 0 \forall i]{} U_{RMS,uv} = \frac{1}{\sqrt{2N}}\sqrt{\sum_{i=1}^{2N} (u_i^2 + v_i^2)}$$

The triangular inequality is given by:

$$|a_1 + a_2 + \cdots + a_n| \leq |a_1| + |a_2| + \cdots + |a_n|$$

Comparing this to $U_{RMS,uv}$ and $\overline{U_{RMS}}$ shows that:

$$\sqrt{\sum_{i=1}^{2N} (u_i^2 + v_i^2)} \leq \sqrt{\sum_{i=1}^{N} u_i^2} + \sqrt{\sum_{i=1}^{N} v_i^2}$$

Furthermore, following inequality holds:

$$\frac{1}{\sqrt{2N}} > \frac{1}{2\sqrt{N}}$$

Both inequalities combined lead to:

$$\frac{1}{2\sqrt{N}}\left(\sqrt{\sum_{i=1}^{N} u_i^2} + \sqrt{\sum_{i=1}^{N} v_i^2}\right) \neq \frac{1}{\sqrt{2N}}\sqrt{\sum_{i=1}^{2N} (u_i^2 + v_i^2)}$$

Both inequalities are opposing. In some rare cases, which will never occur in practice, both results can yield the same value.

This leads to:

$$U_{RMS,uv} \neq \overline{U_{RMS}}$$

This equation states that the result by doubling the measurement time is different than a result obtained by averaging two results obtained by the single measurement time each.

Stated otherwise: when using the RMS-detector, longer measurement times are to be used to stabilize readings. The use of trace averaging is not recommended, for the values obtained have a different meaning.

It should be clear that this applies to a single measurement on e.g. a single radio device. If one performs radio tests on different devices, then - of course - one can average the values to assess the average RMS-value related to a series of devices.

When using the Average-detector, longer measurement times or trace averaging can be used to stabilize readings.

Nonetheless, trace averaging is a fast solution if one tries to detect (detection is something completely different than measuring) a signal, especially on low Signal-to-Noise-ratios.

5.4 The resolution bandwidth (RBW)

The RBW determines the bandwidth of the signal that is passed to the detector. This means, that the spectra seen on the instrument's display is seen through the "looking glass" of the RBW's filter shape: spectrum components outside the RBW are attenuated.

The RBW filter has an important effect on signals with high frequency components. A pulse that is so short that it can be seen as a Dirac pulse will appear behind the resolution band filter as the inverse Fourier transform of the RBW filter function itself, modulated on the middle frequency of the measurement instrument, see Figure 1. The amplitude of the signal's envelope is proportional to the Dirac pulse's area ($\int u \, dt$). So, the detector does not 'see' the shape of the pulse itself. This property is what makes the RBW-filter act as a "looking glass" as stated above.

5.5 The video bandwidth (VBW)

A video-filter is a low pass meant to smooth the signal's envelope. It can also remove noise and high-frequency terms from the voltage. One has to be aware that fast changes in the signal of interest are reduced if the VBW is too narrow, resulting in a too small measurement result. A VBW is found in spectrum analysers only.

Often, the VBW-setting is expressed as a factor related to the RBW.

Most analysers have an automatic coupling of the RBW/VBW-ratios. An RBW/VBW-coupling ratio of 0,1 means: the VBW is ten times the RBW. It is generally not advisable to disable that automatic coupling. But it is preferred to adjust the coupling ratio according to the type of intermittent signal, as long as no specific VBW is specified.

For a CW-signal, the RBW/VBW-coupling ratio has to be in the range of 0,3 … 1. For pulsed signals, the coupling ratio has to be far less than 1 (usually: 0,1) to ensure that the level can follow the pulse edges instead of smoothing them out. This is especially important when the pulse width is small: the VBW is a first-order lowpass. Small pulse widths at the input can never charge the filter's capacitor to the pulse's actual level, leading to false results.

If an RMS detector is used, then the VBW has to be at least 3 times of the RBW (which is done automatically by many modern spectrum analysers when selecting the RMS detector).

5.6 RBW- and VBW influence to sweep time

One has to be aware that the RBW- and VBW-filters need a certain time to settle from their transient response to a stable state. The time required is the reciprocal value of the filter's bandwidth and shape (see for example CENELEC EN 55016-2-3 [i.19]). As a consequence, the appropriate sweep time not only depends on the number of trace points and the time to measure on each frequency, it also depends on the narrowest filters bandwidth. That means that the sweep time should be at least the product of trace-points and 1/RBW (for the most common case that the RBW is smaller than the VBW), e.g. 50 ms for 500 trace points and RBW = 10 kHz.

This statement also holds for FFT-based measurement instruments, where the filters are modelled digitally. Due to the parallel calculation of all frequency bins within the FFT measurement bandwidth, the settling time applies only once to all frequency bins within the FFT measurement bandwidth. In contrast to that, a non-FFT-based measurement instrument, the settling time applies for each frequency step during the sweep.

Spectrum analysers are offering usually an automatic sweep time function, where the sweep time is automatically coupled with the selected RBW/VBW. This function should be used carefully. Guidance for the setting of sweep time can be found in CENELEC EN 55016-2-3 [i.19].

5.7 Differences between spectrum analysers and EMI receivers

Spectrum analysers and EMI receivers might seem to be the same (they measure levels across a certain frequency range) - but they are not. This clause outlines some key differences.

- An EMI receiver has no VBW.
- EMI receivers have pre-selection filters prior to the first mixer stage; spectrum analysers do not have any preselection.
- The measurement detectors of EMI receivers and spectrum analysers may be different (see clauses 6.2 and 6.3).
- Often, EMI receivers have a higher sensitivity than spectrum analysers. In many cases, this is due to the built-in preamplifier.
- EMI receivers are specified in CENELEC EN 55016-1-1 [i.1], [i.2]. For spectrum analysers, a normative specification like CENELEC EN 55016-1-1 [i.1], [i.2] does not exist. It is not guaranteed for a spectrum analyser to have features like e.g. a QP-detector.
- On the other hand, spectrum analysers offer more sophisticated measurement functions like channel power measurements or occupied bandwidth by several methods. Furthermore, spectrum analysers can be equipped with additional filter shapes/bandwidth for specific radio standards.
- For EMI receivers, the bandwidths are defined in CENELEC EN 55016-1-1 [i.1], [i.2]. These bandwidths are defined by the transfer function's 6 dB-points to reflect the impulse bandwidth. The bandwidth selection depends on the tuned center frequency and hence the CISPR-Bands as shown in the following Table 3.

Table 3: Bandwidths for EMI receivers according to CENELEC EN 55016-1-1 [i.1], [i.2]

f_{start}	f_{stop}	Bandwidth	CISPR-Band
9 kHz	150 kHz	200 Hz	A
150 kHz	30 MHz	9 kHz	B
30 MHz	1 GHz	120 kHz	C/D
1 GHz	18 GHz	1 MHz	E

- In comparison to EMI receivers, the resolution bandwidth of spectrum analysers is defined by transfer function's 3 dB-points. The filters usually have a Gaussian shape. Typically, the following bandwidths are available: 100 Hz, 300 Hz, 1 kHz, 3 kHz, 10 kHz, 30 kHz, 100 kHz, 300 kHz, 1 MHz.
- For EMI receivers bandwidth selection is automatically coupled to the measurement frequency setting according to Table 3. For spectrum analysers the resolution bandwidth can be chosen arbitrary according to the requirements by the standard and measurement procedure.

The main differences between spectrum analysers and EMI receivers are in addition summarized in Annex I of CENELEC EN 55016-1-1 [i.1], [i.2] and in [i.3]. Some information on the use of spectrum analysers is provided in Annex B of CENELEC EN 55016-2-3 [i.19].

6 Description of detectors

6.0 Introduction

Measurement detectors rate the envelope of the IF-voltage by a defined function, cf. clause 5. The detectors are not pieces of equipment as such; they are integrated in the measurement instrument. Their behaviour cannot be seen loose from the instrument.

The choice of the detector depends on what is to be measured. It is essential to note that different detectors give different results on the same signal. The more specific it is defined how a value is to be measured - including the assorted detector and the measurement time - the more unambiguous measurements can be performed.

The detectors that occur on the radio testlabs are often the ones known from the EMI world, where they are used for RF emission measurements. The description of EMI measuring receiver detectors (CISPR-detectors) in accordance with CENELEC EN 55016-1-1 [i.1] is provided in clause 6.2. The description of detectors as used in spectrum analysers is provided in clause 6.3.

6.1 General notes on detectors

A basic principle that is also used in the calibration of the measurement instrument, is that when an unmodulated sine wave of the tuned frequency is brought to the input of the measurement instrument, all detectors will give the same indication, which is the RMS level of the sine wave on the input:

PK = QP = RMS = RMS-AV = AV (valid for unmodulated sine wave)

The maximum deviation given in CENELEC EN 55016-1-1 [i.1], [i.2] on the indication is 2 dB for all detectors, and 2,5 dB above 1 GHz. However, modern technology should make much better instrumentation possible.

The differences between the detectors can be seen with time-variant signals, for example:

- The level of amplitude modulated signals varies in terms of time.
- Frequency modulated or frequency hopping signals are not always in the receiver's measurement bandwidth.

In CENELEC EN 55016-1-1 [i.1], [i.2] the pulse responses are defined for the detectors. This leads to a predictable weighting factor for time-variant signals:

PK > QP > RMS > RMS-AV > AV (valid for time-variant signals, e.g. pulse signals)

Figure 4 shows these weighting factors grouped by the CISPR-detector (more detailed in clause 6.2). Figure 5 shows these weighting factors for the spectrum analyser detectors (more detailed in clause 6.3).

Figures 4 and 5 can be read as follows: for the applied signal (short pulses), different detectors give different readings. The differences depend on the pulses repetition frequency f_p, shown on the abscissa in a logarithmic scale. The weighting factor (in deciBel), shown on the ordinate, quantifies the decrease of the level readings in the given situation depending on the detector.

Example for Figure 4: a short pulse with a repetition frequency of 10 kHz (one pulse every 100 µs) reads 100 dBµV when the peak detector is applied. The same signal will roughly give the same reading (100 dBµV) when the Quasi-Peak detector is used. If the RMS-Average detector is used, then 89 dBµV (100 dBµV - 11 dBµV) is shown. Still observing the same signal, this time with a CISPR-Average detector, the result will read 78 dBµV.

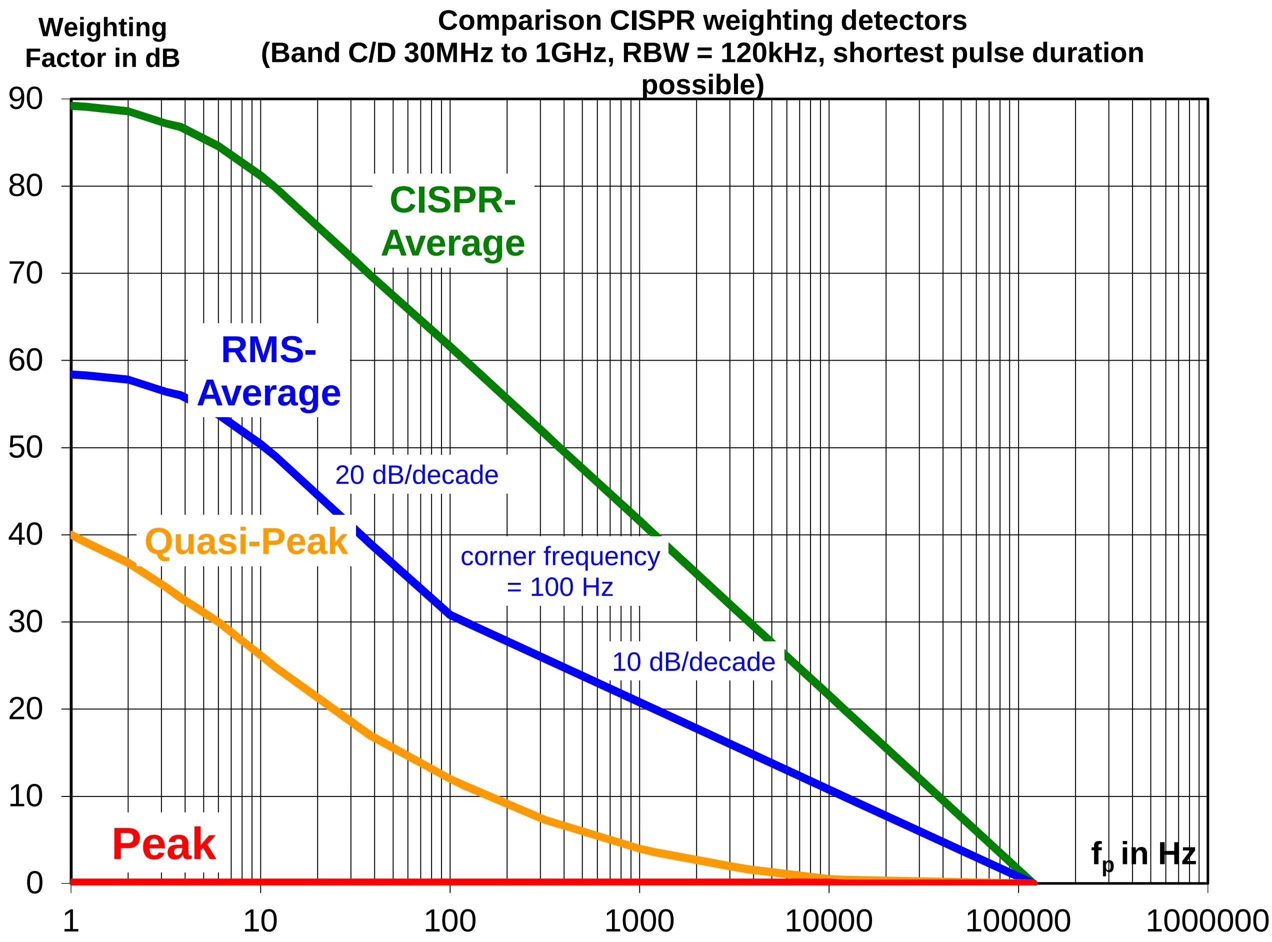

Figure 4: Comparison of weighting factors of CISPR detectors for impulse noise

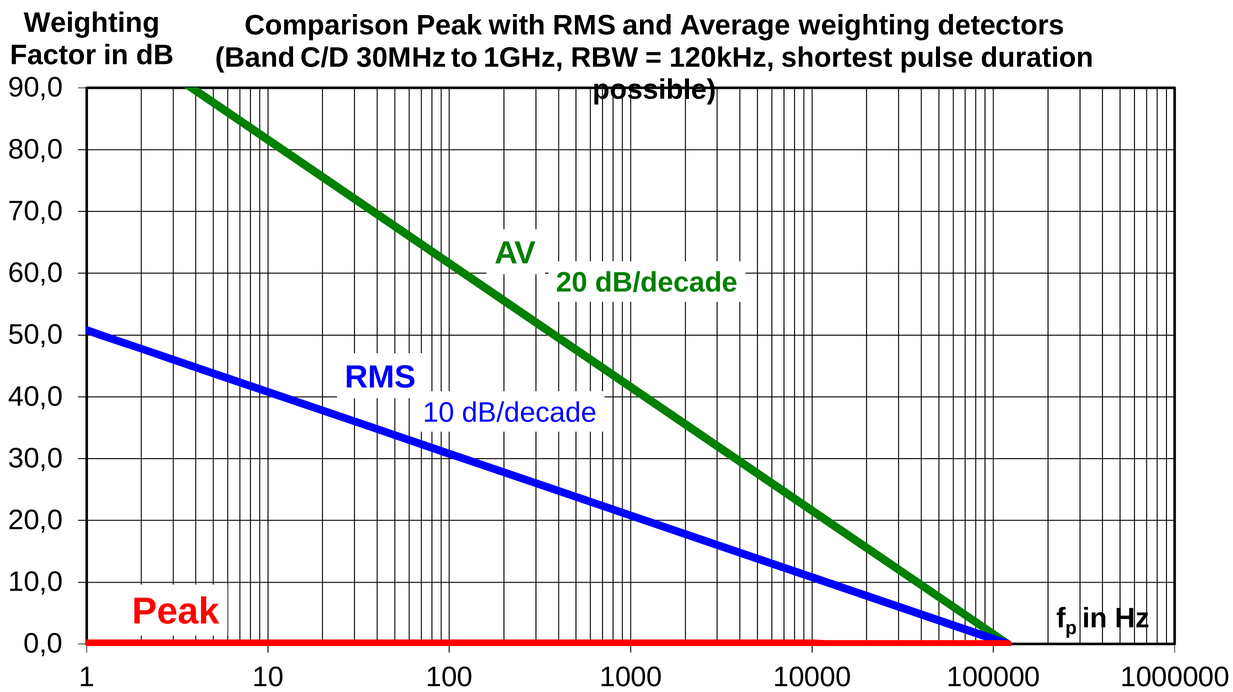

Figure 5: Comparison of weighing factors of spectrum analyser detectors for impulse noise

It has to be noted that the above weighting factors in Figures 4 and 5 do only have a limited value for radio measurements because these curves do not consider the transmission time of the signal but only the repetition time of a very short pulse. Therefore these weighting curves are valid for the shortest pulse width applied, i.e. pulse width $< 1/(10 \times \mathrm{RBW})$.

6.2 CISPR-detectors

6.2.0 General

EMI detectors are defined in [i.1].

6.2.1 The CISPR peak detector

General info: The CISPR peak detector follows the signal at the output of the IF envelope detector and holds the maximum value during the measurement time (also called dwell time) until its discharge is forced. This indication is independent of the PRF.

Frequency range: The CISPR peak detector is defined from 9 kHz to 18 GHz in CENELEC EN 55016-1-1 [i.1].

Influence on measurement time: Depending on the type of disturbance, it provides the shortest measurement time possible.

Measurement Bandwidth: For CISPR bandwidths 200 Hz, 9 kHz, 120 kHz and 1 MHz as well as decadic bandwidths from 1 Hz to 1 MHz.

Typical uses: Assess a spectrum's peak envelope. It can be used for either broadband or narrowband disturbance measurements.

Common pitfalls: For EMI measurements the Peak detector indicates a higher interference potential of impulsive disturbance than the interferer actually represents (i.e. it overweighs the disturbance).

Additional info: EMI limits with peak detector are typical for frequencies above 1 GHz. Below 1 GHz there is an EMI rule that, when the peak read out is compliant against the limits for the other detectors, the measurement can usually be accepted as compliant. As measurements with the peak detector are relatively fast, this rule can be attractive for a testlab.

6.2.2 The CISPR Quasi-peak detector

General info: The Quasi-peak detector (QP) was the first weighting detector that was developed. It takes into account the psychophysical annoyance of the interference effect. For example, to a listener of AM radio in CISPR Band B the degradation of reception quality, caused by a 100-Hz pulse, is equivalent to the degradation from a 10-Hz pulse, if the pulse level is increased by an amount of 10 dB. The weighting function of the QP detector is prescribed for CISPR Bands A, B, C and D in CENELEC EN 55016-1-1 [i.1], [i.2]. The first CISPR measuring receiver in 1939 was already equipped with a QP detector. Originally, the QP detector is a classic electromechanical measuring instrument with defined mechanical behaviour, a defined RC charging circuit, and defined RC discharging circuit, with the discharging time much longer. This works out so that interference signals coming from, for instance, a sparking electromotor commutator are more or less homogenized. Modern measuring receivers comes to the same output using a digital detector board.

Frequency range: The QP detector is defined from 9 kHz to 1 GHz in CENELEC EN 55016-1-1 [i.1].

Influence on measurement time: The application of the QP detector requires a minimum measurement time of 1 s as defined in CENELEC EN 55016-2-3 [i.19].

NOTE: Depending on the type of disturbance, the measurement time may have to be increased - even for QP measurements. In extreme cases, the measurement time at a certain frequency may have to be increased to 15 s, if the level of the observed emission is not steady. However, isolated clicks are excluded.

Measurement Bandwidth: For CISPR bandwidths 200 Hz, 9 kHz and 120 kHz only.

Typical uses: For the weighted measurement of broadband disturbance and for the assessment of audio annoyance to a radio listener, but also usable for narrowband disturbance. The QP detector is the most used detector for EMI measurements.

Common pitfalls: The QP detector indicates a higher interference potential of impulsive disturbance on digital radio services than the interferer actually represents (i.e. it overweighs the disturbance).

Additional info: Unlike the other detectors treated in the present document the QP detector cannot easily be modelled.

6.2.3 The CISPR-Average detector

General info: This detector is designed to indicate the average value of the envelope of the signal behind the resolution band filter. Average detectors including the CISPR-Average detector are generally used for the measurement of narrowband disturbance and signals, and particularly to discriminate between narrowband and broadband disturbance. In addition the CISPR-Average detector is suitable for measuring intermittent, unsteady or drifting narrowband disturbances correctly. In CENELEC EN 55016-1-1 [i.1], [i.2] the response to intermittent, unsteady and drifting narrowband disturbances has to be such that the measurement result is equivalent to the peak reading of an instrument with a meter time constant of 160 ms for Bands A and B and of 100 ms for CISPR Bands C, D and E. This can be accomplished by a meter-simulating network following the envelope detector of the receiver.

Frequency range: The CISPR-Average detector is defined from 9 kHz to 18 GHz in CENELEC EN 55016-1-1 [i.1].

Influence on measurement time: In order to measure the carrier of a modulated signal, the modulation has to be suppressed by signal averaging over a sufficiently long time, or by using a video filter of sufficient attenuation at the lowest frequency. If fm is the lowest modulation frequency, and assuming that the maximum measurement error due to a 100 % modulation is limited to 1 dB, then the measurement time Tm should be Tm = 10/fm.

Measurement Bandwidth: For CISPR bandwidths 200 Hz, 9 kHz, 120 kHz and 1 MHz only.

Typical uses: To show the weighted peak reading for intermittent, unsteady or drifting narrowband disturbances using a standardized meter time constant. In addition, to suppress amplitude modulation (AM) in order to measure the carrier level of AM signals or to suppress impulsive noise for the measurement of CW components in disturbance signals.

Common pitfalls: Spectrum analysers may not be equipped with the CISPR-Average detector.

Additional info: CENELEC EN 55016-1-1 [i.1], [i.2] specifies the average detector measurement result as the maximum scale deflection of an instrument with a meter time constant. This is necessary to avoid reduced level indication for a pulse modulated disturbance by using long measurement times and for measuring the response to intermittent, unsteady or drifting narrowband disturbances correctly. Above 1 GHz two modes of the average (weighting) detector are defined in CENELEC EN 55016-1-1 [i.1], linear and logarithmic with different behaviours.

6.2.4 The CISPR RMS-average detector

General info: RMS-average weighting detectors employ a weighting function that is a combination of the RMS detector (for pulse repetition frequencies above a corner frequency fc) and the average detector (for pulse repetition frequencies below the corner frequency fc), thus achieving a pulse response curve with the following characteristics: 10 dB/decade above the corner frequency and 20 dB/decade below the corner frequency.

Frequency range: The RMS-average detector is defined from 9 kHz to 18 GHz in CENELEC EN 55016-1-1 [i.1].

Influence on measurement time: For a measurement time shorter than 20 ms the detector weighting will be equal to a response of the RMS detector.

Bandwidth: For CISPR bandwidths 200 Hz, 9 kHz, 120 kHz and 1 MHz only.

Typical uses: The aim of this is to make an adequate protection of digital radio-communication possible with a detector that can work much faster than the QP. After all, the QP was originally developed for the protection of AM broadcast.

Common pitfalls: Spectrum analysers may not be equipped with the RMS-average detector.

Additional info: The RMS-average detector was first adopted in product standard CENELEC EN 55013 [i.22]. It makes assessments possible with the RMS-average as alternative to QP and CISPR-Average. The RMS-average detector may also be adopted in future product standards for EMC emission measurements.

6.3 Spectrum analyser detectors

6.3.0 General

The detectors in spectrum analysers are based on common understanding of the underlying math. Most of the spectrum analysers feature negative peak (sometimes called min peak), positive peak (sometimes called max peak), auto peak (showing both min peak and max peak), average, rms and sample detectors. Common understanding is that the term peak detector is associated with the positive peak or max peak detector. Spectrum analysers may also be equipped with detectors as specified in [i.1].

6.3.1 The peak detector (positive or max peak)

General info: The peak detector follows the signal at the output of the IF envelope detector and holds the maximum value during the measurement time (also called dwell time) until its discharge is forced. From the samples allocated to a pixel, the one with the highest level is selected and displayed.

Frequency range: The peak detector is applicable in the entire frequency range of the spectrum analyser.

Influence on measurement time: Depending on the type of signal, it provides the shortest measurement time possible.

Measurement Bandwidth: Applicable with any measurement bandwidth the spectrum analyser is designed for.

Typical uses: Assess a spectrum's peak envelope. It can be used for either broadband or narrowband disturbance measurements.

Common pitfalls: If a spectrum analyser is used for peak measurements, the video bandwidth should be set to a value greater than or equal to the resolution bandwidth.

Additional info: Even if wide spans are displayed with very narrow resolution bandwidth, no input signals are lost (see clause 5.4).

6.3.2 The RMS detector

General info: The indication is proportional to the root of impulse area and pulse frequency. Its function rates the square of the voltage at its input, so the RMS detector rates power within a selectable time according to the following formula:

$$U_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} u_i^2}$$

The RMS detector has never been used in the EMI field. Therefore, the RMS detector was deleted in CENELEC EN 55016-1-1 [i.1]. It was still defined in CENELEC EN 55016-1-1 [i.2].

Frequency Range: The RMS detector is applicable in the entire frequency range of the measuring receiver or spectrum analyser.

Influence of measurement time: By increasing the sweep time, the number of samples available for the calculation is increased, thus allowing smoothing of the displayed trace.

Measurement Bandwidth: Applicable with any measurement bandwidth the measuring receiver or spectrum analyser is designed for.

Typical uses: Assess the power supplied by a transmitter into a load (transmitter output power).

Common pitfalls: If an RMS detector is used, then the VBW has to be at least 3 times of the RBW (which is done automatically by many modern spectrum analysers when selecting the RMS detector).

Additional info: The detectors meaning is as follows: if one would replace the RF-power into a load by a DC power, then the DC source has to deliver the RMS power of the RF-signal to heat up the load in the same way. If the signal of interest is active for a long time, the readings are preferably stabilized by longer measurement times.

NOTE: The RMS value is used for the calibration of all detectors (see clause 6.1).

6.3.3 The average detector

General info: This detector is designed to indicate the linear average value of the voltage of the signal behind the resolution band filter:

$$U_{Av} = \frac{1}{N}\sum_{i=1}^{N} u_i$$

The average detector is used to measure narrowband signals to overcome problems associated with either modulation content or the presence of broadband noise. The indication is proportional to the level of the signal and, in case of pulsed signals, proportional to impulse area and pulse frequency.

Frequency range: The average detector is applicable in the entire frequency range of the spectrum analyser.

Influence on measurement time: In order to measure the carrier of a modulated signal, the modulation could be suppressed by signal averaging over a sufficiently long time, or by using a video filter of sufficient attenuation at the lowest frequency. If fm is the lowest modulation frequency, and assuming that the maximum measurement error due to a 100 % modulation is limited to 1 dB, then the measurement time Tm should be Tm = 10/fm.

Measurement Bandwidth: Applicable with any measurement bandwidth the spectrum analyser is designed for.

Typical uses: To suppress amplitude modulation (AM) in order to measure the carrier level of AM signals or to suppress impulsive noise for the measurement of CW components in disturbance signals.

Common pitfalls: The average detector should be used carefully for the measurement of impulsive signals. Compared to the CISPR average detector (see clause 6.2.3) the average detector may underestimate signals with low PRFs (e.g. 10 Hz or less) and may not be suitable for measuring the response to intermittent, unsteady or drifting narrowband signals.

Additional info: A spectrum analyser with a video bandwidth setting much lower than the resolution bandwidth approaches the behaviour of the average detector.

6.3.4 The sample detector

General info: The sample detector samples the IF signal envelope for each pixel of the trace to be displayed. It selects only one value (usually the first one) from the samples allocated to a pixel.

Frequency range: The sample detector is applicable in the entire frequency range of the spectrum analyser.

Influence on measurement time: The sweep time has no effect on the displayed value since the number of the recorded samples is independent of the sweep time.

Measurement Bandwidth: Applicable with any measurement bandwidth the spectrum analyser is designed for.

Typical uses: Only to get a quick overview/indication of the measured spectrum, not suitable for final measurements.

Common pitfalls: If the span to be displayed is much greater than the resolution bandwidth, input signals are no longer reliably detected.

Additional info: The sample detector always displays a sample recorded at a defined point in time. Due to the distribution of the instantaneous values, the trace displayed in the case of Gaussian noise therefore varies about the average value of the IF signal envelope resulting from noise. This average value is 1,05 dB below the RMS value [i.20] and [i.21].

7 Measurement examples

7.0 Introduction

This clause gives examples regarding different detectors and different instrument settings throughout four different signal types. The examples should provide an impression about the impact of the chosen detector and measurement instrument settings to the measurement result.

7.1 Test signals

This clause describes the signals used in the examples provided.

Signal 1: non-pulsed continuous; digital modulation

- Generator: R&S®SMU200A
- Generator output power level:
  - RMS Power = -30 dBm
- Peak power = -23,7 dBm
- Center frequency 400 MHz
- 16 QAM, 1 MSymbols/s, bandwidth about 1 MHz, cos-filtered with α = 0,35

Signal 2: slow pulsed, non-modulated (CW is switched on and off)

- Generator: R&S®SMT06
- Generator output level:
  - Peak power = -30 dBm
- Center frequency: 400 MHz
- On-/Off-keying: Ton 10 ms, Toff 30 ms (1/Ton = 100 Hz, PRF = 25 Hz)

Signal 3: slow pulsed AM signal (AM modulated signal is switched on and off)

- Generator: R&S®SMT06
- Generator output level:
  - RMS carrier power -30 dBm
- Center frequency: 400 MHz
- On-/Off-keying: Ton 10 ms, Toff 30 ms (1/Ton = 100 Hz, PRF = 25 Hz)
- AM, Modulation degree 80 %
- Tone frequency 700 Hz, tone shape: sine

Signal 4: fast pulsed, non-modulated (CW is switched on and off)

- Generator: R&S®SMT06
- Generator output level:
  - Peak power = -30 dBm
- Center frequency: 400 MHz

- On-/Off-keying: Ton 10 µs, Toff 30 µs (1/Ton = 100 kHz, PRF = 25 kHz)

7.2 Measurement equipment

- Measurement instruments:
  - R&S®ESPI, with spectrum analyser mode and EMI receiver mode
  - Tektronix®RSA, realtime spectrum analyser (FFT-based)
- Signal generators:
  - R&S®SMU200A
  - R&S®SMT06

7.3 Measurement result discussion

7.3.0 General

An overview of all measurements, separated by signal type, are provided in this clause. The full documentation of the resulting spectra/instrument displays is given in Annex A.

Throughout the tables, following abbreviations are used:

SA: Spectrum Analyser (spectrum/sweep mode)

EMI: EMI receiver

RTA: RealTime spectrum Analyser (FFT-based)

CR: Trace mode clearwrite

MH: Trace mode Maxhold

SZ: Spectrum analyser (zero span/fixed frequency mode)

": no change as compared to previous line

n.a.: not available

The tables are to be read from top to bottom. Entries that remain unchanged from one line to the other are marked with a colon (").

The column "Figure N0." References to the figures in Annex A. Column "Mode" provide information about the used instrument, its operating mode (spectrum or zero span) and the trace mode. The further columns provide information about the resolution bandwidth (RBW, given by the measurement filter's 3 dB bandwidth if not stated otherwise), the video bandwidth (VBW), the Sweep time and the readings from the different detectors. Additional remarks are given in the column "Comment".

It should be noted that RMS and AV measurements with the EMI receiver are since 2002 not anymore defined in CENELEC EN 55016-1-1 [i.1], [i.2]. In addition is should be clear that there is a difference between the AV detector and the CISPR-AV detector, which is explained in clause 6. The below measurements do only use the AV detector.

A description explaining the influence and effect of the key findings is given for each signal type.

7.3.1 Signal type 1 (16-QAM)

Table 4: Overview of measurement examples, signal type 1 (16-QAM)
Reference powers inside 99 % signal bandwidth: -30 dBm RMS, -23,7 dBm Peak

Figure No.	Mode	RBW kHz	VBW kHz	Sweep time ms	PK dBm	QP dBm	RMS-AV dBm	RMS dBm	AV dBm	Comment
A.1	SA CR	100	1 000	100	-34			-40	-41	
A.2	"	"	"	2,5	-37			-40	-41	not stable
A.3	"	"	"	25	-34			-37	-38	not stable
A.4	"	"	"	1 000	-33,5			-40	-41	
A.5	SA MH	100	"	"	-32,5			-40	-41	
A.6	SA CR	300	"	"	-29,3			-35,5	-37,3	
A.7	"	100	1	"	-40			-41	-41	
A.8	"	"	10	"	-36			-41	-41	
A.9	"	"	100	"	-33,7			-40,3	-41	
A.10	"	3 000	3 000	"	-23,7			-31	-32	
A.11	SZ CR	300	1 000	2	-29					
A.11	"	"	1	2	-38					
A.12	EMI	120	n.a.	100	-33,3	-35,5	-40,3	-40,4	-41,4	
A.13	SA CR	120 6 dB-BW	10 000	10 000		-35				Spectrum shape is distorted: detector's voltage lags
A.13	"	"	"	50 000		-35				
A.13	"	"	"	1 000		-41				

Signal 1 is not pulsed. Its approximate bandwidth is 1,35 MHz. Using a smaller RBW aids in showing the spectrum's shape and to separate unwanted emissions in close spectral vicinity from the wanted emission. As a consequence, only a fraction of the signal's total power is fed to the detectors, leading to results smaller than the actual power (over the whole bandwidth). Contrary to this large RBWs are useful to assess the signal's power over its full bandwidth as shown in Figure A.10. The use of longer sweep times helps to stabilize the result, as fluctuations in the readings due to the modulation are suppressed.

A too narrow VBW also leads to a reduction in the level's readings. This is demonstrated in the two lines for Figure A.11.

Comparing Figure A.12 (EMI receiver) with Figure A.1 (spectrum analyser) - where the RBW's are almost the same - shows that in this case the results are quite similar.

Figure A.13 shows the difficulty with the QPk-Detector in spectrum analyser mode: it is not quite easy to find settings that do not distort the shape (discharging of the detector's capacitors needs time), and if the settings are roughly working, then long sweep times are needed.

7.3.2 Signal type 2 (slow pulse)

Table 5: Overview of measurement examples, signal type 2 (slow pulse)
Power of unmodulated carrier: -30 dBm

Figure No.	Mode	RBW kHz	VBW kHz	SWT ms	PK dBm	QP dBm	RMS-AV dBm	RMS dBm	AV dBm	Comment
A.14	SZ CR	3 000	10 000	62	-30					
A.15	SA CR	100	1 000	100	-30			-30	-30	Display is not stable; sees 0,2 ms/pixel, signal period is 40 ms; Averaging effect would start to appear at SWT 5 s = 500 display points x 10 ms on-time (detector is active during signal's off-time)
A.16	RTA	0,5	n.a.	22	-30					

Signal 2 is a continuous wave signal that is switched on and off for a specified amount of time (Ton 10 ms, Toff 30 ms). Since all detectors are calibrated to give the same reading for continuous wave signals, any detector that is active during the time the signal is in its "On"-State gives the same reading. In spectrum mode, the display fluctuates as the analyser is not synchronized in time to the signal's on and off time. During the time the signal is not active differences can be seen in the noise floor and the switching spikes which are caught by the peak detector, but averaged down to (worst case) the noise level. By luck, the analyser's sweep frequency was in the vicinity of the carrier's frequency - also there all detector's show the same. In this case, using trace-mode "Maxhold" will give the correct result for the signal's power, while the noise is overly emphasized. Both the spectrum's shape and power over the whole bandwidth can be seen in Figure A.16.

If - in spectrum mode - a long sweep time is used (starting at 5 s for this signal type), then the detector types RMS and Average would be fed during times with both the active and inactive signal's period, leading in a too small result.

7.3.3 Signal type 3 (slow pulsed AM)

**Table 6: Overview of measurement examples, signal type 3 (slow pulsed AM)
Power of unmodulated carrier: -30 dBm; Peak power of modulated carrier: -25 dBm**

Figure No.	Mode	RBW kHz	VBW kHz	SWT ms	PK dBm	QP dBm	RMS-AV dBm	RMS dBm	AV dBm	Comment
A.17	SZ CR	10	100	20	-25			-29	-30	Readings taken during the time between red vertical bars
A.18	SA CR	100	1 000	100						See text below
A.19	SA MH	"	"	"	-25			-25	-25	Need to wait for many sweeps; SA sees only 0,2 ms of the 40 ms signal period in each pixel; it does only see a small fraction of the full burst of 10 ms in each pixel; due to the small resolution time the Maxhold catches always the maxima of the AM modulation
A.20	SA MH	"	"	5 000	-25			-29	-30	Need to wait for many sweeps; SA sees only 10 ms of the 40 ms signal period in each pixel; does not always get the full burst in each pixel, but results are in the order of those in Figure A.17; this represents the values measured over the burst duration (equivalent to Figure A.17)
A.21	SA MH	"	"	50 000	-25			-35	-41	SA sees 100 ms (two 40 ms periods) in each pixel; RMS and Average values show the results if measured over the on- and off periods, which should not change more if measurement time would be increased
A.22	RTA	3	n.a.	10	-25			-29		(peak level in 100 kHz bandwidth)
	EMI	120	n.a.	100	-25	-26,2	-38	Up to -35	Up to -42	RMS and AV not stable

Signal type 3 is equal to signal type 2 with an additional AM modulation. In Figure A.17, the signal was measured during the transmitter's active state. The measurement time is marked by the two vertical red bars. The peak power is larger than for signal 2 due to the additional modulation. The entry "RMS" in the figure relates to summarize the pixels in-between the red bars and calculate the level corresponding to RMS-equation in clause 5.4. The entry "Mean" indicates the average value based on the values in-between the red bars.
In contrast to this, Figure A.18 (taken in spectrum mode) does not guarantee to give stable results as in Figure A.17 due to the modulation content. This leads to different readings from the different detectors.
In Figures A.19 to A.21, several sweeps had to be made using trace-mode "Maxhold" until the shown recordings had been captured - the spectrum had to fill up since the signal is not guaranteed to be caught in the active state. Small sweep times lead to RMS and AV readings up to the level of the PK detector (Figure A.19); Longer sweep times (Figures A.20 and A.21) lead to a level reduction for time-dependent, averaging detectors like RMS and AV, since longer measurement times also leads to more "no signal"-times and thus lower level readings. The trace mode "Maxhold" takes care to remove even smaller values, but it does not guarantee to catch the correct value - which is only measurable when the instrument is triggered and set to a measurement time according to the time the transmitter is actually active.

It was not possible to get stable readings for RMS and AV in the EMI receiver mode.

7.3.4 Signal type 4 (fast pulsed)

Table 7: Overview of measurement examples, signal type 4 (fast pulse)

Figure No.	Mode	RBW kHz	VBW kHz	SWT ms	PK dBm	QP dBm	RMS-AV dBm	RMS dBm	AV dBm	Comment
A.23	SZ CR	3 000	10 000	0,1	-31			-31	-31	PK, RMS, AV equal during the burst (between the red vertical bars)
A.24	SA CR	100	1 000	100	-31			-38	-43	Averaging effect over several Ton/Toff periods (it sees 200 µs/pixel, signal period is 40 µs)

Signal 4 is a continuous wave signal that is switched on and off for a specified amount of time (Ton 10 µs, Toff 30 µs). Since all detectors are calibrated to give the same reading for continuous wave signals, any detector that is active during the time the signal is in its "On"-State gives the same reading.

Figure A.24 shows a measurement with spectrum mode and long sweep time (compared to the signal period); the detector types RMS and Average are fed during times with both the active and inactive signal's period, leading in a too small result.

8 Summary

The present document aims to give recommendations and background information for radio standards regarding measurement parameters. The explanations throughout the present document serve as a comprehensive, but not exhaustive overview focused on the selection of the measurement detector. It should serve the rapporteurs in the selection of measurement parameters in standards and give certainty to the test engineer regarding the validity of the measurement settings when applying that standard.

As seen in clause 4, regulatory requirements can often be quite general for an unambiguous choice of measurement procedures and parameters. In contrast to that, a technical standard document is expected to be as unambiguous as necessary to fulfil its standardizing role. As a consequence, even in absence of clear measurement parameters by the regulator, a standard has to state these parameters.

Clause 5 shows that measurement instruments require a careful selection of measurement parameters, which partially depend on each other. The selection of a detector is only one of these aspects, and was explained more thoroughly in clause 6. Apart from that, the differences between EMI receivers and spectrum analysers were highlighted regarding their architecture and their selection range of detectors.

Clause 7 demonstrates the influence of the various parameters and detector choices for several examples, highlighting the consequences of the different settings.

Summarizing the present document, radio standards that feature radio frequency measurements should define measurement parameters. Those measurement parameters should include at least:

- The resolution bandwidth (RBW)
- The measurement detector
- The measurement time

Further guidance on the choice of measurement parameters can be found in publications like [i.19], [i.20], [i.21].

A non-exhaustive list of findings relevant to the drafting of radio standards is given below.

- **Measurement Detectors:**
  - Peak:
    - Common choice for fast overview measurements.
    - Sensitive to corruption by events occurring only once or for a very small amount of time or by different devices than the DUT.
  - RMS:
    - True power measurements.
    - Can be used to measure wanted and unwanted emissions in radio standards.
  - Average:
    - Can be used to suppress the modulation components in order to measure the carrier level of a signal or to suppress impulsive noise for the measurement of CW components in signals.
  - QP:
    - Leads to long measurement times due to a fix measurement time per frequency (at least 1 s).
    - Not a suitable detector to assess spectrum of an emission (of a radio transmitter), especially due to the fixed bandwidths according to the frequency range of interest. A separation between the wanted and out-of-band emissions is generally hard to achieve.
    - Suitable to measure only at single frequencies.
    - Usually not built-in into spectrum analysers.
    - One of the reasons for the continuing popularity of the CISPR Quasi Peak detector could be that in quite some cases this detector gives a more stable reading. But this weighting detector was built to assess the interference effect into AM-receivers (and thus the hearing impression of a human) and to do so the reading of the QP detector is dependent on the repetition time of the signal weighted over at least one second (see Figure 4); and this weighting has nothing to do with parameters required to classify communication systems (e.g. RMS power).
  - CISPR-Detectors:
    - Reduced sensitivity: CISPR always demands at least 10 dB attenuation at the instrument's input, limiting the dynamic range.
    - CISPR-Bands - and thus the detector's calibration - end at 18 GHz.
- **Sweep time/Measurement time:**
  - Sweep time/measurement time are only adjustable with spectrum analysers; EMI receivers detectors do have a fixed measurement time.
  - First of all the sweep time should be sufficient long to respect the settling time of the RBW- and VBW-filters; a spectrum analyser usually considers this automatically.

- Knowledge of the signal to be measured should be available before the measurement, e.g. continuous/non-continuous signal, signal repetition time, transmitter on/off times, modulation.
- For continuous signals the sweep time (measurement time) should be increased until a stable reading is achieved (which means that a further increase of sweep time will not further change the result significantly); see for example the measurements of a 16QAM-signal in Figures A.1 to A.4 in Annex A.
- Care has to be taken if non-continuous signals are to be measured, because averaging/measuring over the off-periods of the signal can significantly reduce the reading. For non-continuous signals the correct use of the measurement time depends on the aim of the regulatory limit:
  - If the power is to be measured only over the Transmitter on-period (or only over the off-periods), then the use of triggering techniques is recommended; a measurement example is shown in Annex A, Figure A.17; alternatively the correct power level during the on-period could also be achieved in the sweep-mode by setting the measurement time of every frequency point to the on-time of the signal (eventually using the Maxhold trace mode in addition); a measurement example is shown in Annex A, Figure A.20.
  - If the power is to be measured over transmitter on- and off -periods, then the sweep time (measurement time) should be increased until a stable reading is achieved (which means that a further increase of sweep time will not further change the result significantly); a measurement example is shown in Annex A, Figure A.19 to A.21 and A.24.

- **RBW:**
  - The choice of the RBW depends on the regulatory requirements. Either the RBW can be set to the reference bandwidth of the regulatory limit or the RBW is set to a smaller value and measurement functions (e.g. post processing to obtain the channel power) are used to calculate the power in the reference bandwidth of the regulatory limit. Spectrum analysers are usually offering such measurement functions (e.g. channel power); a measurement example of such a post processing function is shown in Annex A, Figure A.17.
  - If the RBW is wide enough for the signal to fit in (e.g. RBW ≥ OBW), then the signal level can be determined directly without post processing; a measurement example is shown in Annex A, Figure A.10.
  - If the RBW is small (compared to the OBW), then the signal's spectral shape can be seen; wanted and unwanted emissions can be separated. Furthermore, the level is not the absolute level of the emission; it rather reflects the power spectral density; a measurement example is shown in in Annex A, Figure A.4.

- **VBW:**
  - If VBW << RBW (e.g. VBW 1kHz, RBW 100 kHz) then level readings can be significantly reduced, leading to wrong results; a measurement example is shown in Annex A, Figures A.7 and A.8.
  - If an RMS detector is used, then the VBW has to be at least 3 times of the RBW (which is done automatically by many modern spectrum analysers when selecting the RMS detector).
  - For other detectors the VBW should be at least equal to the RBW.

- **Trace functions**
  - Trace function should not be confused with the measurement detector; trace functions can be seen as kind of a "history"-function related to previous traces.
  - The Maxhold trace function can be used to store the maximum display value over a longer time period.
  - In the clearwrite trace function only the current values are shown.
  - With trace averaging a displayed trace can be stabilized by averaging over several sweeps; but this is not valid for the RMS-detector since the result is not anymore a RMS; for the Average-detector trace averaging (linear trace averaging) can be used to stabilize readings (only if the VBW ≥ 3 × RBW).

- **Measurement instrument:**
  - Spectrum analyser:
    - Higher flexibility in the choice of measurement parameters compared to an EMI receivers (which is bound to [i.1]).
    - More influence on the measurement process, tailoring the analysers setup to the signal that is to be measured.
    - Better suited for measurements of power due to their hardware structure and especially due to the presence of the RMS-detector.
    - Offers advanced measurement functions like occupied bandwidth; channel power, etc.
    - Preferred choice for many types of measurements regarding emissions of a radio transmitting station, including unwanted emissions.
  - EMI receiver:
    - Used for definition and measurement of radiation limits, e.g. for electrical devices.
    - NOT designed to assess characteristics of an emission by a radio transmitting station.
    - Does not contain an RMS-detector (can only simulate it).
    - Designed to measure voltages.

9 Recommendations

ETSI should consider adding in future SRdocs the relevant information on measurement detectors, resolution bandwidth and measurement time to make the emission limit proposals unambiguous.

Annex A: Measurements

A.1 Signal 1, 16 QAM

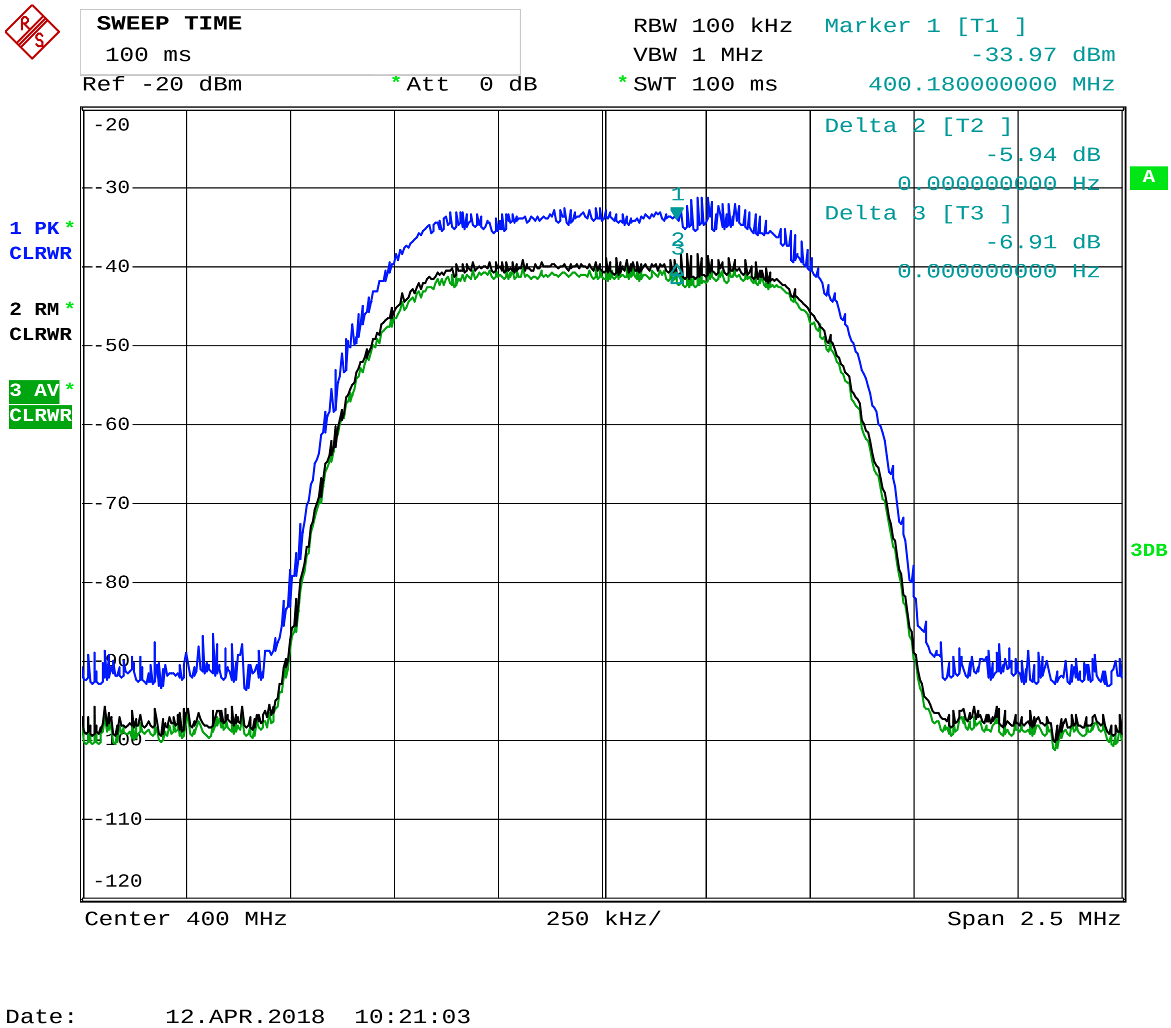

Figure A.1: 16QAM1, SWT 100 ms

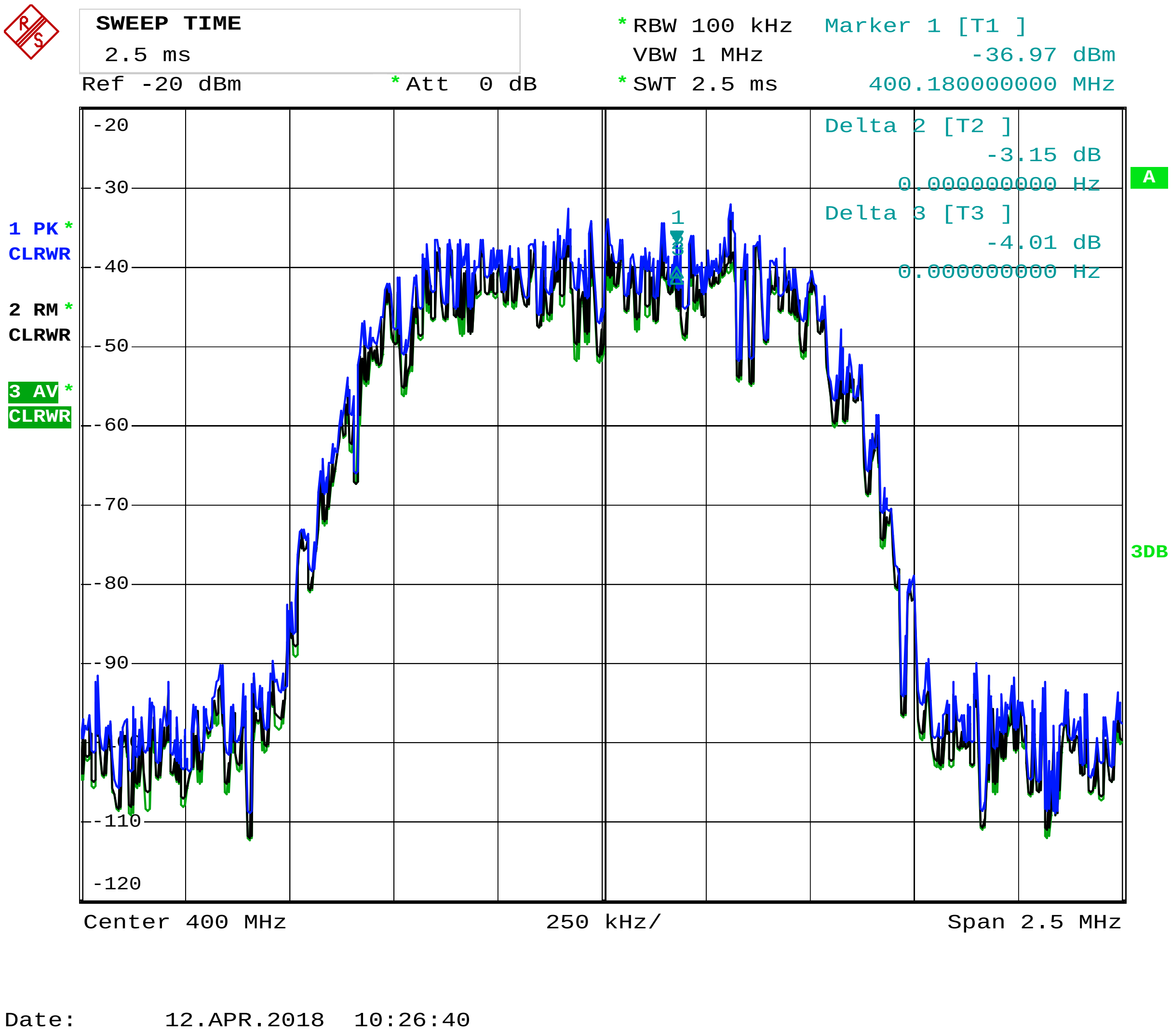

Figure A.2: 16QAM2, SWT 2,5 ms

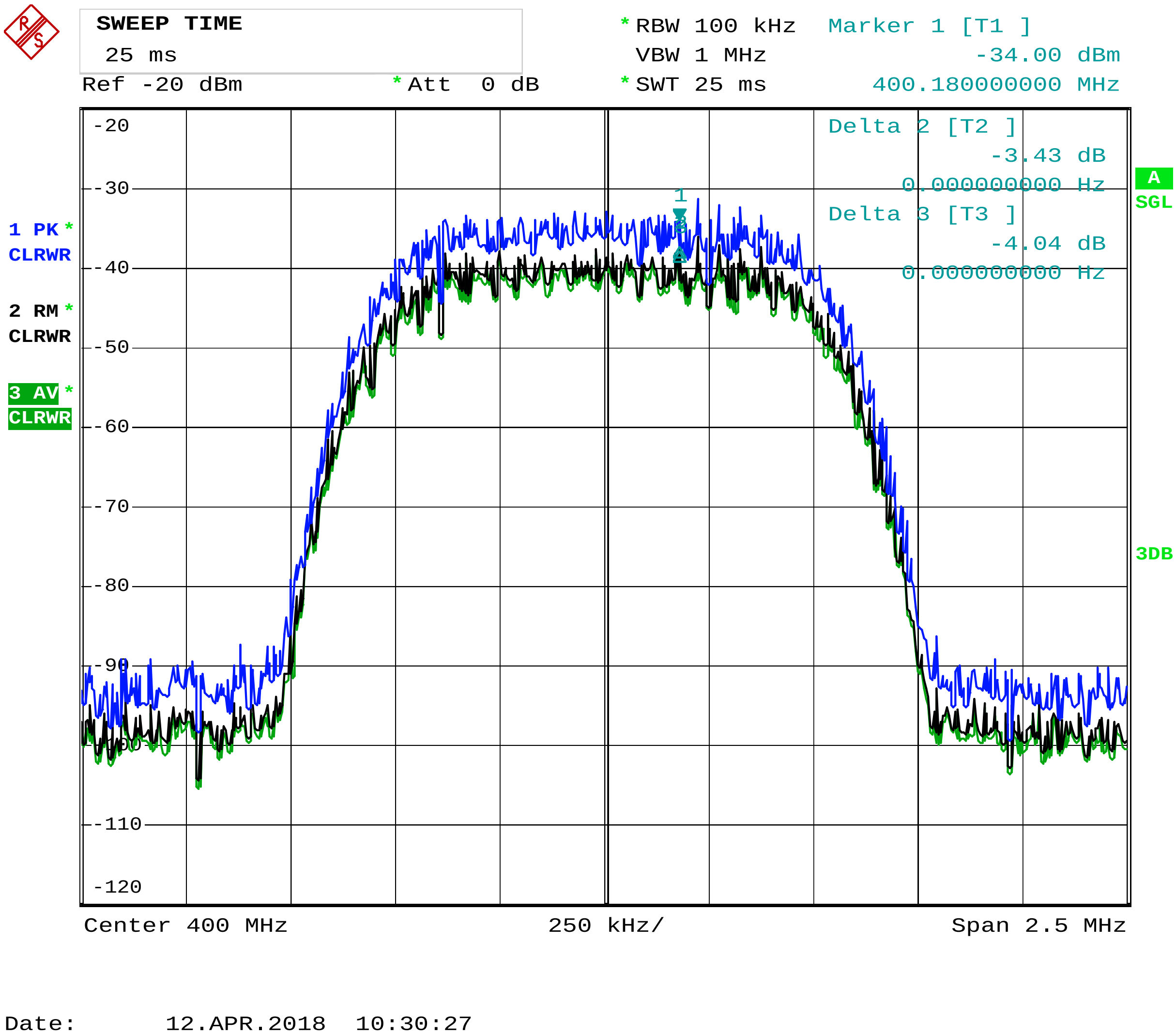

Figure A.3: 16QAM3, SWT 25 ms

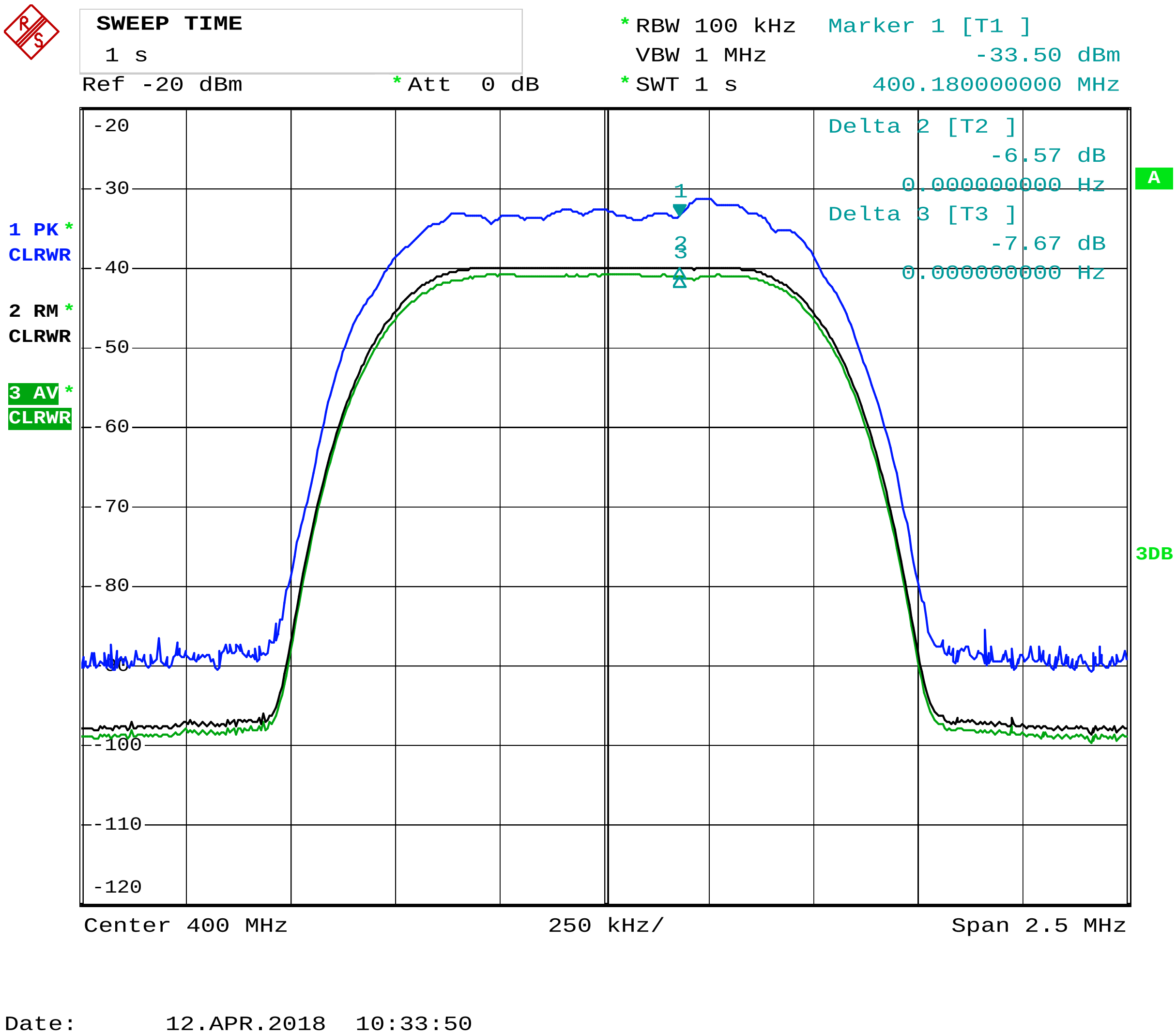

Figure A.4: 16QAM4, SWT 1 s

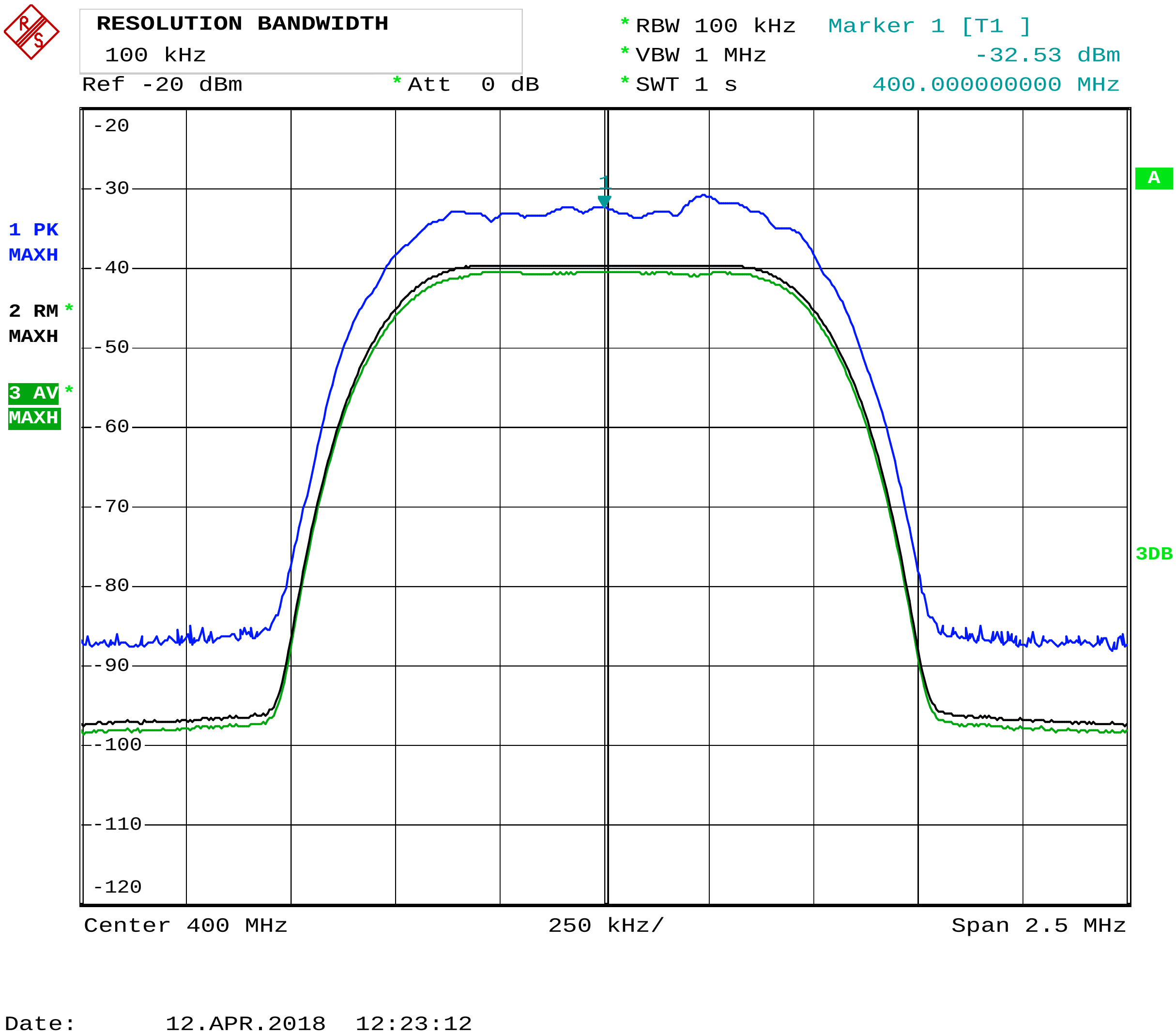

Figure A.5: 16QAM4, Maxhold

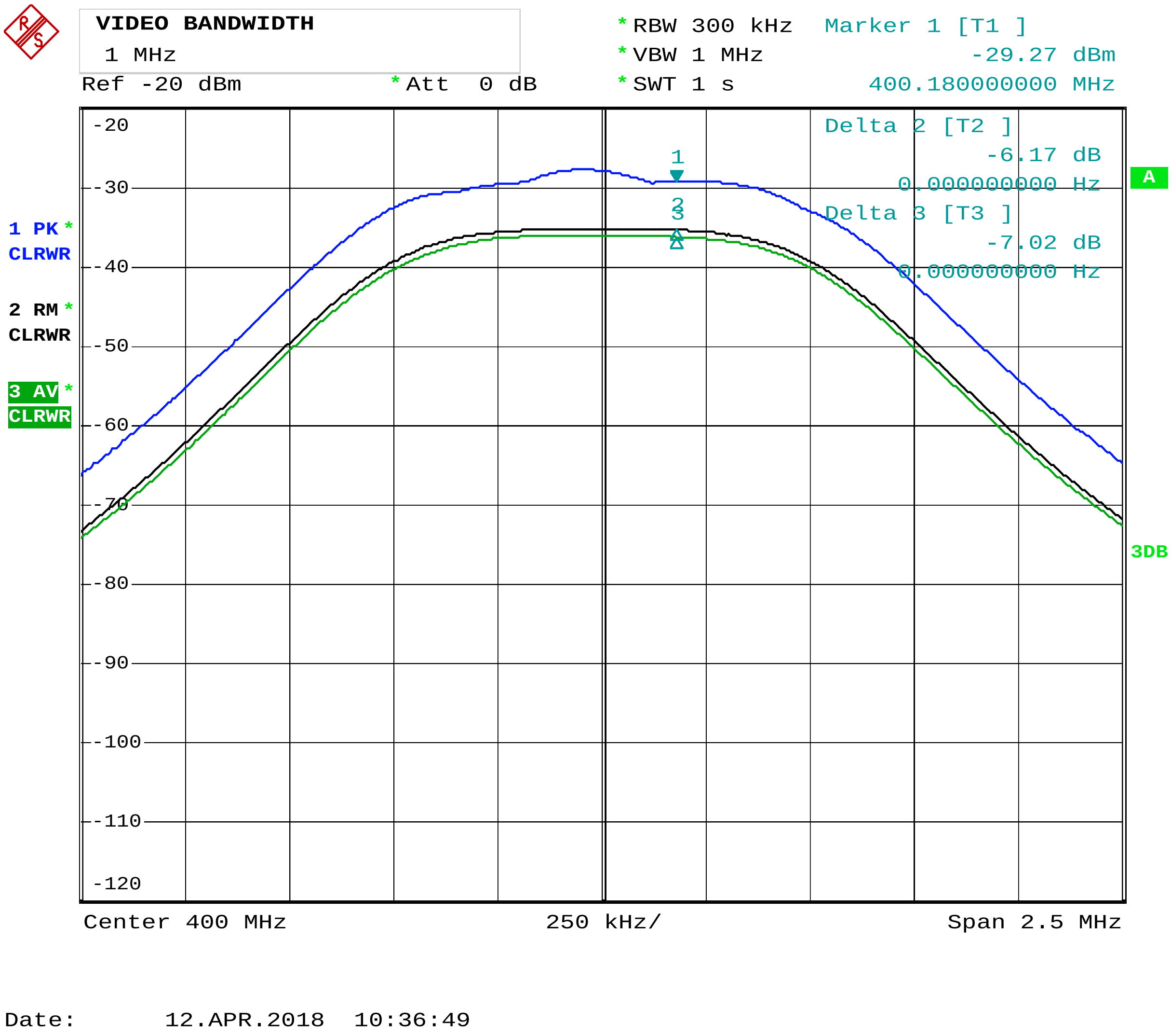

Figure A.6: 16QAM5, RBW 300 kHz

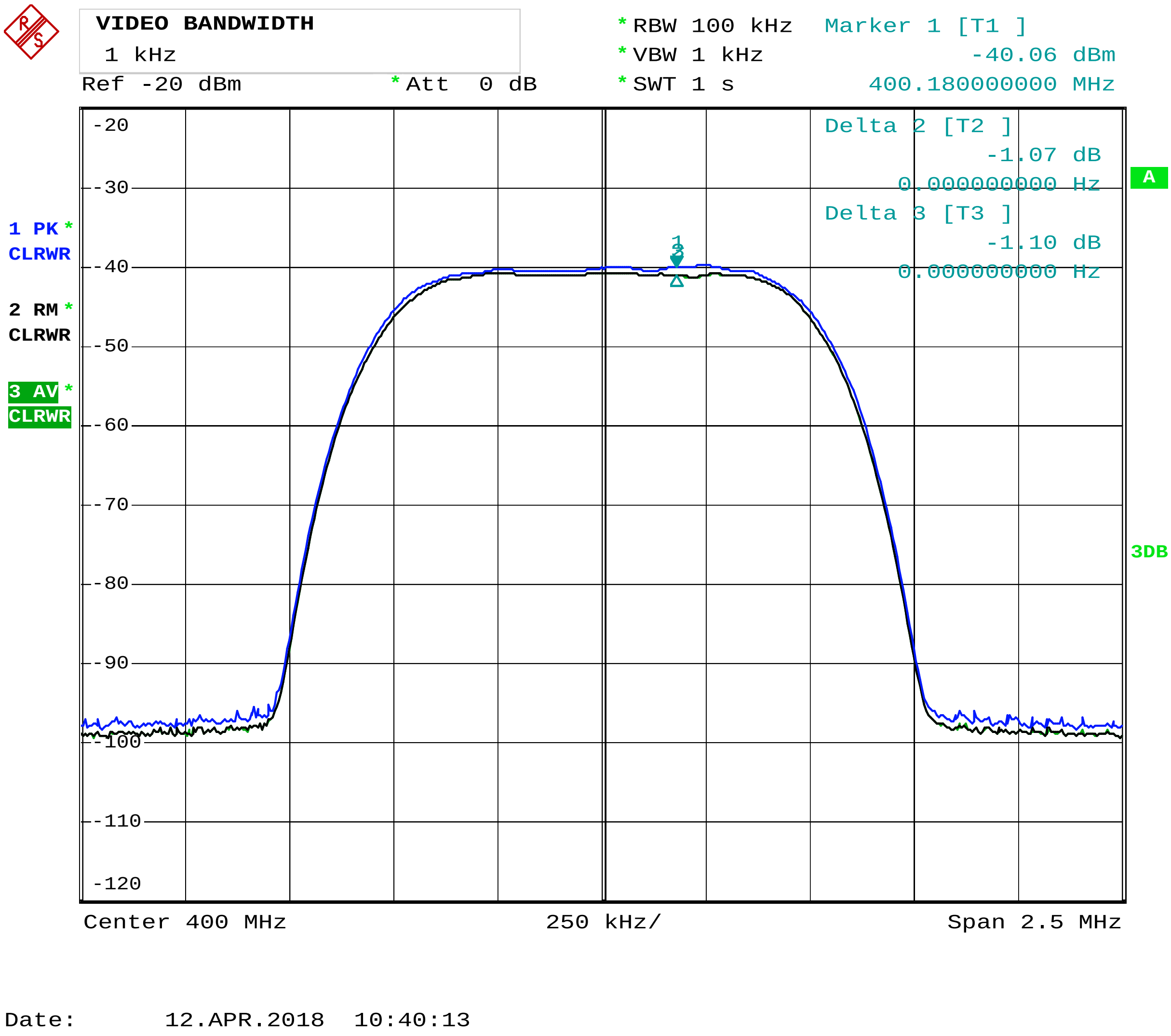

Figure A.7: 16QAM6, RBW 100 kHz, VBW 1 kHz

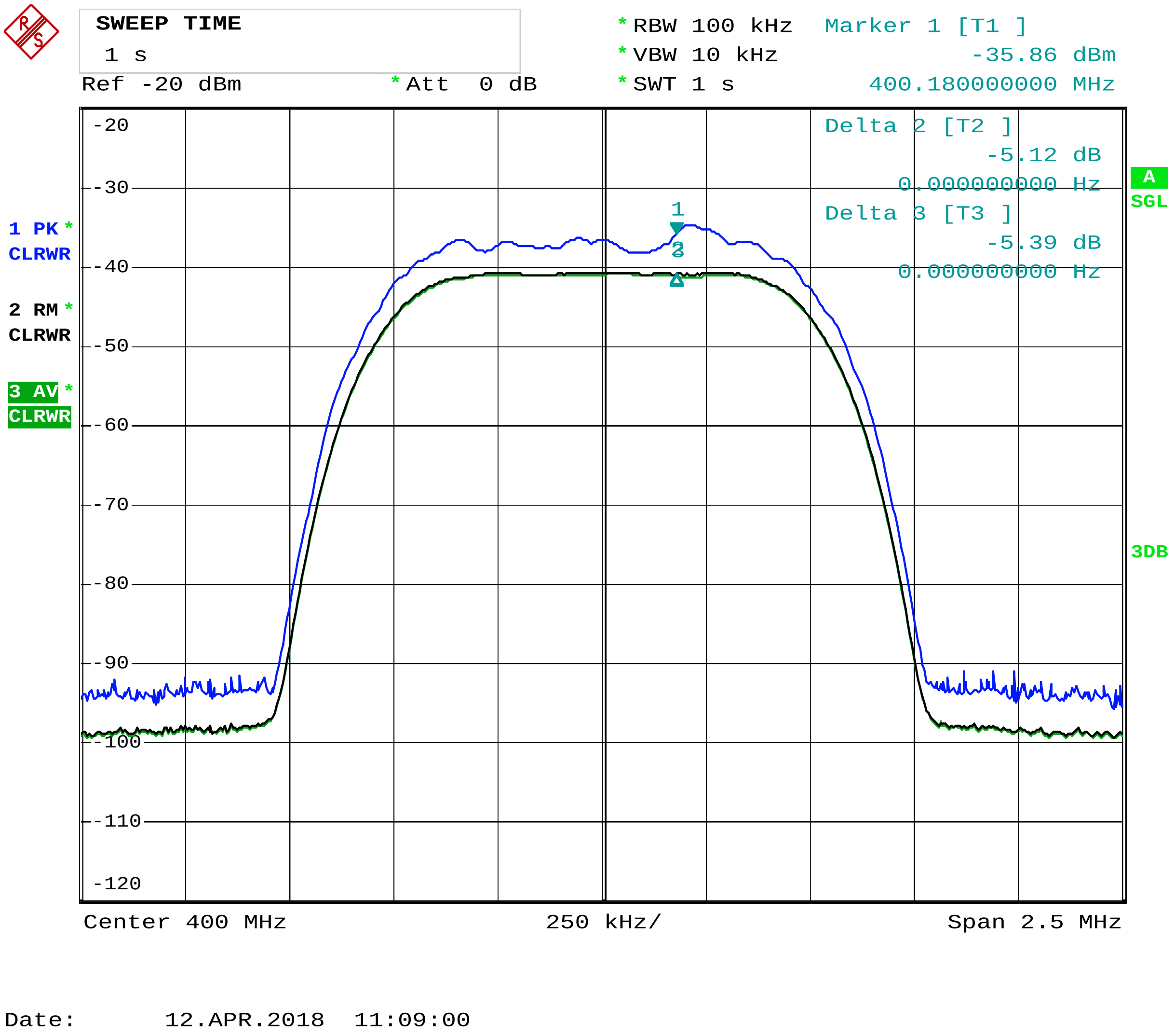

Figure A.8: 16QAM7, VBW 10 kHz

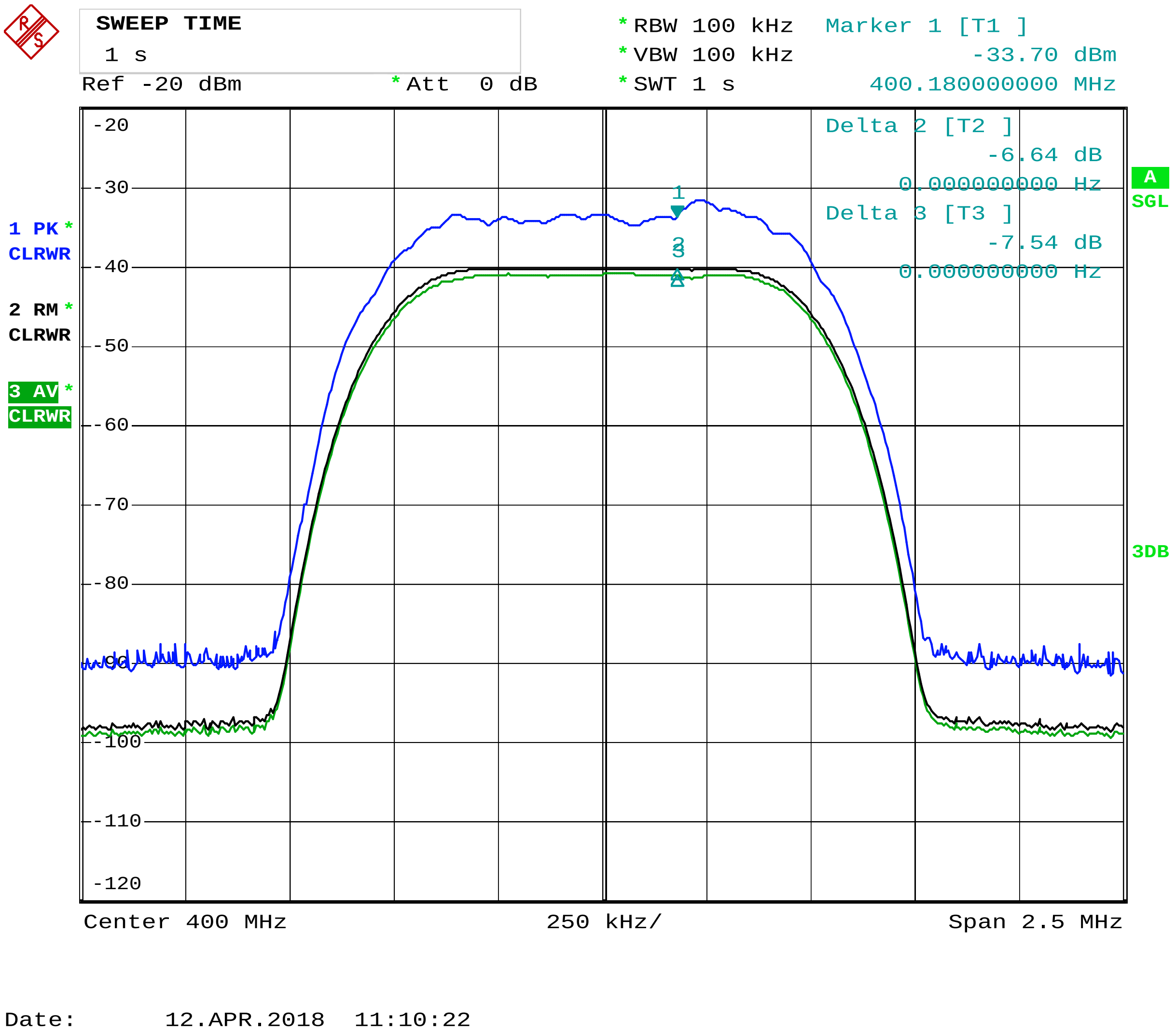

Figure A.9: 16QAM8, VBW 100 kHz

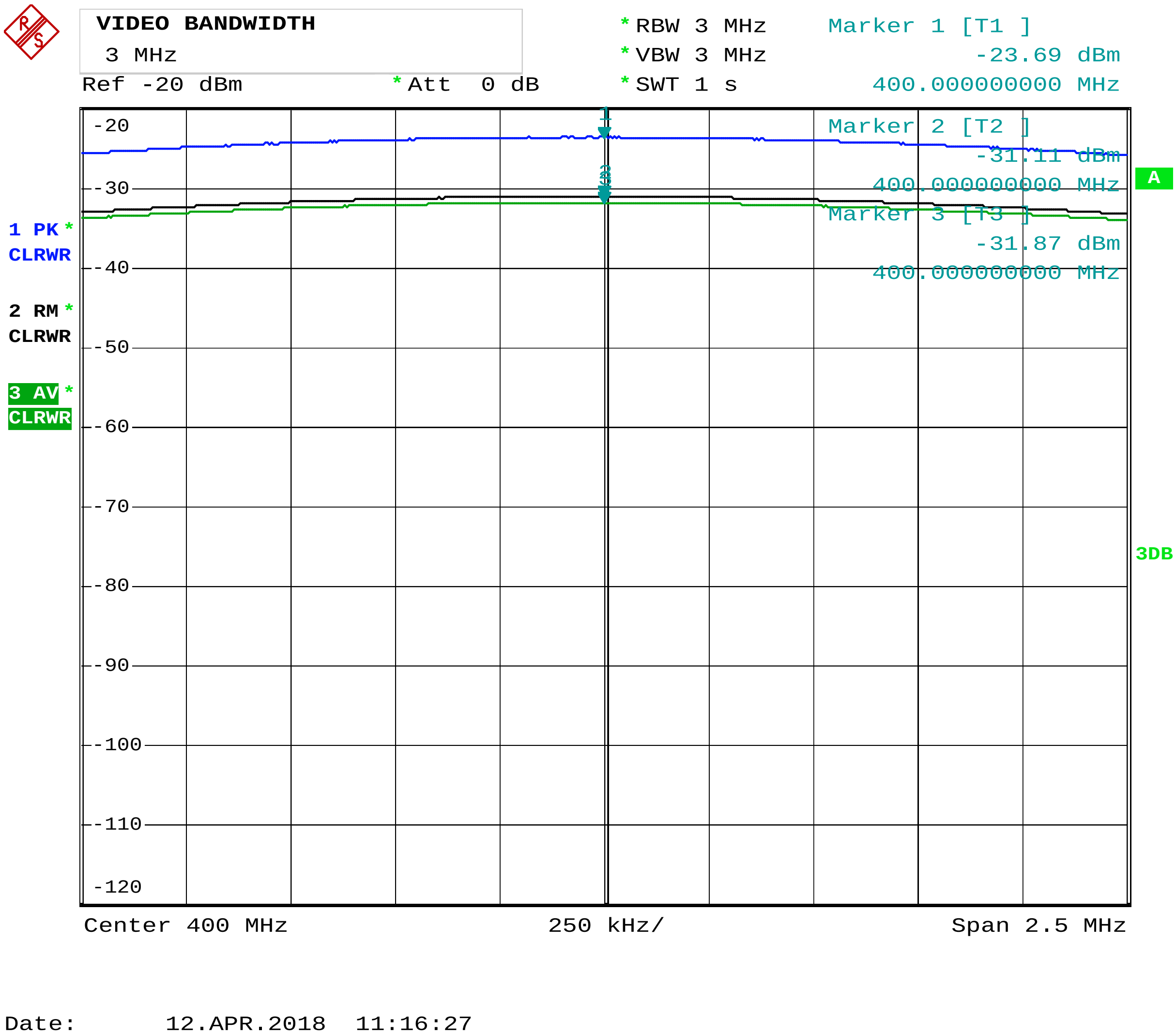

Figure A.10: 16QAM9, RBW 3 MHz, VBW 3 MHz

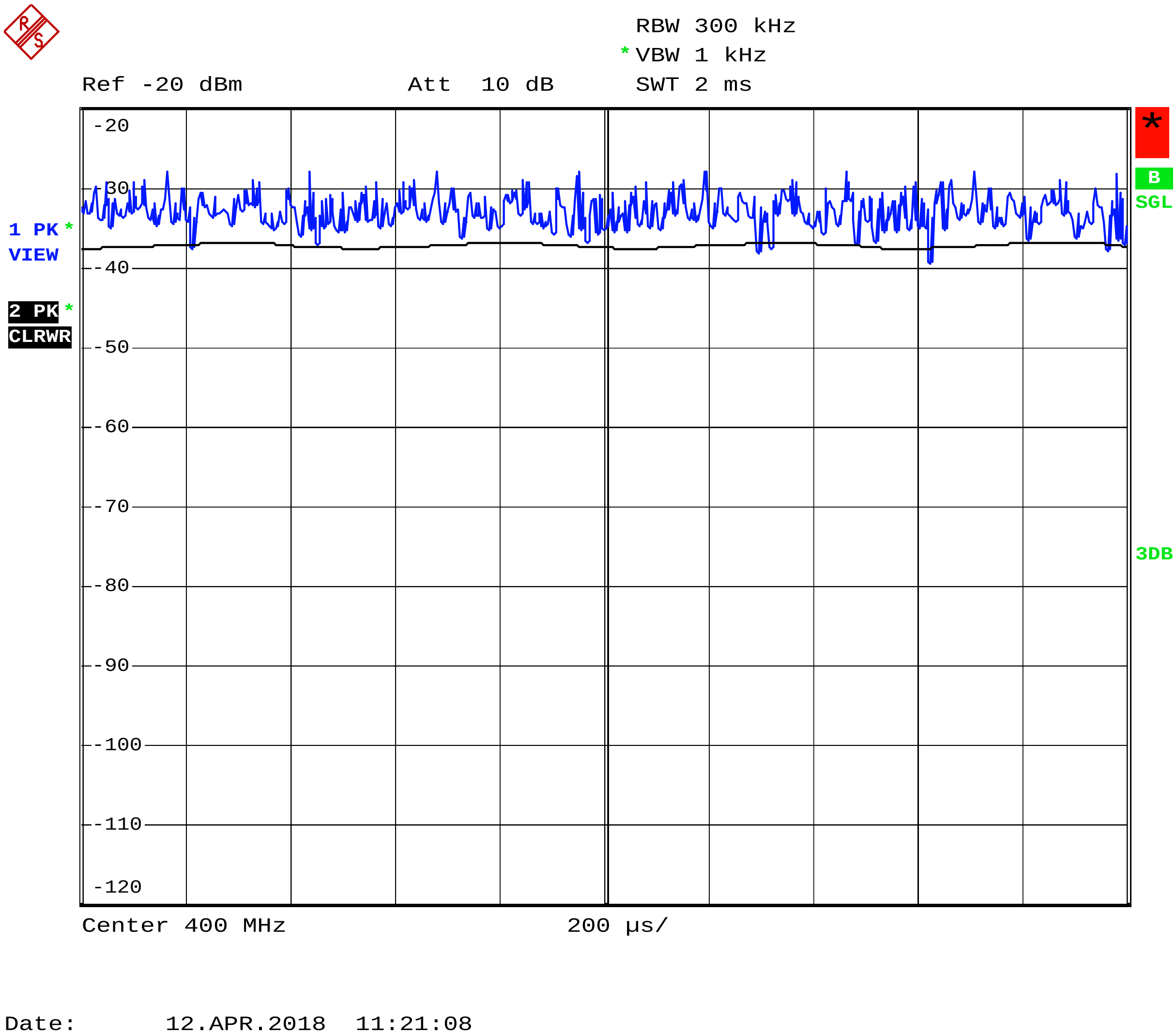

Figure A.11: 16QAM10 zero, RBW 300 kHz, VBW 1 kHz (black) and 1 MHz (blue)

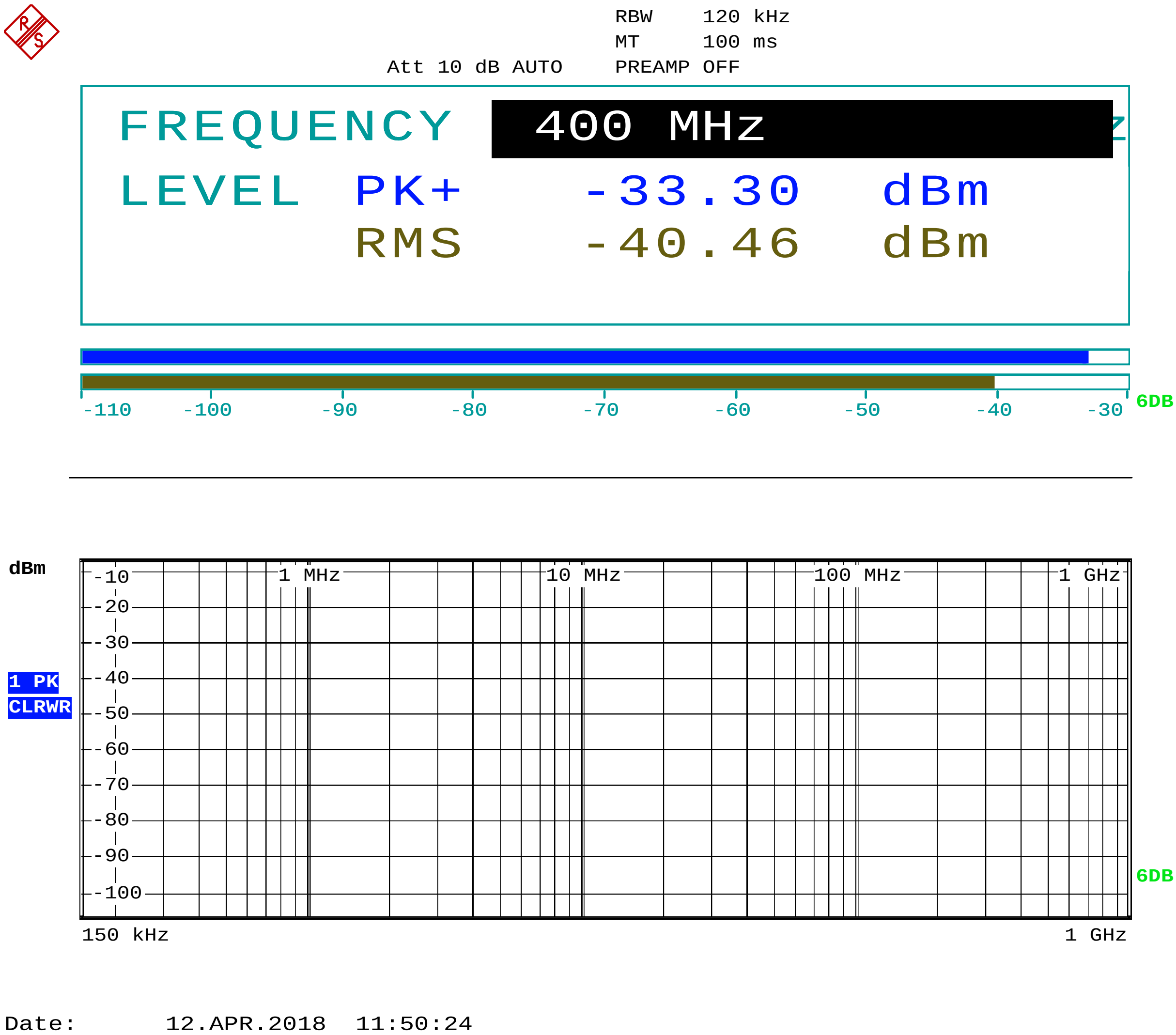

Figure A.12: 16QAM11, EMI receiver mode, RBW 120 kHz (6 dB), measurement time 100 ms

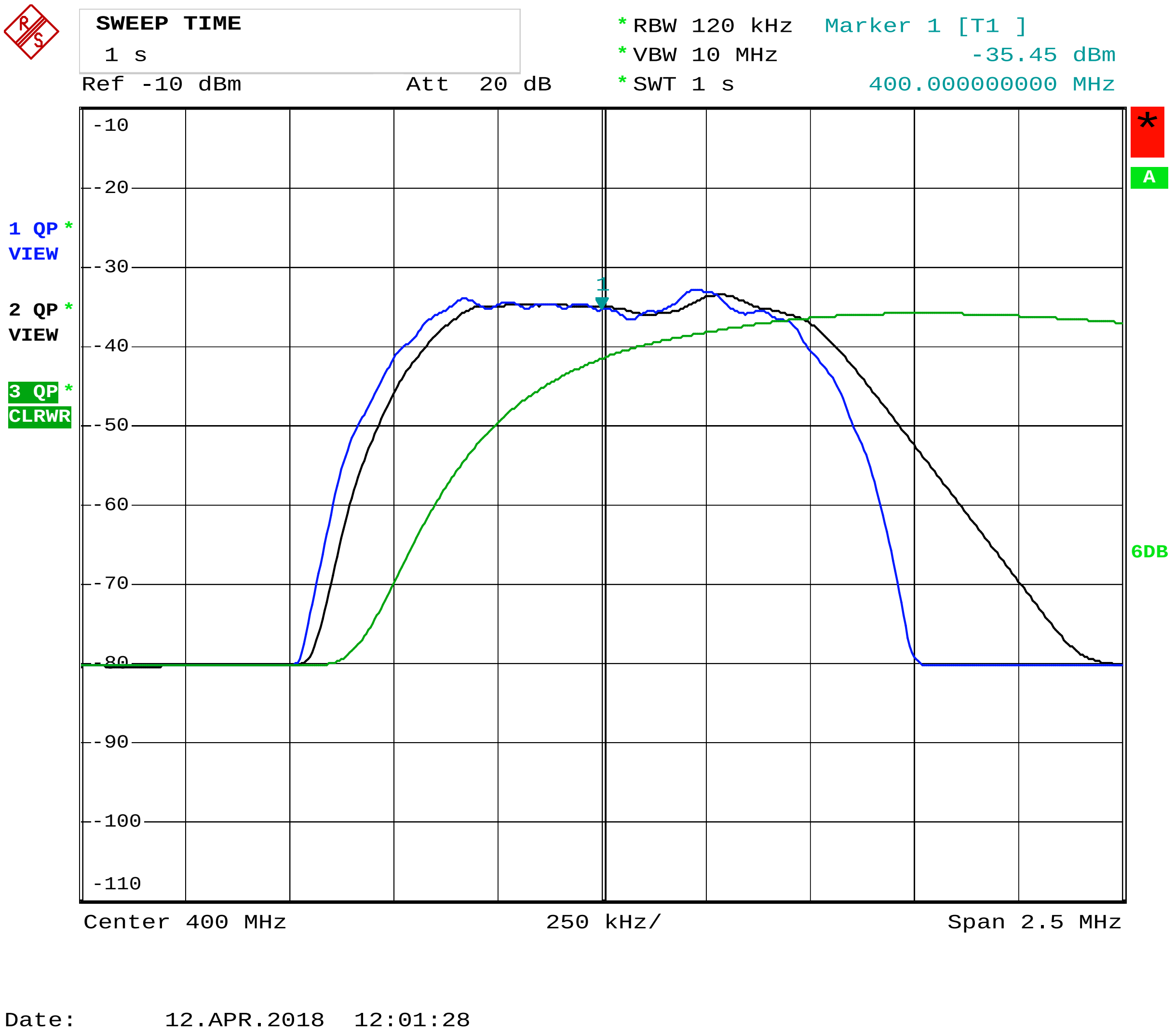

Figure A.13: 16QAM13, QP, RBW 120 kHz, VBW 10 MHz, SWT 50 s (blue), SWT 10 s (black), SWT 1 s (green)

A.2 Signal 2, slow pulsed

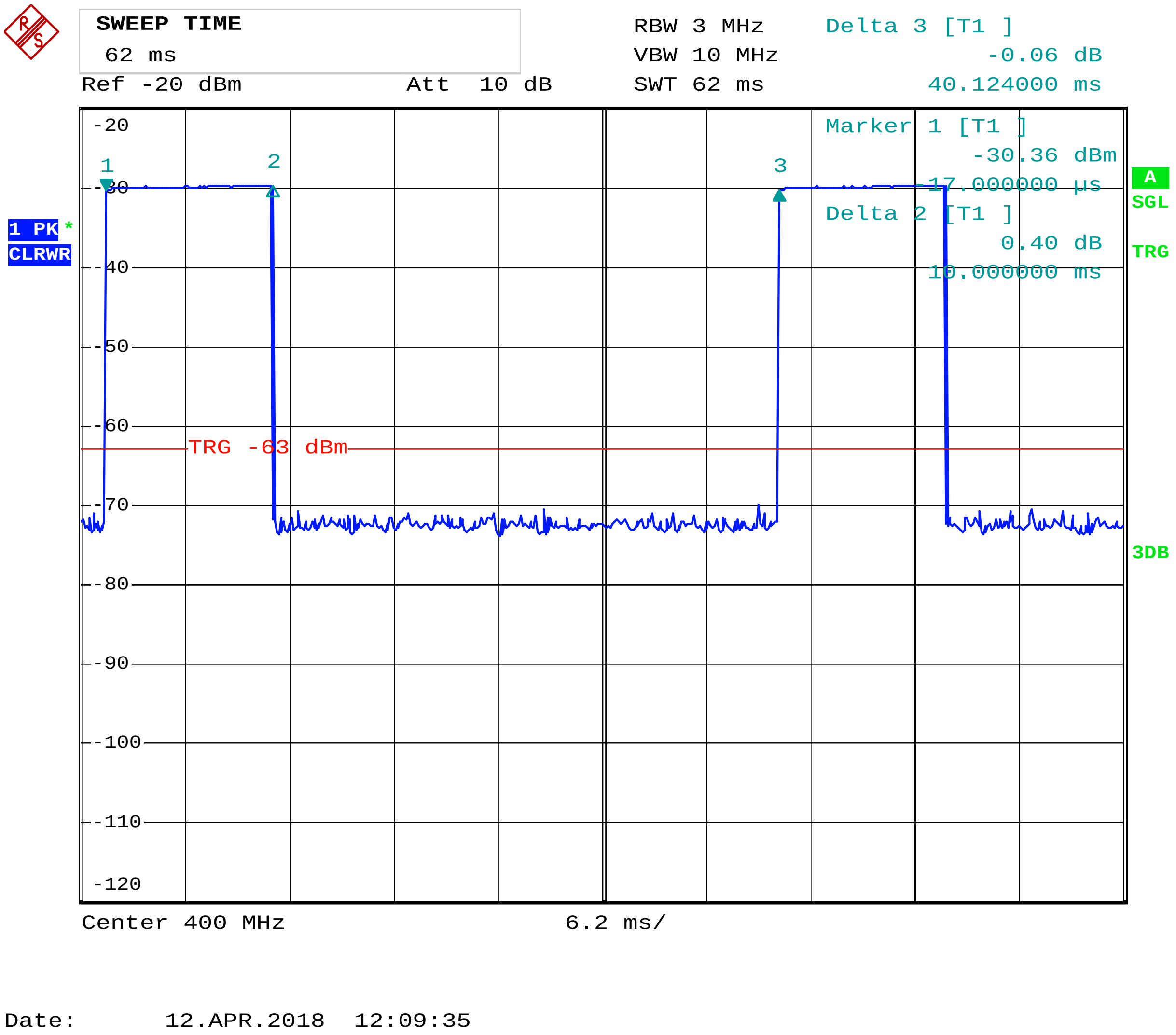

Figure A.14: slow_zero, signal slow pulsed (Ton 10 ms, Toff 30 ms), zero span

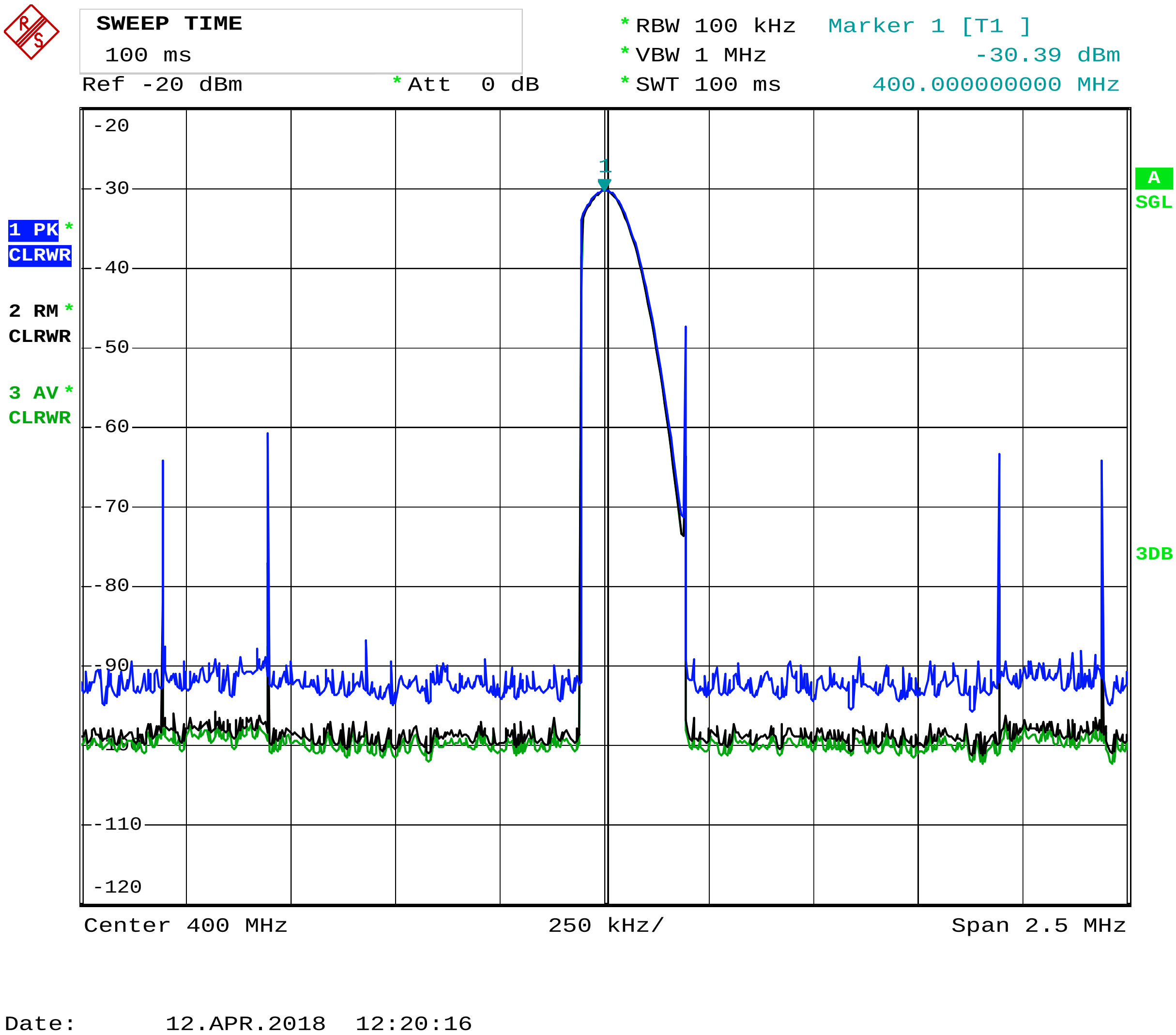

Figure A.15: slow 1, signal slow pulsed (Ton 10 ms, Toff 30 ms), clear write

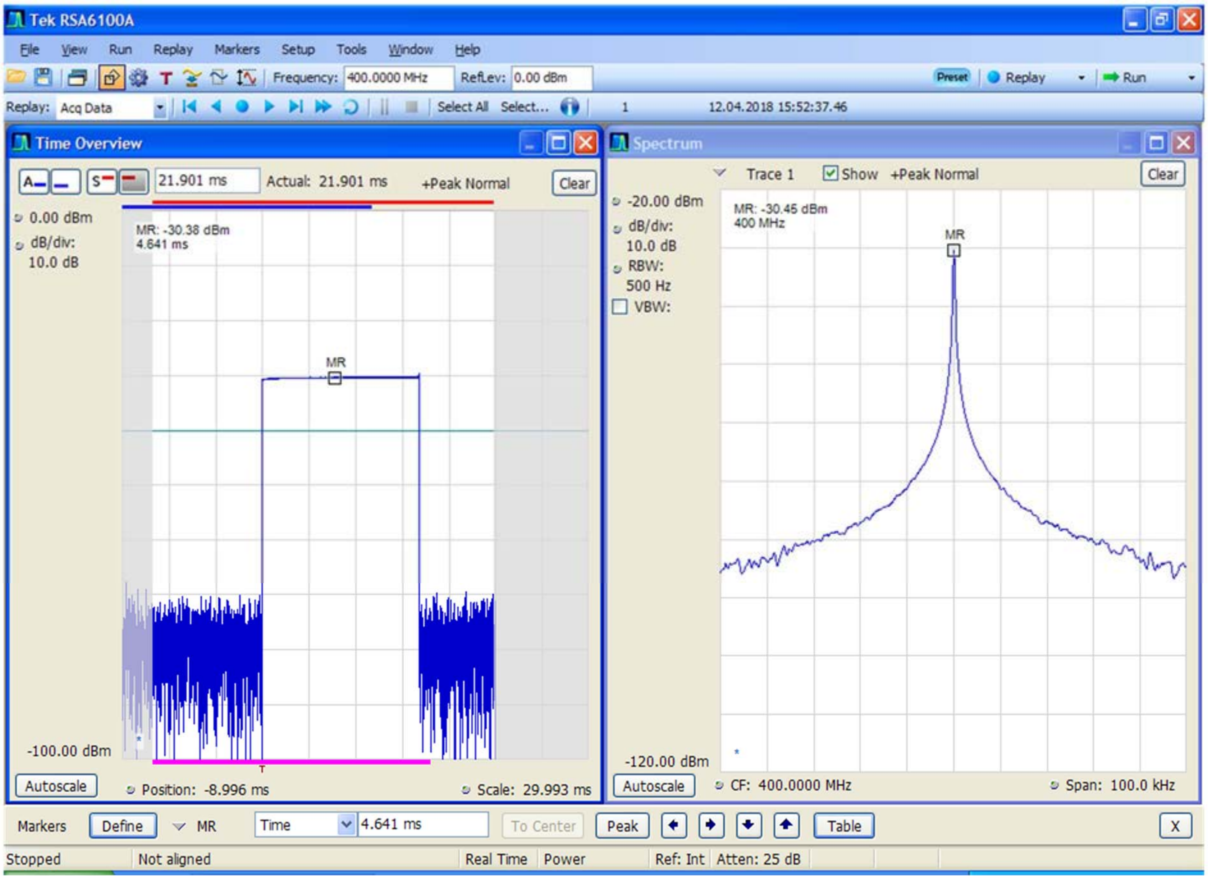

Figure A.16: Signal slow pulsed (Ton 10 ms, Toff 30 ms), RTA

A.3 Signal 3, slow pulsed AM

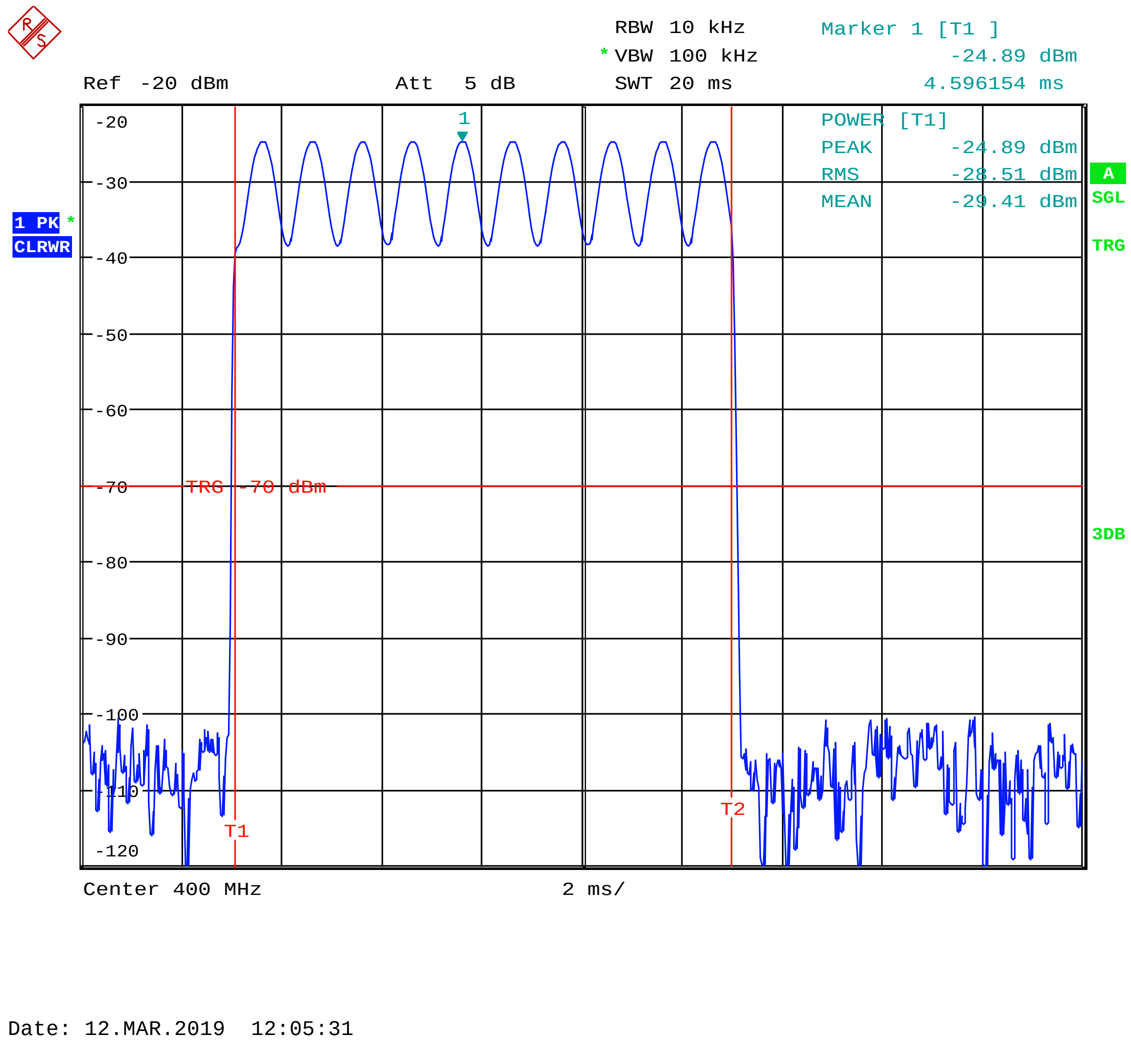

Figure A.17: slowAM_zero , signal pulsed AM (Ton 10 ms, Toff 30 ms, 80 % AM), zero span

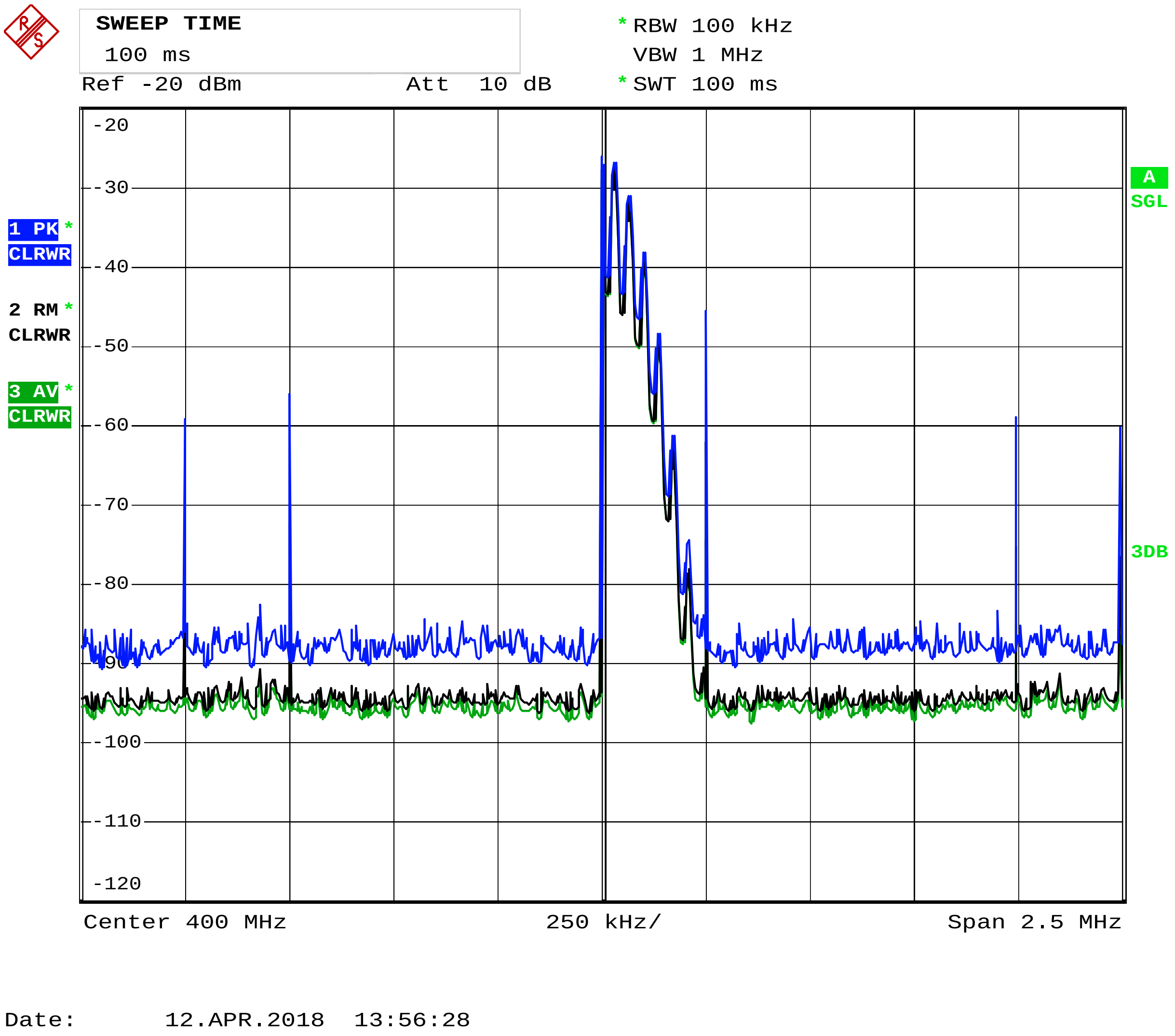

Figure A.18: slowAM1, signal slow pulsed AM (Ton 10 ms, Toff 30 ms, 80 % AM)

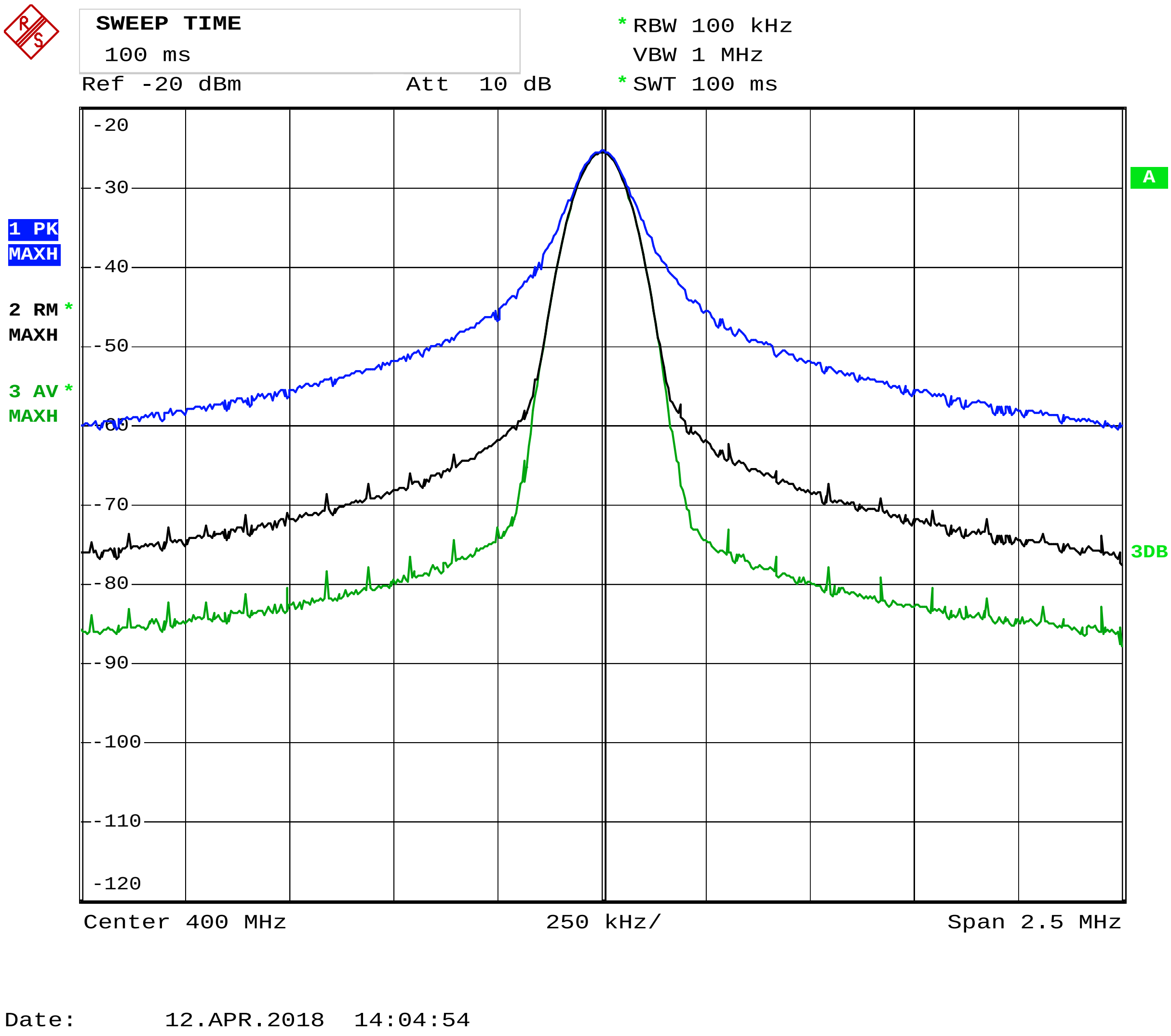

Figure A.19: slowAM2, signal slow pulsed AM (Ton 10 ms, Toff 30 ms, 80 % AM)

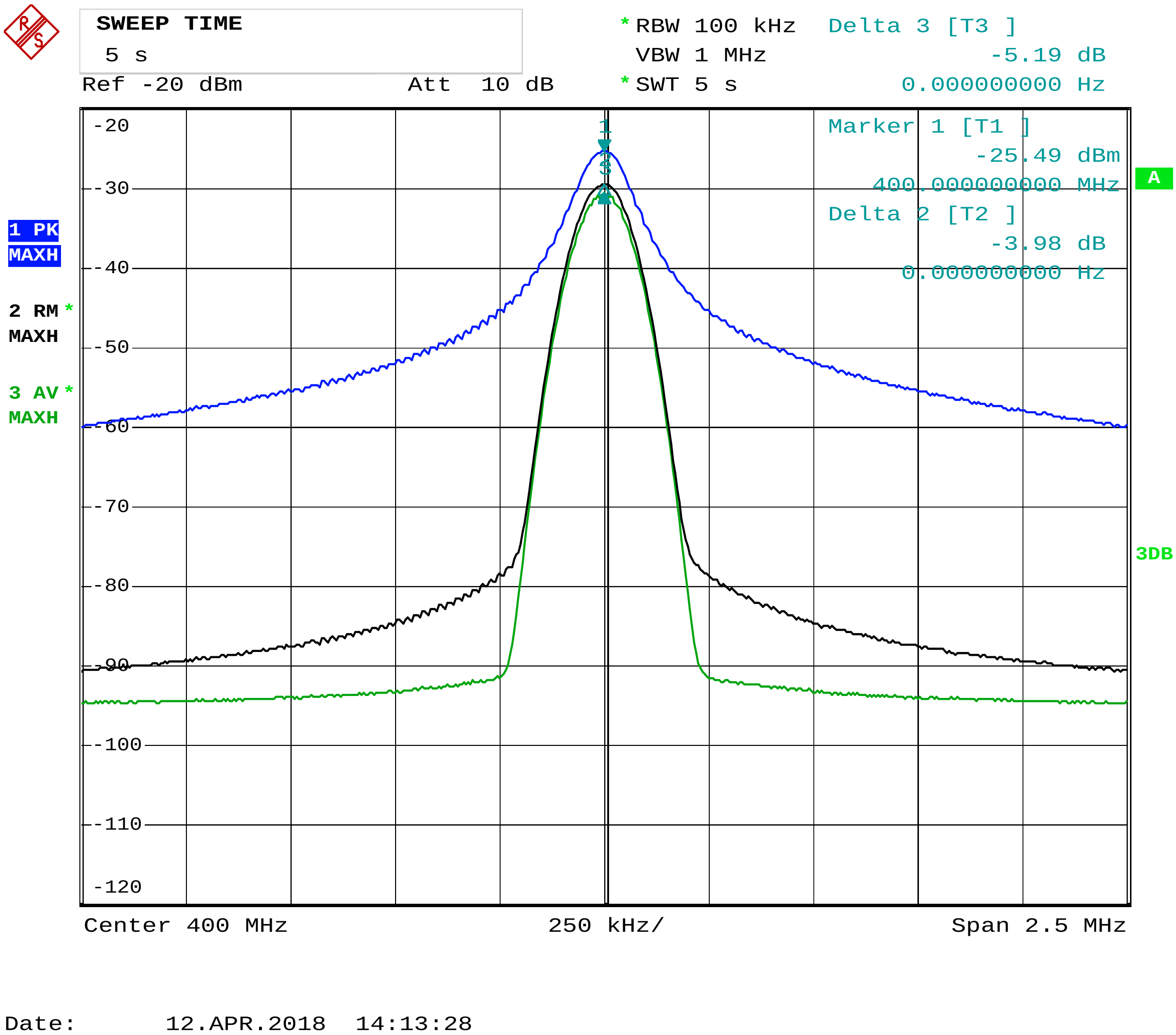

Figure A.20: slowAM3, signal slow pulsed AM (Ton 10 ms, Toff 30 ms, 80 % AM)

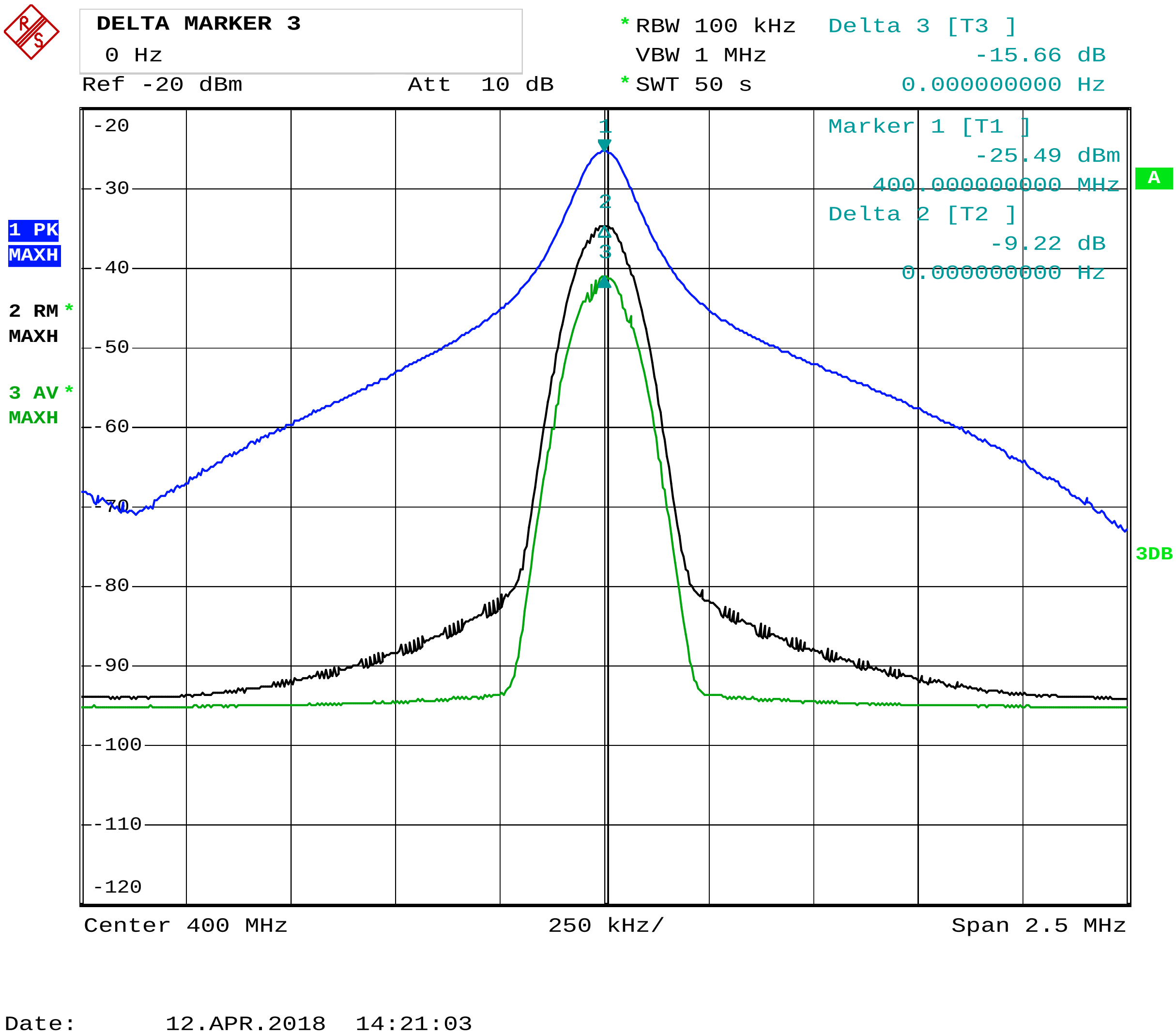

Figure A.21: slowAM4, signal slow pulsed AM (Ton 10 ms, Toff 30 ms, 80 % AM)

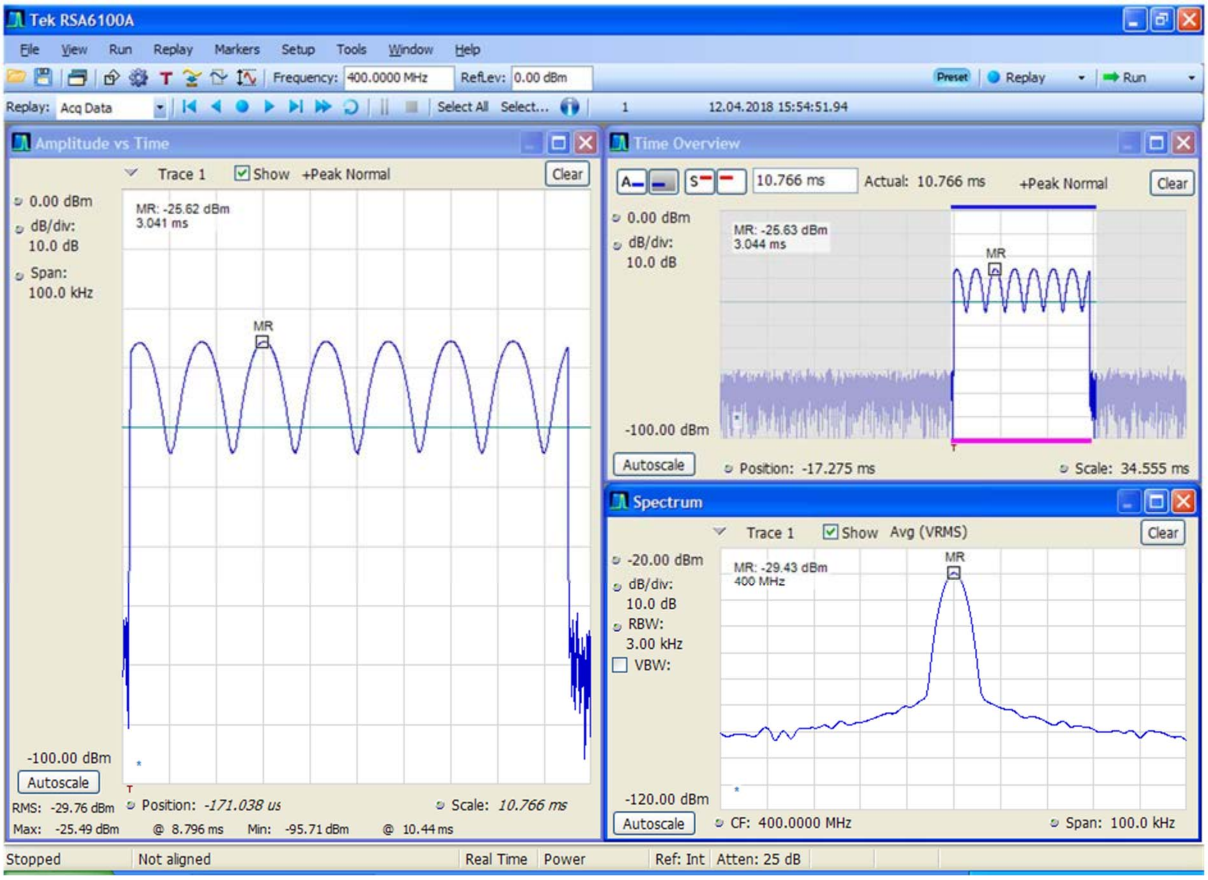

Figure A.22: slowAM, signal slow pulsed AM (Ton 10 ms, Toff 30 ms, 80 % AM), RTA

A.4 Signal 4, fast pulsed

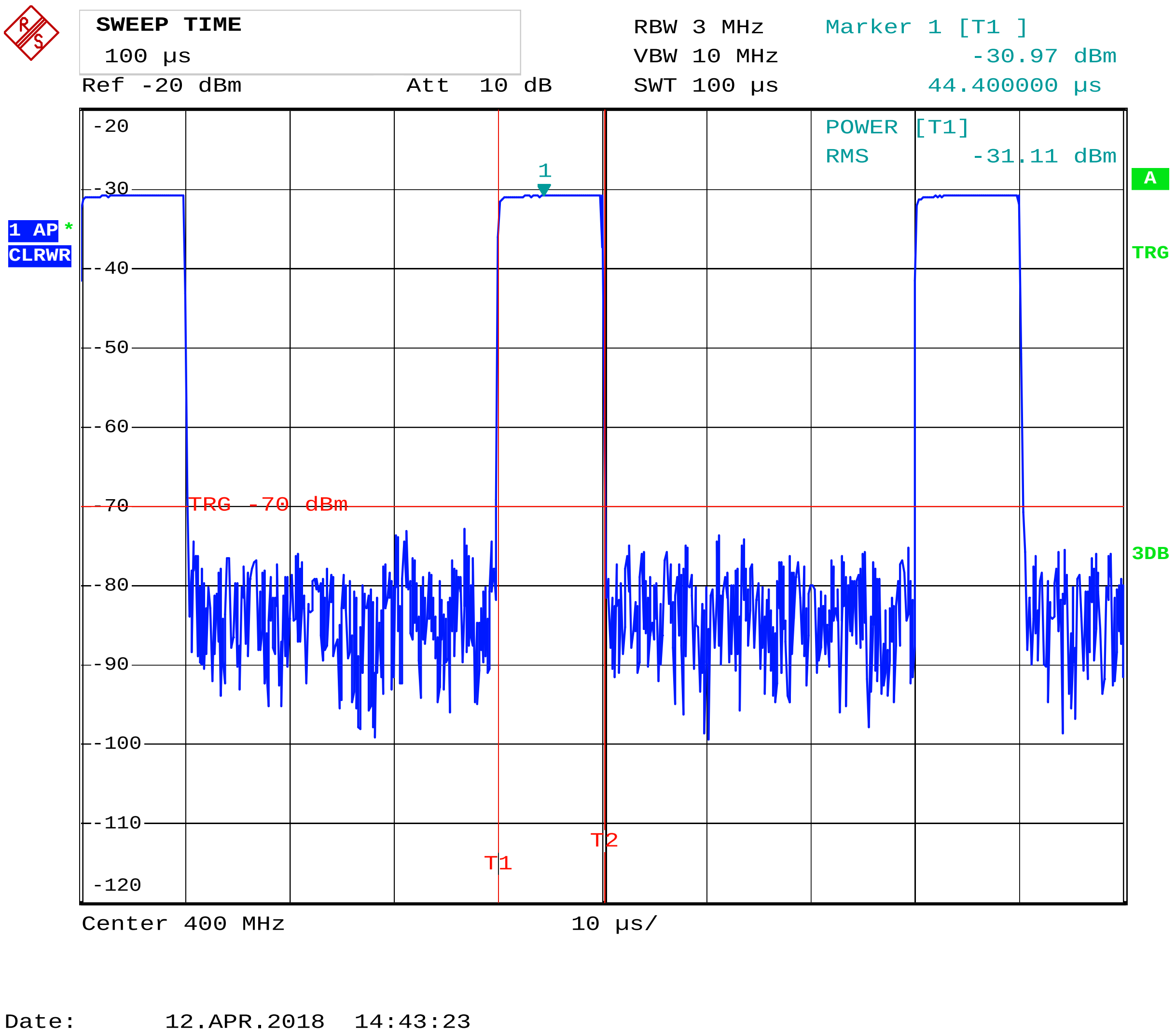

Figure A.23: fast_zero, signal fast pulsed (Ton 10 µs, Toff 30 µs), zero span

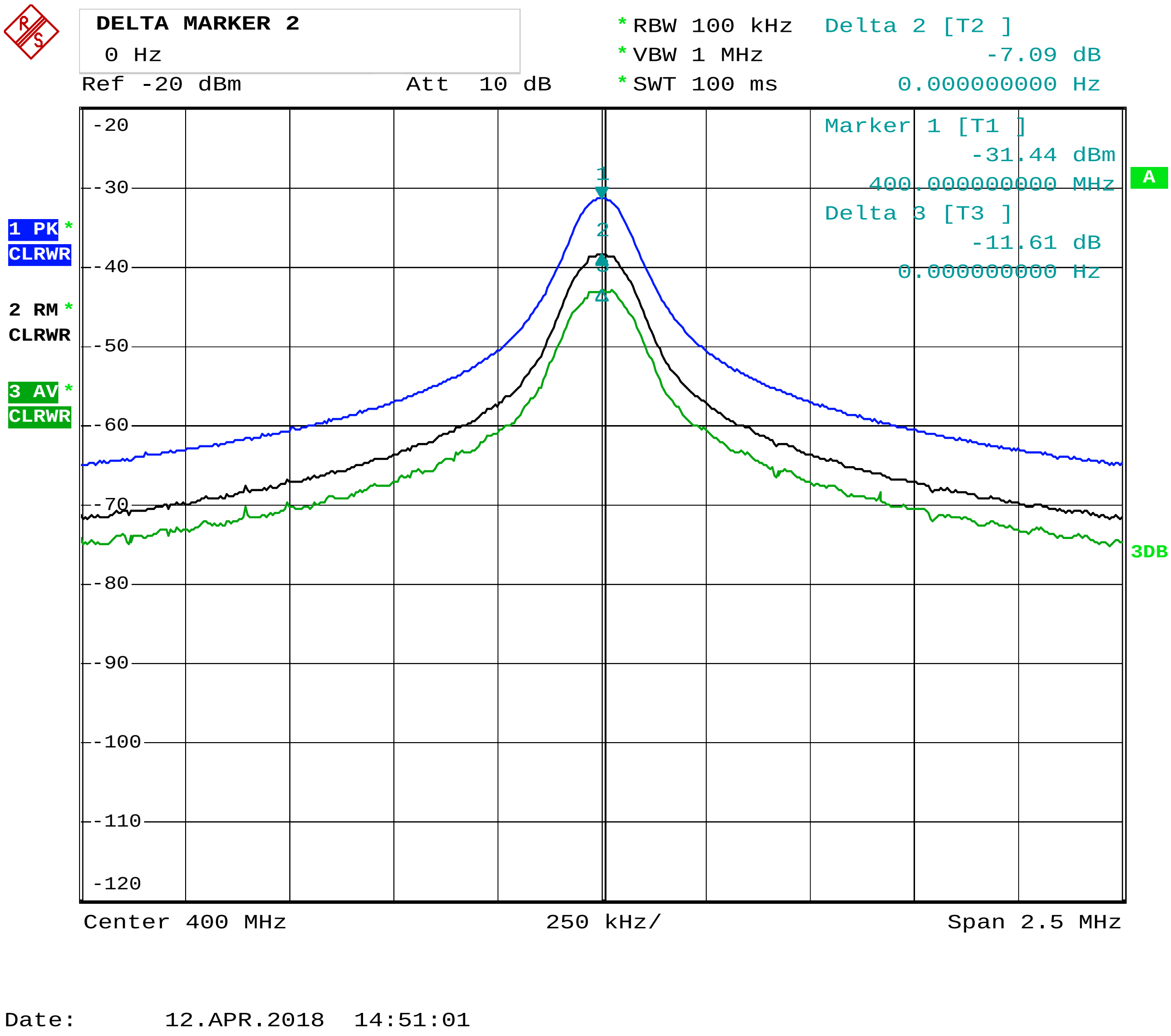

Figure A.24: fast 1, signal fast pulsed (Ton 10 µs, Toff 30 µs)

Annex B: Change History

Date	Version	Information about changes
November 2019	1.1.1	First version of ETSI TR 103 581

History

Document history		
V1.1.1	November 2019	Publication