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**Short Range Devices (SRD)
using Ultra Wide Band technology (UWB);
Time Domain Based Peak Power Measurement
for UWB Devices**

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Contents

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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

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1 Scope

The present document specifies a time domain based procedure for UWB Peak Power measurements. It is intended as an alternative in addition to the frequency domain measurement technique outlined in clause 7.4.4 of ETSI TS 102 883 [i.4].

The proposed procedure is applicable to all UWB signal types. It provides more accurate results compared to the frequency domain measurement in case a correction factor needs to be applied for frequency domain measurements with RBW smaller than 50 MHz.

2 References

2.1 Normative 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 reference document (including any amendments) applies.

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[i.1] ETSI EN 302 065-1 (V1.3.1) (02-2014): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 1: Requirements for Generic UWB applications".

[i.2] ETSI EN 302 065-2 (V1.1.1) (02-2014): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 2: Requirements for UWB location tracking".

[i.3] ETSI EN 302 065-3 (V1.1.1) (02-2014): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band technology (UWB); Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 3: Requirements for UWB devices for road and rail vehicles".

[i.4] ETSI TS 102 883 (V1.1.1) (08-2012): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) using Ultra Wide Band (UWB); Measurement Techniques".

[i.5] Recommendation ITU-R SM.1754 (2006): "Measurement techniques of ultra-wideband transmissions".

[i.6] J. Takada, S. Ishigami, J. Nakada, E. Nakagawa, M. Uchino, and T.Yasui, "Measurement techniques of emissions from ultra wideband devices," IEICE Transactions Fundamentals, vol. E88-A, no. 9, pp. 2252-2263, September 2005.

[i.7] H. Pflug, J. Romme, K. Philips, H. de Groot, "Method to Estimate Impulse-Radio Ultra-Wideband Peak Power," in Microwave Theory and Techniques, IEEE Transactions, vol.59, no.4, pp.1174-1186, April 2011.

3 Symbols and abbreviations

3.1 Symbols

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

dB	decibel
dBm	gain in decibels relative to one milliwatt
$f_{BB}[t]$	baseband filter coefficients at time *t*
f_c	centre frequency for the filter
f[t]	filter coefficients at time *t*, centred on f_c
f_{max}	the highest frequency as determined in clause 7.4.2 "Operating Bandwidth" of ETSI TS 102 883 [i.4]
G	gain of the filter
$P_{filtered}$	peak power in filter bandwidth
$P_{max, filtered}$	maximum peak power in filter bandwidth
σ	standard deviation
t	discrete time variable
$V_{filtered}$	peak voltage in filter bandwidth
Z_0	characteristic impedance

3.2 Abbreviations

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

ADC	A/D-Converter
CW	Continuous Wave
DC	Direct Current
DUT	Device Under Test
IF	Intermediate Frequency
ITU-R	International Telecommunications Union - Radiocommunications sector
PSD	Power Spectral Density
RBW	Resolution BandWidth
UWB	Ultra-WideBand

4 Preface

Current ETSI measurement techniques [i.4] provide a peak power measurement method for UWB signals using the spectrum analyser in clause 7.4.4. The limit is defined in a 50 MHZ bandwidth, while this resolution bandwidth is not implemented on most spectrum analysers currently available in the market. When peak power is measured with a smaller resolution bandwidth *RBW*, a correction factor of 20 log(50/*RBW*) has to be applied. However, for most practical signals, the correction formula grossly overestimates the actual peak power.

It is well known from Fourier theory that linear processing in the frequency domain has a time domain equivalent. Hence, it is possible to measure the peak power from a time domain signal, as for example recognized by ITU in chapter 3 of Recommendation ITU-R SM.1754 [i.5], ETSI measurement techniques in clause A.2.3 of ETSI TS 102 883 [i.4] and in literature [i.6] and [i.7]. The present document therefore defines a time domain alternative to the measurement technique of clause 7.4.4 in ETSI TS 102 883 [i.4].

The time domain method consists of capturing the UWB signal with an oscilloscope and performing the convolution with the resolution bandwidth filter during off-line post-processing. Because the RBW filter is implemented in software, there are no limitations on its bandwidth. A 50 MHz RBW bandwidth can therefore be implemented, eliminating the need for the correction factor. The convolution could be performed in the frequency domain as detailed in Recommendation ITU-R SM.1754 [i.5] and [i.6] or directly in the time domain, as detailed below and in [i.7].

5 Measurement in the time domain

5.1 Test Procedure Summary

The test procedure can be summarized as follows:

- Capture the time domain waveform with a high speed sampling oscilloscope;
- Apply a Gaussian filter to the captured waveform;
- Calculate the power for each sample of the filter output;
- Search for the maximum power;
- Compare with the limit in the relevant harmonised standards (ETSI EN 302 065 [i.1], [i.2] and [i.3]).

Details of the measurement procedure can be found in the following clauses.

5.2 DUT preparation

No specific DUT preparations are necessary for performing a measurement in the time domain.

Despite the connection of an oscilloscope instead of a spectrum analyser, all test setup and DUT characteristics are the same as for a measurement in the frequency domain (see ETSI TS 102 883 [i.4] and the relevant harmonised standards ETSI EN 302 065 [i.1], [i.2] and [i.3]).

In particular, this includes:

- Requirements for test modulation.
- Test conditions, power supply and ambient temperatures.
- Test setups and procedures for radiated and conducted measurements.
- Frequency of measurement (for post-processing).

5.3 General Test Setup

Radiated and conducted tests can be performed. The criteria from ETSI TS 102 883 [i.4] are adopted for both test setups.

5.4 Signal Acquisition

5.4.1 Oscilloscope Specification and Settings

- Input bandwidth > $f_{max.}$
- Sampling frequency > 2 × $f_{max.}$
- Dynamic range set to the maximum value that still allows complete display of the waveform without clipping.

Where, in order to satisfy the Nyquist criterion, f_{max} is the highest frequency as determined in clause 7.4.2 of ETSI TS 102 883 [i.4], i.e. the upper boundary to the operating bandwidth.

5.4.2 Length of data acquisition and storage

A sufficiently long portion of the signal needs to be captured to ensure that the peak power occurs within the acquired portion. Often, the position of the signals causing the maximum peak power will be known to the manufacturer, who can provide a dedicated test peak power mode to speed up the measurements and post-processing.

5.5 Post-Processing

5.5.0 General

The captured time domain signal needs to be filtered with the resolution bandwidth filter whose time domain impulse response is defined in the clause below. This assumes that the convolution will be performed in the time domain. Chapter 3 of Recommendation ITU-R SM.1754 [i.5] details an equivalent frequency domain convolution method.

As defined in ETSI TS 102 883 [i.4], the filter is be centred on the frequency of the maximum mean power spectral density.

5.5.1 Definition of the resolution bandwidth filter

The resolution bandwidth filter has a Gaussian impulse response. The standard deviation σ of the Gaussian is related to the desired -3 dB resolution bandwidth *RBW* via:

$$\sigma = \frac{\sqrt{\ln(2)}}{\pi \cdot RBW} \tag{1}$$

Assuming the resolution bandwidth *RBW* is specified in Hertz, the unit of the standard deviation is seconds. For a resolution bandwidth of 50 MHz, the resulting standard deviation is 5,3 ns.

The baseband filter coefficients are then generated using:

$$f_{BB}[t] = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{t^2}{2\sigma^2}\right) \tag{2}$$

where the (discrete) time variable *t* ranges from -6σ to +6σ in order to truncate the filter response while containing the significant part of the response.

The passband equivalent of the filter, centred on a frequency f_c, is obtained via:

$$f[t] = f_{BB}[t]\cos(2\pi f_c t) \tag{3}$$

To maintain the power of the passband signal, the filter is normalized by the gain *G* of the filter at the centre frequency f_c. Therefore, the gain of the filter is calculated using:

$$G = \sum f[t]\exp(-j2\pi f_c t) \tag{4}$$

and the normalized filter coefficients are obtained by dividing *f[t]* by |*G*|.

To verify the filter, it is useful to note that the equivalent noise bandwidth of a Gaussian filter equals 1,064 times its -3 dB bandwidth.

5.5.2 Maximum peak power determination

The result of the post-processing is a filtered waveform with a amplitude $V_{filtered}$. The corresponding instantaneous power is calculated using:

$$P_{filtered} = \frac{V_{filtered}^2}{2Z_0} \tag{5}$$

where Z_0 is the characteristic impedance of the oscilloscope.

The maximum peak power is then simply:

$$P_{\max,\ filtered} = \max\left(P_{filtered}\right) \tag{6}$$

5.6 Limit

The limit on the maximum peak power is defined in the relevant harmonised standards (ETSI EN 302 065 [i.1], [i.2] and [i.3]).

Assuming $V_{filtered}$ is recorded in Volt, $P_{max,\ filtered}$ is in Watts. It can be converted in dBm using:

$$30 + 10\log_{10}\left(P_{\max,\ filtered}\right) \tag{7}$$

for comparison with the limit defined in the relevant harmonised standards (ETSI EN 302 065 [i.1], [i.2] and [i.3]).

Annex A:
Matlab® reference code for Gaussian filter

```
function filterCoefficients = gaussianFilter(rbwHz,fsHz,fcHz)

% Generates filter coefficients for a resolution bandwidth filter with
% Gaussian impulse response, -3 dB bandwidth of rbwHz, sampling frequency
% fsHz and centred on fcHz

sigmaSec = sqrt(log(2))/pi/rbwHz;
tSec = -6*sigmaSec:1/fsHz:6*sigmaSec;
basebandResponse = 1/sqrt(2*pi)/sigmaSec * exp(-(tSec.^2)/2/sigmaSec^2);
upconvertedFilter = basebandResponse .* cos(2*pi*fcHz*tSec);
centreFrequencyGain = sum(upconvertedFilter .* exp(-1j*2*pi*fcHz*tSec));
filterCoefficients = upconvertedFilter / abs(centreFrequencyGain);
```

NOTE: MATLAB® is the trade name of a product supplied by MathWorks. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Annex B:
Verification Measurements

To verify the technique, a device was tested both on the spectrum analyser and with the proposed time domain method.

The same type of signal was measured with 5 different resolution bandwidths on the spectrum analyser.

For comparison, the signal was also recorded on a high speed sampling oscilloscope and processed for each of the resolution bandwidths with the method described above.

The resulting peak power observed in each resolution bandwidth is shown in figure B.1.

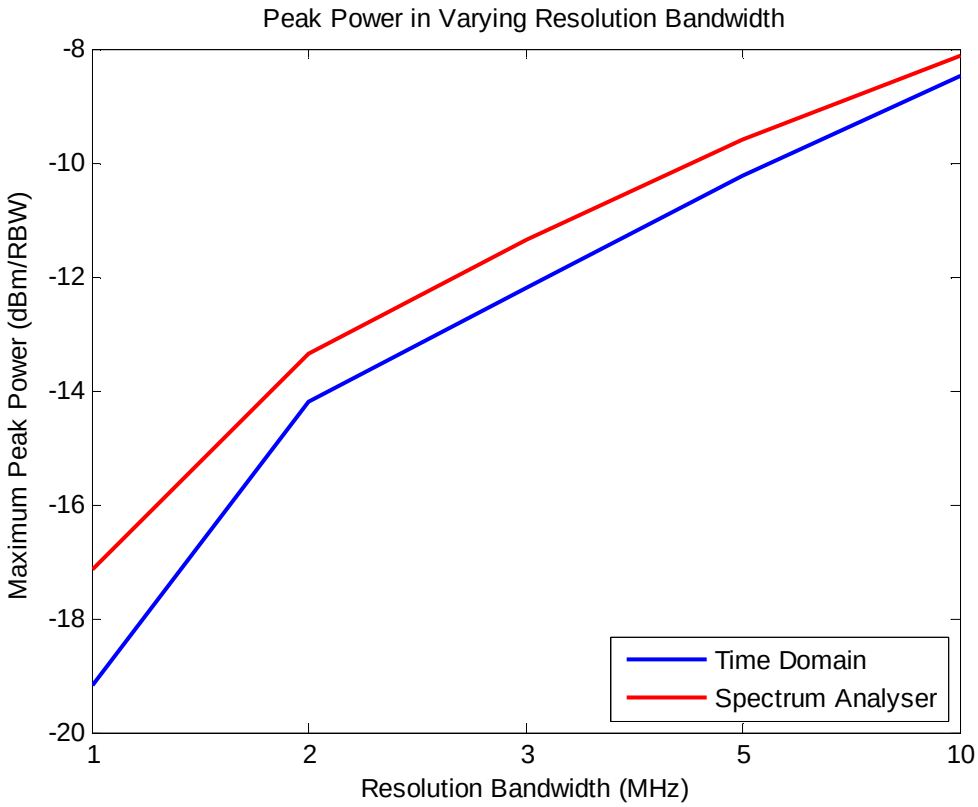

Figure B.1: Peak power in varying resolution bandwidths

To evaluate the similarity between the two methods, figure B.2 shows the difference between the peak power for the time domain method versus the one obtained from the spectrum analyser for each bandwidth. The difference reduces as the resolution bandwidth increases.

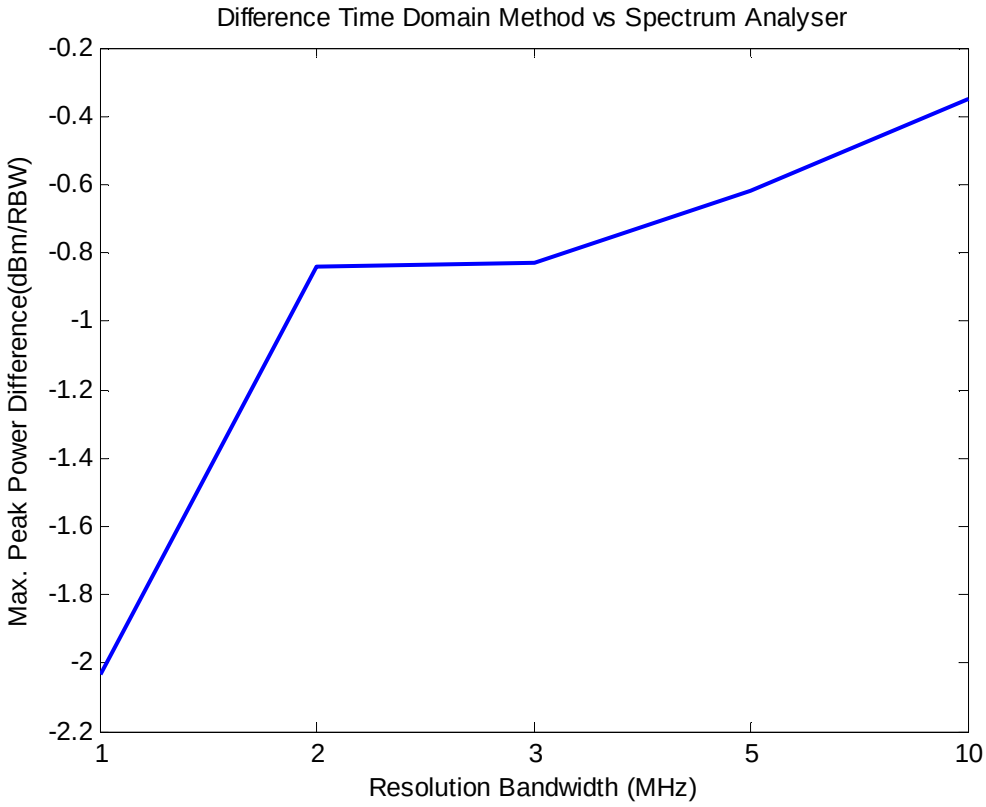

Figure B.2: Difference between time domain method and spectrum analyser measurements

Annex C:
Discussion of peak power and peak voltage

C.1 CW-signal

C.1.1 Peak and rms voltage, average power

Definition of peak and rms (root mean square) voltage of a sine wave as shown in figure C.1.

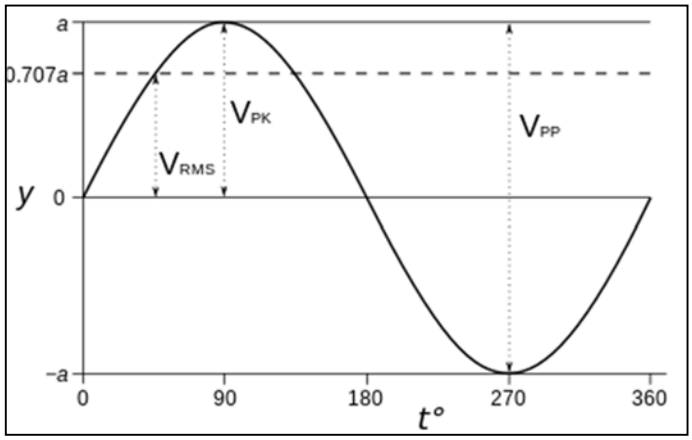

Figure C.1: Peak and rms voltage of a sine wave

Table C.1

Waveform	Equation	RMS
DC, constant	$y = a$	a
Sine wave	$y = a\sin(2\pi ft)$	$\frac{a}{\sqrt{2}}$
Square wave	$y = \begin{cases} a & \{ft\} < 0.5 \\ -a & \{ft\} > 0.5 \end{cases}$	a

$$P_{\text{avg}} = \frac{(V_{\text{RMS}})^2}{R} \quad \text{(C.1)}$$

"This equation can be used for any periodic waveform, such as a sinusoidal or sawtooth waveform, allowing us to calculate the mean power delivered into a specified load."

A CW-signal with 0 dBm (average) power has an rms-voltage of V_{rms} = 223,6 mV and a peak voltage V_{peak} = 316,2 mV, see table C.2. (Source: University of Hamburg HF-Radar group).

Table C.2: calculation peak and rms voltage for 0 dBm

[dBm]	[Watts]	[Volts]rms	[Volts]p	[Volts]pp
0	0.100E-02	223.607 mV	316.180 mV	632.360 mV

C.1.2 "Peak power" measurement of a CW-signal

Measuring the power of a CW-signal with a spectrum analyser yields the same value independent of the detector setting (peak or rms).

The value which is measured corresponds to the average power, which is based on the rms-voltage.

EXAMPLE: A CW-signal with peak voltage V_{peak} = 316,2 mV will be measured with 0 dBm.

The detector type refers to the way the sampled signal is displayed on the screen, as the figures C.2 and C.3 show. (Source Rohde & Schwarz).

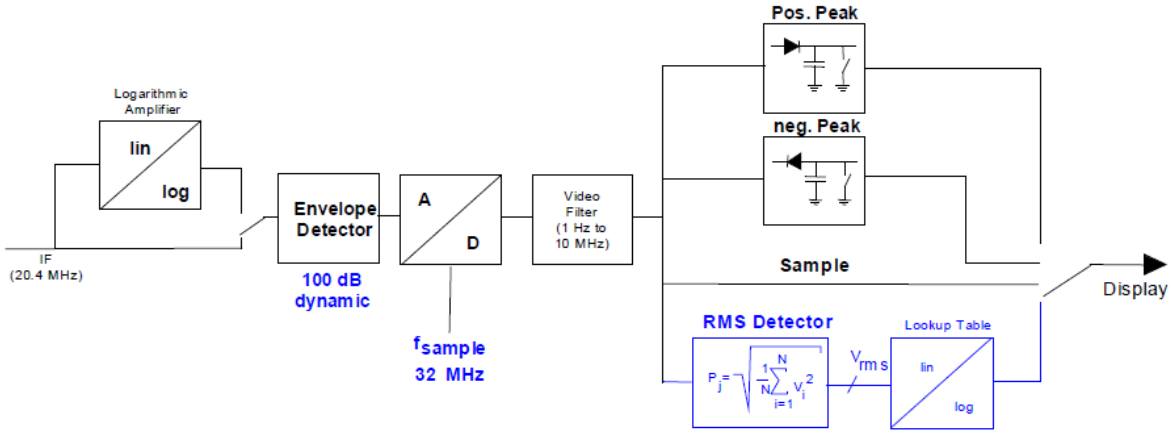

Figure C.2: Block diagram of a spectrum analyser

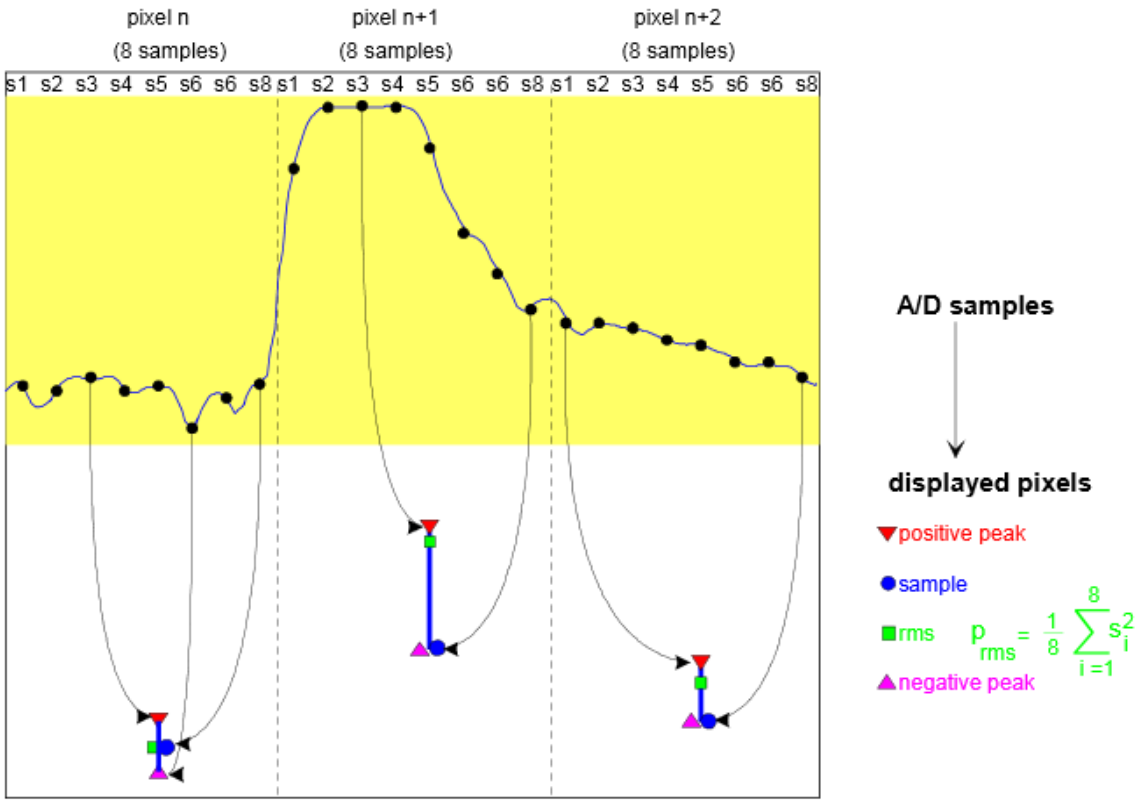

Figure C.3: Relation of ADC samples and detector output

A CW signal has a constant envelope.

Thus, after the envelope detector there is no variation in the signal and the display detector mode - peak or rms - yield the same results.

Thus, measuring "peak power", refers to the "peak" of the envelope, rather to the instantaneous peak power of the modulated signal.

C.2 UWB-signal

C.2.1 "Peak Power" as defined in ETSI EN 302 065

From the basic "peak power" definition in ETSI EN 302 065 [i.1, [i.2] and [i.3] following characteristics can be retrieved:

- spectrum analyser measurement;
- with RBW = 50 MHz;
- at the frequency of maximum of the Mean PSD measurement.

Following conclusions can be taken from that:

- "peak power" refers to the peak in the envelope, not to the instantaneous power;
- as a 50 MHz bandpass filter is applied, no DC component will be present at the output of the filter;
- the variation in the envelope at the output of the filter will be small (~1/50 MHz = 20 nsec) compared to the centre frequency of the filter (e.g. f_c = 4 GHz → $1/f_c$ = 0,25 nsec);
- the peak of the envelope converts to the "peak power". As this conversion does not depend on the original signal, the "peak power" value P_{peak} corresponds to the power of a CW-signal with power P_{peak}.

C.2.2 Deriving "Peak Power" from a time domain measurement

Sampling and post-processing a UWB-signal in the time domain yields an output that corresponds to the output of the IF filter.

The next stage would be the envelope detection and its envelope peak.

An envelope peak will be at most equal to the peak amplitude V_{peak} of the underlying signal, but will never exceed it.

Thus, measuring the peak amplitude of the filtered signal $V_{peak,filtered}$ will provide the intended value of the envelope peak.

To determine the peak power, recall that the peak power corresponds to a CW-signal with $V_{peak,CW}$.

Setting $V_{peak,CW} = V_{peak,filtered}$ yields the result that a spectrum analyser will display.

As the "peak power" is actually the average power of the CW signal, the formula in clause 5.5.2 holds true:

$$P_{peak} = P_{avg,CW} = \frac{V_{rms,CW}{}^2}{50\ ohm} = \frac{V_{peak,CW}{}^2}{2 \cdot 50\ ohm} = \frac{V_{peak,filtered}{}^2}{2 \cdot 50\ ohm} \quad \text{(C.2)}$$

Annex D: Bibliography

- ETSI EN 303 883 (V1.1.1): "Short Range Devices (SRD) using Ultra Wide Band (UWB); Measurement Techniques".
- ETSI ERMTGUWB(15)000002: "Alternative UWB Peak Power Measurement Procedures".

History

Document history		
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