RBW influence on peak or mean power measurement of pulsed signals
Application Note

Products:

- R&S®FSW

Modern radar systems occupy very wide bandwidth, either by using very a short pulse width or through pulse compression techniques. Besides the measurement of the pulse timing characteristics like pulse width or pulse repetition interval, the verification of emissions according to EN or FCC standards is mandatory. ETSI regulations for measuring peak transmission power from in-vehicle telematics equipment and radar operating at 77-81 GHz require 50 MHz bandwidth for the measurements.

This application note provides information how to perform spectral emission measurements on pulsed signals with spectrum analyzers using RBW filters with very wide bandwidth, and explains the capabilities and the limiting factors of the Rohde & Schwarz FSW signal and spectrum analyzer to perform this measurement.

Note:

Please find the most up-to-date document on our homepage https://www.rohde-schwarz.com/applications/

Application Note

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1 Introduction

High-resolution radar is a rapidly growing technology for commercial and military applications, with applications ranging from automotive vehicle sensors to target identification and security scanners. Besides radar, UWB (Ultra Wide Band) is seen as a key technology for the next generation low-cost wireless communication for very short distances, for example remote keyless entry systems for passenger vehicles. The resolution of a pulsed radar improves by using shorter pulse width or by additional modulation on the existing pulse length, such as a linear frequency ramp. Both solutions will increase the occupied bandwidth of the radar signal.

With the allocation of several frequency ranges for UWB signals, many discussions were raised how measurements are performed according to the standards. Many regulations for measuring peak transmission power of automotive radars operating at 77-81 GHz require 50 MHz resolution bandwidth for the measurements. As well as for automotive test, Short Range Devices using Ultra Wideband technology specified by EN 302 065 and others also need 50 MHz resolution bandwidth for peak power measurements in swept mode. Especially the use of Peak- and RMS detection and wide bandwidth measurement are new in the field of certification and people involved in testing devices want to make sure that their test system is fully compliant with the new requirements.

As no spectrum analyzer with 50 MHz resolution bandwidth was available in the past, the regulations include a correction factor of 20 * log (RBW / 50 MHz) to convert measurement results achieved with RBW other than 50 MHz. However, this correction factor is only correct for narrow pulsed signals and over-estimates many signal types like OFDM or CW signals. This may lead to issues in failing test limits whereas the device would meet the regulation if tested with wider bandwidth.

With the R&S FSW peak and average power can now be measured as required by the different regulations in UWB or automotive radars. Option FSW-B8 for increased resolution bandwidths supports a range of RBW up to 80 MHz for sweeps in the frequency domain.

When making measurements using the spectrum analyzer, one needs to be familiar with the parameters of the expected pulse and the important spectrum analyzer settings such as resolution bandwidth (RBW), span and sweep time in order to produce informative results. This application note explains the use of the Rohde & Schwarz FSW spectrum analyzer family for the measurement of peak power and mean power on pulsed signals. The next sections will give further details.

2 Review of Pulsed Signal Measurements

2.1 Fundamentals of the Pulsed Signal spectrum

Measurements on pulsed signals with the spectrum analyzer require good knowledge of the pulse parameters and the important spectrum analyzer settings such as resolution bandwidth (RBW) and sweep time.

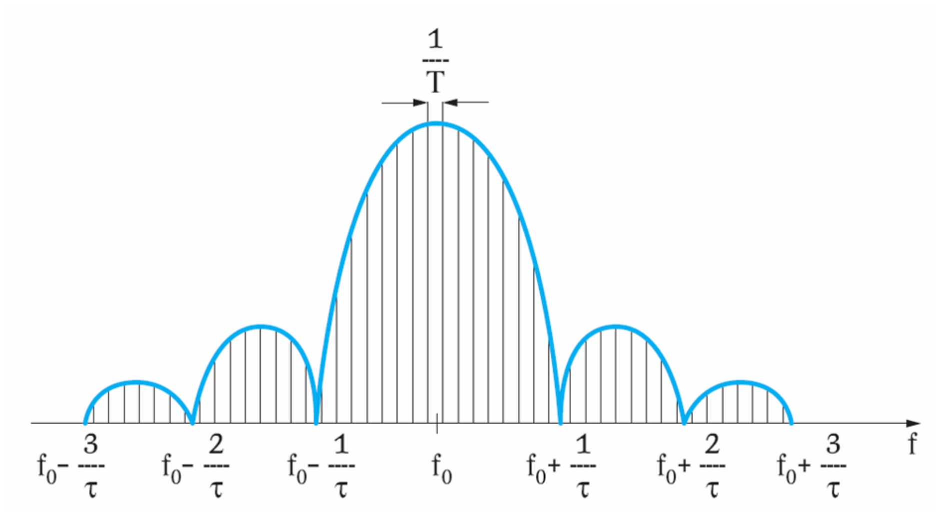

Figure 1: Typical display of a pulse signal spectrum showing pulse width τ and pulse interval T

Due to the periodic switching the typical pulse spectrum is a sin x / x function. Important parameters are the pulse width (t) and the Pulse Repetition Interval time (T).

The pulsed signal consists of many spectral lines across a wide frequency range. Depending on the pulse parameters and the RBW we can find three different cases of the spectral result display.

When measuring the spectrum with a resolution bandwidth (RBW) set to a value significantly less than the pulse repetition frequency (= 1/T) the individual spectral lines can be resolved. The line spacing is equal to the inverse of the pulse period (pulse repetition interval) and is independent of the setting for the sweep time on the analyzer. The height of the individual spectral lines is also independent of the RBW.

The largest spectral line displayed in the spectrum display is below the amplitude of the actual pulse by the pulse desensitization factor (PDF). The PDF is dependent upon the pulse width to the pulse period ratio:

$$PDF_{line} = 20 * \log(\tau/T)$$

Using the line spectrum, the peak power of the pulse signal is calculated from the power of the largest line and the pulse period ratio:

Peak power = marker reading – PDF

This pulse desensitization considerably reduces the indicated maximum power of the spectral lines compared to the real peak power. As the spectrum analyzer input is loaded with the peak power it can easily be overloaded, if that factor is not taken into account.

When the RBW of the analyzer is increased such that it is greater than the reciprocal of the pulse period (but still smaller than the reciprocal of the pulse width), the spectrum analyzer will display the spectrum envelope. The amplitude of the envelope increases linearly with the RBW, thus doubling the RBW produces a 6 dB increase in the amplitude when using the peak detection method.

The **pulse desensitation factor** is now depending on the pulse width and the RBW.

$$PDF_{envelope} = 20 * \log(\tau * K * RBW)$$

The pulse desensitation factor depends on the pulse bandwidth of the RBW. The correction factor K depends on the shape of the RBW filter and thus depends on spectrum analyzer model. Most modern spectrum analyzers use a digital implementation of gaussian shaped RBW filters, with a K-factor of about 1.5 (pulse bandwidth = 1.5 * 3 dB-bandwidth).

By continuing to increase the RBW until the RBW is greater than the reciprocal of the pulse width (wider than the null spacing), the whole spectrum of the pulsed signal falls within the resolution bandwidth. With a wide RBW and VBW the spectrum analyzer is able to track the envelope of the RF pulse and measures the impulse response of the filter. The maximum RBW and VBW limits the spectrum analyzers capability to measure very narrow pulses. As a rule of thumb the shortest pulse width that can measured is equal to the settling time of the RBW:

$$\text{Pulse width} > 2 / RBW$$

Most traditional spectrum analyzers have a maximum RBW filter bandwidth up to 10 MHz. With modern analyzers like the R&S FSW, the option FSW-B8 increases the RBW range up to 80 MHz.

Peak power measurements for UWB emissions are defined under the assumption of an ideal gaussian shaped filter with 50 MHz bandwidth. On most modern spectrum analyzers with digital IF filter implementation, resolution bandwidths (RBW) of 10 MHz or less closely approximate the ideal Gaussian filter characteristics. If a spectrum analyzer is used to make the peak measurement using a RBW greater than 10 MHz care has to be taken that the RBW filter is still gaussian shaped and that video bandwidth and other limitations don´t prevent accurate measurements.

The next chapters describes a test setup to verify the performance of the FSW wideband RBW filters and compare the test results on various pulsed signals with the theoretical values.

3 Test setup for pulsed signals

The pulse desensitation factors are verified with conducted tests by comparative measurements between a thermal power sensor (reference readings) and the R&S FSW spectrum analyzer. Several measurement methods based on various instrument settings and correction factors are tested to determine suitable correction factors. Figure 2 shows the block diagram of the test set up:

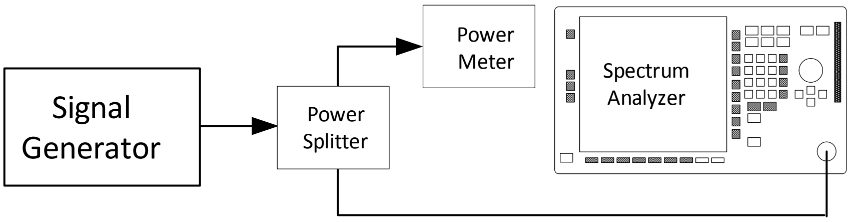

Figure 2: Test setup for pulsed measurements

The R&S vector signal generator SMW generates the pulsed radar signals with various pulse length and repetition rates. The output signal of the generator is divided, and a thermal power sensor measures the true average power of the pulsed signal (reference sensor). The second output of the splitter connects directly to the RF input of the FSW spectrum analyzer. The direct connection with the power sensor and the RF input avoids any difference in level due to cable loss.

3.1 Test parameters for the measurements on pulsed signals

While the power sensor always measures the correct mean power (=reference) of the pulsed signal (the sensor is a thermal power sensor type), the spectrum analyzer is able to perform two important types of level measurements.

Depending on the pulse width and the available RBW it is either possible to measure the peak power directly, or by applying a pulse desensitation factor. The other type of measurement is the mean power, this is possible with most modern spectrum analyzers that include true RMS detectors and band power functions. The requirement of using a pulse desensitation factor in the peak power measurements and the settings for an accurate band power measurement of the mean power are verified in the next sections.

For all following tests, the output level of the signal generator is set to about 7 dBm in order to achieve 0 dBm input power at the power sensor and the FSW spectrum analyzer RF input connector.

The pulse generation in all tests is using a pulse repetition rate of 1 kHz (1 ms pulse repetition interval).

As a simulation of common pulsed radar signal types, the pulse width is varied over a wide range. The goal was to cover long pulses that are easy to measure even with narrowband spectrum analyzers (RBW < 10 MHz), and very fast (short) pulses that are used in modern wideband type radars. The following pulse width range is used:

Pulswidth: 1 us, 500 ns, 200 ns, 100 ns, 50 ns, 20 ns, 10 ns

The peak and mean power measurement on the FSW spectrum analyzer is performed with a wide range of RBW settings in order to verify direct peak power measurement as well as the use of pulse desensitation factors. Measurements are performed with the following range of RBW settings:

RBW: 1 2 5 10 , 20 50 MHz

The measurement of peak and average power requires the spectrum analyzer to use a wide video bandwidth filtering that avoids any impact on the output signal of the RBW filtering and detection. The FSW spectrum analyzer was therefore set to use a VBW which is coupled to the RBW and 10 times wider (VBW = 10 * RBW) or to the maximum possible value of 80 MHz.

The following picture shows the complete test setup:

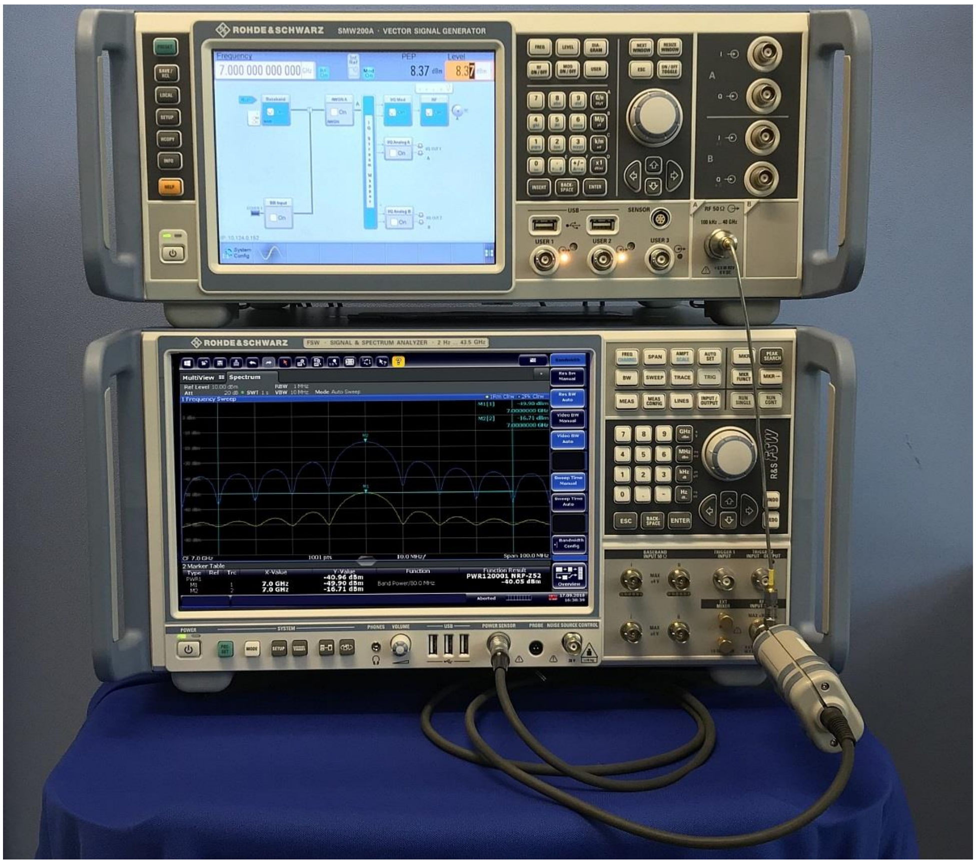

Figure 3: Picture of the test setup for pulsed measurements

4 Measurement results

The FSW spectrum analyzer is used to measure mean and peak power of the pulsed signal. The FSW spectrum analyzer uses a default value of 1001 measurement points per sweep. It is important to adjust the sweep time in such a way that an integer number of pulses is captured in each point to get a reliable RMS result. A sweep time of 1 second (equals the pulse repetition rate) will provide a 1 ms integration period for every measurement point. For the first example, the pulse width is set to 100 ns and the level is set to 0 dBm (unmodulated CW signal level). The mean power of the signal can be calculated by the duty cycle of the pulse (100 ns / 1 ms = 0.0001) to be -40 dBm.

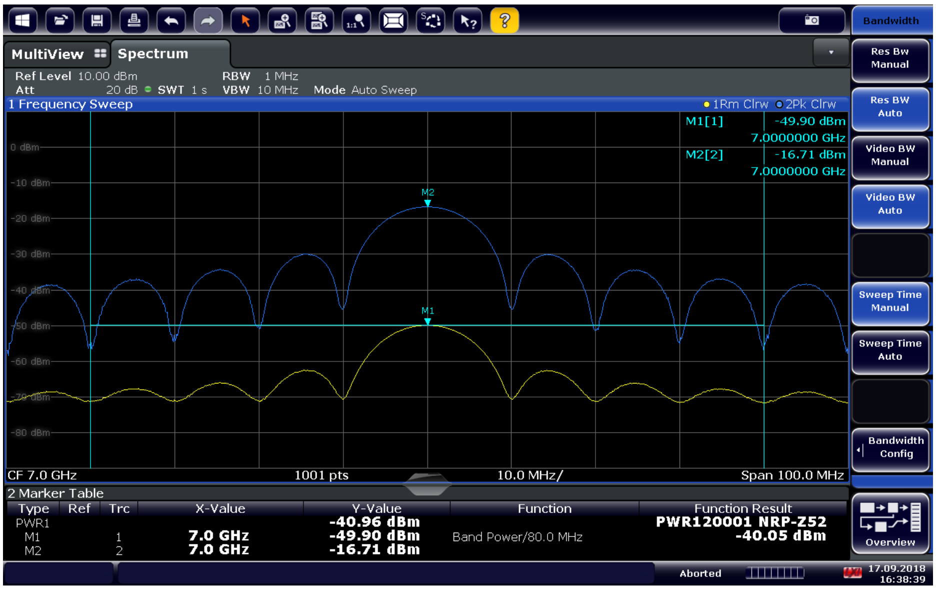

Figure 4: Test result screen display for mean and peak power of a pulsed signal

The above screen shot shows an example of this measurement result for a signal with 100 ns pulse width and a RBW of 1 MHz. Due to the pulse modulation, the output signal spreads across a wide bandwidth. The spectrum analyzer displays the well-known sin x/x spectrum shape.

For band power measurement the spectrum analyzer provides a software routine to calculate power within a given bandwidth. The screen shot above shows the measurement result of the band power measurement (marked with the vertical light blue lines on each side of the spectrum) in trace 1 (yellow trace). This function calculates the power by integrating the displayed trace points within the frequency range of interest (IBW = Integration Band Width). For the measurement of mean power each measurement point must be measured as mean power as well. This requires the use of the RMS detector. On a radar signal the integration over several sidelobes will allow the calculation of the mean power, since most of the energy is contained in the main and adjacent sidelobes of the sin x/x spectrum. The channel bandwidth is set to a value of 80 MHz to capture the main lobe and most of the adjacent sidelobes. The measurement result of -40.05 dBm band power (right lower part of the table) agrees well with the calculated mean power of the input signal. This method of measuring the mean power of a radar signal requires no knowledge of the pulse modulation parameters.

In parallel to the band power measurement the readout of the power sensor is displayed in the marker table below the spectrum. The power sensor reads -40.96 dBm, which is well in line with expected value and close to the band power measurement of the spectrum analyzer.

The envelope spectrum does not allow for a direct reading of the peak power. Without knowing the modulation parameters (like pulse width) the calculation of the peak power is not possible. The screen shot above shows the peak reading with 1 MHz RBW in trace 2 (blue trace). The marker on top of the highest point in the main lobe reads -16.71 dBm. To calculate the true peak power of the signal, the pulse desensitation factor is required:

$$PDF_{envelope} = 20 * \log (\tau * K * RBW) = 20 \log (100\ ns * 1.5 * 1\ MHz) = -16.48\ dB$$

The marker reading in trace 2 (-16.71 dBm) must be corrected with the calculated pulse desensitation factor (-16.48 dBm) in order to figure out the peak power of the pulse. This calculation results in a peak power of -0.23 dBm, a very good agreement with the input signal. The following table shows the above measurement with various pulse width settings to verify the mean power and peak power measurement on pulsed signals.

Pulse width	Duty cycle	RMS power	Power Meter	Channel Pwr FSW reading	Pulse Desens.	Peak Power SA	
ns	[1]	dBm	dBm	dBm	dB	w/o desens. Factor [dBm]	with desens. factor [dBm]
10000	0,01	-20,00	-19,89	-20,03	0,00	0,01	0,01
5000	0,005	-23,01	-22,88	-23,04	0,00	0,00	0,00
2000	0,002	-26,99	-26,84	-27,01	0,00	0,00	0,00
1000	0,001	-30,00	-29,82	-30,05	0,00	-0,52	-0,52
500	0,0005	-33,01	-32,78	-33,17	n.a.	-3,70	-3,70
200	0,0002	-36,99	-37,27	-37,02	-10,42	-10,62	-0,20
100	0,0001	-40,00	-40,29	-40,01	-16,44	-16,48	-0,04
50	0,00005	-43,01	-41,9	-42,96	-22,46	-22,47	-0,01
20	0,00002	-46,99	-48,3	-46,91	-30,42	-30,41	0,01
10	0,00001	-50,00	-51,4	-49,50	-36,44	-36,40	0,04

Fig. 5: Test results of pulsed signals with different pulse length

For all tested pulse widths the channel power reading of the FSW is in perfect alignment with the expected mean power of the pulsed signal. The power sensor and the FSW readings both show very good alignment to the calculated RMS power. Below -40 dBm the power sensor readings are marked in red as the level is too close to the noise floor for accurate readings. The Channel Power method provides very accurate average power measurements of pulse modulated signals. The integration bandwidth must include the main lobe and adjacent lobes of the envelope spectrum of the pulsed signal. No further correction factor is required.

The peak power readings on the FSW show the peak power within the used RBW of 1 MHz. For the true peak power of the signal, the marker readings must be corrected with the appropriate pulse desensitation factor to make accurate measurements of pulsed signals. The pulse desensitization factor to compensate the settling effect of the RBW (measurement bandwidth) for the R&S FSW spectrum analyzers using gaussian shaped RBW filters is 20 * log (τ * K * RBW), with τ being the pulse width, K the correction factor to convert from gaussian to pulse bandwidth (1.5 for the FSW), and B the 3dB-bandwidth setting of the analyzer. This correction factor is only valid for pulses shorter than 0.2 / RBW, in this case the measurement shows the envelope spectrum. The table shows the calculated factors for each setting. The expected peak level of the input signal is 0 dBm for all settings, the corrected readings (with desensitation factor) show very good agreement.

For pulses wider than 1/RBW the complete pulsed signal spectrum fits into the resolution bandwidth and the spectrum cannot be recognized any more. With increasing pulse width the impulse response of the filter approaches the time function of the pulse-modulated carrier. In this case the resolution bandwidth filter has enough time to settle to the peak pulse level and the accurate peak level is displayed without any correction factors. The pulse desensitation factors in the above table are therefore set to zero for all pulse width settings of 1 us and longer (marked in blue).

The effect of the transition between the envelope measurement and the peak measurement is recognizable with a chart displaying the peak readings versus the pulse length:

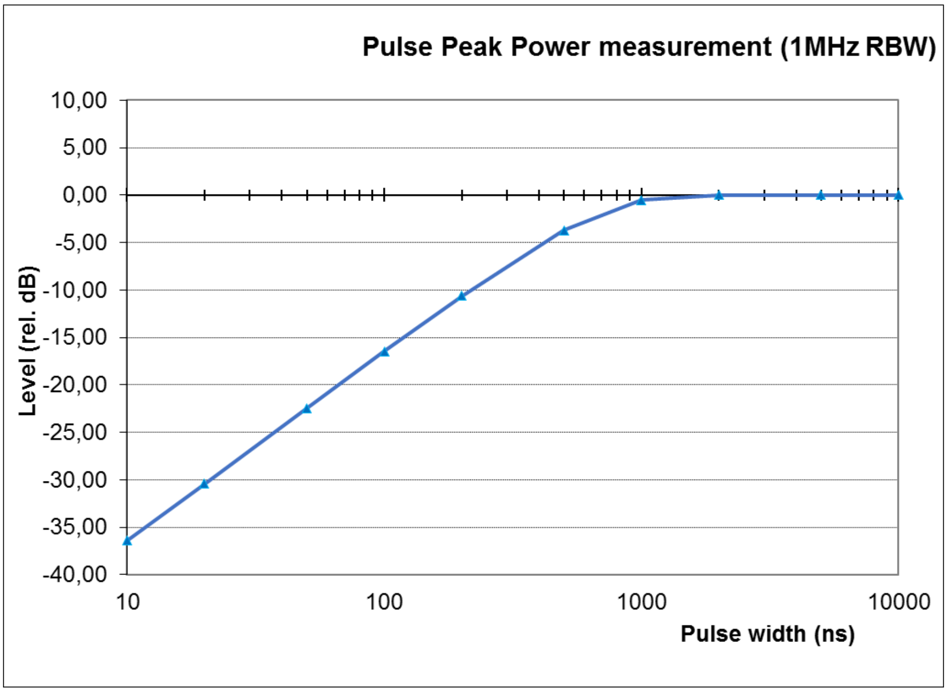

Fig. 6: Pulse peak power reading versus pulse length for 1 MHz RBW setting

For the pulse width from 10 ns to 200 ns the displayed peak reading is increased by 6 dB in the amplitude when doubling the pulse width. For pulse width beyond 1 us, the peak reading remains constant, as the true peak power is already displayed.

In this section the fundamentals of mean and peak power measurements on pulsed signals have been discussed and the performance of the FSW was verified to show excellent agreement with the theory and to a thermal power sensor. The RBW of 1 MHz is usually required in many standards for mean power measurement of emissions, while the peak power measurement requires a wider bandwidth. This measurement is explained in the next chapter.

4.1 Measurements on very short pulses

Many regulations define a 50 MHz RBW for UWB peak power measurements. However, not many spectrum analyzers offer such a wide bandwidth and the peak power must be calculated by applying the peak desensitation factor, which is an additional risk for failures. The RBW requirement assumes a gaussian shaped bandwidth ideal for peak power measurements. The wideband RBW of many SAs, however, is defined as 3 dB-bandwidth, with no or little information about the shape of the filter. Since the spectrum analyzer is calibrated for sinewave signals, there is often no specification available for peak power measurements of UWB or other pulsed signals.

Following the same test procedure as before, it is possible to verify the peak power measurement accuracy of the wideband RBW filters. The test signal is a very short pulse signal that has a flat frequency response within the measurement bandwidth. In this case only the effects of the RBW filter and the signal processing will influence the peak level reading.

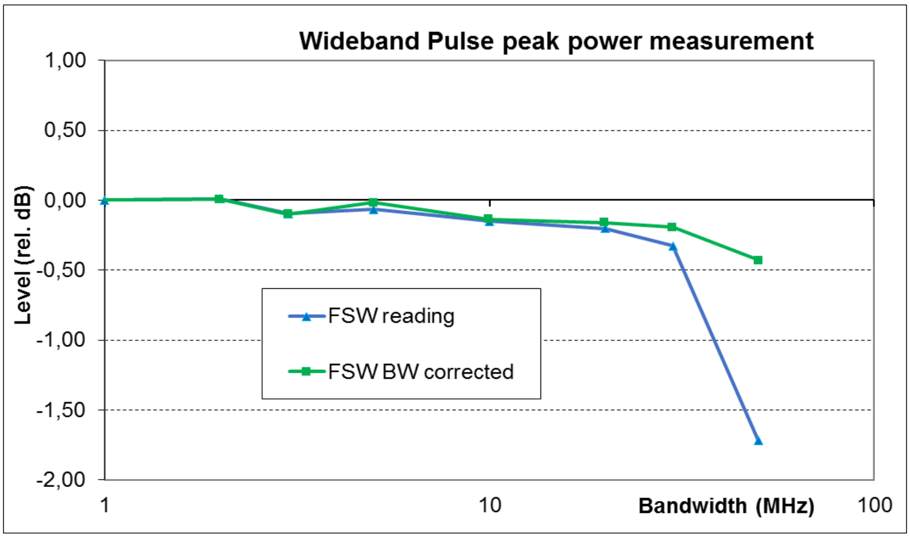

Fig. 7: Pulse peak power reading versus RBW setting for very short pulses

The above diagram shows the relative level error of the FSW level reading for a wideband pulsed input signal. The measurement data is referenced to the reading at 1 MHz RBW (= 0 dB). For every doubling of the RBW the peak level is expected to increase by 6 dB, only the relative deviation to this calculated signal level change is plotted in the diagram. The blue trace shows an accurate reading for RBW up to 20 MHz. The readings at 30 MHz and at 50 MHz RBW start to deviate from the expected value.

The full details of this measurement are shown in the following table. For each RBW setting the true 3dB-bandwidth is measured (3dB BW). This value is the reference for the peak level calculation (3dB-BW ratio), which refers every RBW to 1 MHz (20 log 3dB BW / 1 MHz). For each RBW setting the true 3dB-bandwidth is measured (3dB BW). This value is the reference for the peak level calculation (3dB-BW ratio), which refers every RBW to 1 MHz (20 log 3dB BW/1 MHz).

RBW setting MHz	3dB BW (3dB-down) MHz	3dB-BW ratio dB	**Measured Peak level dBm**	Peak rel. to 1MHz dB	**Error of peak read. dB**	Pulse RBW correction factor dB	**Error after corr. factor dB**
1	0,995	0	**-40,18**	0,000	**0,000**	0	**0**
2	1,99	6,021	**-34,15**	6,030	**0,009**	0,002	**0,008**
3	2,99	9,557	**-30,72**	9,460	**-0,097**	0,002	**-0,098**
5	4,99	14,006	**-26,24**	13,940	**-0,066**	-0,047	**-0,018**
10	9,95	20,000	**-20,33**	19,850	**-0,150**	-0,016	**-0,134**
20	19,93	26,034	**-14,35**	25,830	**-0,204**	-0,044	**-0,159**
30	29,87	29,548	**-10,96**	29,220	**-0,328**	-0,134	**-0,194**
50	50,15	34,049	**-7,85**	32,330	**-1,719**	-1,289	**-0,430**

Fig. 8: Peak power reading versus RBW setting for very short pulses

The "Peak rel. to 1 MHz" column shows the peak level readings relative to the reading at 1 MHz. The error of the peak shows the data compared to the expected peak level (blue trace in the above diagram "figure 7").

In case of the R&S FSW-B8 option the extended range of RBW filters do not follow the ideal gaussian shaped filter. This can be recognized with a plot of the normalized shape of the filters. The following diagram illustrates this result:

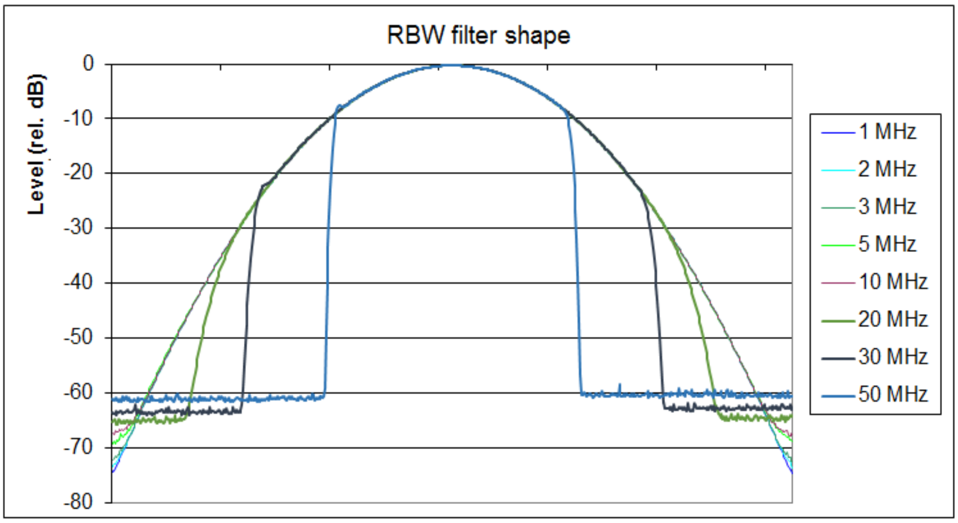

Fig. 8: Normalized RBW shape for the range from 1 MHz to 50 MHz

The RBW filters in the FSW spectrum analyzer use a digital IF filter implementation with a 200 Ms/s A/D converter to sample the IF signal. The sampling rate limits the maximum usable bandwidth to 80 MHz. This bandwidth limit (decimation filter) is always active and overlays to the gaussian shaped RBW filter. As such the wider RBW filter are only gaussian shaped in the upper part of the filter curve, the lower part is band limited. As the signal power outside the channel filter is missing, the effective pulse bandwidth of the wideband RBW filter is lower compared to the narrow band filters. This effect of a narrower impulse bandwidth requires a correction factor for the wide RBW filter (20, 30 and 50 MHz) that is applied to the peak power measurement. This correction is shown in the right column of the upper table and with the green trace in figure 7 (FSW BW corrected). With this additional correction factor the FSW performs peak pulse power with excellent accuracy. The remaining error at 50 MHz RBW is due to the VBW that is limited to 80 MHz and start to influence the peak measurement.

5 Conclusion

The R&S FSW signal and spectrum analyzer equipped with the R&S®FSW-B8 option forms the basis of a solution to accurately measure peak and average power of wideband pulsed RF signals. The integrated peak and true RMS detectors together with the band power functions is a powerful tool that performs peak and average power measurements according to the regulations.

A Pulse Desensitization Factor is required to make accurate measurements of the peak power of pulse modulation in order to compensate effects of the RBW (measurement bandwidth). The pulse desensitation factor for spectrum analyzers using gaussian shaped RBW filters is:

$$PDF_{envelope} = 20 * \log(\tau * K * RBW)$$

with τ being the pulse width, K the correction factor to convert from gaussian to pulse bandwidth (1.5 for the FSW), and B the RBW setting of the analyzer. This correction factor is valid for pulses shorter than 0.2/RBW, for pulses wider than 1/RBW the peak level is displayed without any correction.

No further correction factors must be applied to read the true mean power of a pulsed signal, and the wide dynamic range of the FSW allows this test over a wide measurement range.

6 Literature

[1] R&S®FSW Signal and Spectrum Analyzer – Product Brochure

[2] R&S®FSW Signal and Spectrum Analyzer – Data Sheet

[3] US 47 CFR Part 15 Technical requirements for UWB systems, 15.517

[4] Dependence of Peak Power Measurement of Ultra Wideband Signals on Impulse Bandwidths of Spectrum Analyzers, 2008 IEEE Radio and Wireless Symposium

7 Ordering Information

R&S FSW8	Signal- and Spectrum analyzer 2 Hz to 8 GHz	1312.8000.08
R&S FSW13	Signal- and Spectrum analyzer 2 Hz to 13.6 GHz	1312.8000.13
R&S FSW26	Signal- and Spectrum analyzer 2 Hz to 26.5 GHz	1312.8000.26
R&S FSW43	Signal- and Spectrum analyzer 2 Hz to 43.5 GHz	1312.8000.43
R&S FSW50	Signal- and Spectrum analyzer 2 Hz to 50 GHz	1312.8000.50
R&S FSW67	Signal- and Spectrum analyzer 2 Hz to 67 GHz	1312.8000.67
R&S FSW85	Signal- and Spectrum analyzer 2 Hz to 85 GHz	1312.8000.85

The herein described wide bandwidth RBW filter is available in the R&S®FSW equipped with option FSW-B8 (Resolution Bandwidth > 10 MHz).

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

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