Application Note

UWB EMISSION MEASUREMENTS WITH SPECTRUM ANALYZERS

Products:

► R&S®FSW

► R&S®FSWP

Kay-Uwe Sander | 1EF109 | Version 1E | 06.2021

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Contents

1 Overview

UWB (Ultra-Wide Band) communication technology became a very popular technology for high-speed data communication and location-tracking service with very high resolution into the mm range.

The allocation of several frequency ranges for licensed and unlicensed operation of UWB signals happened within ETSI and FCC regulations over the past 20 years, the frequency allocation from 3.1 to 10.6 GHz for these signals is harmonized across most countries and based on the fact that UWB signal are low power, low range and very wide bandwidth which will avoid any interference with the existing users of these frequency bands.

The verification of emissions according to EN or FCC standards is mandatory to avoid any interference with existing users. Besides the common emission tests with measurement bandwidth up to 1 MHz and mean power measurements, most regulations also require to test peak transmission power within a 50 MHz bandwidth to avoid interference with any existing wideband applications, for example radar receivers.

The use of 50 MHz measurement bandwidth may present a challenge to the compliance testing of the UWB device, as the use of wideband measurement bandwidth was not common in the past or not even possible with older test equipment. A limited number of instruments on the market support this requirement, and it is important to understand the limitations of those instruments that offer a wide bandwidth.

Most standards allow the use of a smaller measurement bandwidth and correction factors as no spectrum analyzer with 50 MHz resolution bandwidth (RBW) was available in the past. However, this correction factor is only correct for 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. The use of these correction factors might lead to a disadvantage compared to a measurement with the full bandwidth.

Especially the use of Peak-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. The R&S FSW spectrum analyzer offers a wide RBW filter option (FSW-B8) that supports a range of RBW up to 80 MHz for sweeps in the frequency domain.

This application note provides information how to perform spectral emission measurements on UWB signals with spectrum analyzers using wide bandwidth RBW filters, and explains the capabilities and the limiting factors of the Rohde & Schwarz FSW signal and spectrum analyzer to perform this measurement. The next sections will give further details.

2 Review of UWB Signal characteristics

2.1 Fundamentals of the UWB signal measurements

UWB describes a technology for signals with low power spread over a wide frequency range. The FCC has approved a frequency range from 3.1 to 10.6 GHz for UWB transmissions, and with some small modifications these frequency ranges are also used in other counties. There is a wide range of standards that refer to UWB as the common technology, common to all of them is the use of a very wideband (> 50 MHz) and low power in order to avoid interfering with other services in the same frequency range.

There are a lot of different technologies to generate a wideband signal. Common practice is a pulse modulated RF carrier using very narrow pulses, or a direct sequence spread spectrum technique to realize the wide bandwidth. Other technologies include multi-band OFDM signals or frequency chirp modulation. As a result of these various signal types, the UWB waveform can exhibit different signal characteristics depending upon the receiver bandwidth. For example, a pulse or impulse-generated UWB waveform can appear as CW-line spectrum or as a noise-like signal, if pulse modulation techniques are used. Due to these possible receiver bandwidth dependent variations, measurements of a UWB spectrum requires the use of several signal detectors.

The characterization of a UWB device typically starts with a measurement in a 1 MHz resolution bandwidth and RMS detection, as this most accurately reflects the interference potential of the signal. This measurement can be performed with almost every spectrum analyzer in the market as 1 MHz is a common RBW and RMS detection has become a standard and is available in most spectrum analyzers since many years.

In addition to the 1 MHz wide average power measurement the peak emissions shall be measured with 50 MHz bandwidth. This measurement was added to the standards to reflect the interference potential with existing wideband applications like radar systems. As some spectrum analyzers do not offer a 50 MHz RBW filter the measurement is also possible with a RBW in the rage from 1 to 50 MHz and the application of a correction factor of 20 * log (RBW / 50 MHz). The correction factor in the regulations defines a conservative approach that is valid for real pulsed signals, but leads to an overestimation for noise-like signals that are proportional to 10 * log (RBW) rather than 20 * log (RBW). The use of a wider bandwidth will therefore lead to a test result that is closer to the real output power of the DUT.

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 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 describe the architecture of a modern spectrum analyzer and with the detailed view on the bandwidth limitations in the signal processing that may have an influence on the UWB testing on wideband signals.

2.2 Spectrum analyzer architecture

Most modern spectrum analyzers are based on a digital signal processing architecture to realize the resolution bandwidth filters, signal detection and video filtering. This concept has the advantage of very accurate filter realization, and most analyzers offer RBW up to 10 MHz which reflect a close approximation of the ideal Gaussian filter characteristics. The following block diagram gives an overview.

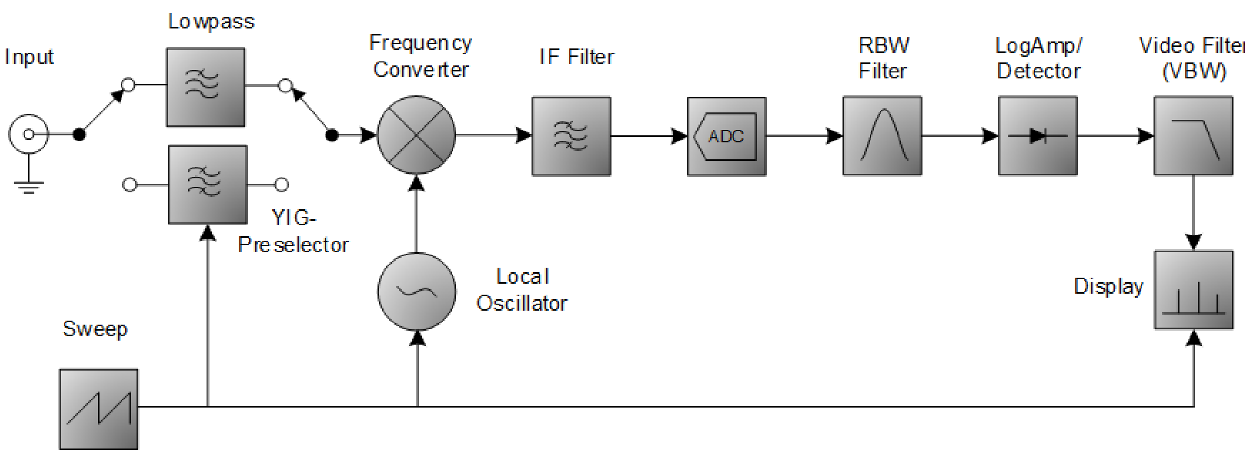

Figure 1: Simplified Spectrum Analyzer block diagram

The architecture of a modern analyzer with digital signal processing consists of two main parts: On the left side in the above diagram we have the analog front ends that perform the frequency conversion from the RF input to the IF frequency. The analog frequency conversion of most modern microwave spectrum analyzers consists of two different converter types, where both may have bandwidth limitations:

► The RF converter that covers the lower RF frequency range up to 3 or 8 GHz, depending on the model. This is typically very wide in bandwidth.

► The microwave converter that covers all RF and uW-frequencies from 8 GHz to the upper limit of the spectrum analyzer, i.e. 26.5 GHz, 50 GHz or higher. This stage has a limited preselection bandwidth that may have an influence.

On the right side we have the digital backend that performs the IF filtering, detection, scaling, and video signal filtering. The video bandwidth and phase linearity limitations of the RBW might prevent accurate and reproducible measurements for RBWs above 10 MHz bandwidth. As we need to measure Peak power spectral density (PSD) of the UWB emissions, it is also important to know about any bandwidth limitation of the peak detection circuit.

When the peak power is measured in a bandwidth wider than 10 MHz, it is generally recommended to verify the available bandwidth due to limitations in the different stages of the signal path as shown above. Besides the RBW itself there are many different stages of the signal path that may have bandwidth limitations and thus introduce unexpected measurement errors. A test setup is presented in the next chapters to verify the performance of the wideband RBW filters, and more details on every stage that may have an influence on wideband signals are presented.

3 First results for pulse bandwidth verification

The pulse bandwidth can be verified with high confidence by comparative measurements between a narrow reference RBW setting and the wideband RBW setting of interest. A R&S vector signal generator SMW generates a wideband pulsed signal with short pulse length. The bandwidth of the signal shall be such that a flat frequency response across bandwidth of interest is reached around the center frequency.

The measurement of peak 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 typical setting for pulsed measurements in a spectrum analyzer is to use a VBW which is 10 times wider than the RBW (VBW = 10 * RBW).

With the wideband pulse signal it is possible to verify the peak power measurement accuracy of the wideband RBW filters. The peak power measurement on the FSW spectrum analyzer is performed in a range of RBW settings in order to verify direct peak power measurement. Measurements are performed with the following settings:

RBW: 1 MHz, 2 MHz, 3 MHz, 5 MHz, 10 MHz, 20 MHz, 30 MHz and 50 MHz

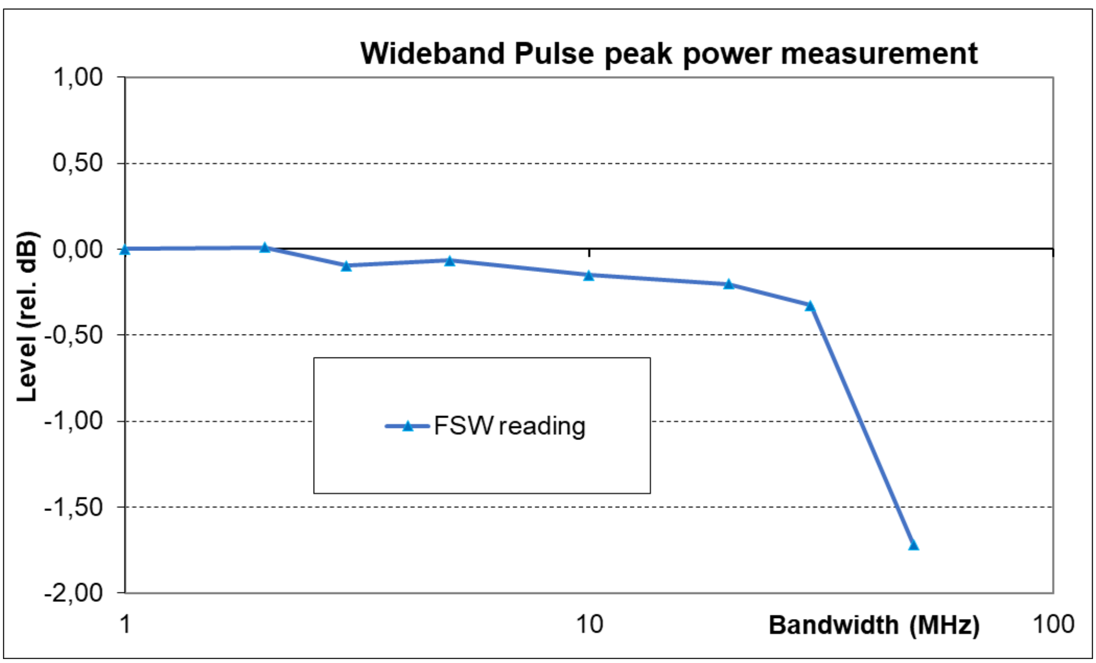

Fig. 2: Pulse peak power reading versus RBW setting for UWB pulses

The above diagram shows the relative level error of the R&S 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 trace shows an accurate reading for up to 20 MHz RBW. The readings at 30 MHz and at 50 MHz RBW start to deviate from the expected value.

More details of this measurement and how to improve the performance are shown in the following sections.

4 Bandwidth limitations of the architecture

As shown in the previous chapter there are limitations that lead to a reduced measurement accuracy for wideband signals and wide RBW settings. As most of the regulations allow the use of 1 MHz to 50 MHz RBW for UWB peak power measurements, it is important to understand the limitations of the spectrum analyzer architecture in terms of measurement bandwidth limitations and select the bandwidth that offers the best accuracy for the measurement of UWB signals.

4.1 Wideband RBW and VBW limitations

The test requirement assumes a Gaussian shaped bandwidth ideal for peak power measurements. However, the RBW of many spectrum analyzers 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 wideband signals. A detailed view on the spectrum analyzer signal processing helps to understanding these limitations.

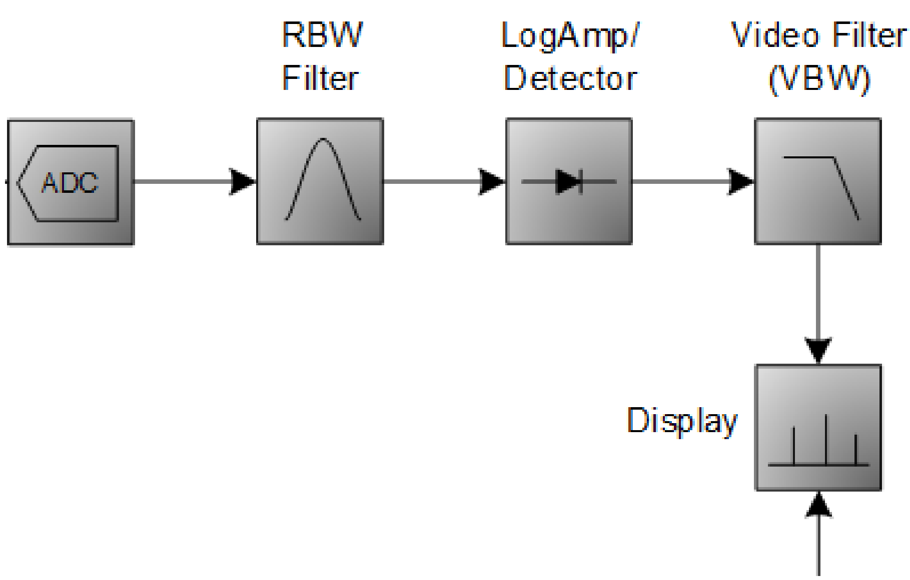

Figure 3: Digital signal processing block diagram of a Spectrum Analyzer

The RBW filters in the FSW spectrum analyzer use a digital IF filter implementation. The IF signal from the RF converters is sampled with an A/D conversion rate of 200 Ms/s to create the digital IF signal. The sampling rate limits the maximum usable bandwidth to 80 MHz due to the Nyquist criteria. This bandwidth limitation is realized as a decimation filter and is always active and limits the available bandwidth.

In case of the R&S FSW-B8 option the extended range of RBW filters (RBW >10 MHz) do not follow the ideal Gaussian shaped filter due to the overlay of the decimation filter and the Gaussian shaped RBW filter. This effect can be recognized with a plot of the normalized shape of the RBW filters. The following diagram illustrates this result:

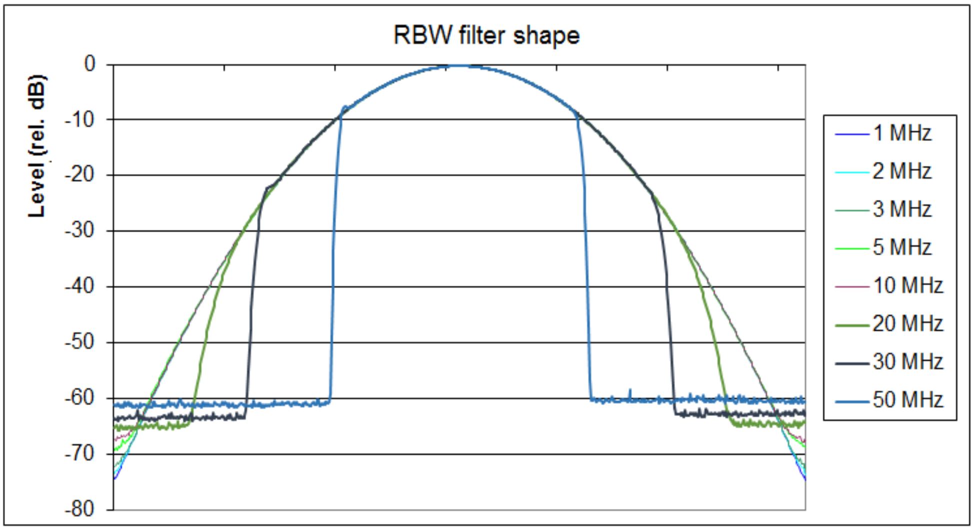

Fig. 4: Normalized shape for the RBW range from 1 MHz to 50 MHz

On the above picture we see an overlay plot of different RBW filters. All filter curves are normalized to the 3 dB bandwidth of the RBW filter. For RBW up to 10 MHz we can see a true Gaussian shape of the filter down to very low levels. For wider bandwidth like the 30 and 50 MHz filter, we see a filter that is only Gaussian shaped for the upper part of the filter. At wide offsets these filters look more like a channel filter. This is the effect of the overlay of the RBW and the digital filter that is part of the sampling architecture. This bandwidth limitation plays an important role in the measurement of peak power on wideband signals.

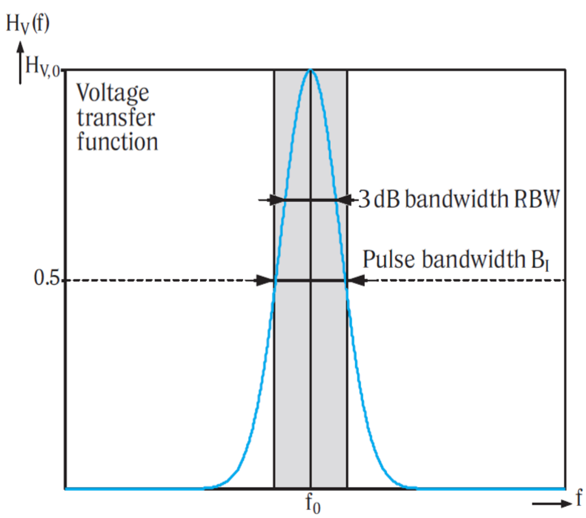

Fig. 5: Pulse bandwidth and 3dB-bandwidth seen in the voltage transfer function

In spectrum analysis it is common practice to specify the 3 dB bandwidth (the frequency spacing between two points of the transfer function at which the insertion loss of the filter has increased by 3 dB relative to the center frequency). In the case of Ultra Wideband the signal bandwidth is wider than the resolution bandwidth that is used to measure the level. In many cases the signal is a pulsed modulation, therefore the pulse bandwidth of the RBW filter is of interest in this case. The pulse bandwidth is calculated by integration of the voltage transfer function. The pulse bandwidth equals a rectangular filter with the same area as the shape of the resolution bandwidth filter in the linear or voltage view. The pulse bandwidth of a Gaussian shaped filter is typically 1.5 times wider than the 3 dB bandwidth, and almost equal to the 6 dB bandwidth.

Looking on the plots of the real wideband RBW filters in figure 4 we can see that the area under the filter curve is missing the spectral energy outside of the channel filter limitation. This missing energy leads to a reduced effective pulse bandwidth and to an additional peak level error for wideband signal measurements.

The full detail of this correction is 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).

RBW setting	3dB BW (3dB-down)	3dB-BW ratio	**Measured Peak level**	Peak rel. to 1MHz	**Error of peak read.**	Pulse RBW correction factor	**Error after corr. factor**
MHz	MHz	dB	**dBm**	dB	**dB**	dB	**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. 6: Peak power reading versus RBW setting for very short pulses

In addition the effective pulse bandwidth is determined (integration across the filter shape) and the resulting pulse correction factor relative to the 1 MHz RBW is calculated. Up to a resolution bandwidth of 30 MHz there is almost no error, while the 50 MHz RBW in the FSW reads 1.7 dB lower values. However, with the application of the correction factor this error can be largely reduced. The effect of this correction is plotted in the next figure:

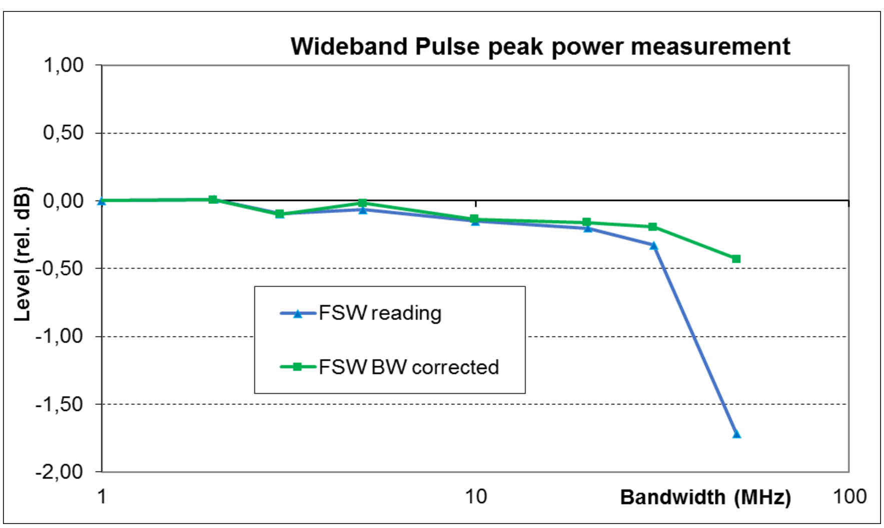

Fig. 7: Pulse peak power reading versus RBW setting for very short pulses

The remaining error at 50 MHz RBW is due to the limited video bandwidth. The VBW for pulsed measurements should be at least 3 times wider than the RBW, which is not possible due to the bandwidth limitation to 80 MHz in the signal processing.

4.2 Frequency converter bandwidth limitations

Besides the bandwidth limitation in the RBW and signal processing stages of the spectrum analyzer there may be also limitations in the RF converter stages.

Most spectrum analyzer in the market share a common architecture based on heterodyne receivers to convert the RF input signal to a final IF frequency. Depending on the RF frequency range of the instrument there are several converters for different frequency bands. The frequencies or band breaks mentioned in this application note refer to the R&S FSW spectrum analyzer platform. Other instruments may use a similar architecture with different frequency band breaks.

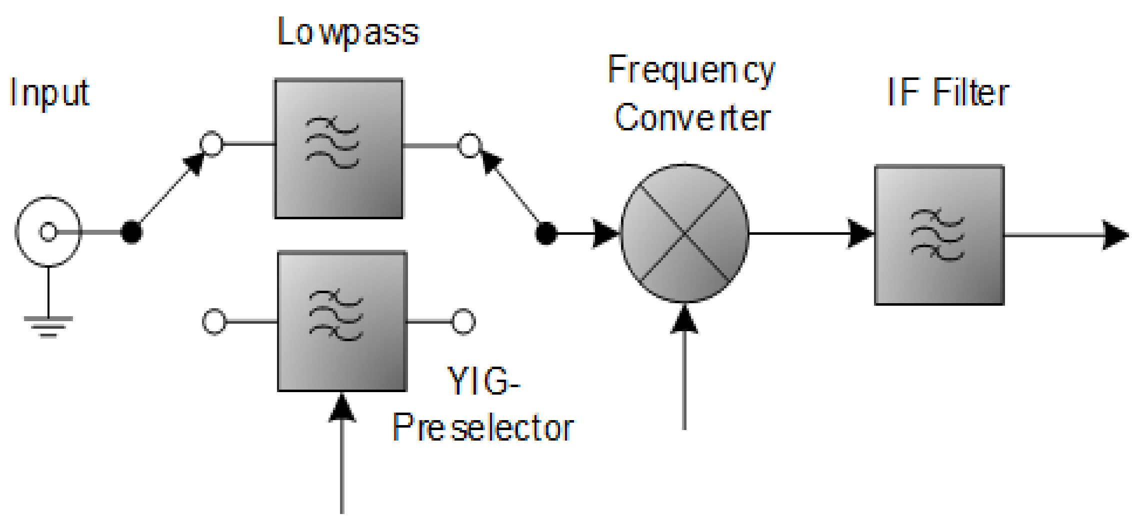

Fig. 8: Frequency converter block diagram of a Spectrum Analyzer

The heterodyne receiver converts the input signal with the aid of a mixer and a local oscillator (LO) to an intermediate frequency (IF). With a tunable local oscillator frequency the complete input frequency range is converted to a constant intermediate frequency by varying the LO frequency. In practice there are typically several frequency conversion from the RF to the IF frequency. Each of these conversion stages uses band-pass filters to suppress unwanted sidebands from the mixing process, and the available bandwidth of these filters may influence the total measurement bandwidth of the analyzer.

The RF converter for the lower band input frequencies (below 8 GHz in case of the FSW) has most often a wideband architecture that covers up to several hundred MHz of signal bandwidth. In this frequency range no bandwidth limitations will occur as the converter bandwidth is much wider than the RBW of 50 MHz bandwidth. In case of the R&S FSW the RF converter for the frequency range below 8 GHz has more than 500 MHz RF bandwidth. For measurement of UWB signals in the frequency range from 3.1 to 8 GHz this RF converter works without any bandwidth limitations.

The microwave converter covers RF frequencies from 8 GHz to the upper limit of the spectrum analyzer. In most cases this microwave receiver uses a swept preselection band-pass filter with limited RF bandwidth, the so called YIG filter. This filter is needed to suppress the unwanted sideband images of the frequency conversion stages in this frequency range.

The RF bandwidth of the YIG filter varies over the RF frequency that the filter is tuned to, which is the center frequency in zero span or the actual tuned frequency in a sweep. The typical bandwidth of the YIG filter starts at about 30 MHz for RF frequencies around 4 GHz, and increases over the RF frequency to about 80 MHz at 50 GHz RF frequency. In the frequency range of interest for UWB measurements from 8 to 10 GHz, the YIG filter bandwidth is only 35 to 40 MHz and thus may have an influence on the effective RBW. This influence comes from the fact that the band-pass characteristic of the YIG filter is overlaid to the Gaussian shape of the RBW filter. This is illustrated in the following figure for some RBW settings.

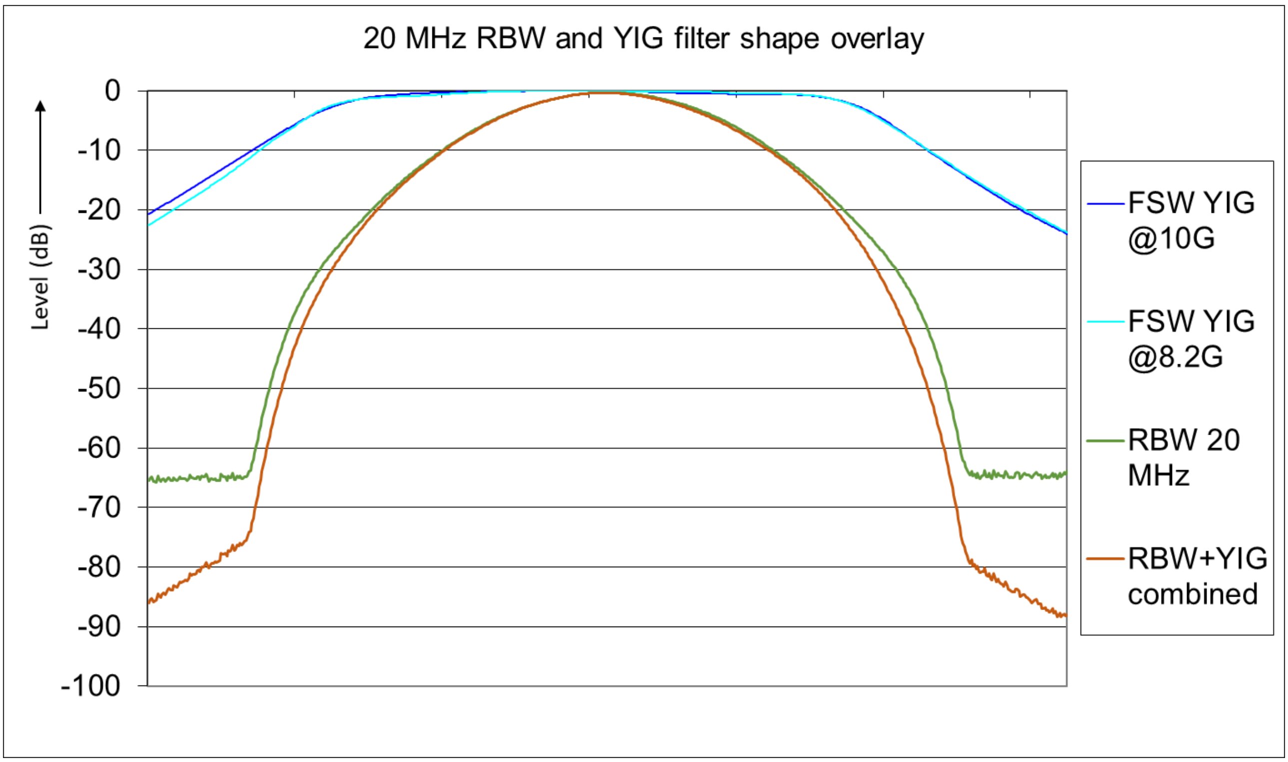

Fig. 9: Frequency response of YIG filter and 20 MHz RBW in the FSW Spectrum Analyzer

The above figure shows the combination of the YIG pre-selector band-pass and the 20 MHz wide RBW filter. On the plot we see the frequency response of the YIG filter, in this example settled to the lowest and highest frequency of interest for UWB measurements at 8.2 GHz and 10 GHz. The green trace shows the Gaussian shaped 20 MHz RBW filter, both plots share the same frequency axis. The red trace shows the combination of both filters. As we see, there is almost no effect on the RBW filter shape due to the YIG pre-selector filter. No additional level error will happen in wide bandwidth signal measurements in this case.

Most users are not aware of this bandwidth limitation in a microwave spectrum analyzer.

The next step is to perform the same measurement with wider RBW filtering.

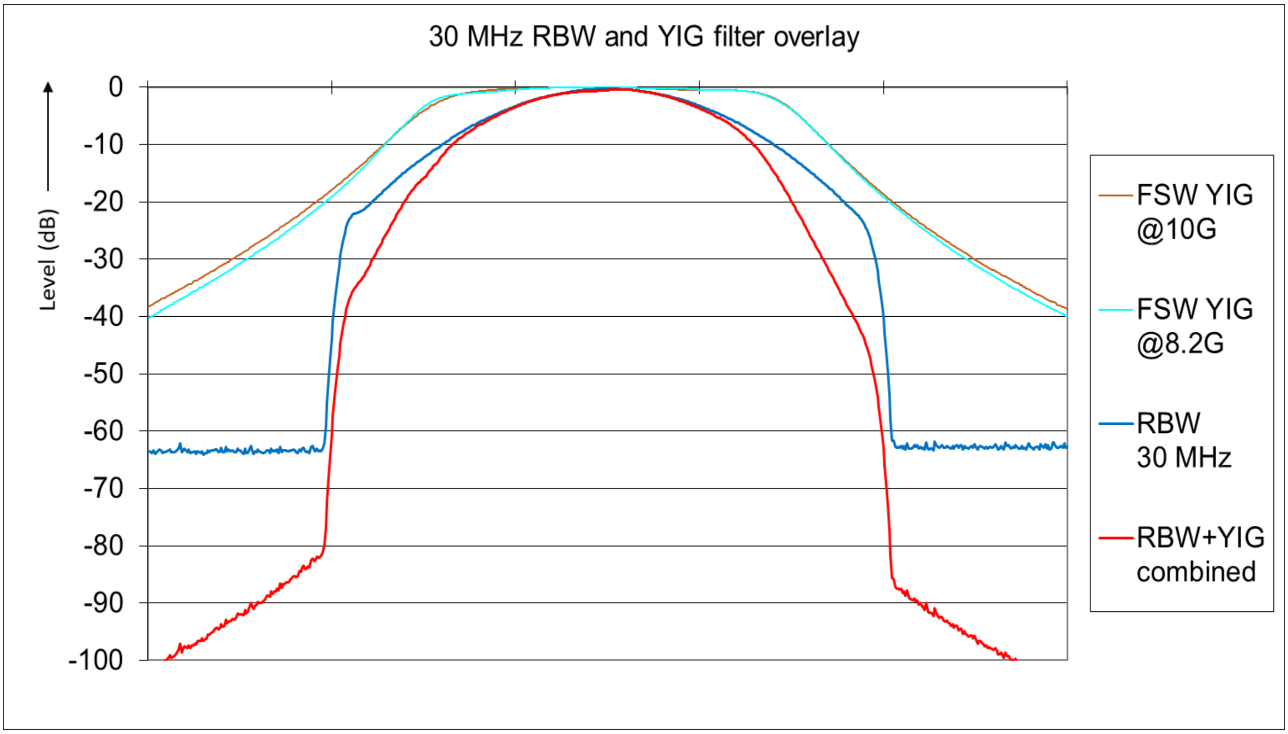

Fig. 10: Frequency response of YIG filter and 30 MHz RBW in the FSW Spectrum Analyzer

In this case the bandwidth of the YIG is just a little bit more than the RBW filter. It is important to know that the bandwidth specification of the YIG filter describes the flat part of the pass-band filter curve and thus has no influence on the upper level part of the Gaussian shaped RBW filter. For lower levels (about 10 dB below the peak level) we can see that the YIG filter starts to influence the Gaussian shape of the RBW filter. In this case of 30 MHz RBW the effect on the effective pulse bandwidth can be calculated and results in an additional error of 1 dB. This error is within the level measurement accuracy in this frequency range and thus the 30 MHz resolution filter can be used with no risk and no additional correction factor.

However, any wider RBW with 40 MHz or even 50 MHz at these low RF frequencies will be affected by the YIG pre-selector filter and thus level errors will occur in peak wideband signal measurements. The additional error in case of 50 MHz RBW at 8 GHz is about 3 dB and thus has an influence on the measurement accuracy.

The R&S FSW monitors the settings of the RBW filter and the used frequency range and notifies the user in case of a bandwidth limitation due to the YIG pre-selection filter. The available resolution bandwidth without a warning is 30 MHz at 8 GHz RF frequency, increasing to 50 MHz bandwidth above 40 GHz receive frequency.

A warning message on the screen informs the user whenever the RBW setting is wider than the available bandwidth due to the YIG pre-selection bandwidth.

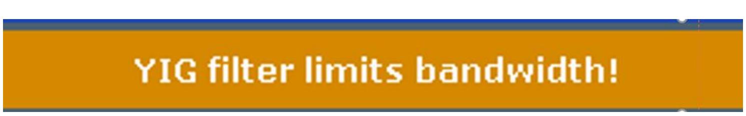

Fig. 11: Warning message for bandwidth limitations from the YIG filter

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 power of wideband 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. An option allows to increase the available resolution bandwidth above 10 MHz in order to perform measurements according to the standards.

A very small correction factor may be used to make accurate measurements of the peak power in order to compensate effects of the RBW limitations (pulse bandwidth). In any case of bandwidth limitations within the RF signal path the user is warned in order to avoid wrong measurements.

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

Designation	Type	Order No.
Signal- and Spectrum analyzer 2 Hz to 8 GHz	R&S®FSW8	1312.8000.08
Signal- and Spectrum analyzer 2 Hz to 13.6 GHz	R&S®FSW13	1312.8000.13
Signal- and Spectrum analyzer 2 Hz to 26.5 GHz	R&S®FSW26	1312.8000.26
Signal- and Spectrum analyzer 2 Hz to 43.5 GHz	R&S®FSW43	1312.8000.43
Signal- and Spectrum analyzer 2 Hz to 50 GHz	R&S®FSW50	1312.8000.50
Signal- and Spectrum analyzer 2 Hz to 67 GHz	R&S®FSW67	1312.8000.67
Signal- and Spectrum analyzer 2 Hz to 85 GHz	R&S®FSW85	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) or FSW-B8E (Resolution Bandwidth max. 40 MHz).

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