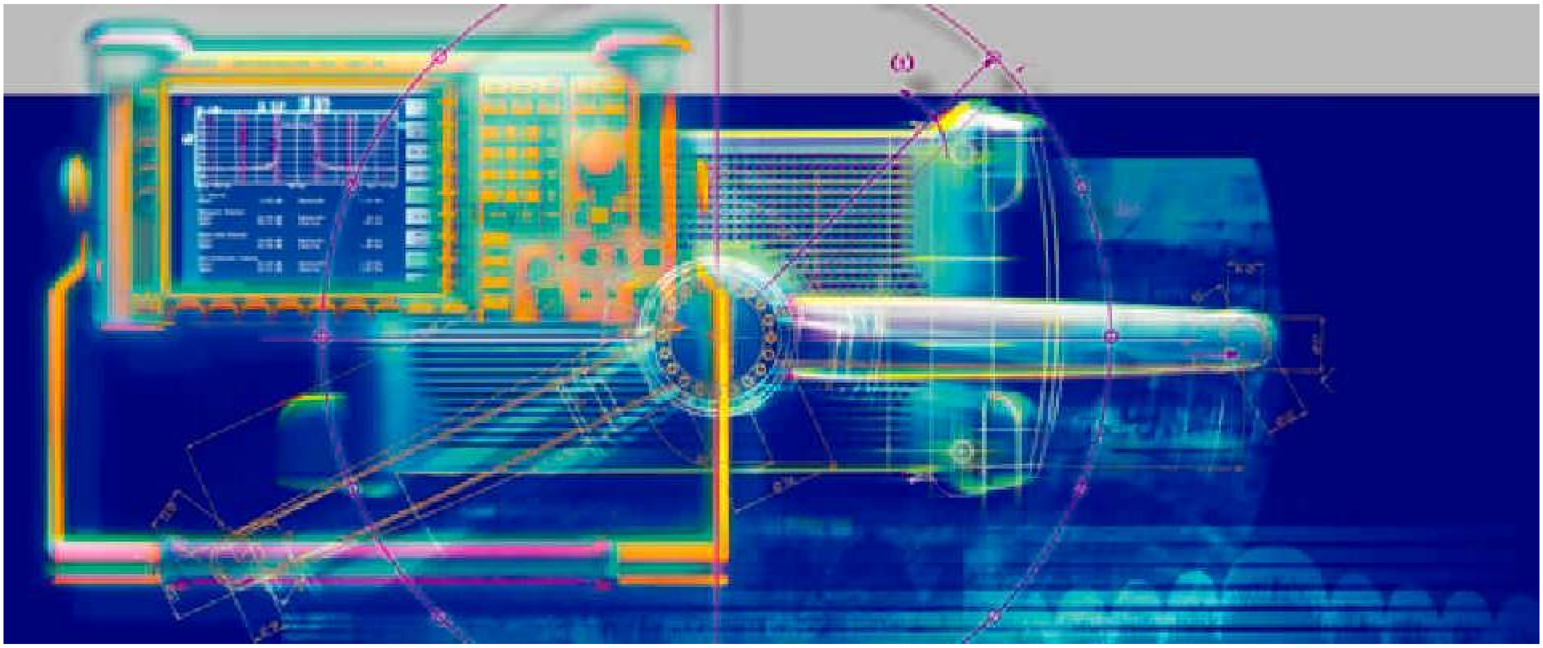

Product: Spectrum Analyzer Rohde&Schwarz FSP

Power Measurement on Pulsed Signals with Spectrum Analyzers

Application Note

This application note provides information about measurements on pulsed signals with a spectrum analyzer. Examples show the practical realisation of measurements like pulse width, peak power and mean power, and the limitations of spectrum analyzer measurements. A method for long time average power measurement is explained.

ROHDE&SCHWARZ

Contents

1 Overview

A spectrum analyzer is an important instrument for measurements on radar signals. Many of the different parameters of a radar signal, like carrier frequency, occupied spectrum, carrier ON/OFF ratio, pulse repetition frequency, rise-/fall-time, phase noise and peak power, can be directly measured with a spectrum analyzer.

Testing for output power is one of the important measurements on radar transmitters. For output power on a pulsed signal such as radar there are several different types of power measurements. Average power is one of the common measurements usually made as mean power measurements with power meters. Another very important value is peak power. With the knowledge of the Pulse Repetition Frequency (PRF) and the pulse width, one can calculate the peak power from the measured mean power. This function is available in many power meters.

This application note explains the use of the Rohde & Schwarz FSP spectrum analyzer family for the measurement of peak power and mean power on pulse modulated signals. The knowledge about pulse parameters of the radar is not necessary for this measurement. The recommended setups are supported by example measurements on a radar signal simulated by a signal generator.

2 Requirements

Modern radar applications use continuously changing pulse parameters. The pulse width and pulse repetition frequency is not constant and depends on the radar mode. Due to these changing parameters, the calculation of peak power from mean power as measured with a power meter is not possible anymore. This application note shows how the measurement of peak power and mean power on these changing signals can be made with modern spectrum analyzers.

Additionally the measurement of mean power over a long time frame is explained. This is a very important measurement in the antenna field of radar transmitters for the protection against personal injury due to high power transmission, especially while the antenna is rotating.

3 Peak- and Mean Power Measurement

Modern spectrum analyzers display the frequency spectrum or the waveform of a signal in the time domain using a raster scan cathode ray tube (CRT) or a liquid crystal display (LCD). Characteristic for these displays is that the number of pixels in the level axis as well as in the frequency or time axis is limited. This leads to limited resolution for both level and frequency or time. To display the full amount of measurement data taken in a sweep, detectors are used to compress the data samples into the number of displayed pixels.

For the measurement of peak power, the spectrum analyzer offers a peak detector. The peak detector will display the highest peak within the measurement interval.

For the mean power measurement of amplitude modulated signals (like pulse modulation) the peak detector commonly used in spectrum analyzers is not appropriate, as the peak voltage is not related to the power of the signal. For power measurements the spectrum analyzers provides the sample detector or the RMS detector. The following figure gives an overview of the difference of the detector results on a symbolic graph:

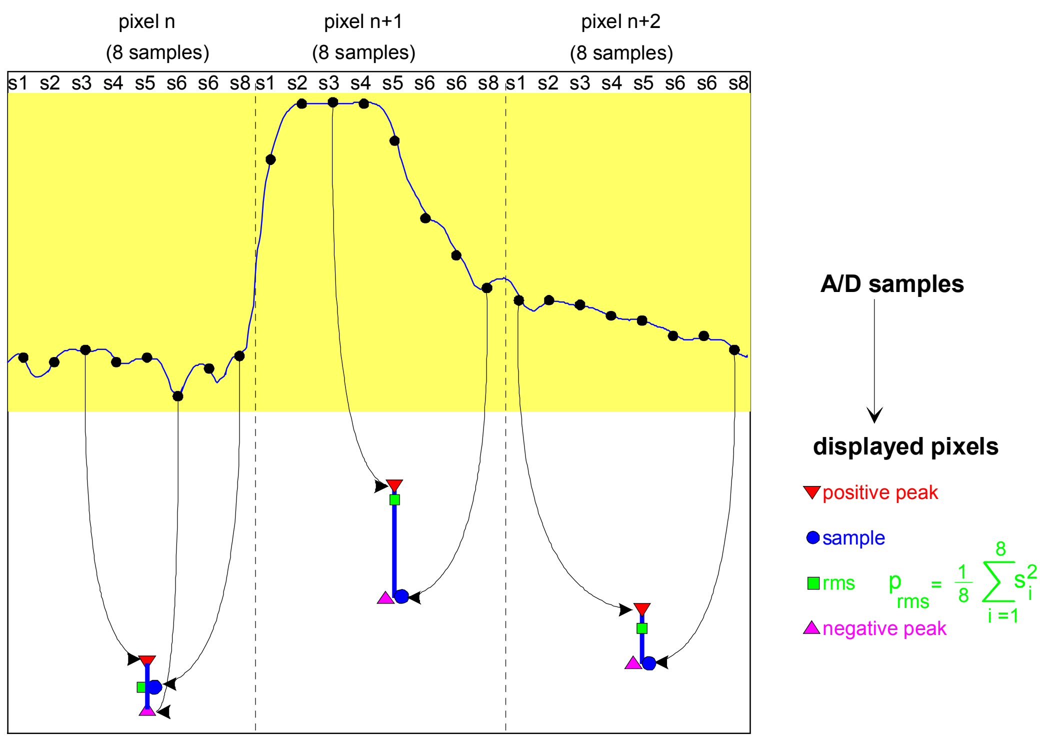

Fig. 1 Symbolic graph of data reduction on the display.

The displayed graph is using 8 samples per pixel as an example. The sample detector samples the envelope voltage once per measurement point (pixel) and displays the result on the screen. This can cause a total loss of signal information, because the complete information is reduced to the number of samples corresponding to the number of pixels available in the x-axis of the screen. However, the sample detector is the only detector available for power measurement of non-CW signals in many spectrum analyzers.

The peak detector will display the highest peak within the measurement interval (sample), while the negative peak will display the lowest level within the pixel. In Autopeak detector mode both peak and negative peak will be displayed and connected with a line on the screen.

With the RMS detector the envelope signal is sampled at the full sample rate of the A/D converter (R&S FSP: 32 MHz) and all samples within the range of one pixel are used for the RMS power calculation. Therefore the number of measurement samples is much higher compared to the sample detector. The following simplified block diagram shows the implementation of the RMS detector in the R&S FSP spectrum analyzer.

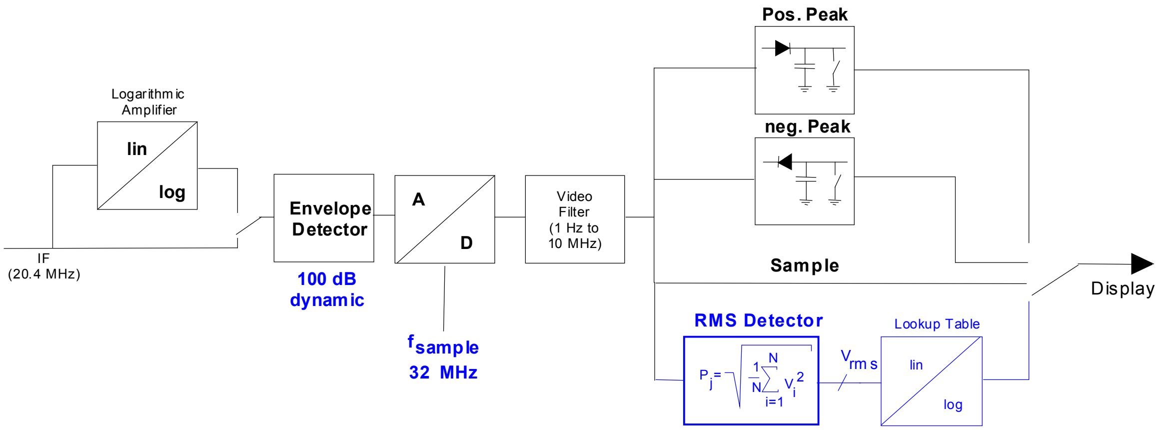

Fig. 2 Block diagram of the detector implementation.

All detectors are implemented separately. This allows using different detectors at the same time with separate result traces on the screen of the spectrum analyzer.

The RMS detector measures the power of the spectrum represented by a pixel by applying the power formula to all samples. For higher repeatability the number of samples per pixel can be controlled by the sweep time. With longer sweep times the time for power integration for each pixel increases. In the case of pulsed signals, the repeatability is dependent on the number of pulses within the pixel. For a stable RMS result, the sweep time must be set to a value long enough to capture several pulses within one pixel to get a smooth trace result.

The RMS detector calculates the RMS value of all samples linearly represented by a single pixel on the screen according to the formula:

$$P_{rms} = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} s_i^2}\,, \qquad (1)$$

where:

P_{rms} = level value of a single pixel
N = number of samples represented by the pixel
s = sample from A/D converter

For the accurate measurement of peak and mean power on pulse modulated signals it is important that the IF bandwidth and the A/D converter sampling rate of the spectrum analyzer is high enough not to influence the pulse shape. With the 10 MHz resolution bandwidth and 32 MHz sampling rate available in the R&S FSP spectrum analyzer, it is possible to measure pulse modulated signals down to 500 ns pulse width with high accuracy.

4 Performing the Measurements

Test Setup

This section shows how to set up the R&S FSP for mean and peak power measurements on a pulsed radar signal. For the measurement examples a signal generator is used to simulate the radar signal. The output signal is an AM-modulated RF carrier. The broadband AM modulation is done with an arbitrary waveform generator to generate a sequence of pulses with 500 ns pulse width and 1 kHz pulse repetition frequency. The pulse level is changed over time to simulate the effect of the antenna rotation for the long-term average power measurement.

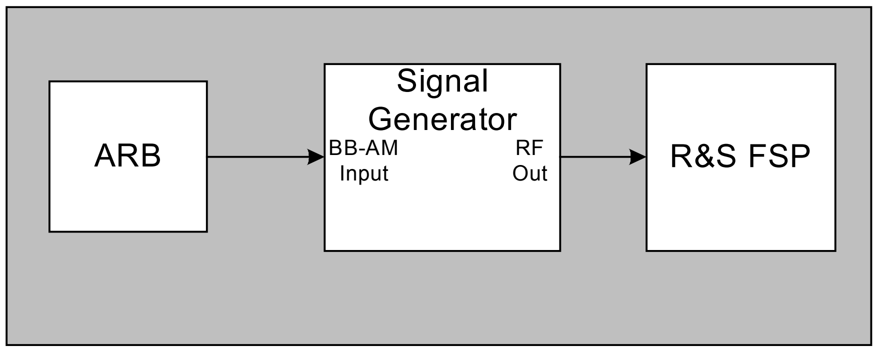

Fig. 3 Test setup for the measurement examples

Measurement examples

In the following section some basic measurements on the radar signal are presented. The measurements can be divided into the following categories:

- Measurements of basic parameters like peak power and pulse width.
- Measurement of the mean power using a channel power aproach.
- Measurement of average and peak power over long time periods.

Measurement of peak power and pulse width

Peak power and pulse width are some of the basic measurements on a pulsed radar signal. The peak power is a very important figure since all parts in the RF path, especially the power amplifier, will be loaded with this power for a short period of time. For the measurement of peak power the spectrum analyzer has to be set to a resolution and video bandwidth wide enough to settle within the pulse width. As a rough estimation, the settling time of the filter is approximately the inverse of the filter bandwidth:

$$T_{SET}\ (s) = \left[\frac{1}{RBW\ (Hz)}\right] \qquad (2)$$

where:
T_{SET} = settling time
RBW = Resolution bandwidth

This estimation holds very well for the gaussian shaped resolution filters used in spectrum analyzers. However, for the 10 MHz filter used in the R&S FSP, a factor of 2 for the calculated settling time has to be used to cover the fact that the 10 MHz filter is a channel type filter.

In the following measurement the RBW and VBW is set to 10 MHz bandwidth. The spectrum analyzer is set to Zero Span and displays the power over time. The sweep time is set to a value which will allows investigation on one single pulse. The spectrum analyzer uses video trigger to show a stable display of the pulse shape. The pulse width is varied, 3 measurements are plotted with 100 ns, 200 ns and to 500 ns pulse width to investigate the effect of the resolution filter settling time.

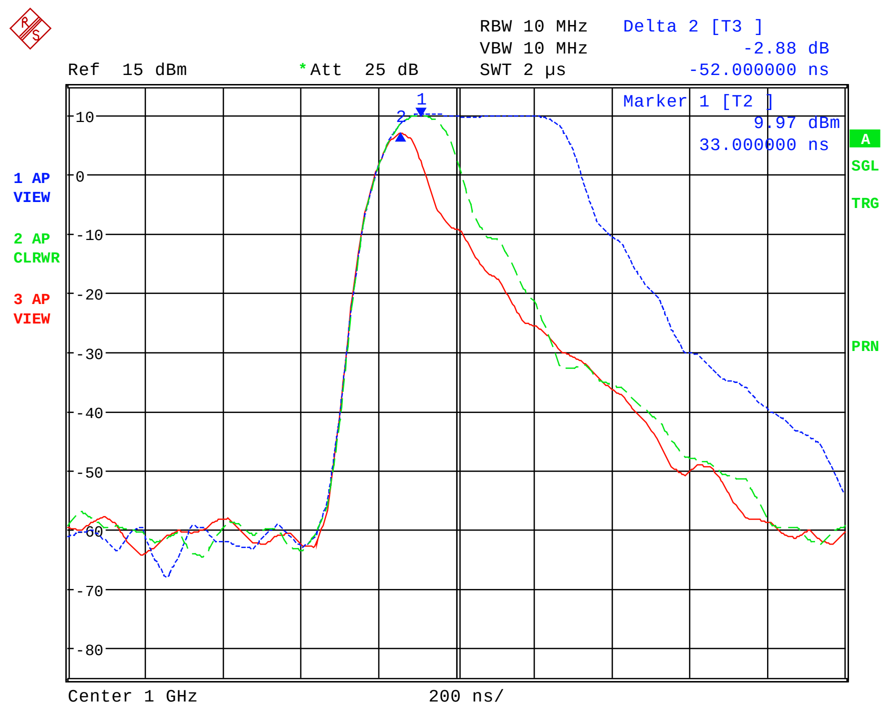

Fig 4: Peak power reading at the top of the pulse.

The figure above shows the three results of peak power measurement. The blue, dotted trace is measured with 500 ns pulse width and shows a flat response on the top of the pulse. The green, dashed trace is measured with 200 ns pulse width. This value is equal to the calculated settling time. The peak level in this measurement just reaches the value measured with the 500 ns pulse, the Marker 1 [T2] is set to the peak value and shows 9.97 dBm. This pulse width is the minimum value that can be accurately measured with the 10 MHz resolution bandwidth. The red, solid trace is measured with 100 ns pulse width, which is shorter than the settling time of the resolution filter. In this plot the delta marker reading “Delta 2 [T3]” is set to the peak value and shows a loss of about 3 dB versus the nominal pulse level.

The next step is a measurement of the pulse width:

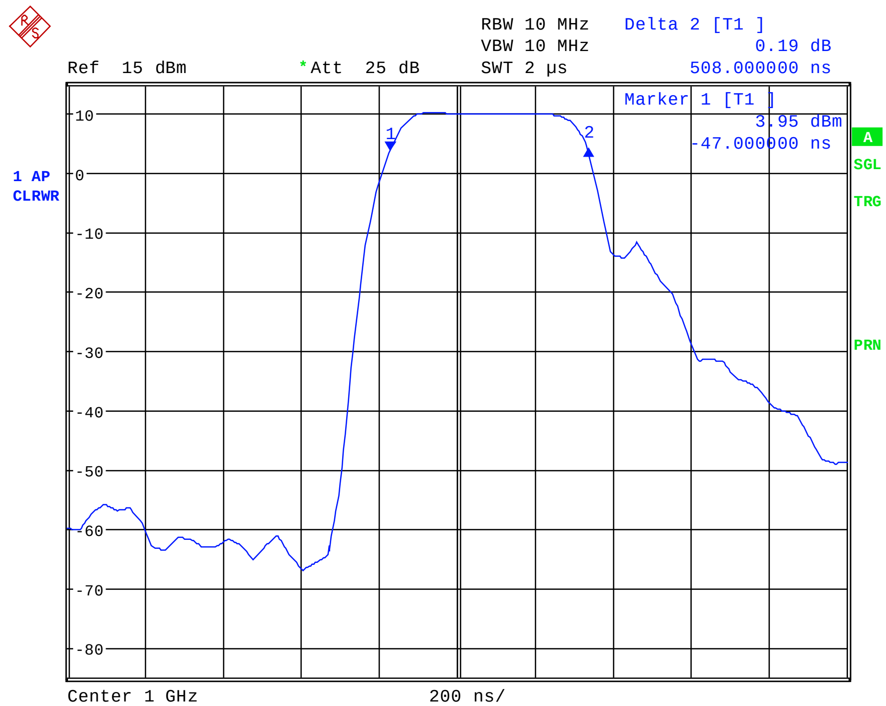

Fig 5 Pulse width reading with delta markers.

The pulse width is usually defined as the point where the signal level is at 50% of its average voltage across the pulse length. This point is at 6 dB below the peak level in a logarithmic level grid typically used on a spectrum analyzer. For the measurement of the pulse width, a marker is set to 6 dB below the average pulse power on the rising edge, and delta marker on the point 6 dB below the average power on the falling edge of the pulse. The level reading of the delta marker in this case should be 0 dB, due to the limited resolution of the measured points a small level difference has to be accepted. The reading of the delta marker "Delta 2 [T1]" in this measurement shows the pulse width of 508 ns. The accuracy of this measurement is influenced by the A/D converter sampling rate, which defines the positions within the trace where real measurement values are available. In between these points, the trace data is interpolated to generate the displayed points of the trace. The sampling rate of the A/D converter is 32 MHz, leading to measurement samples spaced by 31.25 ns.

Measurement of the mean power

Knowing the pulse width and the pulse repetition frequency (which can also be measured with the spectrum analyzer with a sweep time long enough to capture two successive pulses) one can calculate the mean power of the signal:

$$P_{MEAN} = P_{PEAK} + 10 \cdot \log[PW * PRF] \qquad (3)$$

Where:

P_{MEAN}	= Mean power of the pulse signal
P_{PEAK}	= Peak power of the pulse signal (10 dBm)
PW	= Pulse width (= 500 ns)
PRF	= Pulse repetition frequency (= 1 kHz)

In this case, with the pulse width of 500 ns and a pulse repetition frequency of 1 kHz, the above formula results in a mean power of -23.01 dBm.

Due to the pulse modulation the output signal of a radar transmitter is spread across a wide bandwidth. This behaviour can be seen on a spectrum analyzer as the well-known sin x/x spectrum shape. The individual spectral lines do not allow for a direct calculation of the peak or mean power. Without knowing the modulation parameters (like pulse width, PRF) the calculation of power is not possible at all.

For channel power measurement most modern spectrum analyzers provide software routines for calculating power within given channels. These routines calculate the power by integrating the power represented by the displayed trace pixels within the frequency range of the channel bandwidth (IBW = **I**ntegrated **B**and**W**idth). For the measurement of mean power each measurement point must be measured as mean power as well. This requires 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. By using a channel bandwidth broad enough to capture the main and several sidelobes of the signal, the mean power can be measured.

The figure below shows the measurement result of a channel power measurement. The channel bandwidth is set to a value of 10 MHz to capture the main lobe and both adjacent sidelobes.

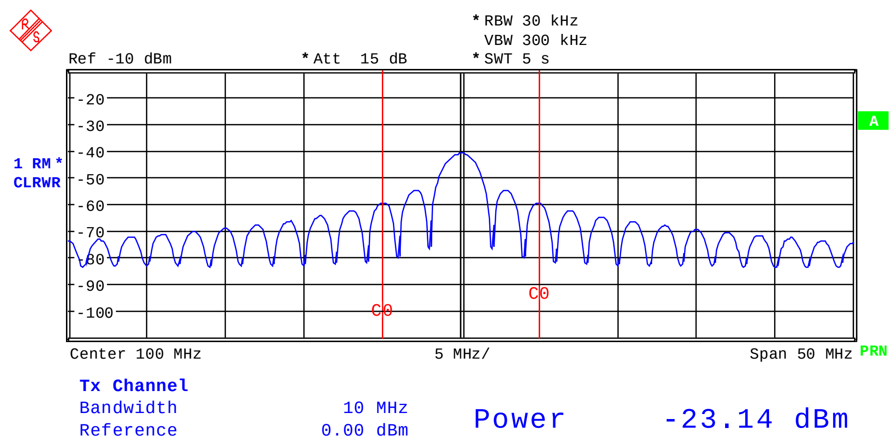

Fig 6 Channel power measurement with 10 MHz channel bandwidth.

The same measurement with 50 MHz channel bandwidth captures a little bit more than 10 sidelobes on each side:

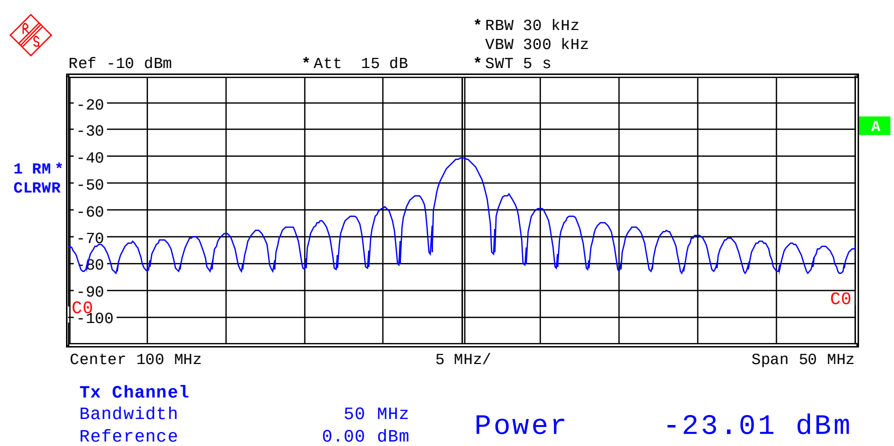

Fig 7 Channel power measurement with 50 MHz channel bandwidth.

The measurement result of -23.01 dBm channel power agrees with the calculated mean power of the pulse signal. Even the measurement with 10 MHz shows good agreement with the target value, since most of the power is concentrated in the main and the first adjacent sidelobes. For this method for measuring mean power of a radar signal, no knowledge of the pulse modulation parameters is necessary. This method is also usable for pulse signals with continiously changing pulse parameters.

Measurement of the average and peak power

A very important characteristic of a radar system is the average radiated power in the antenna field at defined distances. This measurement is important due to the fact that safety regulations describe power flux density limits as a protection for humans exposed to RF energy.
The measurement of average power is made over a defined time period, which must include at least a complete rotation of the antenna system. In this time frame the average and peak power must be measured. For the measurement of peak power the spectrum analyzer offers the peak detection. The measurement of average power requires the calculation of the RMS value of all samples within the time needed for at least one full rotation of the antenna system.
For this measurement task the R&S FSP provides a Summary Marker function, which calculates the RMS value from all measurement points (pixels) of one sweep. Together with the RMS detector, the result of this measurement is the average power of all samples collected within the sweep time.
For a rough simulation of changed power level due to a rotating antenna system, the level of the pulse sequence is varied over time for the next measurement. This level change is done in 6 dB steps every second over 4 steps, resulting in a sequence with 0, -6, -12 and -18 dB relative pulse level. Each 6-dB step equals a quarter of the power.
The expected average power can be calculated with the following formula:

$$P_{AVER} = P_{MEAN} + 10 \cdot \log\left[\frac{1}{4}\left(1 + \tfrac{1}{4} + \tfrac{1}{16} + \tfrac{1}{64}\right)\right] \qquad (4)$$

Where:
P_{AVER} = Average power of the complete signal sequence
P_{MEAN} = Mean power of the highest pulse sequence

This results in an average power of -4.8 dB below the mean power of the main pulse sequence (highest peak power) or a total average power of -27.8 dBm.
The figure below shows the summary power measurement of this pulse sequence together with the peak power measurement:

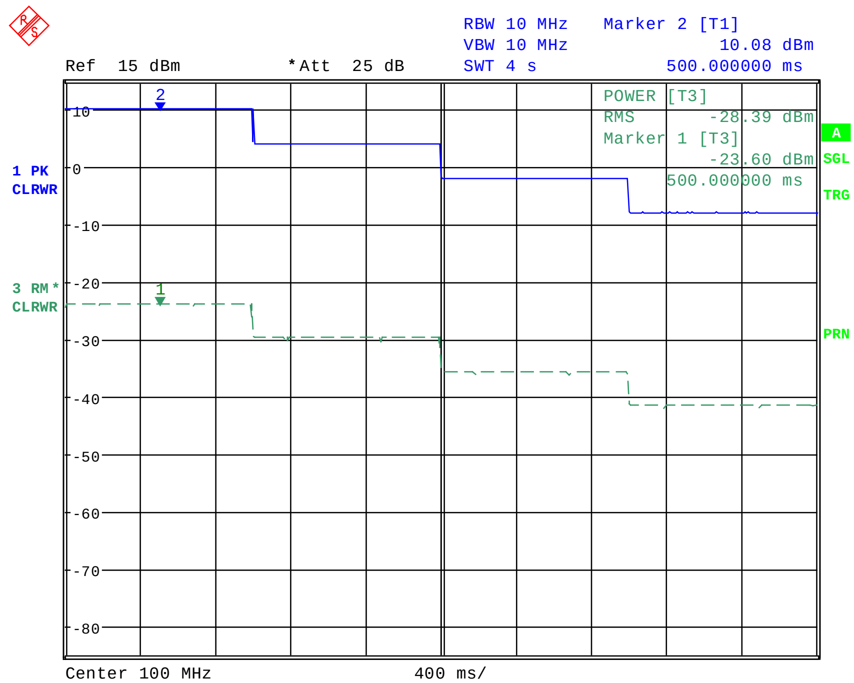

Fig 8 Summary power reading of mean power.

This plot shows the advantage of the parallel detectors available in the R&S FSP spectrum analyzer: In the upper Trace 1 (blue, solid) the measurement is done with a peak detector, with marker 2 settled to the peak value within the trace. The peak reading is +10.08 dBm (reading of Marker 2 on Trace1). At the same time the Trace 3 (green, dashed) is using the RMS detector to measure the mean power on each pixel. The marker on trace 3 is showing the highest value as -23.6 dBm. This directly compares to the previous channel power measurement, with a difference of -0.6 dB. This difference can be traced to the settling time of the 10 MHz resolution and video bandwidth filter, which starts to be the limiting factor with the short pulse width used.
The average power measurement function activated on Trace 3 calculates the mean power of all samples (pixels) within trace 3 and displays the result in the upper right edge of the screen as POWER [T3], RMS -28.39 dBm. This value agrees well with the calculated average of the used sequence, which results in a value of -28.4 dBm (-23.6 dBm -4.8 dB).

Sources of measurement errors

As already mentioned in the section above, the measurement of pulse signals with high modulation frequencies will introduce some additional level errors besides the well known level uncertainty of a spectrum analyzer:

- errors of average power due to different or wrong period time
- errors due to the sampling rate of the RMS detector.

The average power measurement of periodic events requires an accurate setting of the measurement time. The overall measurement time must include an integer number of periods of the modulated signal to aquire the average power. This is very important if one or a few periods are measured. In the above example with the 4-level stepped pulse signal, the period of the amplitude modulation that simulates antenna rotation is 4 seconds. If the measurement time of the average power measurement differs from 4 seconds, this may result in a capture of two successive peaks or minimum peaks, depending on the start position of the measurement. The following plot shows a measurement with 4.4 seconds sweep time:

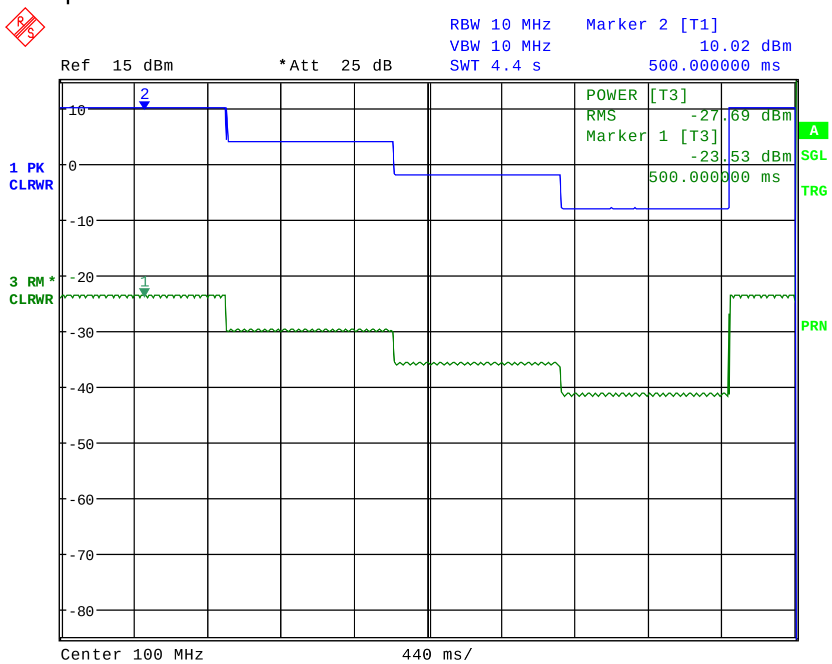

Fig 9 Summary power with wrong measurement time.

The result of the average power measurement in this example shows a value of -27.69 dBm, compared to -28.39 dBm in the measurement with the correct sweep time an error of +0.7 dB. Shifting the peak to the center of the screen can reduce this error:

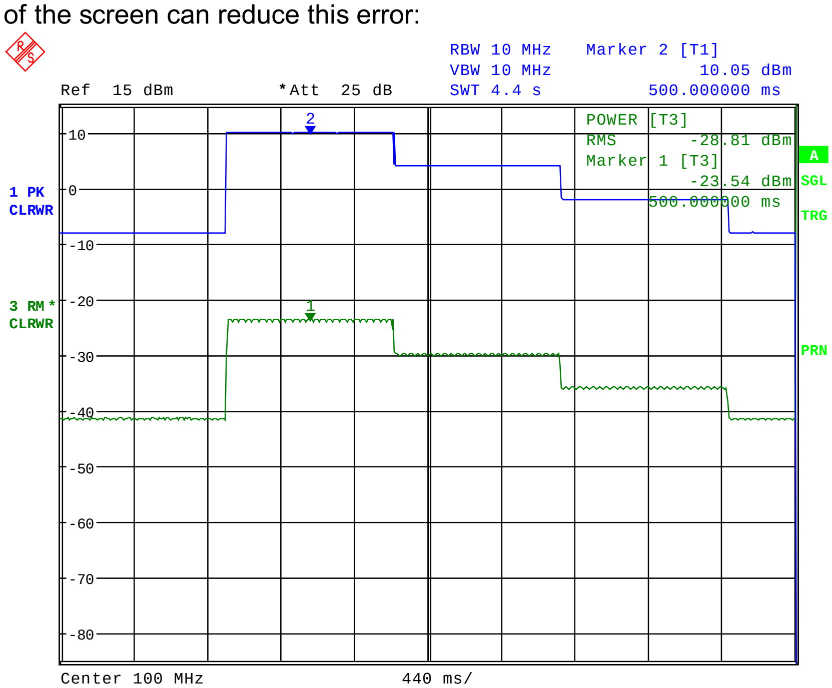

Fig 10 Summary power with shifted measurement.

Thus the measurement only includes one peak, while the additional area with low level does not change the overall power too much. The reading of the average power is -28.81 dBm, which is only -0.4 dB lower than the measurement with correct sweep time.

Another source of error is the sampling rate of the RMS detector. The lower trace (Trace 3, RMS detection) in the above measurement shows a small ripple. For use with pulsed signals, the 32 MHz sampling rate results in a time resolution (T_{Sample}) of 31.25 ns.

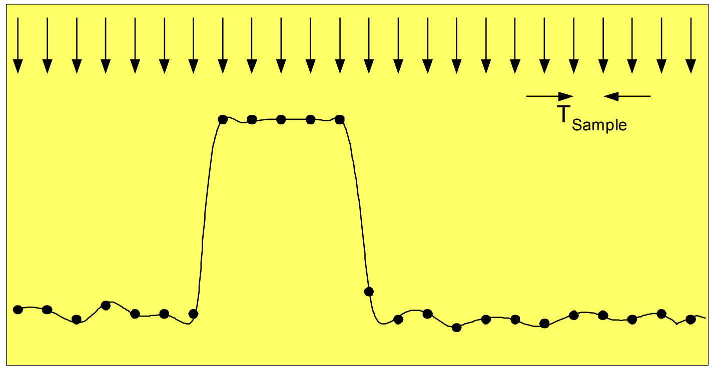

Fig 11 Sampling of a pulse signals in time domain.

The above drawing shows the sampling of a pulse. In this drawing the pulse is captured by 5 samples. In the example with the 500 ns pulse with at 1 kHz PRF, the peak will be captured by a maximum of 16 samples (500 ns / 31.25 ns = 16). In the worst case the pulse is shifted by half of the sampling period, this results in only 15 samples on the peak of the pulse. In this case the mean power of the signal will be -23.3 dBm, which equals a maximum error of 0.3 dB due to the missing sample. For longer pulses or higher PRF this effect can be neglected since there are more pulses within the pulse width.

5 Literature

[1]) Josef Wolf and Bob Buxton, "Measure Adjacent Channel Power With a Spectrum Analyzer, " *Microwaves & RF*, January 1997, pp. 55-60.

[2] Application Note 1EF45_E, "Spurious Emission Measurement on 3 GPP Base Station Transmitters"

[3] Application Note " Pulsed Signal Spectrum Analysis", Morris Engelson, Tektronix Inc, 5/93

6 Ordering information

Type of instrument

		Order number
Rohde & Schwarz FSP30	9 kHz to 30 GHz	1093.4495.30
Rohde & Schwarz FSP40	9 kHz to 40 GHz	1093.4495.40
Rohde & Schwarz FSU26	20 Hz to 26.5 GHz	1129.9003.26

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