Peak and Mean Power measurements on wideband FMCW radar signals
Application Note

Products:

- R&S®FSW

Modern automotive radar systems occupy very wide bandwidth in order to have a good location resolution. In most cases the bandwidth is a result of frequency modulation or fast frequency hopping techniques, in some cases also pulse modulation is used. Besides the measurement of the frequency variation over time like deviation and linearity, the verification of emissions according to EN or FCC standards is mandatory. ETSI regulations for measuring peak transmission power from radar operating at 77-81 GHz require 50 MHz resolution bandwidth for the measurements. Publications are available that describe the measurements on pulsed UWB or MB-OFDM signals in detail, for frequency-modulated signals the information is limited.

This application note provides information how to perform spectral emission measurements on frequency modulated CW 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:

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Application Note

Kay-Uwe Sander

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1 Introduction

With increasing object resolution requirements for the future of fully autonomous driving, the bandwidth of automotive radars is going to increase rapidly. Most radars installed in passenger cars use a frequency modulated continuous wave (FMCW) signal, for example a linear frequency ramp (chirp). The resolution of a FMCW radar is proportional to the bandwidth of the chirp, and to improve the resolution the radars will use wider frequency modulation.

With the allocation of several GHz of bandwidth for automotive radars, 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. 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 for 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 frequency modulation 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 FMCW signals. The next sections will give further details.

2 Review of FMCW Signal Measurements

2.1 Fundamentals of the FMCW Signal

Measurements on frequency-modulated signals with the spectrum analyzer require some knowledge of the modulation parameters and the important spectrum analyzer settings such as resolution bandwidth (RBW) and sweep time.

The typically used signal type in automotive radar is a linear frequency ramp modulation (chirp). The important parameters for level measurements of this signal type are the frequency deviation and the chirp rate or chirp length.

Figure 1: Demodulated chirp signal showing frequency deviation and chirp length

The above screen shot shows the result of a frequency demodulated radar chirp in time domain view. The frequency of the signal sweeps linear upward between the minimum and maximum frequency. The frequency deviation describes the maximum frequency change of the RF carrier frequency. The signal in this screen shot has a nominal deviation of 500 MHz, we can see the maximum (+ peak) and minimum (–Peak) reading of the FM demodulator in the screen shot. This parameter has a direct impact on the occupied bandwidth of the FM chirp signal. The chirp length or chirp rate describes how fast the frequency sweep is done between the minimum and maximum frequency, in this case the ramp takes 10 us.

The spectrum of such a frequency-modulated signal consists of many spectral lines across the occupied frequency range, the spacing of these lines is equal to the chirp rate. When measuring the spectrum with a resolution bandwidth (RBW) set to a value significantly less than the chirp rate the individual spectral lines can be resolved.

Most level measurements on the chirped radar signals are performed with RBW settings much wider that the spectral line spacing of the signal. In this case the analyzer will display the envelope of the spectrum. The amplitude of the envelope spectrum depends on the resolution bandwidth, the chirp rate and the frequency deviation.

Figure 2: Typical spectrum of a chirped signal showing equal level across bandwidth

The above screen shot in figure 2 shows the envelope spectrum of the chirped signal from the previous demodulation measurement with a carrier power of 0 dBm.

The marker 1 on the trace reads a peak power of -16.35 dBm in 1 MHz resolution bandwidth. The reason for the low reading is the fact that the RBW filter does not settle to the real peak power of the signal. In the normal operation of a spectrum analyzer the sweep time is adjusted in a way that allows the RBW filter to settle for a correct level reading. In this test case the sweep of the analyzer is set very slow in order to see the complete envelope of the signal, but the signal itself performs a very fast sweep. The observation time (the time while the frequency of the input signal is within the 1 MHz bandwidth) is much shorter than the settling time of the filter. The input signal sweeps across 1 GHz in 10 us, or just 10 ns/1 MHz, while the settling time for a gaussian shaped 1 MHz wide RBW filter is about 1/RBW or 1 us in this case.

Most modern spectrum realize the RBW filtering in digital signal processing. The transient response of digital filters is defined and known. Using suitable correction factors, digital filters allow shorter sweep times than analog filters of the same bandwidth. The same correction factors can be used to calculate the true peak power of the chirp signal when the measurement is performed on the non-settled narrow RBW filter. The correction factor for chirps depends on the span (peak-to-peak deviation), the chirp length and the RBW:

$$\mathbf{CF_{chirp}} = \mathbf{5} * \mathbf{log}\,(\mathbf{1} + \mathbf{K} * \left(\frac{\mathbf{Span}}{\mathbf{t} * \mathbf{RBW^2}}\right)^{\mathbf{2}}$$

with t being the length of the chirp and K a correction factor for the settling process of the gaussian shaped filter (~0.1947).

Measurements that do not fall below the settling time of the filter will not require any correction factor and are thus easier to perform. 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 usually defined to use 50 MHz measurement bandwidth.

3 Test setup for FMCW radar signals

The FMCW chirp correction 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:

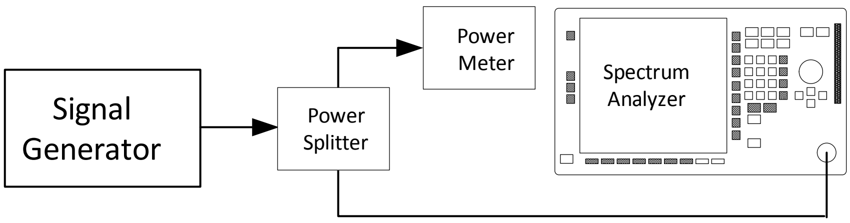

Figure 2: Test setup for FMCW measurements

The R&S vector signal generator SMW generates the frequency-modulated signals with various chirp length and frequency deviation. The output signal of the generator is divided, and a thermal power sensor measures the true average power of the FMCW 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 FMCW signals

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

The peak power of the chirped signal is measured directly with a marker, depending on the chirp rate and the used RBW the required correction factor is calculated and added. 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 peak power results when using the chirp correction factor in the 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 frequency modulation settings in all tests are using a linear FM chirp with 1 GHz frequency deviation from peak to peak.

As a simulation of common automotive radar signal types, the chirp rate is varied to cover a range of chirp rates. The goal was to verify the required correction factors on different chirps. The following chirp length range is used:

Chirp length: 10 us, 20 us, 50 us, 100 us

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 the correction factor. Measurements are performed with the following range of RBW settings:

RBW: 1 MHz, 2 MHz, 5 MHz, 10 MHz, 20 MHz and 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 3 times wider (VBW = 3 * RBW) or limited to the maximum possible value of 80 MHz.

The following picture shows the complete test setup:

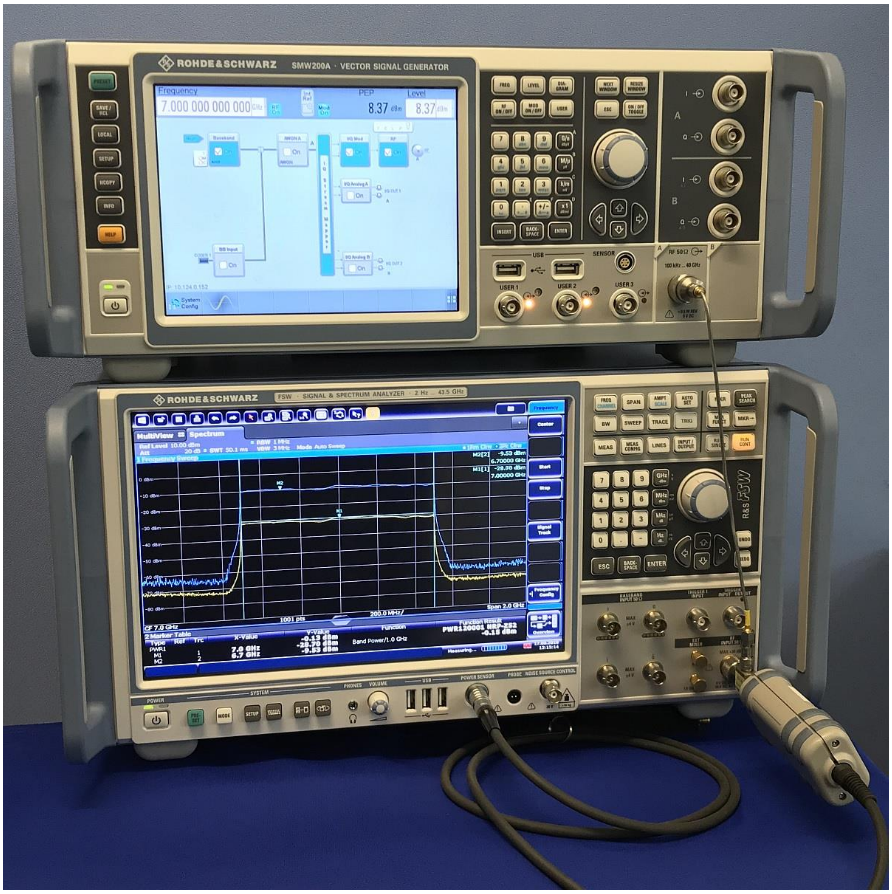

Figure 3: Picture of the test setup for FMCW measurements

4 Measurement results

The FSW spectrum analyzer is used to measure mean and peak power of the FMCW 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 chirps is captured in each point to get a reliable RMS result. A sweep time of 1 second will provide a 1 ms integration period for every measurement point (equals the chirp repetition rate). For the first example, the chirp length is set to 100 us and the level is set to 0 dBm (unmodulated CW signal level). The mean power for a frequency modulated CW signal is equal to the peak power as no amplitude variations occur in frequency modulation.

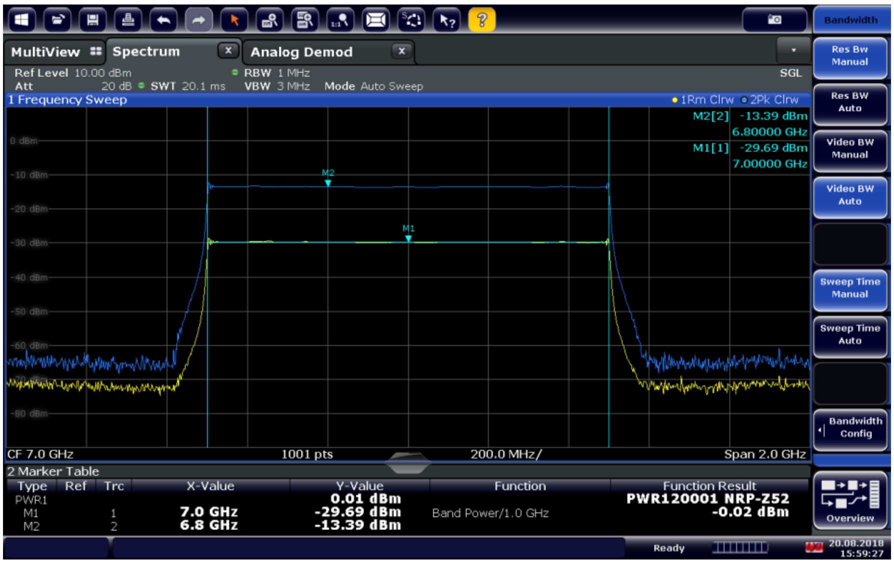

Figure 4: Test result display for mean and peak power of a chirped signal

The above screen shot shows an example of this measurement result for a signal with 20 us chirp length and a RBW of 1 MHz. Due to the frequency modulation, the output signal spreads across the 1 GHz bandwidth that is used as the frequency deviation of the chirp. The spectrum analyzer displays a flat level across the bandwidth of the signal as the power is spread equally for each frequency point for a linear frequency chirp.

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 the chirp signal the integration over the complete frequency deviation will allow the calculation of the mean power, since all of the energy is spread across the used spectrum. The channel bandwidth is set to a value of 1 GHz to capture the complete chirp bandwidth. The measurement result of -0.02 dBm band power (right lower part of the table) agrees very well with the mean power of the input signal. This method of measuring the mean power of an automotive radar signal requires no knowledge of the modulation parameters, as the occupied bandwidth is directly visible on the spectrum analyzer screen.

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 0.01 dBm, which is perfectly in line with expected value and very close to the band power measurement of the spectrum analyzer.

The FM spectrum does not allow for a direct reading of the peak power. Without knowing the modulation parameters (like chirp length and deviation) 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 trace 2 reads -13.39 dBm. To calculate the true peak power of the signal, the correction factor for chirps is required:

$$CF_{Chirp} = 5 * \log (1+ K * (Span / (\tau * RBW^2)^2)$$

$$= -5 * \log (1+ (0.1947 * (1\ GHz / (20\ us * 1\ MHz^2)^2)$$

$$= 13.44\ dB$$

The marker reading in trace 2 (-13.39 dBm) must be corrected with the calculated correction factor (13.44 dB) in order to figure out the peak power of the FM chirp signal. This calculation results in a peak power of 0.05 dBm, a very good agreement with the input signal. The following table shows the above measurement with various RBW settings to verify the mean power and peak power measurement on frequency modulated signals.

RBW	VBW	RMS power	Power Meter NRP-Z52	Channel Pwr FSW reading	FMCW Peak Corr. Factor	Peak Power FSW reading	
MHz	MHz	dBm	dBm	dBm	dB	w/o desens. Factor [dBm]	with desens. factor [dBm]
1	3	0,0	0,01	-0,01	16,45	-16,40	0,05
2	5	0,0	0,00	-0,02	10,44	-10,42	0,02
3	10	0,0	0,00	-0,03	6,99	-6,97	0,02
5	20	0,0	0,00	-0,01	3,07	-3,04	0,03
10	28	0,0	0,00	-0,02	0,39	-0,34	0,05
20	80	0,0	0,00	-0,05	0,03	-0,01	0,02
30	80	0,0	0,00	-0,06	0,01	-0,01	0,00
50	80	0,0	0,00	-0,24	0,00	0,03	0,03

Fig. 5: Test results of FMCW signal with 1 GHz / 20 us chirp and different RBW settings

For all tested settings the channel power reading of the FSW is in perfect alignment with the expected mean power of the signal. The power sensor and the FSW readings both show very good alignment to the signal level of 0 dBm. The Channel Power method provides very accurate average power measurements of frequency-modulated signals. The integration bandwidth must include the complete occupied bandwidth of the chirped signal. No further correction factor is required.

The peak power readings on the FSW shows 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 correction factor to make accurate measurements of FMCW signals. 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 correction factor) shows very good agreement.

The decision whether the peak correction factor must be used depends on the parameters of the chirp (span and length) and the RBW. The effect of the transition between the non-settled measurement and the true peak measurement is recognizable with a chart displaying the peak readings versus the RBW for different chirp length:

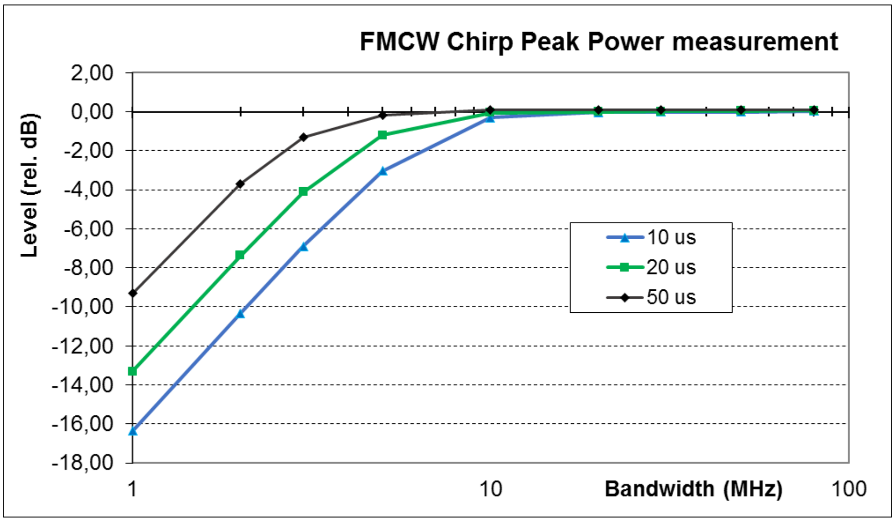

Fig. 6: FMCW peak power reading versus chirp length for 1 GHz wide chirps

For chirps slower than the settling time of the RBW filter the peak power of the frequency-modulated signal can be measured directly. In this case the resolution bandwidth filter has enough time to settle to the peak level and the accurate peak level is displayed without any correction factor. The rule for this decision is equal to the traditional spectrum analyzer minimum sweep time calculation:

$$\mathbf{SweepTime} = \mathbf{K} * \left(\frac{\mathbf{Span}}{\mathbf{RBW^2}}\right)$$

In the above formula the factor K depends on the architecture of the RBW filter, for gaussian filters this factor is typically 2. As the sweep is performed by the measured signal, the span in the formula equals the chirp width, and the sweep time equals the chirp length. The calculation for some of the above used RBW filters gives the following results:

RBW	5 MHz	10 MHz	50 MHz
Min. Chirp Time	80 us	20 us	0.8 us

The above chart shows very good agreement with the theoretical values, the traditional formula is an easy way to decide whether a correction factor must be used for peak power measurements. FMCW chirps with 1 GHz bandwidth and chirp length as short as 1 us can be measured with the 50 MHz RBW filter in the FSW without correction factors.

In this section the fundamentals of mean and peak power measurements on FMCW 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 50 MHz bandwidth also available in the R&S®FSW.

5 Conclusion

The R&S FSW signal and spectrum analyzer equipped with the option R&S®FSW-B8 forms the basis of a solution to accurately measure peak and average power of wideband frequency modulated 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.

The measurement of the true mean power of a wideband frequency modulated signal is possible with the channel power measurement of the FSW spectrum analyzer, together with the built-in true mean power detector (RMS detector). No correction factor is required for this measurement.

For FMCW signals a correction factor may be required to make accurate measurements of the peak power of very fast chirp modulation in order to compensate effects of the RBW (measurement bandwidth). The correction factor for spectrum analyzers using gaussian shaped RBW filters is equal to the settling time of the RBW filters for fast sweep rates and well known. The requirement to use the correction factor can easily be determined with the traditional calculation method for the minimum sweep time of a spectrum analyzer.

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] R&S AN 1EF106, RBW influence on peak or mean power measurement of pulsed signals

[5] Keysight AN 5952-1039, Spectrum and Signal Analysis Pulsed RF

7 Ordering Information

R&S FSW8	Signal- and Spectrum analyzer 2 Hz to 8 GHz	1331.5003.08
R&S FSW13	Signal- and Spectrum analyzer 2 Hz to 13.6 GHz	1331.5003.13
R&S FSW26	Signal- and Spectrum analyzer 2 Hz to 26.5 GHz	1331.5003.26
R&S FSW43	Signal- and Spectrum analyzer 2 Hz to 43.5 GHz	1331.5003.43
R&S FSW50	Signal- and Spectrum analyzer 2 Hz to 50 GHz	1331.5003.50
R&S FSW67	Signal- and Spectrum analyzer 2 Hz to 67 GHz	1331.5003.67
R&S FSW85	Signal- and Spectrum analyzer 2 Hz to 85 GHz	1331.5003.85

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

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Regional contact

Europe, Africa, Middle East
+49 89 4129 12345
customersupport@rohde-schwarz.com

North America
1-888-TEST-RSA (1 888 837 87 72)
customer.support@rsa.rohde-schwarz.com

Latin America
+1 410 910 79 88
customersupport.la@rohde-schwarz.com

Asia Pacific
+65 65 13 04 88
customersupport.asia@rohde-schwarz.com

China
+86 800 810 82 28 |+86 400 650 58 96
customersupport.china@rohde-schwarz.com

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Rohde & Schwarz GmbH & Co. KG
Mühldorfstraße 15 | D - 81671 München
Phone + 49 89 4129 - 0 | Fax + 49 89 4129 – 13777

www.rohde-schwarz.com