Level Uncertainty Calculation for R&S®FSV Signal and Spectrum Analyzer

Application Note

Products:

- R&S®FSV3
- R&S®FSV7
- R&S®FSV13
- R&S®FSV30
- R&S®FSV40

This application note helps to understand the measurement uncertainty calculation for a modern spectrum analyzer and provides a tool to calculate the total measurement uncertainty for different measurements.

Application Note

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Table of Contents

1 Abstract

Ensuring accurate RF level measurements is perhaps the most basic element in the RF measurement process. Although a power meter can provide a high degree of accuracy for moderate RF levels, a spectrum analyzer such as the R&S®FSV can provide more flexibility and measurement speed especially for low level signals.
This application note helps to understand the measurement uncertainty calculation and provides a tool for a modern spectrum analyzer to calculate the total measurement uncertainty for different measurements.

2 Overview

RF level or power measurement especially of modulated signals is one of the basic tasks in RF measurements . Whereas the first choice in terms of accuracy for power measurement of any carrier (modulated or non-modulated) is a power meter, level measurement of spurious signals or in the adjacent channel of a transmission system requires a selective measurement with high dynamic range like a spectrum analyzer. A power meter is a non-selective device that measures power levels over a wide bandwidth with limited dynamic range and is not appropriate for these types of measurements.
A spectrum analyzer is the prefered solution because of its selectivity. Compared to a power meter its power measurement accuracy is lower. In general this can be overcome by substitution methods using a power meter, an attenuator and a signal generator. But substitution is time-consuming and requires more investment in test equipment than a single instrument. Therefore, it is most important to have a spectrum analyzer, which can fulfill at least most of the requirements in terms of measurement accuracy.
The R&S®FSV signal and spectrum analyzer offers outstanding level measurement accuracy. Where the power meter measures power levels with a wide bandwidth, a spectrum analyzer benefits from a narrowband front-end architecture. When spurious signals or adjacent channel power must be measured, filtering and frequency selection become more critical to accurately determine low-level signals.
The R&S®FSV incorporates a superheterodyne swept-frequency front end with analog RF and intermediate-frequency (IF) Downconversion stages, leading to a high-speed analog-to-digital converter (ADC) with excellent linearity. Once test signals are digitized, additional signal processing is handled by means of a digital signal processing and its digital filters to achieve power-meter-like accuracy during narrowband, low-level measurements.

The uncertainty when measuring power can be divided into three classes:

- Inherent measurement uncertainty of the signal analyzer
- Error due to the device-under-test, e. g. impedance of the RF interface and
- Error due to limited signal-to-noise ratio

3 Level Uncertainty Calculation

3.1 Method of the Level Uncertainty Calculation

The overall measurement uncertainty with power measurement consists of different errors contributing to the total error. The method of calculating the total uncertainty of a measurement is to calculate the standard deviation for the distribution of the accumulated error (BIPM method, International Bureau of Weight and Measures). It is assumed that all errors are stochastic and the total error is Gaussian distributed. This is true if the total error is a combination of many individual errors, where the latter are not necessarily Gaussian distributed.
Therefore the measurement uncertainty can be calculated for a required confidence level. Calculating the standard deviation of the accumulated error is achieved by combining the standard deviations of the individual errors that contribute to the measurement uncertainty. Therefore the distribution of the individual errors should be known or assumed.
The standard deviation for the total accumulated error distribution corresponds to a level of confidence of 68 %. This is true when the number of the individual errors is high and all errors are of a similar magnitude. The resulting distribution of the uncertainty can then be approximated by a normal distribution. Therefore other levels of confidence can be calculated using a coverage factor (Confidence level should be stated in test reports to allow users to calculate other measurement uncertainties).
Coverage factor for a level of confidence of 95 % is 1.96, for 99 % level of confidence the coverage factor is 2.58.

Error distributions and standard deviations

For systematic errors a rectangular distribution is assumed, unless the actual distribution is known. This means that the error is distributed with equal probability anywhere between the error limits. The error limits can be converted into the standard uncertainty or the statistical variance:

error limit ± a, variance $\sigma^2 = \frac{a^2}{3}$.

Systematic errors are for example the frequency response, the input attenuator uncertainty or the linearity of the logarithmic display.

Random errors are Gaussian distributed (e. g. noise). Their standard deviation is known or calculated by means of repetitive measurement. Insufficient signal-to-noise ratio causes random errors.

Mismatch errors or errors caused by temperature deviations have a U distribution. This reflects the fact that the error caused by mismatch is more likely to be close to the limits than close to be small or zero:

error limit ± a, variance $\sigma^2 = \frac{a^2}{2}$

The variance of the total combined measurement uncertainty σ_{tot}^2 is calculated by summing the different variances σ_i^2:

$$\sigma_{\mathrm{tot}}^2 = \sigma_1^2 + ... + \sigma_n^2$$

The total combined standard uncertainty of the measurement σ_{tot} is calculated from its variance by taking the square root:

$$\sigma_{\mathrm{tot}} = \sqrt{\sigma_{\mathrm{tot}}^2}$$

The standard deviation has a level of confidence of 68 %. For other levels of confidence the standard deviation has to be multiplied with the coverage factor. The coverage factor for 95% confidence level is 1.96.

All errors have to be given in the same unit for calculation of the sum error. With the R&S®FSV most errors are available in dB. The bandwidth error is given in percent of the nominal bandwidth. It has to be converted to dB. Assuming a power measurement of a modulated signal the error related to the bandwidth error is as follows:

$$\mathrm{RBW\_error}\,[\mathrm{dB}] = 10 \cdot \mathrm{lg}(1 + \frac{(\mathrm{RBWerror})/\%}{100})$$

In the data sheet of a spectrum analyzer the different errors contributing to the total error are specified. To attain the overall level error for a specific measurement all applicable errors have to be summed. This is a tedious procedure, if it has to be performed at different levels or frequencies. With the signal and spectrum analyzer family R&S®FSV a total measurement uncertainty is specified for some specific settings, for example 0.28 dB for frequencies up to 3.6 GHz and a level between reference level and 70 dB below reference level. For frequencies up to 30 GHz the specified total measurement uncertainty is 1.32 dB. This frees the user from the need to calculate the error in many cases.

In cases when not all errors apply, for example with relative measurements, the specific error can be calculated from the different error sources.

3.2 Sources of Level Uncertainties

Different sources contribute to the overall level uncertainty of a spectrum analyzer.

These sources are:

- absolute level uncertainty of the internal calibrator source,
- frequency response of the RF input,
- uncertainty of the input attenuator switching,
- uncertainty of resolution bandwidth switching,
- display linearity of the detector

In the case of channel power measurement or adjacent channel power measurement also the error of the resolution bandwidth contributes to the measurement uncertainty:

- Resolution bandwidth uncertainty

The uncertainty of the IF gain setting (reference level switching) does not occur in the R&S®FSV as no IF gain switching is used in this instrument.

Another source of error is the signal-to-noise ratio. If it is insufficient, the noise signal is added to the signal to be measured and the result is a value higher than the actual value. The error depends on the detector used, as noise is weighted differently with different detectors. It is worst using the peak detector and is less critical with the sample or RMS detector.

If the signal-to-noise ratio is known, e.g. by measurement, the error can be corrected by subtracting the respective correction factor.

4 Level Uncertainty Calculation in practice

For level uncertainty calculation a spreadsheet is provided with this application note. It lists all the different items applicable for level uncertainty calculations.

Level Uncertainty Calculation for R&S FSV		
General Calculation		
Inherent errors	**specified error**	**standard uncertainty**
Absolute error @128 MHz [dB]	0.2	0.12
Frequency response [dB]	0.3	0.17
Input attenuator switching [dB]	0.2	0.12
IF Gain switching [dB]	0	0.00
Display linearity [dB]	0.1	0.06
Bandwidth switching error [dB]	0.1	0.06
Resolution Bandwidth error [%]	3.00	0.08
combined variance		0.07
combined standard uncertainty		0.26
rss error [dB] (95 % confidence level)		**0.52**
Error due to source mismatch		
VSWR of SA	1.5	
VSWR of DUT	1.5	0.25
combined variance		0.13
combined standard uncertainty		0.36
error including source mismatch (95%)		**0.71**

Fig 1 Spreadsheet for level uncertainty calculation

The specified error limits are taken from the R&S®FSV data sheet. They are valid in the frequency range from 10 MHz to 3.6 GHz and from reference level to 70 dB below reference level. For other frequencies and level ranges the respective values can be inserted from the specifications.

Additionally the error due to the source mismatch can be taken into account by entering the VSWR of the signal analyzer and the device under test.

The spreadsheet calculates the uncertainty with 95 % level of confidence from the individual errors.

If the R&S®FSV is used in connection with other devices in a test system, the calculated combined variance can be used to calculate the total uncertainty of the system.

The variance of uncertainty of the R&S®FSV is added to the variance of uncertainty of the other devices of the system. By taking the positive square root of the combined variance the overall uncertainty can be calculated with the requested level of confidence.

4.1 Example: Uncertainty calculation for phase noise measurements

Phase noise measurements are relative measurements of a CW signal. Therefore the absolute error at 128 MHz can be set to zero.

The frequency response is typically very flat over small frequency ranges. Therefore, the frequency response does not apply for phase noise measurements close to he carrier. This is valid for frequency offsets up to 1 MHz.

In case of phase noise measurements the resolution bandwidth is not changed in the measurement, the bandwidth switching error does not apply.

The IF gain switching error is always zero in the R&S®FSV.

Level Uncertainty Calculation for R&S FSV		
Example: Phase Noise Measurement		
Inherent errors	**specified error**	**standard uncertainty**
Absolute error @128 MHz [dB]	0	0.00
Frequency response [dB]	0	0.00
Input attenuator switching [dB]	0	0.00
IF Gain switching [dB]	0	0.00
Display linearity [dB]	0.1	0.06
Bandwidth switching error [dB]	0	0.00
Resolution Bandwidth error [%]	3.00	0.08
combined variance		0.01
combined standard uncertainty		0.10
rss error [dB] (95 % confidence level)		0.19

Fig 2 Level uncertainty calculation for phase noise measurement

In case of noise power measurements also the error of the resolution bandwidth compared to the nominal bandwidth contributes to the overall uncertainty. Therefore the error of the resolution bandwidth is included in the uncertainty calculation.

5 Literature

[1] ETSI Technical Report ETR 028: March 1994 Radio Equipment and Systems (RES); Uncertainties in the measurement of mobile radio equipment characteristics

[2] Guide to the Expression of uncertainty in Measurement; International Organization of Standardization, 1995

6 Ordering Information

Designation	**Type**	**Order No.**
Signal and Spectrum Analyzer	R&S®FSV3	1307.9002.03
Signal and Spectrum Analyzer	R&S®FSV7	1307.9002.07
Signal and Spectrum Analyzer	R&S®FSV13	1307.9002.13
Signal and Spectrum Analyzer	R&S®FSV30	1307.9002.30
Signal and Spectrum Analyzer	R&S®FSV40	1307.9002.40

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