Level Error Calculation for Spectrum Analyzers

Application Note 1EF36_0E

Subject to change

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Products:

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Abstract

Level or power measurement of especially modulated signals using spectrum analyzers is becoming more and more important . Whereas the first choice in terms of accuracy for power measurement of any carrier (modulated or non-modulated) is a power meter, power measurement of spurious or in the adjacent channel of a transmission system needs a selective power meter with high dynamic range. A power meter, however, is a non-selective device with limited dynamic range and is not appropriate for these types of measurements.

The first choice is a spectrum analyzer because of its versatile use as a general-purpose instrument. Compared to a power meter its power measurement accuracy is worse. 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 like the FSE, which can fulfill at least most of the requirements in terms of measurement accuracy.

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

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

1. Method of error 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 (BIPMmethod, 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.

Systematic errors have a rectangular distribution:

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

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), standard deviation 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:

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

Triangular distribution:

$$\text{error limit} \pm a,\ \text{variance}\ \sigma^2 = \frac{a^2}{6}$$

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

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

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

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

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

All errors have to be given in the same unit for calculation of the sum error. With the FSE 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 the power measurement of a modulated signal the error is related to the bandwidth error as follows:

$$error\ (RBW) = 10 \cdot lg(1 + \frac{(RBWerror)/\%}{100})$$

In the data sheets of spectrum analyzers 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 is to be performed at different levels or frequencies. Therefore with the spectrum analyzer family FSE an overall error is specified, for example < 1 dB for frequencies up to 1 GHz and a level between reference level and reference level - 50 dB. For frequencies up to 7 GHz the specified error is < 1.5 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, and less uncertainty is required, the specific error can be calculated from the different error sources.

2. Sources for Level Errors

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

These sources are:

- Absolute error of the internal calibrator source,
- Frequency response of the RF input,
- Error of the input attenuator,
- Error of the IF gain setting,
- Error of bandwidth switching,
- Linearity error of the logarithmic 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.

Another source of error is the signal-to-noise ratio. When 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.

3. Level Error Calculation for the FSE

For level error calculation an EXCEL5 spreadsheet (File ERROR.XLS) is provided with this application note. It lists all the different errors applicable for level accuracy calculations.

Error Calculation for FSE		
Inherent errors	**Specified error**	**Standard un-certainty**
Absolute error 120 MHz[dB]	0,3	**0,17**
Frequency response[dB]	0,5	**0,29**
Input attenuator[dB]	0,3	**0,17**
IF gain (dB)	0,2	**0,12**
Log linearity[dB]	0,3	**0,17**
Bandwidth switching error [dB]	0,2	**0,12**
Bandwidth error [%]	0%	**0,00**
Combined variance		0,20
Combined standard uncertainty		0,45
rss uncertainty [dB] (95 % confidence level)		**0,88**
Error due to source mismatch		
VSWR of SA	1,5	
VSWR of DUT	1,2	**0,11**
Combined variance		0,21
Combined standard uncertainty		0,46
Uncertainty including source mismatch		**0,90**

Fig 1 Spreadsheet for level error calculation

The specified errors are taken from the FSE data sheet. They are valid in the frequency range up to 1 GHz and from reference level to reference level - 50 dB. For other frequencies and level ranges the respective values can be input from the specifications.

With channel or adjacent channel power measurements also the error of the resolution bandwidth compared to the nominal bandwidth contributes to the overall uncertainty. Therefore also the error of the resolution bandwidth is included in the error calculation.

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

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

If relative measurements of cw signals without bandwidth switching are made e. g. for harmonics measurement the errors in the following table apply:

Error Calculation for FSE		
Inherent errors	**Specified error**	**Standard uncertainty**
Absolute error 120 MHz[dB]	0	0,00
Frequency response[dB]	0,5	0,29
Input attenuator[dB]	0	0,00
If Gain[dB]	0	0,00
Log linearity[dB]	0,5	0,29
Bandwidth switching error [dB]	0	0,00
Bandwidth error [%]	0%	0,00
combined variance		0,17
combined standard uncertainty		0,41
rss uncertainty [dB] (95 % confidence level)		**0,80**
Error due to source mismatch		
VSWR of SA	1,5	
VSWR of DUT	1,2	0,11
combined variance		0,18
combined standard uncertainty		0,42
uncertainty including source mismatch (95%)		**0,83**

Fig 2 Level error calculation for harmonic measurement

The error of log linearity has been changed from 0.3 to 0.5 dB as the harmonics to be measured is expected in the range -50 to -70 dB from the reference level.

If the FSE 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 FSE 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.

Example:

For testing high power devices like base stations for mobile communication a power attenuator has to be used in front of the spectrum analyzer to protect its input. Lets assume a specified error of attenuation of $err_{att} < 0.5$ dB and a VSWR of 1.2.

As the distribution of the error is not known a rectangular distribution is assumed. This results in a variance of the error of

$$\sigma_{att}^2 = \frac{err_{att}^2}{3} = 0.083\text{dB} .$$

The VSWR of the attenuator is entered into the spreadsheet of Fig 1. This results in a variance of the FSE including the source impedance of 0.21 dB.

For calculation of the overall uncertainty both variances are added and from the sum the square root is taken. The result is the standard deviation of the error.

To attain a confidence level of 95 % to enable the measurement to be within specific limits the standard deviation has to be multiplied with 1.96.

This results in a measurement uncertainty of 1.06 dB with a level of confidence of 95 %.

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 Organisation of Standardization, 1995

Appendix

The calculation of the combined uncertainty is not in accordance with ETR028. The ETR028 requires for the errors given in logarithmic dB units to be converted into linear percentage values before calculating the combined uncertainty. When a rectangular distribution of the error in the unit dB is given (error < +/-n dB) the rectangular distribution is not valid after transformation into linear units. The calculation of the combined uncertainty requires for example a rectangular distribution, however.

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