Introduction to measurement uncertainty for antenna calibration

Critical items need to be identified for a particular calibration method.

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The purpose of this article is to introduce the reader to basic elements and concepts in the computation of measurement uncertainty for antenna calibration. Measurement uncertainty is a tool used to account for errors associated with a measurement system. Uncertainty can be used for calibration or for actual EUT measurement for radiated or conducted emissions. By fully understanding the types of errors, one can then work to minimize their impact on the overall measurement process and total uncertainty.

There are three main types of error distributions that can be used, normal, rectangular, or u-shaped. Definitions for each of these can be found in the NAMAS NIS 81 document.[1]

NORMAL

This distribution can be assigned to uncertainties derived from multiple contributions, such as when a NAMAS calibration laboratory provides a total uncertainty for an instrument. This will have been calculated at a minimum level of confidence of 95 percent and can be assumed to be normal. The standard uncertainty of a contribution to uncertainty with assumed normal distribution is found by dividing the uncertainty by the coverage factor, k, appropriate to the stated level of confidence.

For normal distributions:

$$u(x_1) = \frac{\text{uncertainty}}{k}$$

RECTANGULAR

This distribution means that there is equal probability of the true value lying anywhere between the prescribed limits. A rectangular distribution should be assigned in which a manufacturer's specification limits are used as the uncertainty unless there is a statement of confidence associated with the specification. In this case a normal distribution can be assumed.

For rectangular distributions:

$$u(x_1) = \frac{a_1}{\sqrt{3}}$$

U-SHAPED

This distribution is applicable to mismatch uncertainty. The value of the limit for the mismatch uncertainty, M, associated with the power transfer at a junction is obtained from

$$20 \log_{10}(1 \pm |r_G||r_L|)\text{dB, or}$$

$$100((1 \pm |r_G||r_L|)^2 - 1)\%$$

where r_G and r_L equal the reflection coefficients for the source and load.

The mismatch uncertainty is asymmetric around the measured result. However, the difference this makes to the total un-

*See advertisement on page 86

certainty is often insignificant, and it is acceptable to use the larger of the two limits, i.e.,

$$20 \log_{10}(1 - |r_G||r_G|)$$

For U-shaped distributions

$$u(x_i) = \frac{M}{\sqrt{2}}$$

With this information, let's now look at an example of a biconical antenna using the Standard Site Method and three antennas under ANSI C63.5. To minimize amplitude linearity error, it is necessary to look at the uncertainty of the biconical antenna in smaller frequency increments. The equations for calculating antenna factor from site attenuation measurements (AF_1, through AF_3) for each of the three antennas under ANSI C63.5 are shown below![2]

$$AF_1 = 10 \log fm - 24.46 + 0.5 [E_D^{Max} + A_1 + A_2 + A_3]$$

$$AF_2 = 10 \log fm - 24.46 + 0.5 [E_D^{Max} + A_1 + A_3 - A_2]$$

$$AF_3 = 10 \log fm - 24.46 + 0.5 [E_D^{Max} + A_2 + A_3 - A_1]$$

UNCERTAINTY BUDGET FOR BICONICAL ANTENNAS FROM 30 TO 60 MHZ

Normal distribution was assigned to uncertainties derived from multiple contributions (Table 1). The standard uncertainty of a contribution with assumed normal distribution is found by dividing the expanded uncertainty by the coverage factor, k, appropriate to the stated level of confidence. Strictly speaking, for a level of confidence of 95 percent, k = 1.96, this document uses a value of k = 2.

Rectangular distribution means that there is equal probability of the true value lying anywhere between the prescribed limits. A rectangular distribution was assigned where a manufacturer's specification was not available. Note that frequency error was not considered since a spectrum analyzer is used with a high stability frequency reference with frequency accuracy of $1 \cdot 10^{-8}$ capability.

- **Repeatability.** This value is determined from a set of a minimum of 20 prior measurements with the standard deviation recorded here.
- **Mismatch.** The connecting attenuators at the input to the spectrum analyzer have a VSWR of 1.2:1, which gives a voltage reflection coefficient of 0.09. The input VSWR to the spectrum analyzer is 1.1:1 or less, which gives a voltage reflection coefficient of 0.047. So the uncertainty limit will be $20 \log (1 \pm r_L r_G) = \pm 0.036$ dB
- **Thermal Error on Coax Cables.** For this evaluation, the heating effect on the interconnecting RF cables is considered. A worst case estimated value of ± 0.15 dB is used here. As historical data is gathered, the respective error value will be used. Note that flex error and cable lay during height scans should also be evaluated, and errors associated with this can also be included in this error item.
- **Spacing Error.** This value is obtained from a minimum of 20 prior measurements.
- **Instrument Error.** This error is from the manufacturer's calibration data for an analyzer based on the amplitude fidelity linearity. This value will vary depending on the relationship of the signal being measured and the reference level used for the measurement.
- **Sensitivity Coefficient.** For values shown of 1.5 in Table 1, this is obtained from 3 x 0.5, which relates to the calculations used for the determination of the antenna factors. This was based on three site attenuation measurements times the value of 0.5 seen in the equations listed above for the three-antenna method.

UNCERTAINTY BUDGET FOR DOUBLE RIDGE WAVEGUIDE FROM 1 TO 18 GHZ

Next, an uncertainty evaluation for a double ridge

Sources of Uncertainty	Value in dB	Distribution	Divisor	Sensitivity Coefficient (C_i)	Result in dB ($C_i \times U_i$)
Repeatability (STD)	± 0.4	Normal	1	1	0.400
Mismatch at Spectrum Analyzer Connection	± 0.036	U-shaped	1.414	1.5	0.038
Thermal Error of Coax Cables	± 0.15	Rectangular	1.732	1.5	0.130
Spacing Error (mtrs)	± 0.02	Rectangular	1.732	1.5	0.017
Instrument Error	± 0.15	Rectangular	1.732	1.5	0.130
Combined standard uncertainty ± $U_c(y)$					0.442
Expanded uncertainty U = ± 2 $U_c(y)$					0.884

Table 1. Uncertainties as a result of multiple contributions.

Note: U_i is obtained from the value in dB column divided by the number in the divisor column.

waveguide (DRWG) horn antenna using the standard field method for calibration of the antenna will be considered (Table 2).

Normal distribution was assigned to uncertainties derived from multiple contributions. The standard uncertainty of a contribution with assumed normal distribution is found by dividing the expanded uncertainty by the coverage factor, k, appropriate to the stated level of confidence. Strictly speaking, for a level of confidence of 95 percent, k = 1.96, this document uses a value of k = 2.

Rectangular distribution means that there is equal probability of the true value lying anywhere between the prescribed limits. A rectangular distribution was assigned where a manufacturer's specification was not available. Frequency error was not considered, since a spectrum analyzer is used with a high stability frequency reference with frequency accuracy of $1 \cdot 10^{-8}$ capability.

- **Repeatability.** This value is determined from a set of a minimum of 20 measurements with the maximum deviation recorded here.
- **Mismatch.** The connecting attenuators at the input to the spectrum analyzer have a VSWR of 1.2:1, which gives a voltage reflection coefficient of 0.09. The input VSWR to the spectrum analyzer is 1.1:1 or less, which gives a voltage reflection coefficient of 0.047. So, the uncertainty limit will be $20 \log (1 \pm r_L r_G) = \pm 0.036$ dB.
- **Spacing Error.** This value is obtained from a minimum of 20 prior measurements.
- **Alignment Error.** This error is based on a set of 20 prior measurements.
- **Power Sensor Error.** This error is based on the worst case error for the power sensor from the manufacturer's calibration data.
- **Directional Coupler Error.** This error is based on the error associated with the directional coupler from a set of 20 measurements.
- **Residual Ground Reflection Error.** This error is estimated based on the residual ground reflection when using a dual 45° angle, absorbing fence for this calibration.
- **Thermal Error for Coax Cables.** This error is calculated to be 0.15 dB for normal temperature variation during calibration.
- **Coax Cable Flex Error.** This error is measured at 0.11 dB for variations tried.
- **Internal Antenna Reflection.** This error is measured with data on file.
- **Ground Reflection.** This error is measured with data on file.
- **Instrument Error.** This error is based on the fidelity linearity of a specific spectrum analyzer.

IN SUMMARY

As seen from the two examples, critical items need to be identified for the calibration method used to properly account for errors associated with that process. Groups such as CISPR 16, VCCI, and ANSI C63.5 committees are currently addressing the issue of uncertainties for calibrations in greater detail. The issue of measurement uncertainty needs to

continued on page 98

Sources of Uncertainty	Value in dB	Distribution	Divisor	Sensitivity Coefficient (C_i)	Result in dB ($C_i \times U_i$)
Repeatability (STD)	± 0.3	Normal	1	1	0.300
Mismatch	± 0.036	U-shaped	1.414	1	-0.025
Spacing Error	± 0.02	Rectangular	1.732	1	0.012
Alignment Error	± 0.2	Rectangular	1.732	1	0.115
Power Sensor Error	± 0.46	Rectangular	1.732	1	0.266
Directional Coupler Error	± 0.12	Rectangular	1.732	1	-0.069
Residual Ground Reflection Error	± 0.1	Rectangular	1.732	1	0.058
Thermal Error for coax cables	± 0.15	Rectangular	1.732	1	0.087
Coax Cable Flex Error	± 0.11	Rectangular	1.732	1	-0.064
Inter. Ant. Reflection	± 0.15	Rectangular	1.732	1	0.087
Ground Reflection	± 0.5	Rectangular	1.732	1	0.289
Instrument Error	± 0.17	Rectangular	1.732	1	0.098
Combined standard uncertainty $\pm U_c(y)$					0.550
Expanded uncertainty $U = \pm 2 U_c(y)$					1.100

Table 2. Uncertainty budget for DRWG horns using a standard field method from 1 to 18 GHz on OATS.

Alternatives in lightning protection devices ... *continued from page 92*

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Introduction to measurement uncertainty for antenna calibration ... *continued from page 87*

become standardized and accepted internationally among these groups. This means that a set of minimum error items needs to be included in the uncertainty analysis and the method for measuring the error must also be included. Unless measurement uncertainty analysis requirements become standardized, comparisons of measurement uncertainties between different organizations will have no meaning. This problem also applies to measurement uncertainties used for radiated and conducted emission measurements.

REFERENCES

1. NAMAS NIS 81, The Treatment of Uncertainty in EMC Measurements, Edition 1, May 1994.
2. ANSI C63.5-1988, American National Standard For Calibration of Antennas Used for Radiated Emission Measurements in Electromagnetic Interference (EMI) Control.

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