Impedance Uncertainty Contribution of Artificial Networks (AN, AMN and ISN)

Application Note

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This application note describes how to determine the uncertainty bounds for a given artificial network impedance for an estimate of the combined standard measurement uncertainty using the Rohde & Schwarz Software “AN Impedance Uncertainty Contribution”.

Application Note

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1 Impedance Uncertainty Contribution of Artificial Networks

1.1 Overview

For Artificial Mains Networks (AMNs) in CISPR 16-4-2 [1], the amount of U_{cispr} was calculated based on the assumption of an “uncertainty circle” ΔZ (see Fig. 1), which in fact is an impedance tolerance circle. In Figure 1, the center of the circle is the nominal load impedance Z of the AMN for a given frequency.

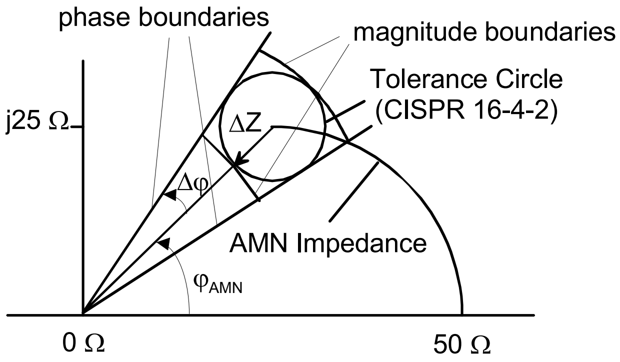


Figure 1: Definition of impedance magnitude and phase tolerances

Existing network analysers however do not allow to specify a tolerance circle for the impedance. Therefore the CISPR decided for CISPR 16-1-2 [2] to use the original specification of the magnitude tolerance and to add a specification of the phase tolerance. Using trigonometric functions, a value of $\Delta\varphi$ = 11,5 degrees follows from

$\Delta|Z|/|Z| = 0{,}2$.

For other artificial networks (ANs), e.g. the Asymmetrical Artificial Network (AAN), which in some standards, e.g. CISPR 22, is called Impedance Stabilization Network (ISN), CISPR 16-1-2 specifies both magnitude and phase tolerances of the network load impedance.

1.2 Uncertainty calculation

Where the phase requirement cannot be met, the measured phase angles may be taken into account in the uncertainty budged in accordance with CISPR 16-4-2 [1]. Guidelines for the calculation of the uncertainty is given in Annex I of CISPR 16-1-2 [2].

Figure 2 shows the principle circuit for the calculation.

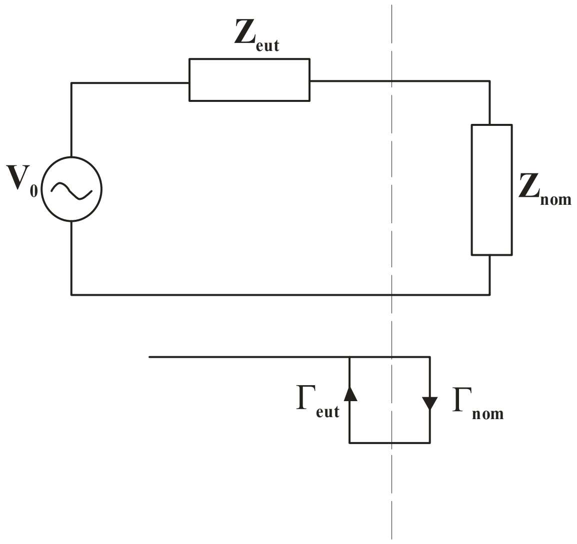


Figure 2: An EUT connected to an ideal AN and its flow-graph representation

For the example of the ideal 50 Ω/50 µH AMN,

$Z_{nom} = 1/Y_{nom}$, with $Y_{nom} = 1/R - j/\omega L$, (1)

where R = 50 Ω and L = 50 µH

For other ANs, similar values apply. For the real ANs, Z_{nom} is replaced by Z_{an}. For the calculation, we use the reflection coefficients Γ corresponding to Z_{nom} and the unknown EUT impedance Z_{eut} in a Z_0 impedance system, which are

$$\Gamma_{nom} = \frac{Z_{nom} - Z_0}{Z_{nom} + Z_0}, \qquad \Gamma_{eut} = \frac{Z_{eut} - Z_0}{Z_{eut} + Z_0} \tag{2}$$

$$V_{nom} = \frac{Z_{nom}}{Z_{eut} + Z_{nom}} V_0 = \frac{(1 + \Gamma_{nom})(1 - \Gamma_{eut})}{2(1 - \Gamma_{nom}\Gamma_{eut})} V_0$$

for the ideal artificial network.

$$\Gamma_{an} = \frac{Z_{an} - Z_0}{Z_{an} + Z_0} \tag{3}$$

$$V_{an} = \frac{Z_{an}}{Z_{eut} + Z_{an}} V_0 = \frac{(1 + \Gamma_{an})(1 - \Gamma_{eut})}{2(1 - \Gamma_{an}\Gamma_{eut})} V_0$$

for the real artificial network.

In general, Z_{an} will not equal Z_{nom}, and so the measured voltage V_{an} will differ from V_{nom}. The maximum value of this contribution to measurement uncertainty is given by the extremes of the magnitude of the ratio of V_{an} to V_{nom},

$$\left|\frac{V_{an}}{V_{nom}}\right| = \left|\frac{1+\Gamma_{an}}{1-\Gamma_{eut}\Gamma_{an}} \cdot \frac{1-\Gamma_{eut}\Gamma_{nom}}{1+\Gamma_{nom}}\right| \qquad (4)$$

1.3 Uncertainty bounds

CISPR 16-4-2 uses the concept of an impedance tolerance circle of the actual impedance Z_{an} centred on the nominal impedance Z_{nom} (see Figure 1), with

$$Z_{an} = Z_{nom} + \alpha|Z_{nom}|exp(j\theta), \text{ where } 0 \le \alpha \le 0{,}2 \text{ and } 0 \le \theta < 2\pi \qquad (5)$$

The value of Z_{eut} is unknown and unbounded. However, by choosing the arbitrary value of the normalizing impedance Z_0 to be real (e.g. 50 Ω), the magnitude of Γ_{eut} cannot be greater than unity, allowing Γ_{eut} to be written as

$$\Gamma_{eut} = \rho\, exp(j\phi), \text{ where } 0 \le \rho \le 1 \text{ and } 0 \le \phi \le 2\pi \qquad (6)$$

Physical considerations suggest that the extremes of (4) are likely to be found when α and ρ take their maximum values of 0,2 and 1,0 respectively. The results in the following table are calculated for the 50 Ω/50 µH AMN with $\alpha = 0{,}2$ and $\rho = 1$, using all possible combinations of θ and ϕ, when each were taken in 1 degree steps [3].

Freq MHz	Max dB	Min dB
0.15	2.68	-2.60
0.16	2.56	-2.53
0.17	2.46	-2.47
0.18	2.37	-2.43
0.19	2.30	-2.38
0.20	2.23	-2.34
0.25	2.01	-2.21
0.30	1.89	-2.13
0.50	1.70	-2.01
1.00	1.61	-1.96
5.00	1.58	-1.94
10.0	1.58	-1.94
30.0	1.58	-1.94

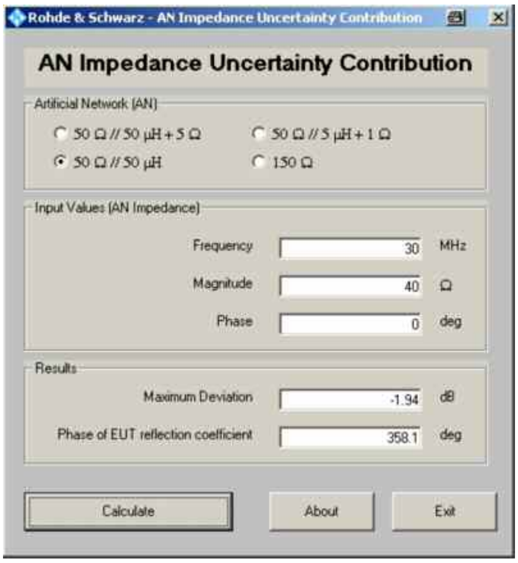
Table 1: Extremes from (4) for the 50 Ω/50 µH AMN [3]

The largest values in Table 1 occur at 150 kHz and were used for calculating U_{cispr} in CISPR 16-4-2.

To solve the task of calculating the maximum ratio of V_{an} to V_{nom} for a given measured impedance, R&S have developed the program “AN Impedance Uncertainty Contribution” which is combined with this Application Note.

2 Maximum Deviation Calculator

The calculator allows the calculation of the uncertainty bounds for a given impedance of a real artificial network, e.g. from the calibration report. It also allows the calculation of the uncertainty bounds where the phase tolerance of the AN cannot be met and thus allows a better estimate of the combined standard uncertainty of conducted emission measurements and whether it is below or above U_{cispr} in CISPR 16-4-2 [1].


Rohde & Schwarz - AN Impedance Uncertainty Contribution

AN Impedance Uncertainty Contribution

Artificial Network (AN)

○ 50 Ω // 50 µH + 5 Ω
○ 50 Ω // 5 µH + 1 Ω
● 50 Ω // 50 µH
○ 150 Ω

Input Values (AN Impedance)

Frequency: 30 MHz
Magnitude: 40 Ω
Phase: 0 deg

Results

Maximum Deviation: -1.94 dB
Phase of EUT reflection coefficient: 358.1 deg

Figure 3: User interface of the AN Impedance Uncertainty calculator

After entering the absolute impedance data (frequency, magnitude and phase) of the AN and pressing the button “Calculate”, the calculator will return the maximum deviation in dB of the measured voltage level from the reference voltage level, see Figure 3.

When using an AN together with a measuring receiver, the reference voltage level will be measured for any EUT source impedance if the AN impedance agrees with the nominal impedance. The magnitude of the EUT reflection coefficient will approach 1. As it is not easy to predict the phase for the maximum deviation, the phase is shown as the second result.

3 Literature

[1] CISPR 16-4-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainties*

[2] Amendment 2:2006 to CISPR 16-1-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-2: Radio disturbance and immunity measuring apparatus - Ancillary equipment – Conducted disturbances*

[3] CISPR/A/WG2(Ad-hoc Measurement Uncertainty/Hunter)99-01

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