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Mismatch Error by Measurement of Radiated Disturbances in EMC Testing

Abstract. *Radiated disturbances by EMC testing are sensed with an antenna and transmitted via the 50Ω coaxial path to the receiver. The recalculation factor between the receiver signal and the measurand is defined with neglecting mismatching. As a matter of course the mismatch error appears. It is not determined but estimated and built-in into the measurement uncertainty budget. Formulas for the mismatch error by the junction antenna-receiver and with the inserted path are derived. Two approaches to estimation of the mismatch error in the bands C and D in the frequency range from 30MHz to 1GHz: the first recommended in the document CISPR 16-4-2 and the second with the Monte Carlo method are presented and illustrated with the numerical calculations. Evidently the first approach is to pessimistic and gives vastly overestimated error.*

Streszczenie. *Zaburzenia promieniowane w badaniach kompatybilności elektromagnetycznej mierzone są anteną połączoną z miernikiem zaburzeń koncentrycznym torem pomiarowym o impedancji charakterystycznej 50Ω. Współczynnik przeliczeniowy sygnalu miernika na wielkosc mierzona anteną (mezurand) zdefiniowany jest z pominięciem niedopasowań w torze pomiarowym. Jest to jeden ze składnikow błędu pomiaru. Błędu tego nie da sie wyznaczyć w sposób deterministyczny. Jest on szacowany i wbudowany w bilans niepewności pomiaru. Wyprowadzono wzory na dwa rodzaje błędu niedopasowania: dla bezpośredniego połączenia anteny z odbiornikiem oraz z wtrąconym torem pomiarowym. Estymację błędu niedopasowania polecaną w dokumencie CISPR 16-4-2 oraz z wykorzystaniem metody Monte Carlo zilustrowano obliczeniami numercznymi dla pomiaru pola elektrycznego zaburzeń promieniowanych w pasmach C i D, w przedziale częstotliwosci od 30MHz do 1GHz. Podejście proponowne w dokumencie CISPR 16-4-2 jest zbyt pesymistyczne i prowadzi do znacznego przeszacowania błędu.* ***(Błąd niedopasowania w pomiarach zaburzeń promieniowanych w badaniu kompatybilności elektromagnetycznej)***

Keywords: Antennas, attenuation, scattering parameters, random variables, estimation.
Słowa kluczowe: Anteny, tłumienność, parametery rozproszeniowe, zmienna losowa, estymacja.

Introduction

The quantity of interest (measurand) by the measurement of radiated disturbances is either electric or magnetic field strength. It is detected with an antenna and converted to the signal in the 50Ω coaxial system. This signal is transmitted to the measurement receiver via coaxial cables and a feedthrough. Components of the transmission paths are usually characterized with scattering parameters (S-Parameters). The factor F transducing the measurand to the signal recorded by the measurement receiver in sense of this paper neglects reflections (mismatching). Such factors are commonly used in EMC test houses. This simplification imposes error which can be used as a correction. To this error the adjective "mismatch" is attributed and complying with the document [1] the symbol δM is assigned. As a matter of course the relation between the measurand and the voltage recorded with the receiver is a product ($F \cdot \delta M$) or a sum ($F + \delta M$) of the transducer factor and the mismatch error, depending on the scale used (linear or dB).

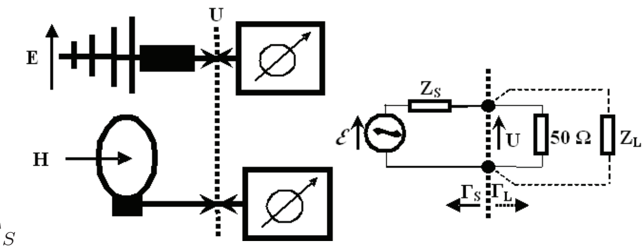
Antenna Factors

By radiated disturbances magnitude of either electric or magnetic field intensity ($|E|$ or $|H|$) is sensed with an antenna located in the far field zone [2]. The measurands $|Q|$ can be generalized as below

$$|Q| \Rightarrow \begin{bmatrix} |E| & \text{electric field disturbance} \\ & \\ |H| & \text{magnetic field disturbance} \end{bmatrix}$$

Two features of the antenna namely the antenna factor F_A (magnitude) and reflections at the antenna feeding-point Γ_S (complex) being on par with the impedance Z_S are evaluated in the calibration process. Only magnitude of the antenna factor is measurable, therefore F_A is a frequency dependent real variable.

The antenna factor F_A is the ratio between the magnitude of field intensity at the place of antenna location and the magnitude of voltage at the antenna feeding-point $|U|$, provide the measurement instrument at the antenna feeding-point is reflection free ($\Gamma_L = 0$)



Γ_S

Fig. 1. Antenna calibration and the equivalent electrical circuit by junction antenna-receiver.

$$F_A \Rightarrow \begin{cases} \frac{|E|}{|U|} & \text{electric antenna factor} \\ & \\ \frac{|H|}{|U|} & \text{magnetic antenna factor} \end{cases} \quad (1)$$

The magnitude of electromotoric force (EMF) $|\mathcal{E}|$ in the equivalent circuit of the antenna (Fig.1), is proportional to the filed intensity. It is valid for electric field as well as for magnetic field antenna

$$|\mathcal{E}| = F_{\mathcal{E}} \cdot |Q| \quad (2)$$

Assigning the equivalent circuit with the 50Ω load as shown in Fig.1, setting calibration features and relation Eq.(2) in it, the antenna factor F_A can be derived

$$F_A = \frac{|Q|}{|U|} = \frac{2}{F_{\mathcal{E}}\,|1 - \Gamma_S|} \quad (3)$$

Neglecting load reflections in Eq.(3) ($\Gamma_L = 0$) is justified if the measurement instrumentation is traceably calibrated. However by disturbance measurement, reflections on the receiver input must be taken into account.

Mismatch Error by Junction Antenna-Receiver

If the antenna is connected directly to the measurement receiver (dotted branch in Fig.1), voltage drop across the receiver input U is as follows

(4) $$|U| = \frac{F_{\mathcal{E}}\,|Q|}{2} \cdot \left|\frac{(1+\Gamma_L)(1-\Gamma_S)}{1-\Gamma_L\Gamma_S}\right|$$

Combination of Eq.(4) with Eq.(3) yields

(5) $$|U| = \frac{|1+\Gamma_L|}{|1-\Gamma_L\Gamma_S|} \cdot \frac{|Q|}{F_A}$$

Taking into account the mismatch on the receiver input (Eq.(14)) yields

(6) $$|Q| = F_A \cdot |1-\Gamma_L\Gamma_S| \cdot |U_R|$$

It is visible that

(7) $$\delta M_{A-R} = |1-\Gamma_L\Gamma_S|$$

is the mismatch error of radiated disturbances by the direct connection antenna-receiver.

Mismatch Error By Antenna-Receiver Connected Via Inserted Path

Usually the antenna is connected to the receiver via the path composed of two coaxial cables and the feedthrough in between Fig.(2), mounted in the chamber wall. Situation coincides with the scheme shown in Fig.7 b) where the source is an antenna, the load is a receiver and an inserted path between Port-1 and Port-2 is characterized with the complex matrix of S-parameters.

Setting together constitutional formula of the insertion loss Eq.(15) and the voltage drop across the receiver input by direct connection of the antenna Eq.(5) and thereafter applying the receiver mismatch Eq.(14) to the voltage drop U_2, relation between $|Q|$ and the registered voltage $|U_R|$ can be found

(8) $$|Q| = \\ = |(1-\Gamma_S S_{11})(1-\Gamma_L S_{22}) - \Gamma_S S_{12}\Gamma_L S_{21}| \cdot \frac{F_A}{|S_{21}|} \cdot |U_R|$$

The recalculation factor of the composition: antenna-inserted path is a product of the antenna factor and the path attenuation

(9) $$F_{A-I-R} = F_A \cdot \frac{1}{|S_{21}|}$$

and

(10) $$\delta M_{A-I-R} = \\ = |(1-\Gamma_S S_{11})(1-\Gamma_L S_{22}) - \Gamma_S S_{12}\Gamma_L S_{21}|$$

is the mismatch error of radiated disturbances by connecting the antenna with the receiver via the path.

Remarks On Antenna and Receiver Reflections

The reflection Γ_S at the antenna feeding-point is present in the mismatch error by not inserted and inserted path, Eq.(7) and Eq.(10) respectively.

Electric antennas are calibrated in the fully anechoic i.e. reflection free chambers. The same electromagnetic environment exist by the measurements of radiated disturbances in the fully anechoic rooms. Therefore Γ_S in this environment

Fig. 2. The path inserted between the antenna and the receiver by measurement of radiated disturbances.

is a deterministic, complex variable independent on the antenna height above the floor and on the antenna polarization.

However, by the measurements of electric disturbances in a semi anechoic chamber, by which the height of the antenna above the floor is scanned, moreover the polarization and sometimes the tilting is changed, Γ_S is a variable dependent on the all mentioned parameters[1]. Strictly speaking extremes of Γ_S depending on the antenna height, polarization and tilting should be found. They constitute the range of variations for Γ_S as a random variable. Fortunately this variation is very weak. Therefore in this paper Γ_S is regarded as a deterministic variable by the typical antenna height, separately for the horizontal and the vertical polarization.

Another simplification stems from the fact that Γ_S is almost independent on the EUT, thanks the far field conditions by disturbance measurement. Therefore influence of the EUT on Γ_S by testing can be neglected.

Variation of the reflection Γ_S in the antenna feeding-point does not take place by testing with the magnetic antennas, because the calibration and the measurement are performed in the same environment, i.e. in the semi anechoic chambers at the fixed height over the floor only by one polarization.

Measurement of the complex reflection Γ_L at the receiver input is possible but expensive. The alternative source of information about it can be the technical specification of the receiver. Usually two extremes can be found there i.e. the extremes of $|\Gamma_L|$ with attenuation switched off and on at the receiver input. By radiated measurements the input attenuator of the receiver is always switched off in order not to worsen the signal to noise ratio and to keep possibly big distance of the noise floor to the limits defined in the standard according to which the measurement is performed. If the preamplifier at the receiver input is available, it is switched on in order to improve these two features.

Estimation of the Mismatch Error

The approach presented in the document [1] consists on such setting the extremes of the mismatch error δM_{A-I-R} in the dB scale (Eq.(10)) that the argument of the log function is an arithmetic sum of magnitudes of all components

(11) $$\delta M^{\pm}_{A-I-R} = 20\log\left[1 \pm (|\Gamma_S|\,|S_{11}| + \\ + |\Gamma_L|\,|S_{22}| + |\Gamma_S|\,|S_{11}|\,|\Gamma_L|\,|S_{22}| + |\Gamma_S|\,|S_{21}|^2\,|\Gamma_L|)\right]$$

Farther it is assumed that Eq.(11) constitutes the range of variation of the ten-dimensional random variable (five complex random variables) with approximately U-shaped probability distribution [2]. Consequently the semi range of variation a and the expected value E are as follows

[1]The same concerns the antenna factor of electric antennas F_A. These variations contributes additionally by the uncertainty budget. It is out of scope of this paper.

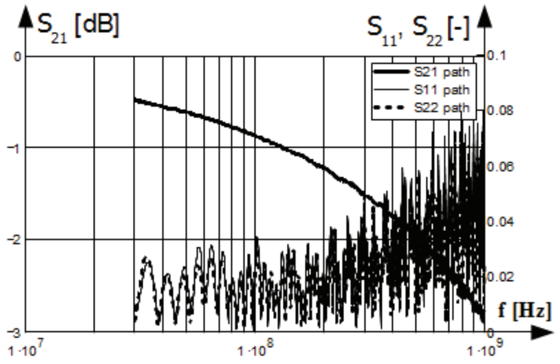


Fig. 3. The S-parameters of the insertion path.

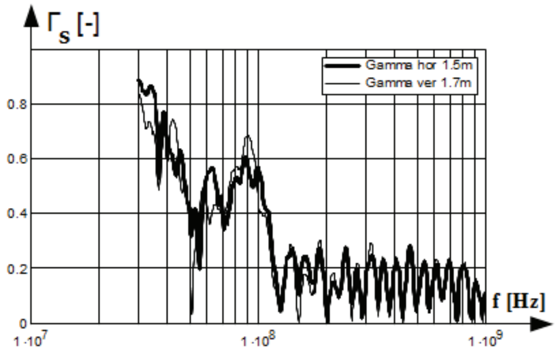


Fig. 4. The reflection $|\Gamma_L|$ at the antenna feeding-point by the horizontal and vertical polarization by height above the floor 1.5m and 1.7m respectively.

$$a = \frac{\delta M^{(+)}_{A-I-R} - \delta M^{(-)}_{A-I-R}}{2} \tag{12}$$

$$E = \frac{\delta M^{(+)}_{A-I-R} + \delta M^{(-)}_{A-I-R}}{2} \tag{13}$$

The ratio $\sqrt{2}$ of a (Eq.(12)) to the standard uncertainty u applies due to the U-shaped distribution. Strictly speaking this distribution is not valid[2].

Actually the mismatch error Eq.(10) is a two-dimensional random variable while only complex $|\Gamma_L|$ is random. The proper and efficient way to estimate it is application of the Monte Carlo method [3], [4], [5]. The author, similarly as in his previous paper [6] used facilities of the Mathcad 13 with its pseudo random generator with the uniform probability distribution. The expected value $E(X)$ was calculated as the arithmetic mean and the standard uncertainty u as $u = \sqrt{E(X^2) - E^2(X)}$.

Calculus of the propagated distribution parameters

Scattering parameters of the path were measured with the vector network analyzer ZVRE from R&S in the frequency range from 30MHz to 1GHz in 801 logarithmically distributed frequency points. The kit 85032B TYPE-N from HP was used for the calibration.

The measurement setup with the receiver type ESIB40 from R&S was considered. According to the manual, the voltage standing wave ratio at the receiver input is not greater than 2.0 by $0dB$ attenuation at it ($VSWR \leq 2.0$). Furthermore, it is not greater than 1.2 if the input attenuation is at least $10dB$ ($VSWR \leq 1.2$), in the whole frequency range from 20Hz to 40GHz. Transposed into the reflection it means $|\Gamma_L| < 0.34$ for the $0dB$ input attenuation. This reflection was taken because as it was explained earlier by radiated emission the attenuator at the receiver input is switched off. There were generated 180 uniformly distributed random magnitudes $|\Gamma_L|$ in the range $[0; 0.34]$. Each time they were accompanied by 180 random arguments of Γ_L in the range $[-\pi; \pi]$.

The measurement path is composed of the 9m coaxial cable in the semianechoic chamber, feedthrough and 3m coaxial cable in the commando room. Magnitude of of the scattering parameters of the path are shown in Fig.3.

The wide band, BiLog antenna type EMCO3141 was considered. The reflection Γ_S at the feeding-point of the antenna was measured in the empty semianechoic chamber by 1,5m and by 1,7m antenna height above the floor by the horizontal and the vertical polarization respectively. Their frequency dependent magnitudes are shown in Fig.4. Only slide divergence can be observed.

Comparison of the results of the CISPR and the Monte Carlo approach for the horizontal and the vertical antenna polarizations are shown in Fig.5 and Fig.6. The extremal standard uncertainties in the bands C (30MHz - 300MHz) and D (300MHz - 1GHz) are gathered in Tab.1 and Tab.2.

[2]The U-shaped distribution permits only a random argument of Γ_L. The magnitude $|\Gamma_L|$ must be determined. Unfortunately only the extreme of $|\Gamma_L|$ is usually specified in a receiver's manual.

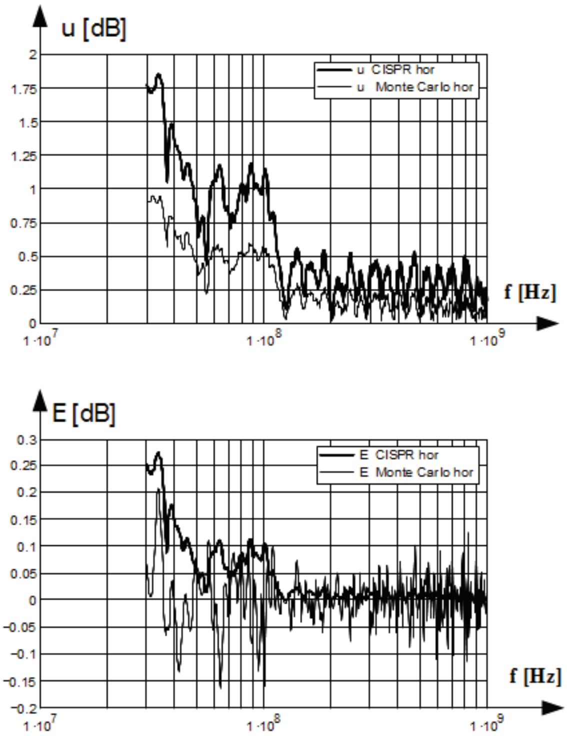


Fig. 5. The standard uncertainty u and the expected value E of the mismatch error by the horizontal antenna polarization.

Table 1. Maximum of the standard uncertainty by the horizontal antenna polarization.

Frequency band (range)	approach used	
	CISPR	Monte Carlo
C ($30MHz$ - $300MHz$)	$1.85dB$	$0.95dB$
D ($300MHz$ - $1000MHz$)	$0.53dB$	$0.26dB$

Conclusion

According to the document [1] the mismatch error δM_{A-I-R} Eq.(10) by the measurement of the radiated emis-

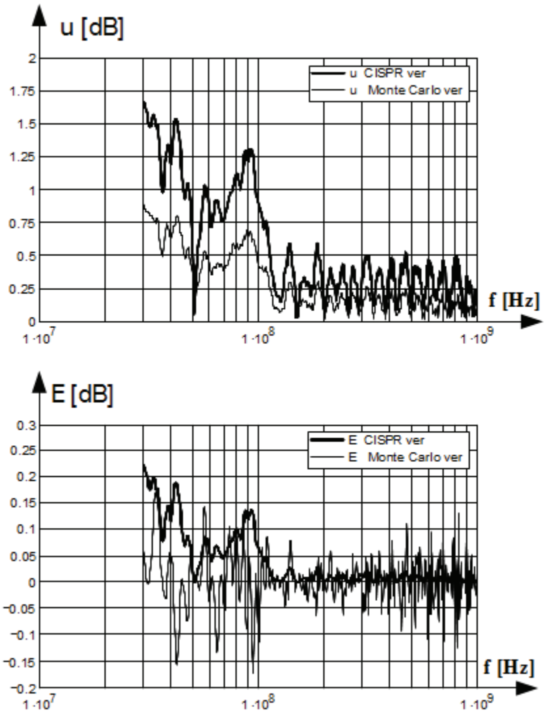


Fig. 6. The standard uncertainty u and the expected value E of the mismatch error by the vertical antenna polarization.

Table 2. Maximum of the standard uncertainty by the vertical antenna polarization.

Frequency band (range)	approach used	
	CISPR	Monte Carlo
C ($30MHz$ - $300MHz$)	$1.68dB$	$0.90dB$
D ($300MHz$ - $1000MHz$)	$0.53dB$	$0.26dB$

sion is a ten-dimensional random variable with approximately U-shaped probability distribution. Its range of variation is estimated generously (Eq(11)). Calculation of the parameters of this distribution (the expected value and the standard uncertainty) is straightforward.

By the measurement of electrical disturbances in the semi anechoic chamber the reflection Γ_S at the antenna feeding-point is deterministic if it is regarded individually for the horizontal and vertical antenna polarization. In such situation the mismatch error Eq.(10) is a two-dimensional random variable due to the random complex reflection Γ_L at the receiver input. The Monte Carlo method can be easily applied for solving such problem.

In the paper an example of two above mentioned approaches was calculated. The expected values are negligible small in both approaches. It concerns particularly the band D. The standard uncertainty calculated with the CISPR approach is unduly and unnecessarily enlarged.

In the band C there is coincidence of big reflection Γ_S at the antenna feeding-point and big extreme of the receiver reflection Γ_L. This concludes with much bigger uncertainty than in the band D.

Appendices

Receiver Mismatch

If reflection Γ_L on the input of the measurement receiver is considered then signal registered and displayed by the receiver U_R is not the same as signal U on receiver input. They are related as follows

(14) $$|U| = |1 + \Gamma_L| \cdot |U_R|$$

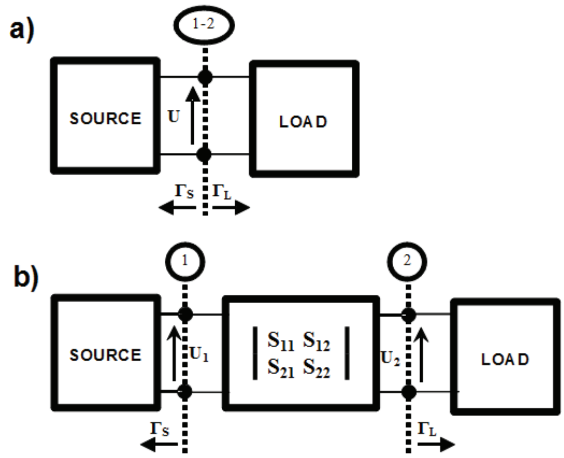


Fig. 7. Diagram defining symbols used in the formula for insertion loss.

Insertion loss L_I

It is ratio between voltage U across the junction of the source and the load if the source is connected directly to the load (Fig.7a)) and voltage U_2 across the load if a two port is inserted between the source and the load (Fig.7b))

(15) $$L_I = \frac{U}{U_2} = \\ = \frac{(1 - \Gamma_S \cdot S_{11}) \cdot (1 - \Gamma_L \cdot S_{22}) - \Gamma_S \cdot S_{12} \cdot \Gamma_L \cdot S_{21}}{S_{21} \cdot (1 - \Gamma_S \cdot \Gamma_L)}$$

In the case of the reflection-less source ($\Gamma_S = 0$) and load ($\Gamma_L = 0$) insertion loss is reciprocal to the transmission factor S_{21}. Magnitude of it is called attenuation $\mathcal{A}$

(16) $$|L_I|\big|_{\Gamma_S = \Gamma_L = 0} = \mathcal{A} = \frac{1}{|S_{21}|}$$

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