Reducing compliance uncertainty with AMN measurements

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Reducing Compliance Uncertainty with AMN Measurements

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***Abstract*— In IEC CISPR 16-4-2 [1, 2] tight impedance requirements are given for artificial mains networks (AMN). Unfortunately, these tight requirements will support measurement uncertainty but still not guarantee low compliance uncertainty if the whole test set-up, up to the port of the equipment being tested, is not taken into account. In this paper the impact of the design of the AMN as well as the mains cable used is evaluated. Incorrect cascading of typical AMN elements: impedance stabilizing network, attenuator(s), high-pass filters and impulse limiter results in erroneous findings which affect measurement uncertainty. Introduction of impedance requirements on the mains cable used enhances the compliance uncertainty by 20 dB, which is demonstrated by simulations and measurements.**

I. INTRODUCTION

In IEC CISPR 16-4-2 tight impedance magnitude and phase requirements are set for the AMN to be used with conducted RF emission tests at the mains port as shown in figure 1 [3, 4]. The present AMN impedance's phase limits are:

- 35.2° to 58.2° @ 150 kHz;
- -2.46° to +20.54° @ 1 MHz;
- +11.8° – 11.2° @ 30 MHz

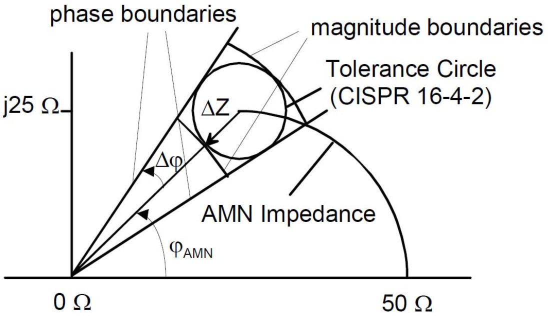

Figure 1 - Definition of impedance magnitude and phase tolerances

These impedance requirements are given by the ideal component values: 50 Ω in parallel to 50 µH + 5 Ω, and small margins apply to the impedance magnitude as well as its phase. To get insight on their influence, Monte Carlo simulations were done with a small tolerance on the components used; R ± 2 %, L, C ± 5 %. The AMN impedance magnitude and phase results as a function of frequency are given in figures 2 and 3.

The AMN impedance magnitude is given on a logarithmic Y-scale where 14 dB equals 5 Ω ($20.^{10}\log(|Z|)$ and 34 dB equals 50 Ω. As can be seen, the asymmetrical AMN impedance at its EUT port is close to 50 Ω for all frequencies above 1 MHz.

II. AMN BUILD-UP ANALYSIS

The tight AMN impedance requirement are set to reduce the overall measurement uncertainty. What is unclear is whether these impedance requirements shall be met with or without attenuator, high-pass filter and impulse limiter used.

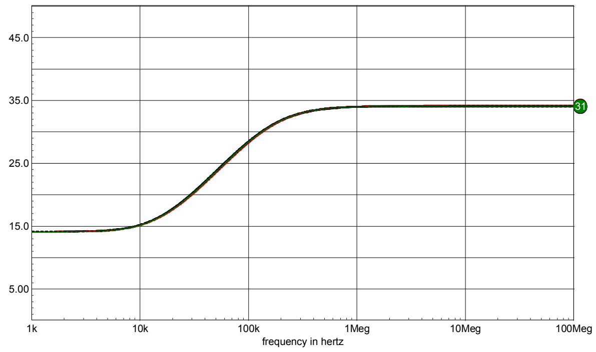

Figure 2 - Ideal AMN input port impedance magnitude (dBΩ) while using component tolerances

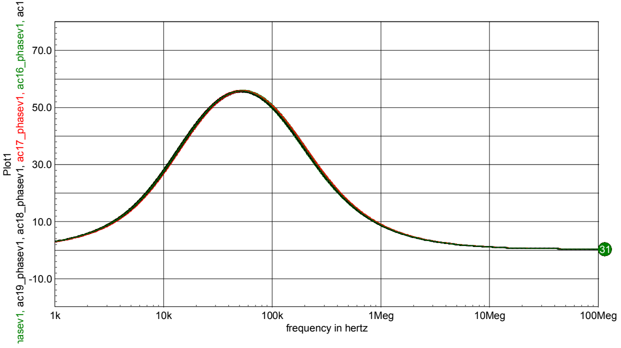

Figure 3 - Ideal AMN input port impedance phase while using component tolerances

For example, a high-pass filter (which can be applied when measurements are being performed above 150 kHz) affects the AMN input impedance below 150 kHz, in particular if it is installed directly following the impedance stabilizing network part. Also no 50 Ω resistance can be provided by the output of the impedance stabilizing network which affects the performance of the high-pass filter.

A typical 3^{rd}-order 150 kHz high-pass is built from a T-type network with 2 capacitors 33 nF in series from input to output and a 33 µH inductor at the center to ground. This high-pass filter only leads to the right characteristic in a 50 Ω impedance environment, see figure 4.

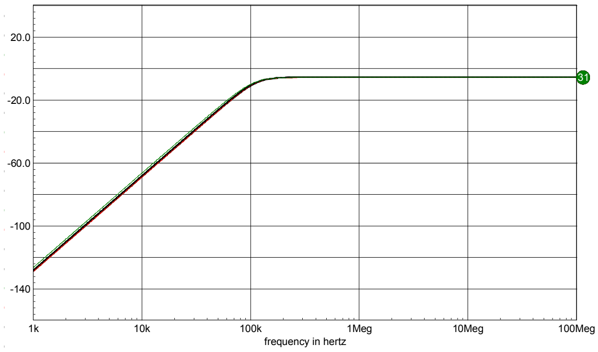

Figure 4 - Transfer characteristic of a typical 3^{rd}-order 150 kHz high-pass filter used in 50 Ω environment

Moreover, when an impulse limiter is applied, directly following the impedance stabilizing part, the 50 Ω resistive loading is no longer valid, at least not at higher interference levels where the limiter starts to react. Furthermore, harmonics are generated by the clipping of the signal provided.

The AMN therefore needs to be defined such that following the impedance stabilizing part, a 10 or even 20 dB resistive attenuator is used prior to entering the high-pass and/or impulse limiter towards the EMI receiver input, which needs to be set to some attenuation too (≥ 10 dB or a VSWR ≤ 1,2) , to ensure an impedance match by the measurement equipment at the end of the cable. The path from the AMN, with or without attenuator, high-pass and impulse limiter used, can be undefined versus the 50 Ω coaxial cable to the EMI-receiver as the two impedances at each side vary on attenuator settings.

The present measurement uncertainty calculations for conducted RF emissions testing do not take all these permutations into account. The AMN construction/stack-up is also quite different between the various AMN suppliers (at the moment of writing this paper).

As can be seen from figure 5, the AMN input impedance goes erratic below 150 kHz when a high-pass filter is used 'incorrectly'. When applied with a 10 dB attenuator in-between the impedance stabilizing part and the high-pass filter, the input impedance comes in a fair shape again, see figure 6.

When this AMN input impedance becomes high below 150 kHz, where most of the switched-mode power supplies operate, the likelihood of overloading the input of the EMC receiver is evident. Another phenomenon is that the AMN's built-in impulse limiter is reacting, creating harmonics itself, rather than stemming from the apparatus being tested.

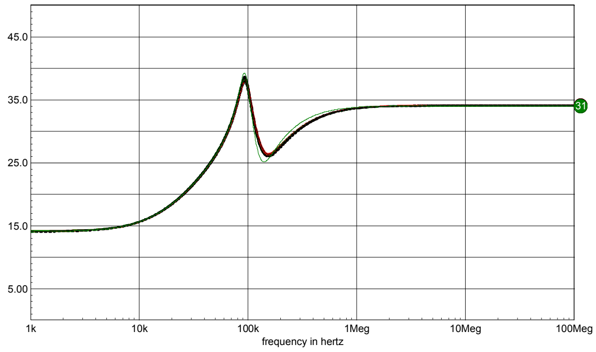

Figure 5 - AMN input port impedance magnitude (dBΩ) when followed by a 3^{rd}-order high-pass filter while using component tolerances

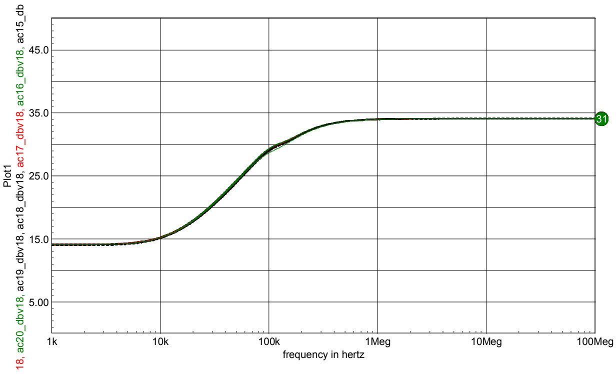

Figure 6 - AMN input port impedance magnitude (dBΩ) when a 10 dB resistive attenuator is inserted in front of the 3^{rd}-order high-pass filter while using component tolerances

Beyond this, the AMN is applied to a ground reference plane by an undefined metal strap impedance, typically bent towards the metal ground floor or to the metal side wall of the test set-up in a shielded enclosure which adds to the input impedance of the AMN as seen by the EUT.

III. COMPLIANCE UNCERTAINTY

Last but not least, any mains leads can be applied between the AMN's input port towards the EUT, put on a pedestal of 0,4 m height or 0,4 m from a metal side wall. There are some rules w.r.t. the excessive length of the mains cable (which then needs to be meandered), but nothing is defined w.r.t. the mains cable itself w.r.t. its characteristic impedance, phase or neutral wire to the protective earth (PE) wire. Neither is any specification given about the crosstalk allowed between the phase and neutral wire in the mains lead which typically have an inductive coupling factor of about 0,5 as where the isolation between the AMN's phase and neutral port has to be 40 dB or higher (up to 30 MHz).

When, by proper design the input port of the AMN is made compliant to the impedance magnitude and phase constraints given, the impedance as seen at the apparatus mains port is totally erratic due to the undefined mains cable used in-between.

In a simple electrical safety class I application with phase, neutral and PE wires, implemented as 3 x 0,75 mm^2 copper wires, the 3-wire cable represents a 2-wire transmission line impedance of 100 – 200 Ω (neutral – PE or phase – PE) determined by the insulation thickness and the insulation materials used. The length of the mains lead is undefined. A mains lead may have been provided with the equipment during sale but no guarantee can be given that that same mains lead will be used throughout the lifetime of the apparatus. Typical mains leads vary in length between 0,6 m and 3 m (when not extended). The impedance magnitude and phase now seen at the equipment's mains supply port will vary wildly, see figure 7 and 8.

Despite the tough impedance requirements imposed on the AMN's input port, with or without all internal permutations as earlier discussed, no relevant asymmetric impedance can be guaranteed above 1 MHz at the equipment's mains port when an undefined mains cable with undefined length is used. The impedances found from the Monte Carlo simulations (30 runs) vary between 34 dBΩ (= 50 Ω) to 53 dBΩ (≈ 447 Ω), while varying Z_0 = 100 Ω ± 70 %, and the propagation delay is set to 10 ns ± 90 %. The resulting deviations are substantially more than the impedance tolerances applied for the AMN equipment port, that being $|\Delta Z|/|Z| \leq 0{,}2$.

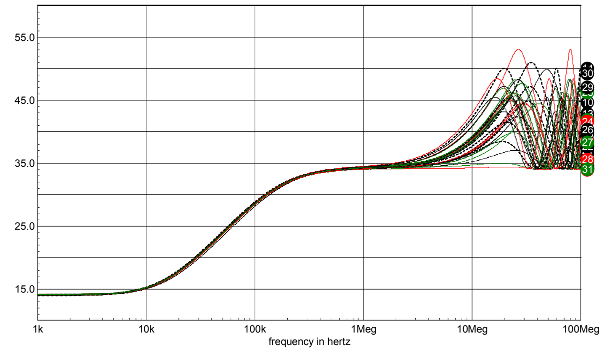

Figure 7 - The impedance magnitude (dBΩ) as seen at the equipment port deviating by the various mains cable lengths used

Also the impedance's phase varies between ± 50° where a phase tolerance of ± 11° is given at the AMN's equipment port @ 30 MHz, see figure 8.

IV. COMPLIANCE UNCERTAINTY IMPROVEMENT MEASURE

There is however a simple measure which can eliminate these excessive impedance magnitude and phase variations by prescribing the cross-sectional topology of the mains cables used.

With an electrical safety class II equipment, just phase and neutral, no PE, the characteristic impedance of the mains lead will be around 100 Ω. By choosing the optimal conductor to insulation diameter ratio, the characteristic impedance can be defined between close bounds 100 Ω ± 10 %, which is the impedance sum of: phase to PE and neutral to PE port, which is the neutral to phase wire impedance. In this case also two 50 Ω coaxial cables, with their screens connected together and being connected to PE at the AMN, can be used in parallel, as further explained in the next paragraph. This Artificial Mains Cable (AMC) topology has no crosstalk between the neutral and phase wires as where the first option has two parallel wires acting as a balanced line.

With an electrical safety class I or a 3-phase supplied equipment, the characteristic impedance can no longer be defined easily. For this equipment, the normal mains leads shall be replaced by a number of 50 Ω coaxial cables in parallel, where the screens are the common PE and the phase/neutral wires are the center wires of the coaxial cables used. The impedance, as seen at the equipment's mains port, come close to the AMN input impedance as defined. Impedance variations may result from the mains socket and plug used at both ends of the AMC. The AMC's length has hardly any influence on the impedances. Here it is assumed that the coaxial lines used for the individual mains phases have equal propagation delay and 50 Ω characteristic impedance, see figures 9 and 10.

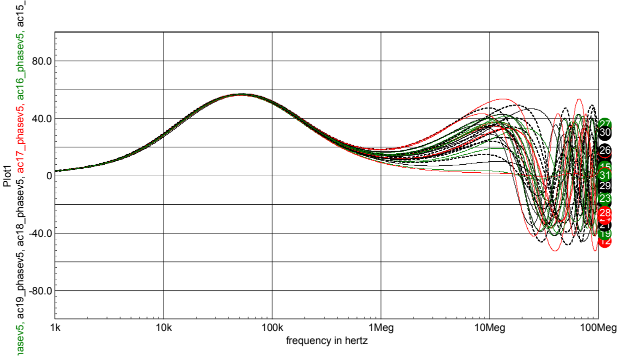

Figure 8 - The impedance's phase as seen at the equipment port as function of various mains cable lengths

While running the Monte Carlo simulations with the AMC, its cable length is varied equal to the previous case. The variation on the characteristic impedance of the coaxial cables used, to build the AMC, are set to 5 % towards the nominal value of 50 Ω.

To build an electrically safe AMC, coaxial cables with stranded center wires shall be used. Furthermore, the AMC shall be designed such that the nominal mains currents, like 16 Amps (= 1,5 mm^2 copper) can be provided at the nominal mains voltages, 230 V_{AC}, applied.

When AMCs are used, the mutual coupling between the phase and neutral wires in the mains cable are low enough to satisfy the cross-talk requirement as set for the AMN: 40 dB.

Dedicated AMCs have been built for electrical safety class I applications with a length of 0,3 and 2 m. No significant impedance variations can be found when measuring the impedances at the equipment socket between neutral or phase against PE.

The short AMC (0,3 m) can also be used with the CDN measurement set-up according IEC 61000-4-6 in combination with a CDN-M3. Another application area is IEC CISPR 15 while testing luminaries at frequencies above 30 MHz. In this particular case, the definition of the common-mode is of importance towards the equipment being connected which is now established by the outer screens of the coaxial cables used.

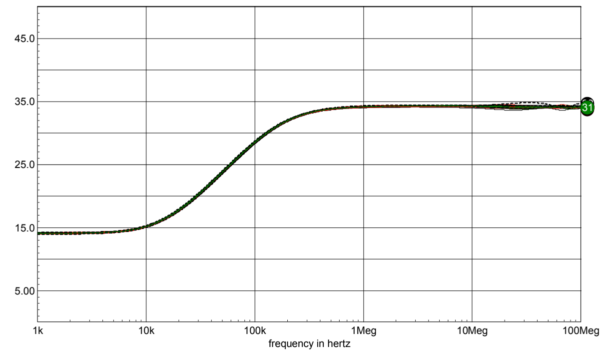

Figure 9 - The impedance magnitude (dBΩ) as seen at the equipment port at the end of an AMC.

As can be seen from the figures 9 and 10, the impedance magnitude and phase as seen at the AMC are near to ideal when comparing those with figures 2 and 3.

Some minor mismatch will result from the mains socket/plugs used in the interface from the AMN to the equipment under test. The definition of the particular requirements to be set to the AMC shall be considered separately.

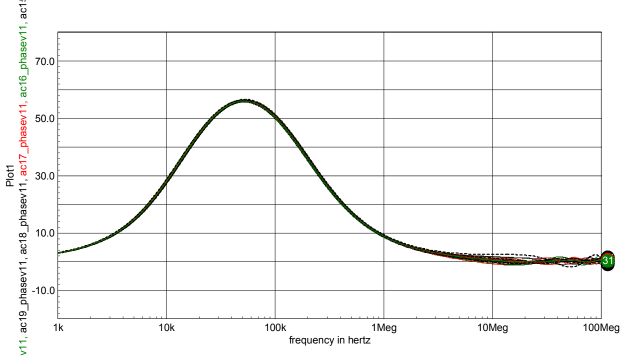

Figure 10 - The impedance's phase as seen at the equipment port at the end of an AMC.

V. CONCLUSIONS

The present IEC CISPR 16-4-2 sets tough requirements on the AMN's impedance magnitude and phase which many AMN manufactures cannot fulfil due to a wrong stack-up of the successive internal networks used: impedance stabilizing part, attenuator(s), high-pass filter and impulse limiter. Errors can be introduced by signals just outside the band of measurement, typically below 150 kHz.

AMNs having a 'wrong' stack-up cannot be modified that easily as an after sales solution. The purchase of a new AMN shall be necessary when the AMN cannot fulfil all impedance requirements under all permutations of the AMN applications given. Unfortunately, various brands have been found which are NOT compliant under all conditions due to a wrong stack-up or by lacking attenuators at some positions.

The full frequency range impedance requirements for an AMN under all optional settings, as well as a non-linearity test shall be added as extra tests. AMN impedance validation at higher signal levels, e.g., 10 or 50 V_{RMS} shall be used rather than those obtained by using low VNA test levels.

The present IEC CISPR 16-4-2 sets tough requirements on the AMN's impedance magnitude and phase at the equipment port but these are heavily affected by the mains cables used towards the equipment. No guidance is given to overcome these mismatch issues which may lead to a compliance uncertainty of 20 dB or more, while the equipment used fulfils all requirements. The use of AMCs, in combination with impedance compliant AMNs, can reduce the compliance uncertainty by more than 20 dB.

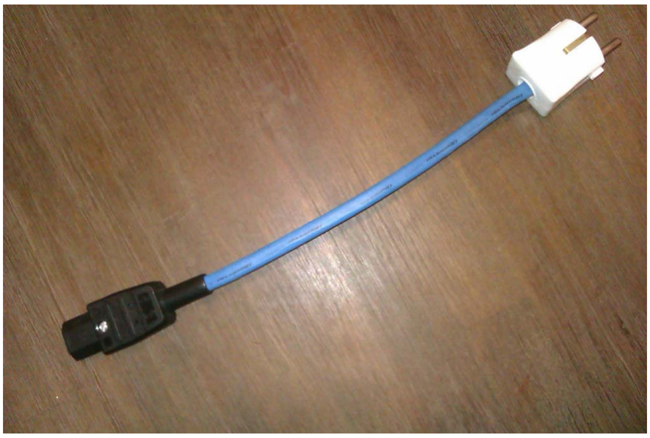

Figure 11 - Example of a short AMC with Euro-plug based on RG 223 coaxial cable

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