



BSI Standards Publication

Study Report on Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range Below 150 kHz

National foreword

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**Study Report on Electromagnetic Interference between Electrical
Equipment/Systems in the Frequency Range Below 150 kHz**

Rapport d'étude sur les perturbations électromagnétiques
entre les équipements / systèmes électriques entre eux
dans la plage des fréquences inférieure à 150 kHz

Studienbericht über elektromagnetische Interferenz
zwischen elektrische Betriebsmittel/Systeme im
Frequenzbereich unter 150 kHz

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European foreword

This document (CLC/TR 50627:2015) has been prepared by CLC/SC 205A "Mains communicating systems".

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This document has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association.

This Technical Report provides useful information for standards related to the following European Mandate(s): M/441, M/490.

This Technical Report is based on the Study Report "Electromagnetic Interference between Electrical Equipment / Systems in the Frequency Range below 150 kHz" of SC 205A (SC 205A/Sec0339/R:April 2013) (second edition) [1b], with some update according to the developments that have taken place since.

Introduction

In April 2010, CLC/SC 205A¹⁾ published their first Study Report on “Electromagnetic Interference between Electrical Equipment in the Frequency Range below 150 kHz” [1a]. Related studies had been made and information gathered due to first cases of EM interference, with Touch-dimmer lamps (TDLs) as an EMI victim, an inverter as an EMI source, and automated meter reading systems using powerline communication (AMR-PLC) figuring as EMI victims as well as sources.

Following this first CLC/SC 205A Study Report, its second edition [1b] and, based on it, this Technical Report aims at:

- a) highlighting the broad relevance of recognized electromagnetic interference for safeguarding EMC also in the frequency range 2 kHz – 150 kHz;
 - b) extending knowledge about:
 - 1) EMI cases having been observed between electrical equipment in the frequency range 2 kHz to 150 kHz, with an emphasis on interference between:
 - i) electrical equipment and its non-intentional emissions (NIE);
 - ii) mains communicating systems (MCS) using (powerline communication) PLC technology with intentional signal injection for the transmission of information over the electricity supply network;
 - 2) different mechanisms causing interference to electrical equipment due to non-intentional or intentional voltage/current components in the considered frequency range;
- as a basis for evaluating the need for closing the recognized gap in standardization as highlighted in the first edition, and considering the recent developments; that:
- c) without evaluating certain types of electrical equipment concerning applied technology or priority;
 - d) and with regard to:
 - 1) problems having occurred with operational equipment of distribution network operators (DNOs), in particular related to smart metering and smart grids control and monitoring equipment;
 - 2) complaints by network users to deliverers and subsequently by deliverers to DNOs or by network users directly to their DNO, about degradation or loss of function of certain electrical equipment;
 - 3) in both cases network users as well as deliverers are primarily annoyed by the troubles they are experiencing with electrical equipment they have traded or bought, trusting in its interference-free operability, which they expect due to the CE mark.

This TR is based on:

- e) reports on EMI cases and, following related complaints, investigations performed by an accredited test house, universities, DNOs, manufacturers and consultants;
- f) measurements performed by an accredited test house, universities, DNOs, manufacturers and consultants. In both cases to extend knowledge of emissions from different equipment in the considered frequency range, in case of the occurrence of EMI:
 - 1) to identify the actual interference source;
 - 2) to clarify the interference mechanism;
 - 3) to evaluate mitigation measures;
- g) the present standardization situation and its actual development.

1) CLC/SC 205A Mains communicating systems.

1 Scope

This Technical Report is based on two Study Reports of CLC/SC 205A, having been worked out by their Task Force EMI [1a][1b] and provides the results and findings of these documents. It was created with the help and input from a broad range of involved stakeholders: network operators, equipment manufacturers, universities, accredited test houses and consultants.

Beside the actual standardization situation it reflects the current emission situation found in supply networks and installations and describes electromagnetic interference (EMI) cases from twelve countries; investigation and analysis of the latter show a wide range of different types of electrical devices to be considered as a source or a victim of related EMI.

This Technical Report highlights the occurrence of high levels of non-intentional emissions (NIE) in the considered frequency range, including values up to and exceeding the standardized limits for intentional signals from mains communicating systems (MCS), which also implies a high potential to cause EMI to other electrical equipment. On the other hand, several types of equipment show susceptibility to related emissions, being insufficiently immune.

The Technical Report addresses the following issues:

- a number of different types of electrical equipment are generating such emissions and/or are susceptible, to such, thus representing EMI potential, as a source or a victim of such EMI;
- the interaction of electrical equipment in a certain supply area respectively installation, with its complex and volatile impedance character, as having an additional EMI potential; that besides NIE from general electrical equipment and signals from MCS and technically being quite different from emissions;
- the fact that besides the conducted interference also radiated interference from NIE or signals from MCS, through the magnetic H-field following to related currents on the mains, is to be considered, what is of some importance also for the interference-free operation of broadcast time-signal systems or electronic circuits controlled by such;
- the ageing of electronic components in electric equipment, which causes increased emissions and EMI to other electrical equipment as a result of not showing the same EMC characteristics as before being placed on the market, therefore no longer being able to conform with EMC requirements;
- the additional aspect of differential mode operation, which should be considered for related immunity and testing specifications.

These findings confirm that EMI in this frequency range is not limited to single types of equipment like inverters or MCS; instead a more general electromagnetic compatibility (EMC) problem concerning a larger spectrum of electrical equipment is identified.

Although a case-by-case mitigation of related EMI cases might be seen as appropriate, the increasing application of technologies and systems with related EMI potential requires a more general solution, through standardization, taking a balanced viewpoint of EMC and economics into account. With regard to the actual standardization situation, a review of the actual EMC and Product standards based on the reported results seems to be advisable.

After initiating the work in CLC/SC 205A, the now ongoing work in IEC SC 77A, as well as the publication of a related Technical Report on testing electricity meters [2] by CLC/TC 13 and of the new Immunity testing standard EN 61000-4-19 [99], appear as right steps into the right direction but needing further, extended efforts.

As stated on European as well as on international EMC standardization level, the availability of compatibility levels for the considered frequency range appears as a key-requirement for future considerations on setting related emission limits and immunity requirements in various standards. A fundamental basis for the co-existence of intentional signals from MCS and NIE needs to be found.

2 General

When talking about EMI in the frequency range 2 kHz to 150 kHz it is appropriate to highlight the development of electricity application respectively the use of the electricity supply network during the past decades, which is characteristic for the today's given situation; this development has led to:

- a) a thorough increase of comfort in the application of electrical energy, including the realization of some energy saving effects, in particular through the application of power electronics, and with that, a somehow changed use of the electricity supply network;
- b) the deployment of smart metering, in Europe using in the large majority of cases PLC for data transmission, with at present:
 - 1) more than 50 m PLC endpoints in Europe, from some ten thousand AMR-PLC in Austria to 36 m in Italy;
 - 2) an expected amount of such smart meters of around 85 m by 2013, 155 m smart meters by the end of 2016 and 250 m smart meters by the end of 2020 [3], [4];
 - 3) an intermediate status of related projects from beginning of rollout (Spain) to 99 % (Italy);
- c) a further extended use of the supply network for operational electricity suppliers' information transmission purposes, in particular with regard to the intended deployment of smart metering and smart grid solutions [5], [6], comprising the installation of about 200 m smart meters in the next 5 years – 7 years with a cumulative investment of up to 40 bn € for smart meters and about 280 bn € for other measures to realize smart grids [7];

that technically accompanied by the superposition of additional voltage components on the practically pure sine wave of the mains voltage.

As a consequence, dependant on the different types of connected equipment/systems at a certain time,

- apparatus/systems using electric energy;
- distributed generation units (DGU) with its ancillary systems;
- MCS;

the original sine wave of the supply develops towards a somehow different shape, which shall be considered for its possibly disturbing effect on the operation of electrical equipment; with regard to the different types of such emissions, figuring as disturbances causing EMI, i.e.

- intentional emissions, i.e. signals;
- non-intentional emissions or
- a combination of both ones;

and following to the cumulative effect of the additional voltage components, for ensuring EMC, the need for appropriate setting of compatibility levels as well as of emission limits and immunity requirements (see also [64]) is given.

Apart from the technical aspects, but connected with it to a certain extent, several EU Directives and Standardization Mandates (see e.g. [5] – [12]) figure as a background for these changes in the use of electricity supply networks. This has also been expressed by the Communication of the Commission on Smart Cities and Communities – European Innovation Partnership [13], which aims at catalyzing progress in areas where energy production, distribution and use, mobility and transport and information and communication technologies (ICT) are intimately interlinked and offer new interdisciplinary opportunities to improve services; that mainly with regard to the global energy situation which, exceeding the primary and basic goal of supplying electrical energy by far, requires measures for ensuring a future-proof energy supply including:

- the efficient use of electrical energy in general;
- increased use of renewable energies, with its ancillary systems for coupling to the supply network, for decentralized generation;
- improved information to the network user about energy consumption together with actual tariffs as well as extended information for the energy supplier about the actual operational and quality status of his network, by extensive information exchange from and to smart meters;
- considerations for the realization of smart grids;
- the realization of appropriate IT infrastructure, as the basis for the aforementioned projects.

3 The frequency range from 2 kHz to 150 kHz

3.1 Challenges in terms of EMI

Regarding EMC (see definition in the EMCD²⁾ [14] and the IECV³⁾ [15]), on principle:

- unintentional emissions from non-mains-communicating equipment / systems (NCE) or communication equipment, or
- communication signals, both figuring as “emissions” and having some potential for causing EMI, or
- a combination of both ones

shall be considered, according to the classical viewpoint in terms of voltage/current levels, that together with:

- the cumulative effect of voltage components from all emitting equipment connected to a supply network;
- different proliferation of different types of electric equipment and its different times and durations of operation;
- utilization of the frequency range below 150 kHz (see also 3.2).

To ensure EMC and to meet the Essential Requirements (ERs) of the EMCD, a balanced co-existence of appropriately set emission limits, appropriately realized equipment immunity to emissions (non-intentional and signals) and to the supply network characteristics is necessary (see also [16]).

Besides the numerical values of voltage/current levels, at least for the frequency range 2 kHz – 150 kHz, the voltage/current shape is a character which has some impact on the sensitivity of electrical equipment to EM disturbances and should therefore be considered when dealing with EMC requirements for this frequency range in general and with related immunity in particular (see 3.3).

Depending on the levels of such emissions as well as on the voltage shapes of these emissions, the resulting modification of the supply voltage’s sine wave through NCE or communication equipment can be followed by:

- degradation of function, maloperation or damage of network users’ or energy suppliers’ equipment;
- degradation of performance of MCS, e.g. AMR-PLC;
- display of wrong meter register values.

Table 1 gives an overview of a somehow more detailed grouping of EMI effects (see also [17] – [19]).

Table 1 — Main groups of EMI effects

(Non-intentional) Emissions from network users’ equipment at or close to frequencies used for MCS interfere with intentional MCS signals, leading to disturbance or loss of MCS communication
Multiples of (non-intentional) emissions from network users’ equipment, being close to frequencies applied for MCS may cause interference with the MCS resulting in failed communication
Distortion of the supply voltage due to discontinuous (non-intentional) currents/voltages from network users’ equipment or signal voltages from MCS may lead to degraded performance or maloperation of network users’ equipment
Network users’ equipment representing a low-impedance path at frequencies used for MCS lead to an attenuation of the intentional MCS signal which might disturb or interrupt communication (“shunting effect”)
(Non-intentional) emissions from network users’ equipment or (intentional) MCS signal voltages may result in somehow higher currents, leading to overheating and accelerated ageing of components in network users’ equipment

2) Electromagnetic Compatibility Directive.
3) International Electrotechnical Vocabulary.

For the frequency range 2 kHz – 150 kHz, at first sight, it appeared that mainly touch-dimmer-lamps (TDLs), inverters and AMR-PLC were involved in related interference [1a]. Anyhow, already in Study Report I,

- EMI cases have been mentioned with other types of equipment having been involved as a source or victim;
- the assumption has been expressed, that somehow more types of equipment could be needed to be considered as EMI sources or victims.

Summarizing information having been gathered from 12 countries (AT, BE, DE, FI, FR, GB, HU, IT, JP, NL, NO, SE)⁴⁾ about related measurements and investigations on EMI cases and measurement results being described in Clauses 4 and 5, Tables 2 and 3 give an overview of types of equipment showing high level emissions in the related frequency band or having already been recognized as a source or victim of such EMI (see also [1a], [20 – 23]).

Table 2 — Equipment figuring as a source of EMI, Examples

Inverters (e.g. in PV installations) and variable speed drives (VSD), (e.g. in elevator drives, ski lift drives, heating system circulation pumps, ventilation systems, household equipment)
Switch-mode power supplies (e.g. in lighting equipment, PCs, consumer electronic/home entertainment equipment (e.g. TV, DVD), ICT equipment, uninterruptible power supplies (UPS), charging devices)
Lighting equipment (e.g. fluorescent lamps, compact lamps, LEDs)
Household equipment (e.g. induction cookers, washing machines, electric shavers)
Portable mains operated tools
AMR-PLC

Table 3 — Equipment figuring as an EMI victim, Examples

AMR-PLC
Solid state meters
Electronic control (e.g. touch-controlled equipment like Touch Dimmer lamps (TDL), alarm systems, traffic control systems, traffic lights, in heating systems, street lighting, in urinals, for doors, in kitchen appliances (e.g. steam irons, coffee machines, ceramic hobs)
Communication systems (e. g. Ethernet-system, ISDN-, ADSL-modems, IP network branch exchange, routers, LAN)
Telephone systems including inductive train radio systems
Earth leakage circuit breakers (ELB)
Contactless magnetic card readers, credit card terminals
Notebooks (cursor position)
Broadcast standard time-signal systems (e.g. DCF77, Japanese system)
Road vehicle smart keys
TV and radio receivers
Mobile radio
Amateur radio

Tables 2 and 3 may need further amendments in future, following further investigations.

Table 4 provides information about different effects of EMI to certain equipment in the considered frequency range.

4) Austria, Belgium, Finland, France, Germany, Great Britain, Hungary, Italy, Japan, The Netherlands, Norway, Sweden.

Table 4 — Effects of EMI to equipment in the frequency range 2 kHz– 150 kHz, Examples

TDLs	Unintentional switching (between light steps, OFF, also ON)
Street lighting	Unintentional switch-on and –off
Traffic lights	Malfunction
Traffic control system for public transportation buses	Malfunction
Solid state meter	Displaying wrong meter register values
MCS	Temporary or quasi-permanent loss of data transmission function
Heat control with time basis through DCF77 signal	Malfunction
Heating systems	Incorrect alarms due to sensor faults
Contactless magnetic card reader	Malfunction of reading function
ADSL modem	Loss of link, CRC error
Routers	Loss of synchronization (40, 50 and 70 kHz) to the network
Notebooks	Disturbed cursor position (37 kHz)
Inductive Train Radio System	Audible noise
Ceramic hobs	Incorrect relay switching
Coffee cooker	Incorrect control lamp function
Steam irons	Insufficient heat, water loss, incorrect control lamp blinking
Washing machines	Self-restart (some hours) after end of operation phase
Automatic urinal water control	switching to permanent operation
Broadcast standard time-signal systems	Electronic clocks: being fast (gaining up to 15 mins per day), Malfunction of control circuits fed by the time-signal
TV and radio receiver	Audible noise (up to 20 kHz)
Amateur radio	Disturbed reception of distant transmitters

With this overview of potential EMI sources/victims as well as EMI effects together with the measurement and investigation results in Clauses 4 and 5 of this Technical Report it may be taken as a fact, that the EMI potential in the frequency range below 150 kHz, already mentioned in Recommendation Com-1 of the Report “Standards for Smart Grids” published by the CEN/CENELEC/ETSI SG-CG in 2011 [24] (see also [25]), is not restricted to PLC devices and domestic appliances but shall be seen as having a quite larger dimension. This will need to be resolved by creative approaches taking into account the installed base, i.e. products on the market, and future technology development.

3.2 Frequency utilization

When considering the utilization of the frequency range below 150 kHz for different purposes, there is to be distinguished between:

- a) conducted voltage/current components representing:
 - 1) non-intentional emissions (NIE), stemming from:
 - i) NCE as a consequence of the applied technology and being a more or less unavoidable waste product of its application of electrical energy;
 - ii) from MCS as spurious emissions from such, i.e. unwanted signals, both types of emissions to be considered as disturbances in the sense of the IEC [15] definition of “electromagnetic disturbances” (see also Recommendation 13. in Clause 9);
 - 2) voltage/current components
 - i) stemming from NIE (see above) or MCS signals (see below),
 - ii) being induced from wires in an installation via the magnetic H-field to another installation or an electronic circuit
 - 3) communication signals from MCS, being intentionally impressed on the 50-Hz-supply voltage for the purpose of transmitting information, e.g. for smart metering/smart grid systems in the

public supply area or for network users' purposes within their installation, e.g. for data transmission within their premises or for home automation.

Figure 1 shows the frequency ranges designated to applications using (narrow-band) MCS:

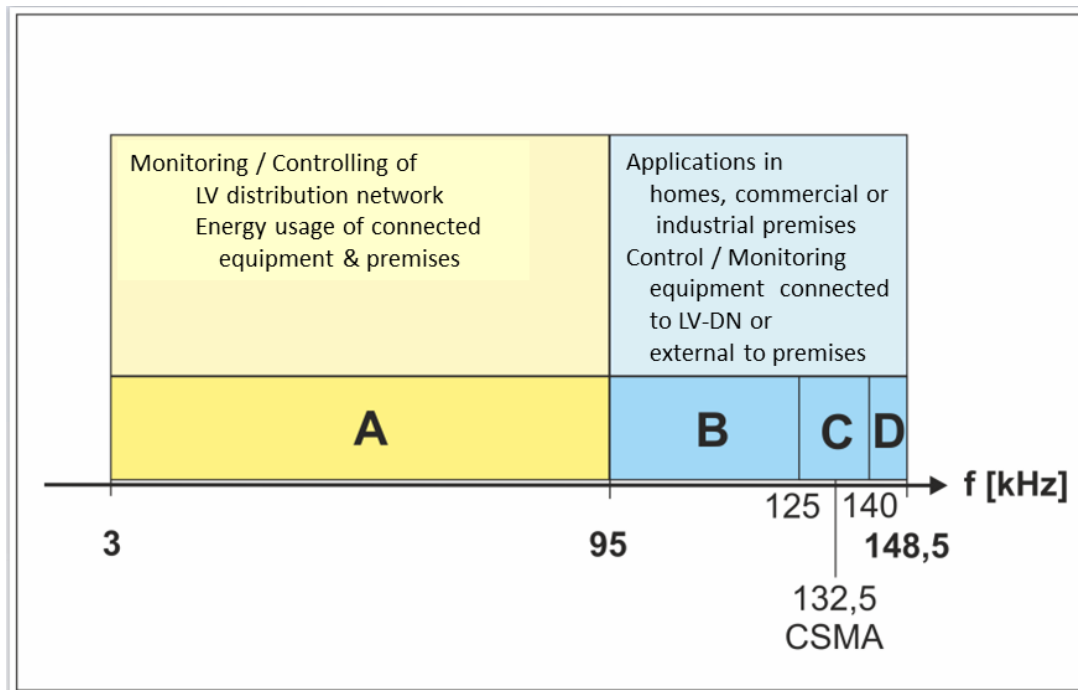


Figure 1 — Frequency band designations according to EN 50065-1 [26]

All the aforementioned voltage/current components have some potential for causing EMI, for which also a combination of the different types shall be considered; that together with:

- the cumulative effect of voltage components from all emitting equipment connected to a supply network;
- different proliferation of different sorts of electric equipment and its different durations of operation.

The aforementioned cumulative effect represents some criterion for dealing with both types of emissions, as:

- NIE are generated from a lot of different equipment operated in a certain supply area and therefore contributing to a certain cumulative load of such emissions at a certain instant, which varies over time;
- MCS signals, in any case in CENELEC-band A (Figure 1), are normally present in a certain supply area only from *one* MCS, therefore not experiencing any accumulation.

That leads also to the recognition, that – e.g. concerning setting immunity requirements – signals need to be treated different from NIE.

b) radiated magnetic fields stemming from

- 1) non-intentional currents due to the operation of electronic circuits, as explained above;
- 2) signal currents from MCS, intentionally impressed on the supply voltage as explained above.

Also these magnetic fields, resulting from non-intentional or signal currents, have some EMI potential, by causing conducted voltages getting induced to installations or electronic circuits (see 5.3.1, List Entry a)).

c) radio applications for services, like broadcast time-signal services.

Concerning the first-mentioned group a):

- contrary to the frequency range up to 2 kHz, where normative specifications exist for harmonics [27] and voltage fluctuations [28] in a LV supply network and up to 3 kHz, where emission levels for intentional signalling from ripple control are standardized (Meister curve) by EN 61000-2-2 [29];
- besides the subject areas of:
 - i) lighting equipment and induction cookers [30], [31];
 - ii) the Basic standard EN 61000-4-16 [32] specifying test conditions for electric and electronic equipment concerning immunity to conducted asymmetrical disturbances in the frequency range 0 kHz – 150 kHz;
 - iii) narrow-band MCS technology, where emission limits and immunity requirements have been standardized for the frequency range 3 kHz – 148,5 kHz, by the EN 50065 series [26], [33] – [35] on from 2001 (see also IEC 61000-3-8 [36] and IEC 61334-3-1 [37] concerning frequency bands and output levels and [38] – [45] for additional normative specifications (filters, couplers, equipment impedance).

this frequency range 2 kHz – 150 kHz, up until now, has not been considered for setting limits for NIE (see 6.1). Recently, some developing situation is given in the field of power electronics, where first proposals for recommending emission values for Active Infeed Converters (AICs) have been approved in IEC/TS 62578 ([46] (see 6.1)).

Concerning radiated magnetic fields no standardized limits exist for this frequency range; that likewise as recently no technical specifications are available for evaluating an EMI situation with EMI to broadcast time-signal systems, although to be seen as protected, in any case in terms of radio interference (see 5.3.1).

With regard to the recognized co-existence problems between equipment generating NIE and MCS in the frequency range 2 kHz – 150 kHz, it is of some interest whether:

- concerning EMC, standards need to consider existing products/technologies on the market
- the intended operation of MCS were to be seen as being protected by the EMCD.

(See also Clause 6.)

The primary status of a standard shall be considered as voluntary, which could be changed if a standard becomes part of a contract

Concerning the EMCD, related discussions resulted in the recognition, that with the inclusion of telecommunication systems/networks in its scope, the EMCD and its ERs are protecting the intended operation also of MCS.

3.3 The impact of voltage / current shapes

From Study Report I [1a] it is known, that besides the numerical values of voltage/current levels, at least for the frequency range 2 kHz – 150 kHz, also the voltage/current shape is a character which has some impact on the sensitivity of electrical equipment to EM disturbances -- what should therefore be considered when dealing with EMC requirements for this frequency range in general and with related immunity in particular.

When having reported about the first investigation results, having been achieved during measurements concerning EMI from AMR-PLC to TDLs, it was shown, that, for the considered frequency range, interference is also a matter of rise (or fall) time of the amplitude/envelope of voltage/current components.

For example, Figure 2 shows the rise of sine wave signal components in the supply voltage with a frequency of 55 kHz respectively 90 kHz, by which a TDL has been switched on. The instant of time of switch-on of the TDL can be recognized through the start of network disturbances from the TDL's triac-controller (see sequences of narrow spikes outside the envelope of the test signal).

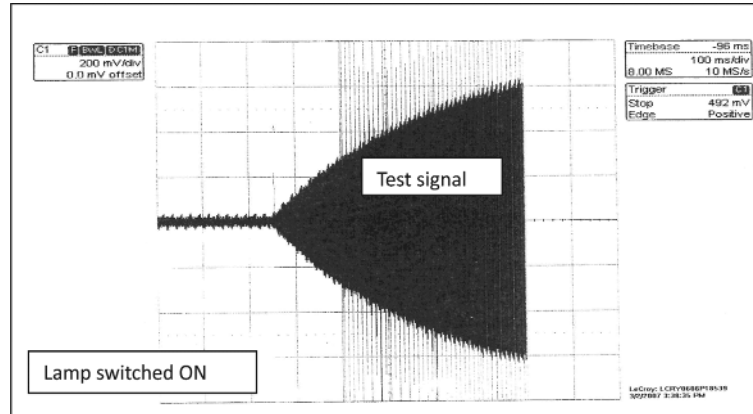


Figure 2 — Sine wave components in the supply voltage, ((test signal) frequency: 90 kHz), leading to a switch-on of a TDL

Additional investigations have been made by an accredited test house [47], with a (modulated) test voltage according to Figure 3 applied to a TDL.

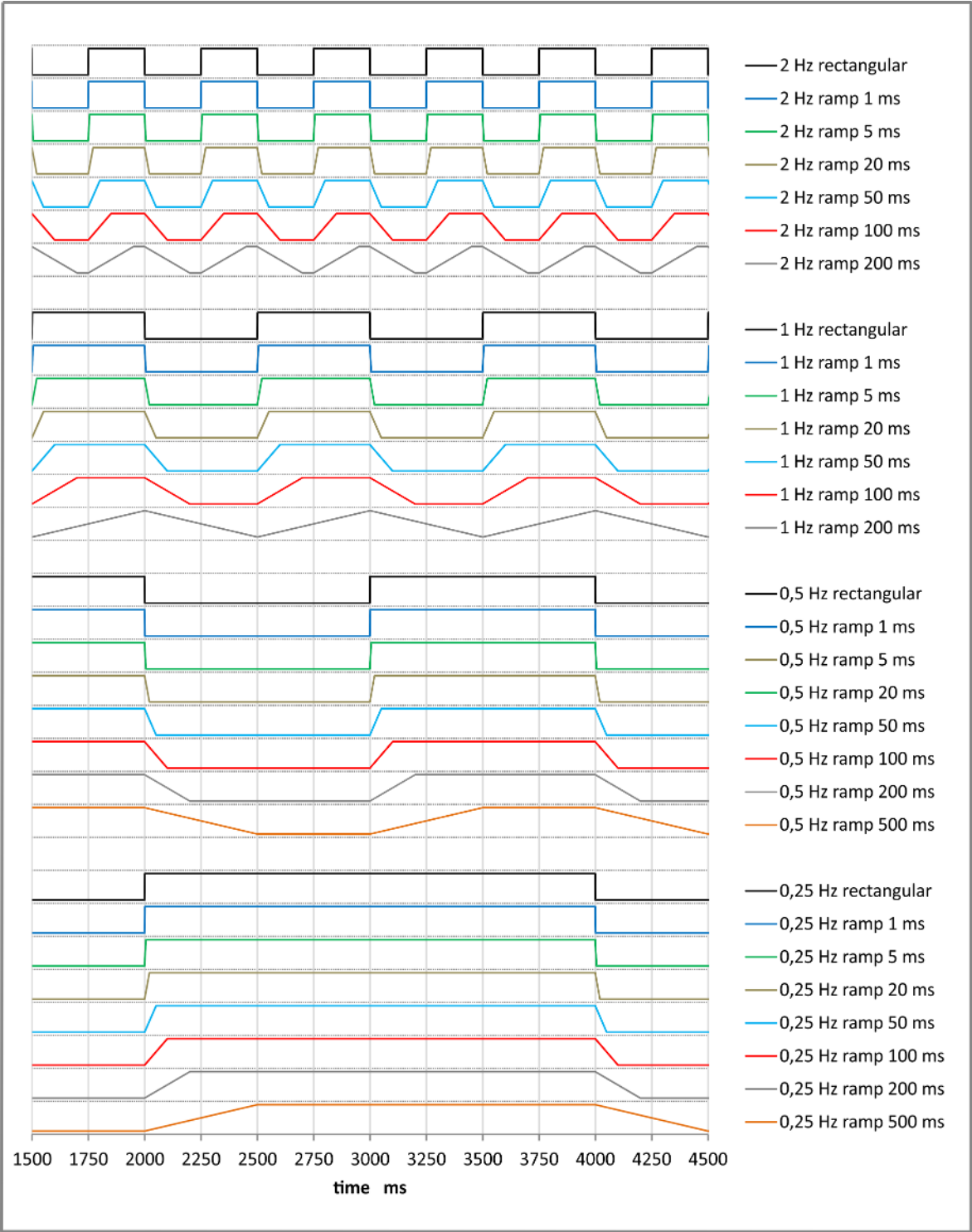


Figure 3 — Test voltage for rise time investigation

The time and the voltage value of the envelope of the modulated test voltage until the EUT appeared as being disturbed (TDL: switched on) were measured with all waveshapes shown in Figure 3 (ramp characteristic, repeating interval times).

It can be recognized as being typical, that the resulting EMI is somehow dependent on the level of the applied test voltage. For testing the impact of rise time for each rise time (1 ms, 5 ms, 20 ms, 50 ms, 200 ms, 500 ms), the disturbance voltage was adjusted to that level causing switch-on of the TDL with a probability of 95 %, due to a simulated interference.

To evaluate this probability, a sequence of 100 rises and falls of a test voltage with a frequency of 50 kHz was applied.

In case of simulating an MCS signal, a rise time of about 0,5 s is not applicable because of the resulting loss of bandwidth.

As results from these tests, Figures 4 and 5 show the achieved dependence of the test voltage level on the rise time and the rise speed.

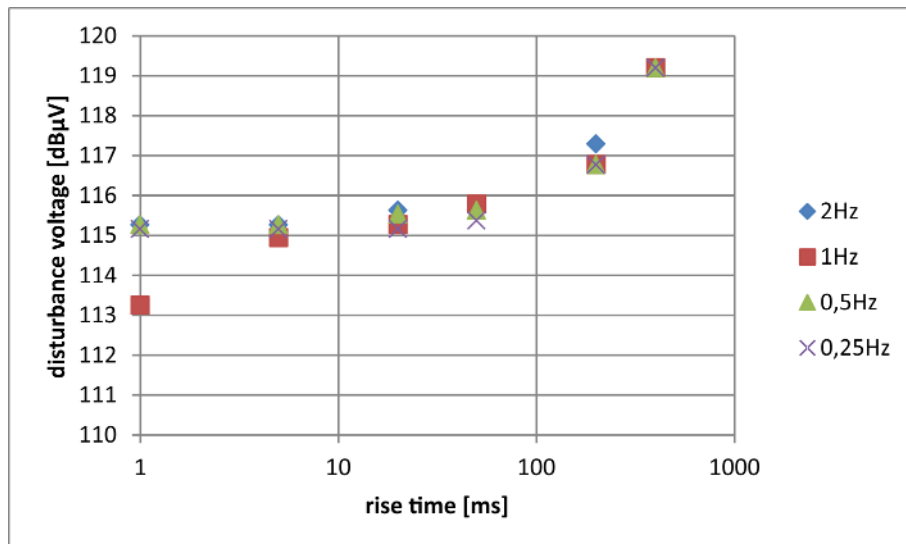


Figure 4 — Rise time tests with a TDL 95%-dependence of threshold on the rise time of an emission / a test level

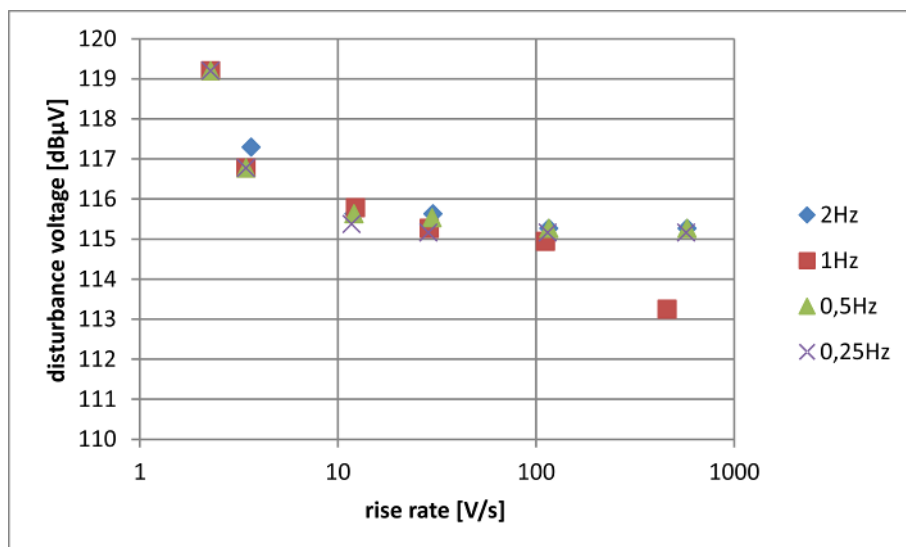


Figure 5 — Rise time tests with a TDL 95%-dependence of threshold on the rise speed of an emission / a test level

The frequency of the periodic rise or fall did not show any impact on the threshold values.

These test results:

- proved the relevance of the rise/fall time of the envelope of an emission/signal respectively a test voltage for the threshold of a control circuit and therefore the relevance of the envelope of a discontinuous voltage for the sensitivity of electronic circuits to such and following to that to related immunity requirements;
- showed, that for a slower rise/fall of the envelope of a modulated emission / signal, the threshold moves to higher values what allows higher emission levels respectively less stringent immunity requirements.

As already mentioned in Study Report I [1a] (5.2), dependent on the coupling method (CM, DM), different EMI effects and thresholds have been observed. Therefore, for comprehensive immunity testing, both coupling methods were to be considered in related tests.

Based on that, it might be deductible, that:

- a solely numerical setting of compatibility levels, emission limits and immunity requirements might not be sufficient in that frequency range;
- leaving consideration of quasi-stationary conditions as the sole basis for setting EMC requirements would offer additional room for ensuring EMC for the considered frequency range.

Combined specification of levels and other characteristics of emissions like (maximum) rise or fall edge of the envelope of a disturbance/signal appears to may offer a technically more appropriate basis for setting related compatibility levels as well as requirements (emissions, immunity) in EMC and Product standards.

3.4 Interaction of equipment

Interactions between different types of NCE connected to the grid, e.g. heat pumps, induction cookers and fluorescent lamps, as well as between such equipment and MCS have been analyzed e.g. in [48], [49], [118].

The effect of such interactions and resulting interference appears as not being predictable due to the permanently changing situation of connected equipment, i.e. sites, power different technologies and duration of connection of loads.

From the related analyses follows, that:

- interaction between connected equipment in the frequency range 2 kHz – 150 kHz differs from the interaction taking place in the frequency range below 2 kHz. That with regard to high frequency emissions flowing between devices and not upstream to the transformer;
- due to technological development of electrical devices, resonances in this frequency range between connected equipment which is simultaneously in operation, e.g. an induction cooker and a heat pump, may increase in future;
- the impact of connected NCE on MCS is much stronger than the impact from the grid itself, such as damping in wires;
- the signal limits for MCS are the highest ones compared with emissions from other equipment; therefore, immunity standards for this frequency range should be based on the standardized signal limits for MCS.

4 Emissions, measurement and test results

4.1 General

This clause provides results of measurements on different types of electrical devices without having been involved in EMI cases before. Related information and measurement results have been provided from Austria, Belgium, Great Britain, Japan, Sweden and IEC SC 77A/WG 8 (see also related contributions to CIREN 2013 [50], [117]).

With regard to the assumption already made in Study Report I [1a], that some additional types of equipment might need to be considered as potential sources of EMI in the frequency range 2 kHz to 150 kHz, the goal of these measurements was to get more knowledge of the given EMI potential and to better clarify assumed EMI potential between certain types of equipment.

As concerns also the investigation results on EMI cases described in chapter 4, related measurements have been made on site as well as under laboratory conditions, using a wide variety of test methods; therefore, the results cannot be taken as exactly comparable but may fulfil the task of providing an overview of the existing situation.

4.2 Noise measured in a block of flats

Austrian measurements of the noise potential in distribution racks in the frequency range 10 kHz – 100 kHz showed without presence of a PC signal quasi-stationary broadband noise with levels from ~40 dB μ V to 66 dB μ V, additionally partly with peaks up to 80 dB μ V, with a dynamic up to 23 dB. The source of this noise is unknown.

Here, at the lines from the transformer station, currents on single frequencies up to 4 mA peak and with broadband measurement up to ~1 mA have been measured. Also here, time-signal systems like DCF77 could get disturbed (see also 5.3.1).

Source of disturbance unknown.

4.3 Lighting equipment

4.3.1 General

When starting investigations on EMI in the frequency range 2 kHz – 150 kHz, TDLs appeared as one of the initiating elements being involved as an interference victim. As already reported in Study Report I [1a], during laboratory tests in Hungary, disturbances to narrow-band PLC communication have been experienced with different equipment, besides UPS's and inverter drives also with compact fluorescent lamps – this time as a source of interference

In the following, results of measurements on related emissions from lighting equipment are described.

4.3.2 Compact lamps

Measurements of the emissions from two compact lamps (2 x 26 W) in the frequency range 9 kHz to 500 kHz, conducted by an accredited test-house [51], show

- emissions of up to 82 dB μ V (around 60 kHz), and with that
- an excess of the limits of EN 50065-1 [26] for spurious signal emissions by nearly 10 dB (Figure 6).

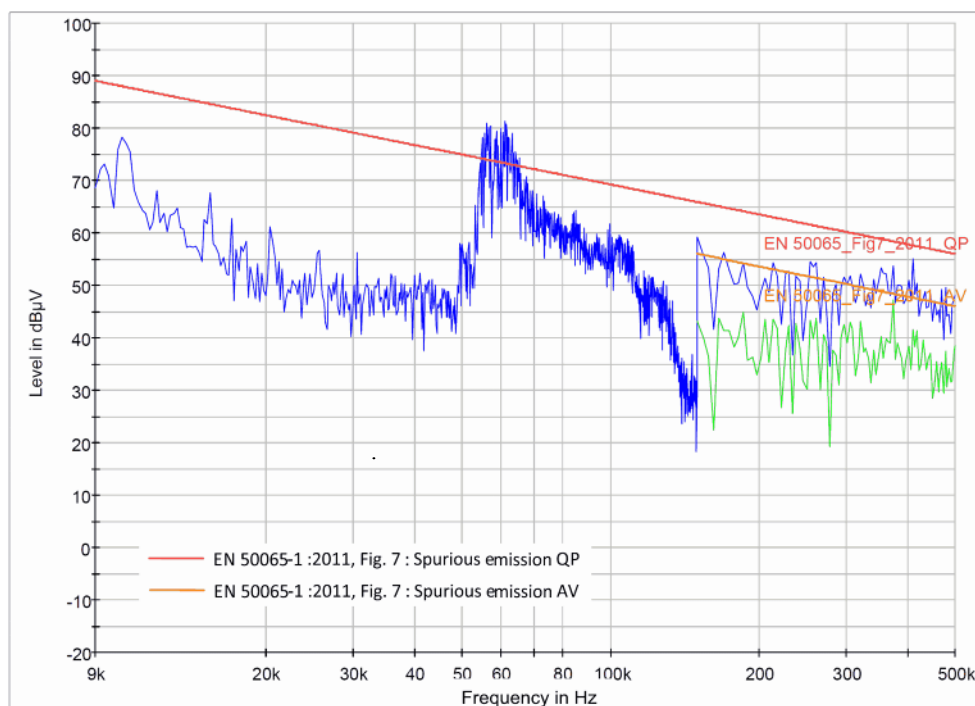


Figure 6 — Emissions from compact lamps

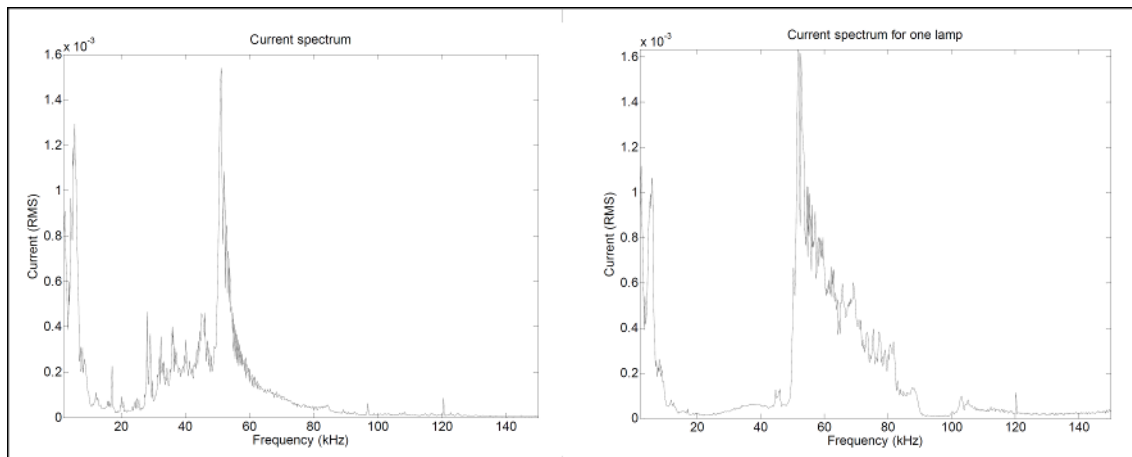
With these levels around 60 kHz, somehow close to the frequencies of broadcast time-signal systems (e.g. 60 kHz, 77,5 kHz; see 7.1.5, Table 7) an EMI potential at least to such broadcast time-signal systems is given.

The edge at 150 kHz is due to the different measurement bandwidth, which is according to Figure 7 in EN 50065-1 [26], (CISPR 16-1-1 [52]):

- 200 Hz for 9 to 150 kHz;
- 9 kHz for 150 kHz to 30 MHz.

4.3.3 Fluorescent lamps

From reports about measurements in Sweden on emissions of up to 48 fluorescent lamps powered by high-frequency ballasts, in the frequency range 2 kHz to 150 kHz [53], [54], the following can be taken:



a) Current of one lamp ON

b) Filtered current of one lamp
when all 48 lamps are turned ON

Figure 7 — Spectrum of emissions from fluorescent lamps

- As Figure 7a) shows, the main component of the current in the considered frequency range feeding one lamp solely is the remains from the switching of the Automatic Power Factor Correction (APFC), with a wideband component decreasing with the frequency, from 50 kHz to about 90 kHz.
- Figure 7b) shows the filtered current of one lamp when all 48 lamps are turned on; compared with Figure 7a), it can be recognized, that the maxima of the current amplitude are about equal but showing a somehow “wider” effect, due to several frequency alternating signals which are most likely remains from other lamps burning at the same time.
- Figure 8 shows the spectrum of the total current feeding all 48 lamps ON. It can be recognized, that the resulting spectrum, divided by 48, shows almost no remains of the APFC switching in the current for one lamp shown in Figure 7a).

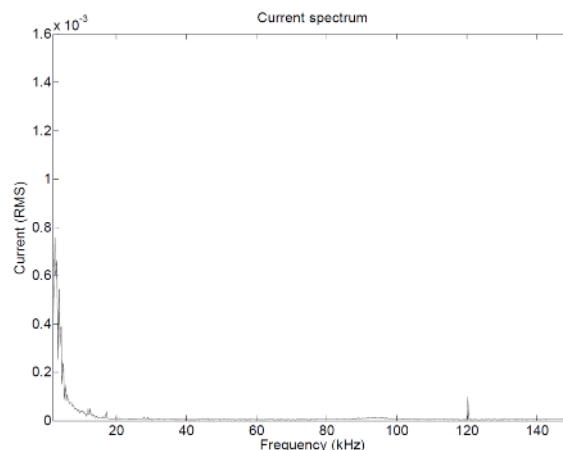


Figure 8 — Resulting spectrum of the total current feeding the 48 lamps

That shows that:

- 1) current spectrum components do not add linearly and
- 2) the general characteristic of the spectrum – except the peak at the switching frequency – is, besides its changes due to other electrical equipment connected and daytime, changing with the number of lamps ON.

d) Emissions are dependent on daytime.

It can be deduced that:

- e) emissions from fluorescent lamps show peak currents in the considered frequency range, resulting in voltage components dependant on the network impedance at the relevant frequencies;
- f) the resulting effect of such fluorescent lamps is variable with:
 - 1) the number of lamps ON;
 - 2) the structure and impedance of the related installation;
 - 3) the degree of mutual reduction of spectral components due to phase-angle shift and transients between the lamps;
- g) generally higher transient currents may flow between electrical equipment in a certain installation,
 - 1) leading to some reduction of the effect of one of its current components;
 - 2) flowing between such equipment but not going upstream, leaving the installation, but
 - 3) possibly contributing to a disturbing effect to other electrical equipment connected to that installation (see also [48]) or to such connected to another installation, via H-field coupling (see 5.3).

4.3.4 LEDs

Measurements in an accredited Austrian test house, with up to 30 LED bulbs of different type connected to the supply network, showed to some extent remarkable emissions in the frequency range between 20 kHz and 100 kHz, with values up to around 107 dB μ V at around 70 kHz.

Figures 9 and 10 show measurement results with

- 1 and 30 LED bulbs of one type (“A”), with emissions far below any signal of PLC
- 1 and 3 LED bulbs of another type (“B”), with quite high emissions, those ones partly not meeting the limits given with EN 55015 [31].

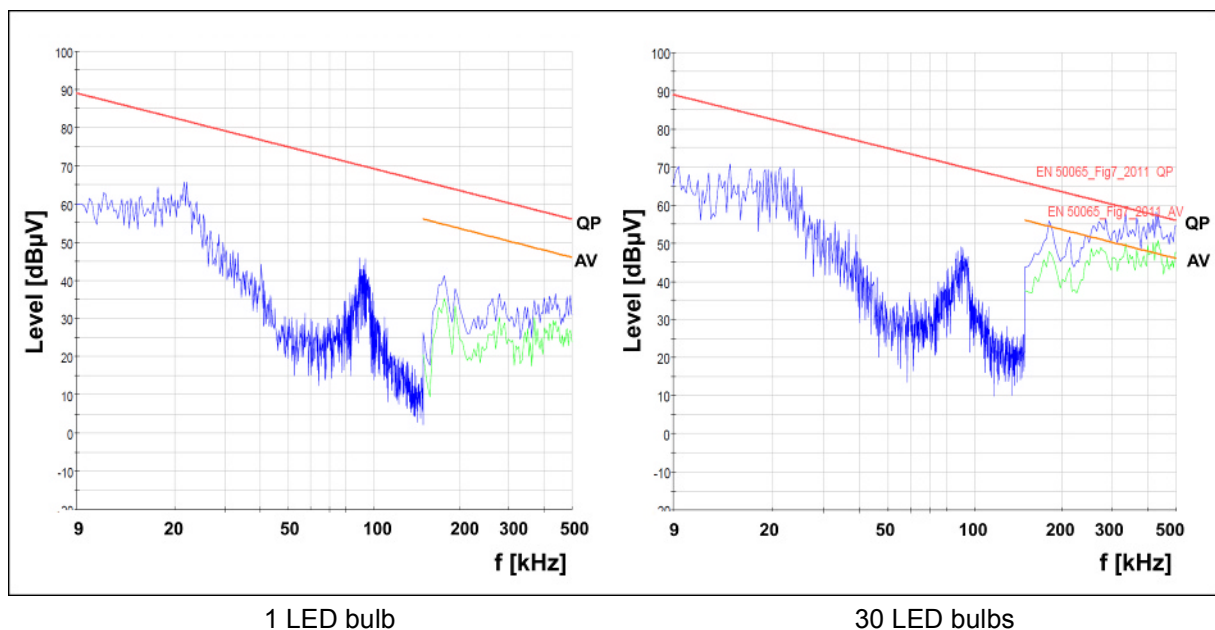


Figure 9 — Emissions from LEDs, type “A”, 8 W
in relation to spurious emission limits for MCS according to EN 50065-1:2011, Figure 7 (QP, AV)

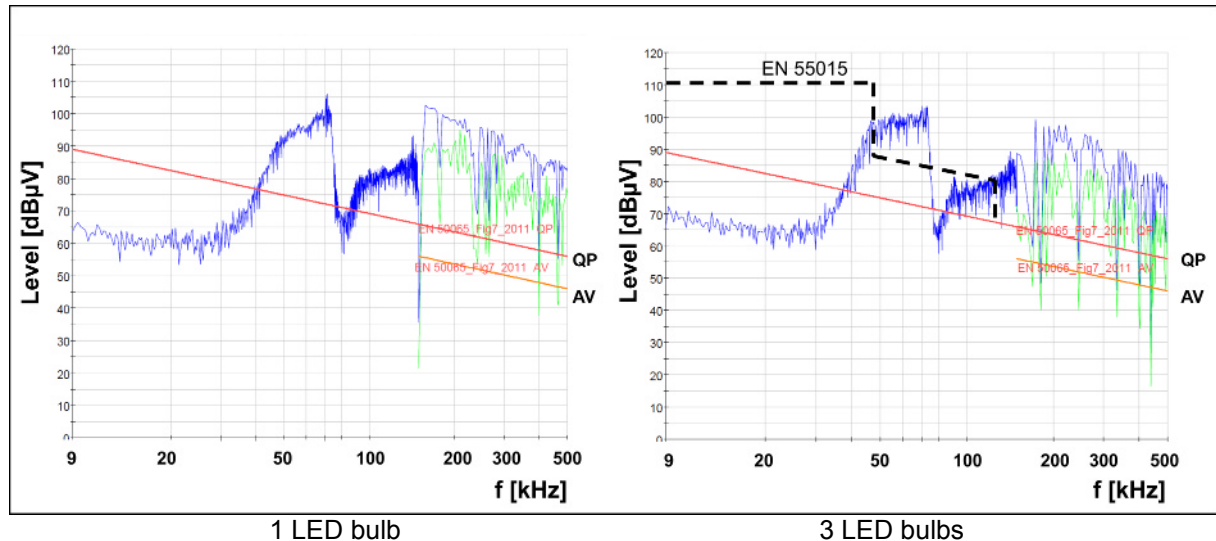


**Figure 10 — Emissions from LEDs, type “B”, 7 W
in relation to spurious emission limits for MCS according to EN 50065-1:2011, Figure 7 (QP, AV)
and to EN 55015**

The edge at 150 kHz is due to the different measurement bandwidth, which is according to Figure 7 in EN 50065-1:2011 [26], (EN 55016-1-1 [52]):

- 200 Hz for 9 to 150 kHz;
- 9 kHz for 150 kHz to 30 MHz.

As can be recognized,

- a) different types of LED bulbs show
 - 1) quite differing spectrum types of emissions, also with;
 - 2) quite different maximum values;
- b) the measured peaks reach an order of magnitude of signal levels generally to be expected along the mains supply, due to attenuation along the supply network, or exceeding it, thus representing some danger of EMI with electrical equipment sensitive to such voltages including e.g. MCS and different broadcast time-signal systems (see 5.3.1);
- c) deviating from what appeared as generally being valid for related EMI (see [53], [54]), measurements with a number of LEDs showed that, considering the peak values over the whole frequency range, the superposition of its emissions occurs in a different way from type to type – one time quite linearly, the other time with a decreasing factor.

Also, and in particular, with regard to the intended future proliferation of such bulbs, this effect should be considered and further investigated.

4.4 Portable mains powered tools

Conducted emissions from different hand tools have been investigated by an accredited test house at the equipments' a.c. ports in the frequency range 9 kHz to 500 kHz [51].

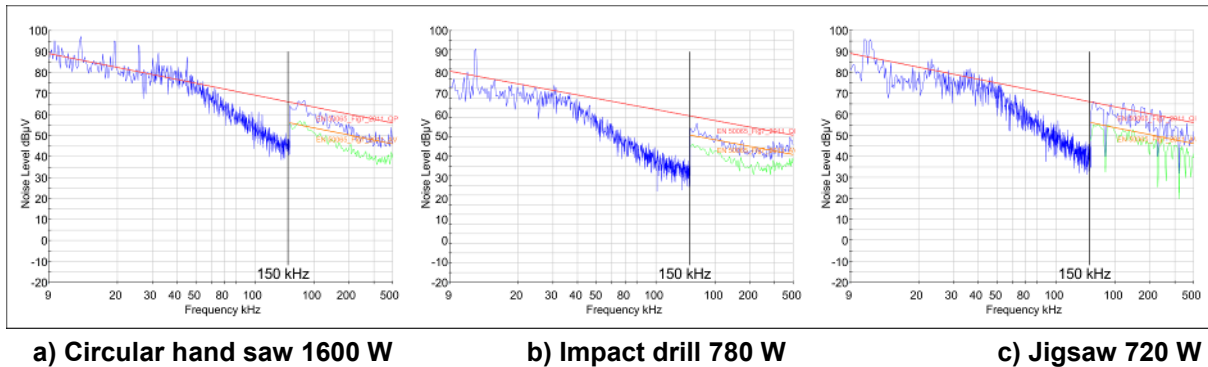


Figure 11 — Emissions from portable mains powered tools

As can be seen from the measurement results,

- at frequencies below 50 kHz, with its peaks, these emissions partly exceed the limits of EN 50065-1 [26] for spurious signal emissions out of band remarkably, by up to 14 dB.
- the peak values, of:
 - up to 97 dBμV (Circular hand saw, Jigsaw),
 - up to 100 dBμV (Impact drill),

are only some 34 dB below the limits for intentional signal emission in-band.

Considering an attenuation of 40 dB to 80 dB for the signal along the supply network, exceeding of the factual signal level by the emission from such tools could occur.

4.5 Power electronic loads including inverters

4.5.1 General

As a Japanese research report of 1998 [55] mentions, power electronics equipment using inverters (e.g. an elevator, a lift, an uninterruptible power supply) are coming into wider use. These types of equipment have become widespread not only in factories, but also in commercial and residential areas.

In general, these types of equipment have a switching circuit operating at a switching frequency from several kilohertz to some tens of kilohertz. Large pulse currents are flowing in the switching circuit resulting also in high frequency noise currents. When noise suppression is not implemented, large noise currents are flowing into ground lines and power lines connected to the equipments. Such emissions from inverters may cause interference with other electrical equipment, due

- to its switching frequency and its harmonics,
- to its voltage shape in time domain
- to higher levels.

Related interference may cause degradation of performance of the concerned equipment (see also 5.2.3.3). Proved examples for such interference are:

- the display of wrong meter register values (see 5.2.2)
- communication loss in MCS (see 5.2.3.2.2, 5.2.3.2.3, 5.2.3.2.5 – 5.2.3.2.8, 5.2.3.2.10 – 5.2.3.2.14).

Further, EMI may occur due to electromagnetic waves being radiated around the supply lines and creating potential for interference to other equipment (see also 5.3).

As already reported in Study Report I, during laboratory tests in Hungary, disturbances to narrow-band PLC communication have been experienced with different types of equipment, besides compact fluorescent lamps and UPSs also inverter drives [1a].

Results of related measurements are presented below; for results of investigations and field measurements on related EMI cases see 5.2.3.3.

4.5.2 Austrian lab tests on inverters

Measurements in the laboratory of an accredited Austrian test house [51] concerning the emissions from inverters, using a standardized AMN, showed the following results:

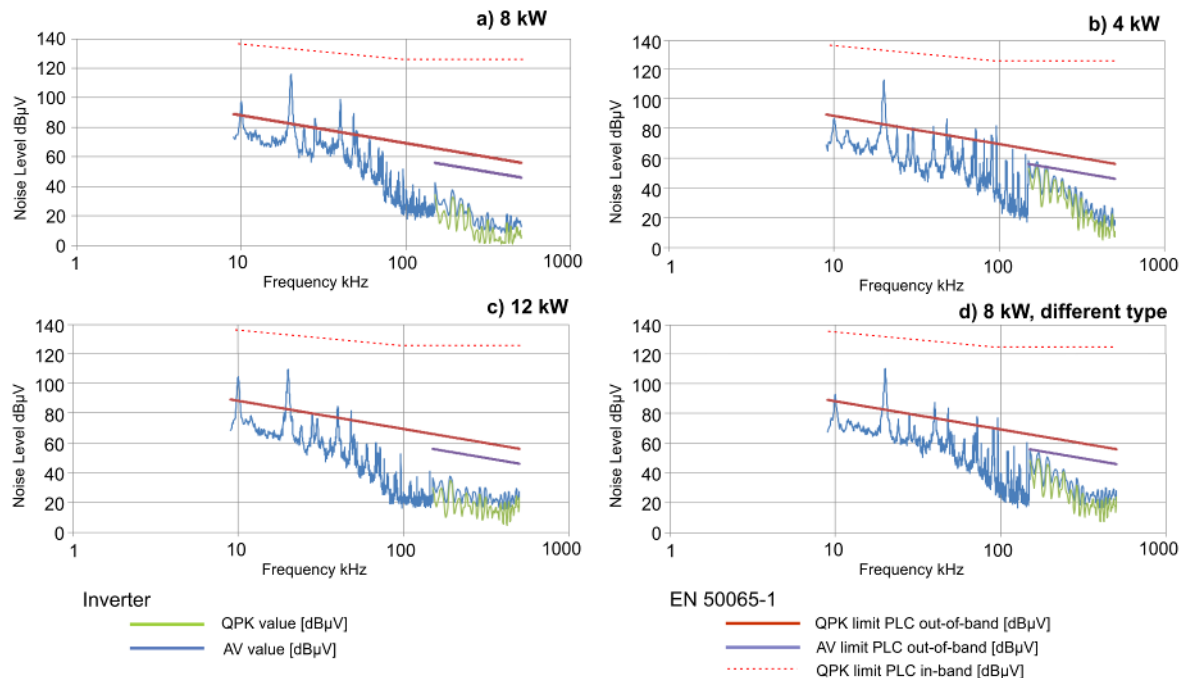


Figure 12 — Emissions from inverters 4 kW – 12 kW

As can be seen, quite irrespective of the infeed power, the emissions

- appear as being quite similar in shape and levels;
- show peaks according to the inverter's switching frequency and its harmonics;
- show mean values in the frequency range 9 kHz – 150 kHz from ~90 dBμV decreasing to ~22 dBμV, thus being somehow below the out-of-band limits for PLC defined in EN 50065-1 [26];
- are exceeding with its peaks the limits for spurious out-of-band emissions of a PLC-system as being standardized in EN 50065-1 [26], in the frequency range 10 kHz – 100 kHz several times, by up to some 36 dB.

Actual signal levels in the supply network, normally attenuated along the supply network by some tens of dB, may be disturbed.

4.5.3 Active Infeed Converters

In order to evaluate the effect of Active Infeed Converters (AICs) on PLC systems, on behalf of IEC SC 77A/WG 8 a laboratory test was carried out. The test configuration was as follows:

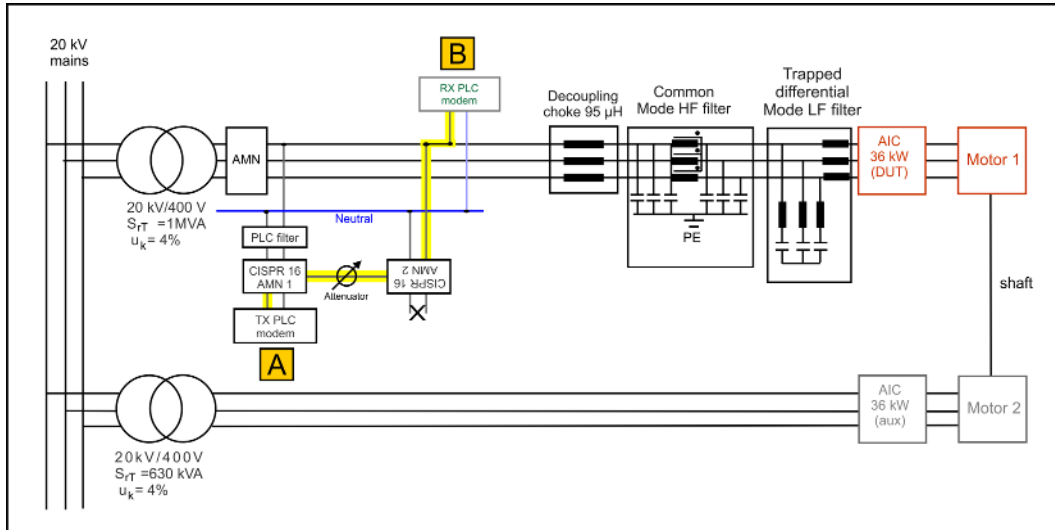


Figure 13 — Test set-up for the measurement of EMI from AIC to PLC

Both, Artificial Mains Network (AMN) and filters, have been used on the LV line; four types of AIC filter configurations have been applied:

- “filter 0”: decoupling choke 95 μH (choke size about 75% of the AIC’s size);
- “filter 1”: trapped differential mode LF filter (filter size similar to the AIC’s size);
- “filter 2”: trapped differential mode LF filter + common-mode HF filter (filter size about 10% of the AIC’s size);
- “filter 3”: trapped differential mode LF filter + common-mode HF filter + 95 μH choke simulating a purely inductive 95 m long LV line.

The AMN was not present in the first configuration -- "filter 0" --, but was present in the others -- "filter 1" to "filter 3".

The PLC signal path is highlighted in yellow.

The PLC technology that has been used during the test sessions was a first generation PLC technology, based on an S-FSK (Spread Frequency Shift Keying) modulation which principle consists in using two different carriers to code a binary '0' or a '1'. The two carriers used to perform the S-FSK modulation were located at 63.3 kHz and 74 kHz and had an amplitude of approximately 118 dB μ V.

The physical and data link layers of this S-FSK technology are standardized as EN 61334-5-1 [56] (PHY & MAC) and EN 61334-4-32 [57] (LLC).

As long as the AIC was switched off, the PLC communication operated properly in a wide dynamic range (55 dB to 60 dB).

As soon as the AIC was switched on, PLC communication failed in most of the test configurations when the receiver was close to the AIC (filter 0 without AMN, filter 1, 2 or 3 with AMN). Some successful PLC communications have been observed only when both transmitter and receiver were connected at the same place (no attenuation between transmitter and receiver, what does not reflect the reality in the field), but in this case, the dynamic range was nonexistent (close to 0 dB). This result was independent from the AIC operating mode, which varied between standby, consumer and regeneration mode.

However, when the noise source was attenuated by 15 dB, it has been observed that PLC communication with a dynamic range of approximately 20 dB has been achieved. However, it was not possible to evaluate which distance represents an attenuation of 15 dB.

The potential impact of disturbances generated by AICs in the frequency band 2 kHz – 150 kHz on PLC communications has been confirmed under laboratory conditions.

4.5.4 PV inverters

In the 3-phase installation of a building, emissions of two photovoltaic (PV) inverters 2,5 kW peak connected to phase 1 and another PV inverter in the close neighbourhood (200 m), connected to phase 2, have been investigated in Belgium with in-situ measurements [58], without standardized emission measurement.

Measurements on phase 1 clearly show a peak at 18 kHz (switching frequency of inverter I). That peak

- is about 60 dB below the fundamental and about 20 dB below harmonics 5 and 7 (the most important ones)
- is independent from the power generated by the PV system, but totally disappears in the evening, when the inverter is on “night shutdown”.

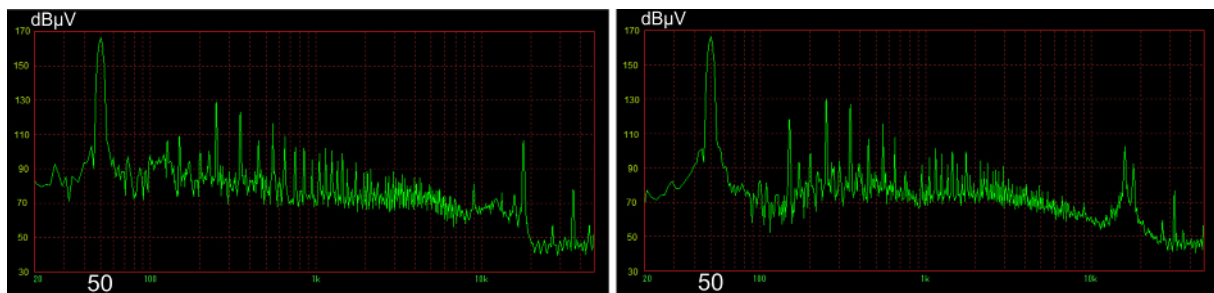
The frequency of 18 kHz is clearly due to the inverter; this is confirmed by the technical specification in the Appendix. Another peak (although another 30 dB lower) is visible at 36 kHz; it is a harmonic of the 18 kHz. Next to the 18 kHz peak, there is a 16 kHz peak, but at a lower level, stemming from the 2nd inverter (see Figure 14a)).

Measurements on phase 2 show an attenuated peak at 18 kHz (switching frequency inverter II; about 80 dB below fundamental), but there is another peak, more spread and about 70 dB below the fundamental. Harmonics at 32 kHz and 36 kHz are also visible (see Figure 14b)).

Measurements on phase 3 also show peaks at 16 kHz, 18 kHz, 32 kHz and 36 kHz, at levels slightly lower than on phase 2.

Internal frequency of the inverter (16 kHz or 18 kHz) however is well present, even at very low production levels. Its level is independent from the photovoltaic power produced; it only disappears when the inverter is shut down. The internal frequency (and to some extent its harmonics) tends to propagate along the whole LV distribution network, and is not blocked by the meters. The attenuation is around 10 dB.

Significant differences can be observed between both installations in this study: the 18 kHz from the first installation has a high phase-to-phase attenuation; the 16 kHz from the second installation has not only a higher level, but also a much lower phase-to-phase attenuation (15 to 20 dB on installation 1, less than 10 dB on installation 2). As a consequence, the 16 kHz switching frequency of installation 2 generates higher disturbances in the neighbourhood.



a) Location 1, Phase 1

b) Location 2, Phase 2

Figure 14 — Emissions from PV inverters in the frequency range 20 kHz to 50 kHz

As can be seen, the inverters generate emissions in the frequency range designated for MCS related to supply network applications (CENELEC-band A [26] (see also 3.2)); although the measurement was done in a frequency range up to 50 kHz only, it can be started from the assumption that also harmonics of higher order exist and the frequency range for narrow-band PLC according to EN 50065-1 [26] is concerned as a whole.

4.5.5 Italian lab and field measurements

In Italy, measurements have been performed on a number of generic market single phase inverters both terminated with a CISPR AMN as well as connected to different batteries of photovoltaic panels with a nominal power ranging from around 1 kW to 4 kW [59].



Figure 15 — Photovoltaic panels feeding a single phase inverter directly connected to an LV power line

Table 5 — Single phase LV inverter features

Nominal Power (kW)	PHV Module Power (kWp)	Phase
1,8	14,65	T
1,8	1,65	T
1,5	1,58	S
1,5	1,58	S
3,6	3,96	R
1,7	1,58	S
1,0	1,06	R

For the purpose of performing conducted voltage emission measurements at the mains port of apparatus, EN 55016-1-2 [52] defines a transducer known as Artificial Mains Network (AMN) or Line Impedance Stabilization Network (LISN) (Figure 16).

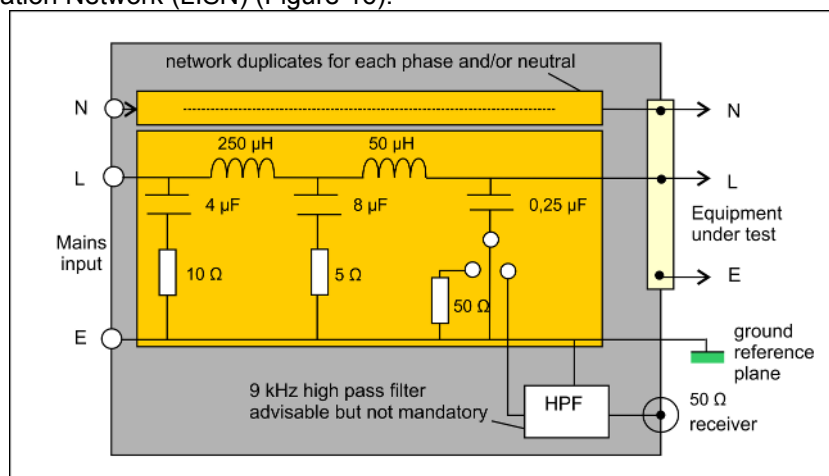


Figure 16 — Artificial Mains Network according to EN 55016-1-2