



Technical Report

**PowerLine Telecommunications (PLT);
MIMO PLT;
Part 2: Setup and Statistical Results of
MIMO PLT EMI Measurements**

Reference

RTR/PLT-00040

Keywords

MIMO, powerline

ETSI

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Powerline Telecommunications (PLT).

The present document is part 2 of a multi-part deliverable covering the MIMO PLT as identified below:

- Part 1: "Measurement Methods of MIMO PLT";
- Part 2: "Setup and Statistical Results of MIMO PLT EMI Measurements";**
- Part 3: "Setup and Statistical Results of MIMO PLT Channel and Noise Measurements".

Introduction

The STF 410 (Special Task Force) was set up in order to study and compare MIMO (Multiple Input Multiple Output) characteristics of the LVDN network in different countries. The present document is one of three parts of TR 101 562 which contain the findings of the STF 410 research.

1 Scope

MIMO PLT EMI is a review and statistical analysis which takes into account such matters as earthing variation, country variation, operator differences, phasing and distribution topologies, domestic, industrial and housing types along with local network loading.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at <http://docbox.etsi.org/Reference>.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- [i.1] Sartenaer, T. & Delogne, P.: "Powerline Cables Modelling for Broadband Communications", ISPLC 2001, pp. 331-337.
- [i.2] R. Hashmat, P. Pagani, A; Zeddani, T. Chonavel: "MIMO Communications for Inhome PLC Networks: Measurements and Results up to 100 MHz", IEEE International Symposium on Power Line Communications and its Applications (ISPLC), Rio, Brasil, March 2010.
- [i.3] A. Schwager: "Powerline Communications: Significant Technologies to become Ready for Integration", Doctoral Thesis at University of Duisburg-Essen, May 2010.
- [i.4] ETSI TR 102 175 (V1.1.1): "PowerLine Telecommunications (PLT); Channel characterization and measurement methods".
- [i.5] ETSI TR 101 562-1 (V1.3.1): "Powerline Telecommunications (PLT); MIMO PLT; Part 1: Measurement Methods of MIMO PLT".
- [i.6] ETSI TR 102 616 (V1.1.1): "PowerLine Telecommunications (PLT); Report from PlugtestsTM 2007 on coexistence between PLT and short wave radio broadcast; Test cases and results".
- [i.7] ITU-R Recommendation BS.1284: "General methods for the subjective assessment of sound quality".
- [i.8] SCHWARZBECK MESS - ELEKTRONIK; EFS 9218: "Active Electric Field Probe with Biconical Elements and built-in Amplifier 9 kHz ... 300 MHz".

NOTE: See <http://www.schwarzbeck.de/Datenblatt/m9218.pdf>.

- [i.9] ETSI TR 101 562-3 (V1.1.1): "PowerLine Telecommunications (PLT); MIMO PLT; Part 3: Setup and Statistical Results of MIMO PLT Channel and Noise Measurements".

[i.10] R&S®HFH2-Z2: "Loop Antenna Broadband active loop antenna for measuring the magnetic field-strength; 9 kHz - 30 MHz".

NOTE: See http://www2.rohde-schwarz.com/en/products/test_and_measurement/emc_field_strength/emc_accessories/.

[i.11] CISPR 11 (Ed. 5.0): "Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement".

[i.12] CISPR 22 (Ed. 6.0): "Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement".

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

A or Att	Attenuation in dB
E	Electrical Field strength in dB μ V/m
H	Magnetic field in dB μ A/m
k	Coupling factor in dB(μ V/m)-dBm
P	Power in dBm
PSD	Power Spectral Density in dBm/Hz
s_{xy}	Scattering parameter in dB
U	Voltage in dB μ V

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AF	Antenna Factor
AM	Amplitude Modulation
ASCII	American Standard Code for Information Interchange
BNC	Bayonet Nut Connector
CDF	Cumulative Distribution Function
CM	Common Mode
CSV	Comma Separated Values
DC	Direct Current
DM	Differential Mode
E	Protective Earth Contact
EMC	Electromagnetic Compatibility
EMI	Electro Magnetic Interference
FD	Frequency Domain
FM	Frequency Modulation
FTP	File Transfer Protocol
GPS	Global Positioning System
HF	High Frequency
HIFI	High Fidelity
IF	Intermediate Frequency
LCZC	Line Cycle Zero Crossing
LISN	Line Impedance Stabilization Network
LVDN	Low Voltage Distribution Network
MIMO	Multiple Input Multiple Output
N	Neutral Contact

NOTE: Used as decoupling filter.

NWA	Network Analyser
P	Phase or Live Contact
PC	Personal Computer
PE	Protective Earth
PLC	PowerLine Communication
PLT	PowerLine Telecommunications
PSD	Power Spectral Density
RF	Radio Frequency
Rx	Receiver
SINPO	Signal, Interference, Noise, Propagation, Overall
SISO	Single Input Single Output
STF	Special Task Force
TD	Time Domain
Tx	Transmitter
VHF	Very High Frequency

3.2.1 Abbreviations used for feeding styles

APN	Signal feed mode: Dual wire feed (version C of clause 7.1.4.5 in [i.5]) to input P N E in figure 28 in [i.5]
CM	Signal feed mode: Common mode, P, N, E terminated to ground (CM is expected to be used only for receiving by PLT modems)
EP	Signal feed mode: DELTA (differential) between E and P, PN and NE terminated
EP-NET	Signal feed mode: Differential between E and P, only NE terminated
EPNT	Signal feed mode: DELTA (differential) between E and P, PN and NE not terminated
NE	Signal feed mode: DELTA (differential) between N and E, PN and EP terminated
NE-EPT	Signal feed mode: Differential between N and E, only EP terminated
NENT	Signal feed mode: DELTA (differential) between N and E, PN and EP not terminated
PN	Signal feed mode: DELTA (differential) between P and N, NE and EP terminated
PNE	Signal feed mode: Dual wire feed (version C of clause 7.1.4.5 in [i.5]) to input P N E in figure 28 in [i.5]
PNNT	Signal feed mode: DELTA (differential) between P and N, NE and EP not terminated (SISO)

4 Major Project Phases

Table 1

No.	Period	Topic	Event
01	Sept. 2010	Project organization Definition of targets, what and how to measure	STF 410 Preparatory Meeting Stuttgart, Germany
02	Nov 2010	Setup of MIMO PLT measurements (EMI, Channel and Noise)	Several STF 410 phone conferences. Drafting of measurement specification
03	Dec. 2010	1 st version of the STF410 couplers	Coupler to send and receive MIMO PLT signals developed
04	Jan 2011 and later	Verification of couplers and filters developed for STF410. 14 identical couplers are manufactured and shipped to the STF experts	Couplers are used by STF410 experts in field measurements in private homes
05	March 2011	Agreement on STF410 logistics, when and where to perform field measurements	
06	April 2011	Approval of 1 st TR on STF410 couplers	ETSI PLT#59
07	March 2011 to June 2011	Field measurements in Spain, Germany, France, Belgium and the United Kingdom	
08	June 2011	Statistical evaluation of results	Several STF 410 phone conferences
09	July 2011	Approval of 2 nd TR on EMI results	ETSI PLT #60
10	Oct. 2010 to August 2011	Evaluation of worldwide presence of PE wire	
11	June 2011 to August 2011	Drafting and STF 410 review and approval process	

No.	Period	Topic	Event
12	Sept. 2011	Presentation of channel and noise measurement to ETSI PLT plenary	ETSI PLT #61
13	Oct 2011	Revision and rearrangement of TR content for all 3 parts	
14	Nov 2012	Approval of all 3 parts of TR 101 562	ETSI PLT #62

5 Motivation

PLT systems available today use only one transmission path between two outlets. It is the differential mode channel between the phase (or live) and neutral contact of the mains. These systems are called SISO (Single Input Single Output) modems. In contrast, MIMO PLT systems make use of the third wire, PE (Protective Earth), which provides several transmission combinations for feeding and receiving signals into and from the LVDN. Various research publications [i.1], [i.2] or [i.3] describe that up to 8 transmission paths might be used simultaneously.

Further description of:

- motivation for MIMO PLT;
- installation types and the existence of the PE wire in private homes;
- measurement Setup description to record throughput communication parameters and their results;

can be found in [i.5] and [i.9].

6 Measurement Description

6.1 Introduction

EMI properties of the LVDN can be recorded in Time- (TD) or in Frequency Domain (FD). The pros and cons of each measure were evaluated early on by STF 410. It was concluded that the FD approach is better suited for the following reasons.

Most of the earlier EMC measurements relating to PLC were performed in FD. Thus the comparison between the results obtained by STF 410 and those of the past is much easier in FD.

The human ear is essentially an FD analyser.

Interferences assessed by human ears like the SINPO measurements use Consumer Electronic devices like AM or FM radio receivers. Such measurements were performed in [i.6] and [i.7]. MIMO test signals are fed to all Tx paths simultaneously or sequentially. These investigations are conducted with a pulsed signal to allow recognition by the human ear-brain-chain.

NOTE: See <http://stason.org/TULARC/radio/shortwave/08-What-is-SINPO-SIO-Shortwave-radio.html>.

Field levels are monitored with a calibrated antenna, which is straight forward to process in FD. EMI measurements in TD have the risk that periodicities in the transmitted PN-sequence may cause additional spurs. Furthermore, the measurement dynamic does not seem to be adequate in TD. EMI principally occurs during transmissions of PLC modems and is considered in statistical evaluations.

FD measurements can be done using a comb generator and spectrum (or EMI) analyser. This setup has the benefit that transmitter and receiver do not need to be synchronized. On the other hand the dynamic range or frequency resolution is limited due to the feeding energy of the comb generator needing to be shared among all signal carriers.

Alternatively, a sweeping source like a network analyser (NWA) might be used. Special care has to be taken with signals received by the antenna, as they can be influenced by additional signals being picked up through the long cables connecting the antenna to the NWA. To minimize this effect, double shielded cables, common mode absorption devices (CMADs) and ferrites have to be installed. This measurement method has been selected by STF 410 due to the faster recoding time of a frequency sweep and the high dynamic range.

To increase the number of measurements recorded, STF 410 is split into several teams operating in parallel in various countries. Measurement campaigns were conducted in Germany, Switzerland, Belgium, France and Spain. To guarantee comparability of the individually recorded data each team is equipped with identical probes or PLT couplers. The antenna was shipped to each team in turn. The actual measurements were performed with a general purpose NWA.

A commercially available, small biconical antenna (with built-in amplifier) was used because of its frequency range of up to 100 MHz. In one location the loop antenna (limited to frequencies up to 30 MHz) is used for a comparison of this field tests with earlier measurement campaigns. Figure 1 shows the measurement equipment used for EMI measurements.



Biconical Active Electric Field Probe [i.8]



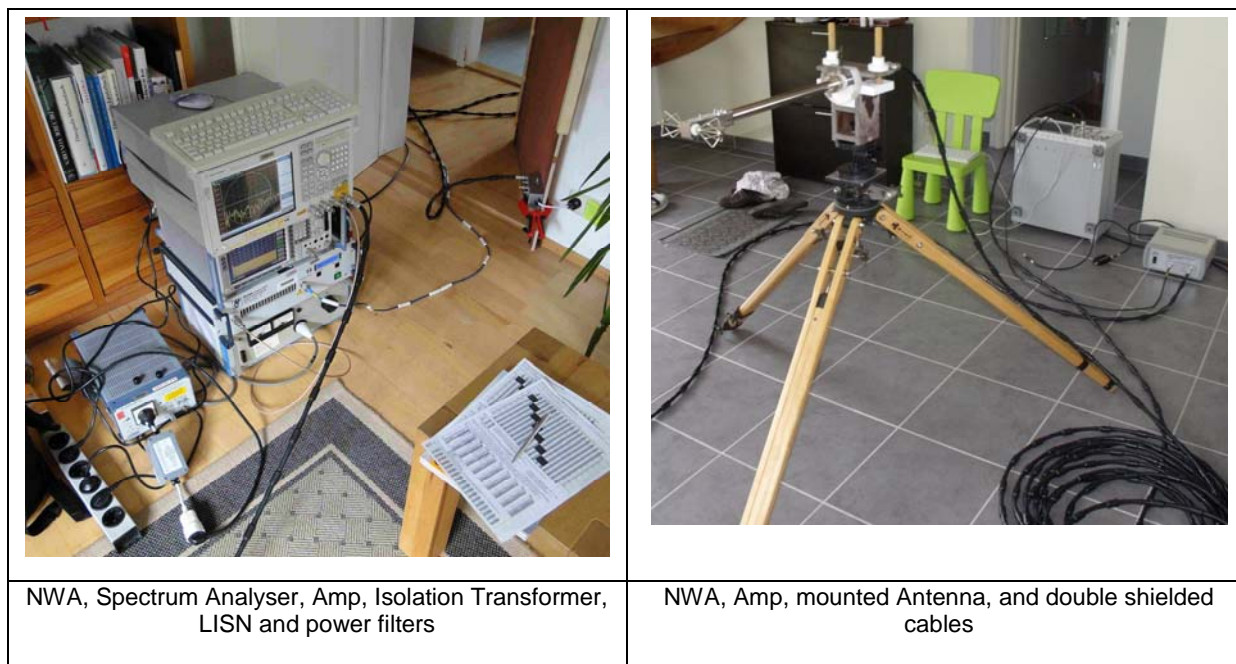
AM, FM radio receiver: Sony® ICF-SW1000T



Biconical Antenna on wooden tripod



Loop Antenna (magnetic field) [i.10]



NOTE: Sony® ICF-SW1000T is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.

Figure 1: Measurement Equipment Used by Individual Teams

6.2 General Requirements for the Measurements

The power supply for measurement equipment has to be prepared prior to starting measurements. The supply should be clean and maximally separated from the grid of the residential unit being tested. It is recommended that the power supply be taken from a neighboring flat, a backup power supply or a least a plug far away from the installation to be assessed. If there is a connection to the electricity grid, the power supply has to be filtered. A filtering device for phase, neutral and the protective earth is documented in [i.5]. Additionally, an isolation transformer is used to filter protective earth as most power filters today do not filter the protective earth wire. This is also true for the embedded filters in the measurement equipment used.

The test signals for all EMI measurements are fed using the MIMO PLC couplers specified in [i.5].

6.3 Radiation Measurements (k-factor)

6.3.1 Set-Up

The measurement setup basically consists of a NWA connected with coupler A to the mains. The power supply of the NWA is isolated from the LVDN being tested, by a filter providing CM- and DM impedances, seen from the LVDN, of $> 1 \text{ k}\Omega$. To enhance the dynamic range of the setup, the NWA is connected to an amplifier and the amplified signal is fed into the MIMO Coupler. On the other side, the antenna is connected through a cable with ferrites to a high-pass and the receiving end of the NWA. The HPF-002 described in [i.9], clause 6.6.1 (Noise Measurement Set-up) can be used as a high-pass filter. It attenuates signals below 2 MHz. In a few cases signals below 2 MHz have been identified, reducing the dynamic range of the NWA. This is why they have to be filtered.

For years experts claimed that NWA k-factor measurements using coaxial cables to connect the couplers were unacceptable, because of the resulting "loop". Thus the measurement setup described herein was validated by comparative measurements with a setup using a fiber-optical link between the antenna and the NWA. No difference could be detected. Thus, the optical link was not further used, because of its limited dynamic range, higher noise and more cumbersome installation.

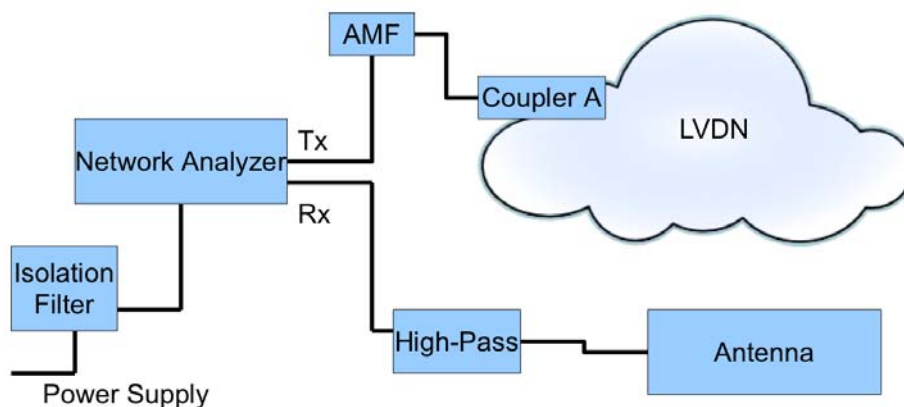


Figure 2: General Measurement Set-up for Radiated EMI

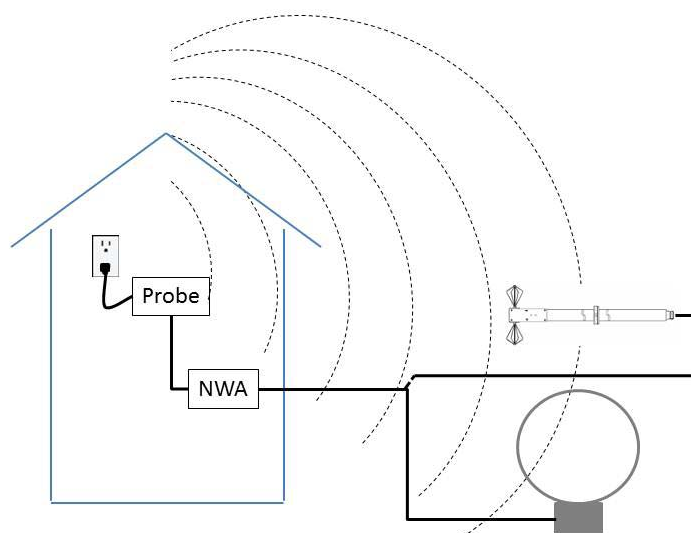


Figure 3: General Measurement Set-up to Record the k-Factor

Outlets used for feeding signals are arbitrarily selected from within the building. The antenna is positioned at a distance of 10 m or 3 m from the exterior wall outside the building. Some antenna points are also selected within the building. Several antenna locations may be selected and the radiation recorded. If the measurement dynamic is not sufficient (signal has to be at least 10 dB above noise floor, i.e. the signal indicated by the NWA without the signal injection connected) an RF amplifier is placed in the line between the NWA generator and the signal injection box. Care should be taken, that the output power does not exceed 1 W to avoid damaging the injection boxes and disturbing the appliances connected to the mains grid. If there is a risk of this happening, an attenuator of 30 dB has to be inserted between the cable connectors for calibration. To calculate the k-factor, the 30 dB has to be subtracted from that derived from Eq.1.

NWA is operated using the following settings:

- Start Frequency: 1 MHz
- Stop Frequency: 100 MHz
- Number of measurement points per sweep: 1 601
- IF Bandwidth: 1 kHz
- Feeding Power: +10 dBm, 0 dBm
- Data are recorded in ASCII format including at least: frequency, Real part, Imaginary part, absolute value in dB.

Care has to be taken that the amplifier is not saturated.

The file name convention of the EMI record is:

Ptt_Fa_Ayy_Dp_o_xx.xx.CSV where:

- 'tt' is the number of the transmitting plug. The 1st digit indicates the level in the building where feeding was done.
- 'Fa' is the port where signals are fed differentially: EP, PN, NE, EPNT, PNNT, NENT, APN, PNE, EP-NET, NE-EPT (see figure 6).
- 'yy' identifies the location of the antenna (e.g. A01, A02, ..., leading zeros are required).
- 'p' specified the place of the antenna: '0' is for 10m distance, '3' for 3m distance outside the building and 'I' for indoor.
- 'o' is the orientation of the antenna:
 - 'v' or 'h' in case of the biconical antenna. 'h' means the axis from dipole to dipole is parallel to the horizon and 'v'-direction is vertically. Since this measurement campaign focuses on the radiation produced by PLT, the measurements are performed with these two polarisations in agreement with typical disturbance field strength measurements for products as defined in CISPR 11 [i.11] and CISPR 22 [i.12]. The higher value of the 2 orientations is used as specified in clause 6.3.4.
 - 'x', 'z' or 'z' in case of the loop antenna (x means H-field parallel to the building wall; z means H-field towards ground). It is common practice to measure the magnetic field in three directions (e.g. see German SchuTSEV). The vector sum of the 3 orientations will give the total H-field as specified in clause 6.3.4.
- 'xx.xx' is the timing distance to the rising LCZC at Tx coupler in ms when the sweep was recorded. If trigger of NWA was not in sync with LCZC 'xx.xx' is not applied.

E.g. if the filename is P22_PNNT_A01_D3_v.csv the feed was done between P and N in the delta style and the 2 other ports (NE and EP) are not terminated. This is the conventional SISO style. The biconical antenna was located at antenna position 01 in 3 m distance from the outside wall of the building in a vertical orientation.

All antenna measurements are saved in the 'EMI' folder of STF410 repository. The folder tree consists of:

STF 410 → Initials of Expert → Name of Location → EMI.

A ground plane is required, at least for the common mode injection. The ground plane has to be directly connected (low inductance) to the coupling box and be at least 1 m² in size.

For convenience the file handling tool (see annex B) can be used. This tool also can be a helpful guide when reading through the measurements.

6.3.2 Calibration of NWA

The NWA needs to be calibrated in order to eliminate the effects caused by the need to use long cables in the building. A response (thru) calibration is done by shortcutting the endings of both coaxial cables. A conventional adapter (BNC female to BNC female) is used as a calibration kit.

Prior to starting measurements, the NWA has to be calibrated according to figure 4. To prevent the NWA from being overloaded with input, the NWA generator setting has to be turned down as much as possible (typically -25 dBm). If the output power of the amplifier is still too much for the NWA input, refer to the alternative calibration procedure in annex A. The Analyser will usually automatically correct the calibration data, after the calibration process, when the feeding power is increased.

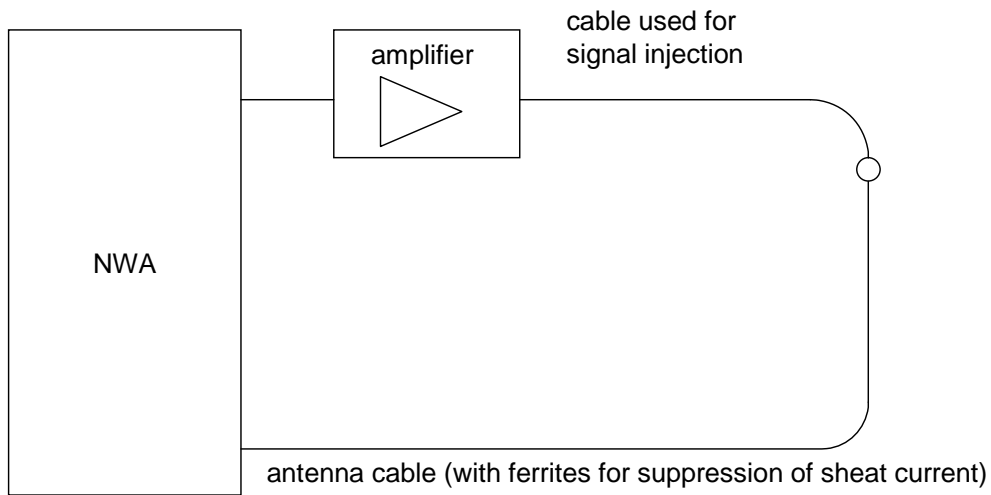


Figure 4: NWA Calibration

During measurements, the cable ends of the NWA have to be connected to the MIMO coupler and the antenna according to figure 5. The generator output power can be increased to improve the dynamic range of the measurements. Care should be taken not to exceed an output power of 1 W, in order to prevent overloading the MIMO coupler.

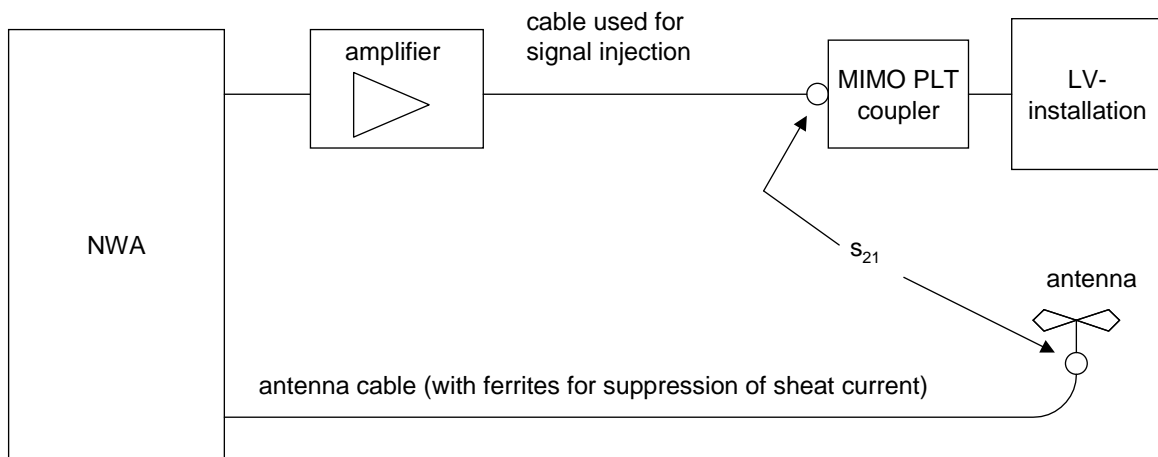


Figure 5: Use of NWA and Set-up for the Measurements

6.3.3 Signal Injection

For the coupling modes, the following switch settings for the boxes are to be used.

Coupling mode	Switch setting
<p>PNNT</p> <p>DELTA (differential) mode PN, NE and EP NOT terminated (standard SISO PN) (see clause 7.1.4.1 of [i.5])</p>	
<p>EPNT</p> <p>DELTA (differential) mode EP, PN and NE NOT terminated (SISO EP) (principle shown in clause 7.1.4.1 of [i.5])</p>	
<p>NENT</p> <p>DELTA (differential) mode NE, EP and PN NOT terminated (SISO NE) (principle shown in clause 7.1.4.1 of [i.5])</p>	

Coupling mode	Switch setting
<p>PN</p> <p>DELTA (differential) mode PN, NE and EP terminated (MIMO) (principle shown in clause 7.1.4.2 of [i.5])</p>	
<p>EP</p> <p>DELTA (differential) mode EP, PN and NE terminated (MIMO) (principle shown in clause 7.1.4.2 of [i.5])</p>	
<p>NE</p> <p>DELTA (differential) mode NE, EP and PN terminated (MIMO) (see clause 7.1.4.2 of [i.5])</p>	

Coupling mode	Switch setting
<p>EP-NET</p> <p>partial delta type injection, signal between P and E, N-E terminated, P-N not terminated (MIMO) (see clause 7.1.4.3 of [i.5]) (MIMO Asymmetric Transmit)</p>	
<p>NE-EPT</p> <p>partial delta type injection, signal between N and E, P-E terminated, P-N not terminated (MIMO) (see clause 7.1.4.3 of [i.5]) (MIMO Asymmetric Transmit)</p>	
<p>APN</p> <p>Dual wire, input P N - E (see clause 7.1.4.5 (version C) of [i.5])</p>	

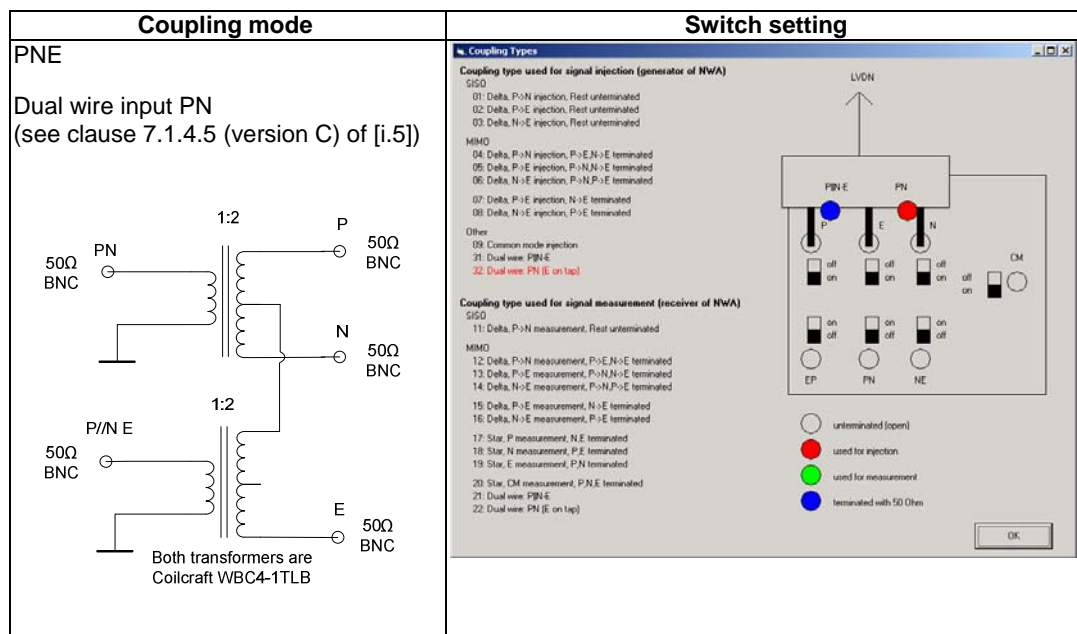


Figure 6: PLT Coupler Switch Settings

The figures shown on the right side of figure 6 are screen shots of the software supporting the measurements. This software is described in annex B of the present document.

6.3.4 Calculation of the Final k-Factor

To evaluate the radiation of buildings the coupling factor (k-factor) is defined by:

$$\begin{aligned}
 k_{E,H} &= E_{antenna} - P_{max,feed} \\
 &= U_{Receiver} + AF - P_{max,amp_output} + A_{PLT_Coupler} \\
 &= P_{Receiver} + 107(\text{dB}\mu\text{V} - \text{dBm}) + AF - P_{max,amp_output} + A_{PLT_Coupler} \\
 &= s_{21} + 107(\text{dB}\mu\text{V} - \text{dBm}) + AF + A_{PLT_Coupler}
 \end{aligned}
 \tag{Eq. 1}$$

with:

$E_{antenna}$: the field strength received at the location of the antenna, unit: dB(μ V/m).

$P_{max,feed}$: signal at the output of the PLT coupler (in case of terminated output), unit dBm.

P_{max,amp_output} : signal at the output of the amplifier provided at the cable end (in case of termination), unit dBm.

$A_{PLT_Coupler}$: Attenuation of the PLT coupler as described in [i.5], unit dB.

$U_{Receiver}$: voltage at the output of the antenna, unit dB(μ V).

$P_{Receiver}$: power from the output of the antenna, unit dBm.

AF : antenna factor of the antenna, unit dB(1/m).

s_{21} : scattering parameter as measured by the network analyser with valid calibration, unit dB.

NOTE: If the alternative calibration procedure of annex A is used, the corrected s_{21} values have to be used in Eq. 1.

$k_{E,H}$: k-factor with regard to the electric field component (k_E) or magnetic field component (k_H), unit dB(μ V/m)-dBm.

The k-factor is used first in [i.4]. The formula above says: If a signal is fed with 0 dBm into the mains of a building an electrical field of E dB μ V/m is recorded outside the building.

From the recorded values s_{21} of the network analyser, the k-factor can be derived using Eq.1. Depending on the antenna used and the coupling, different values have to be used for $A_{PLT_Coupler}$

Table 2: Coupling Types

Coupling type	$A_{PLT_Coupler}$
EPNT, PNNT, NENT	Values taken from clause 7.1.4.1 of [i.5]
EP, PN, NE	Values taken from clause 7.1.4.2 of [i.5]
APN, PNE	Values taken from clause 7.1.4.5 of [i.5]
EP-NET, NE-EPT	Values taken from clause 7.1.4.3 of [i.5]

The combinations of different antenna polarisations or orientations are antenna dependent. The following calculations apply to derive a single k-factor per injection-plug - antenna location combination.

Table 3: Calculation of Resulting k-Factor in Dependence of Antenna Type

Antenna type	Calculation of the resulting k-factor
biconical	$k_{res} = \max(k_{horizontal}, k_{vertical})$
loop	$k_{res} = \sqrt{ k_x ^2 + k_y ^2 + k_z ^2}$

These calculations are performed individually for each frequency in each record.

6.4 Subjective Evaluation of the Interference to Radio Broadcast

6.4.1 General

Subjective evaluations of interference to AM radio reception in the HF bands were performed by ETSI STF 332 (PlugtestsTM on coexistence between PLT and short wave radio broadcast) and are documented in [i.6]. Performing identical tests with all MIMO feeding possibilities would deliver unstable results, because the variance of received signal level (fading in time domain) is more dynamic than an operator might be able to test. During a MIMO test, the interference from all MIMO feeding possibilities should be compared. The signal level is usually never stable in HF bands. [i.3] describes dynamic changes in the HF signal level received caused by reflections on the ionosphere. Broadcasting conditions in VHF are by far more stable over time, allowing a comparison of levels recorded over a period of a few minutes.

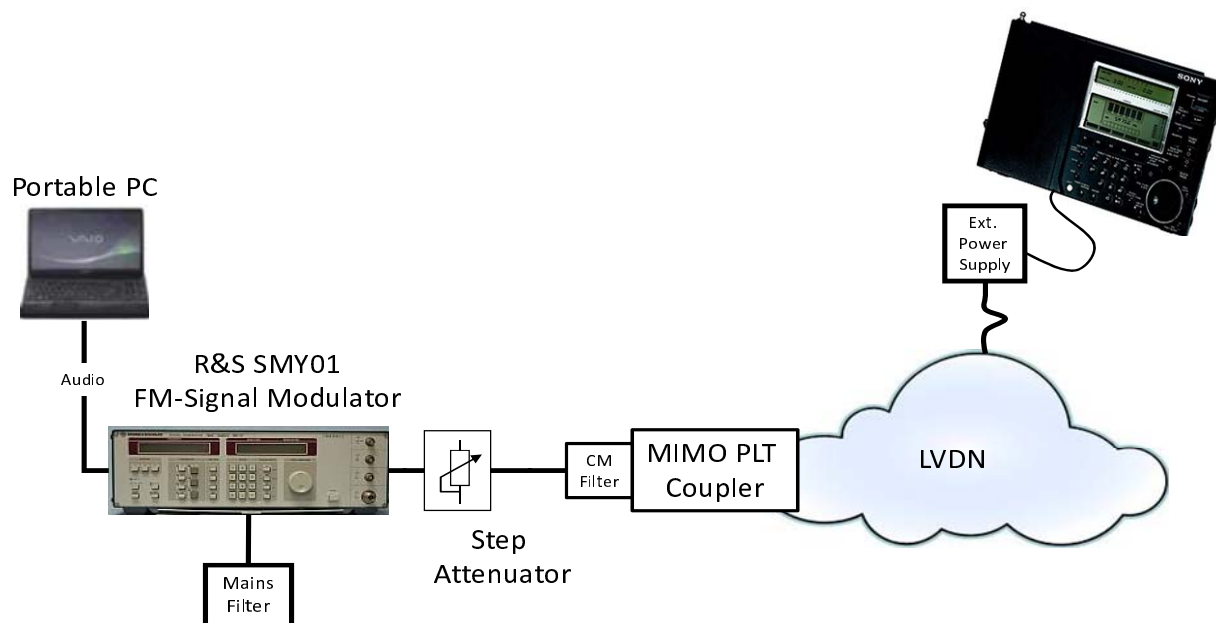


Figure 7: Basic Set-up for FM Interference Tests

How to feed the interference signal to the mains is described in clause 6.3.3. The source of the signal is a broadband noise generator or frequency generator with the option of frequency modulation with variable frequency excursion (e.g. Rohde&Schwarz® SMY, see note 2). This generator is modulated with a noise signal.

NOTE 1: The noise signal can be generated via sound output from a laptop or PC using the scope software (http://www.zeitnitz.de/Christian/scope_de).

NOTE 2: Rohde&Schwarz® SMY is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.

The 3 dB-bandwidth of the modulated signal is at least 240 kHz for the evaluation of radio interference in the ultra short wave bands (FM-Bands).

The generator can be switched on and off, in order to distinguish the disturbed and undisturbed states. A blanking input controlled with a rectangular signal (a few Hertz) is preferable. A sweep in the shape of a sine wave can be inserted into the audio signal, which is to be FM modulated, with the use of a software tool like the one described above. The sweeping tone makes it easier to single out the source of this interference from several interferences when listening to sensitive FM broadcastings, as the tone can be detected by the human ear. The FM modulated signal will be injected as an interfering signal to the mains.

An example of the spectrum realized with the noise source for the FM-Bands is shown in figure 8.

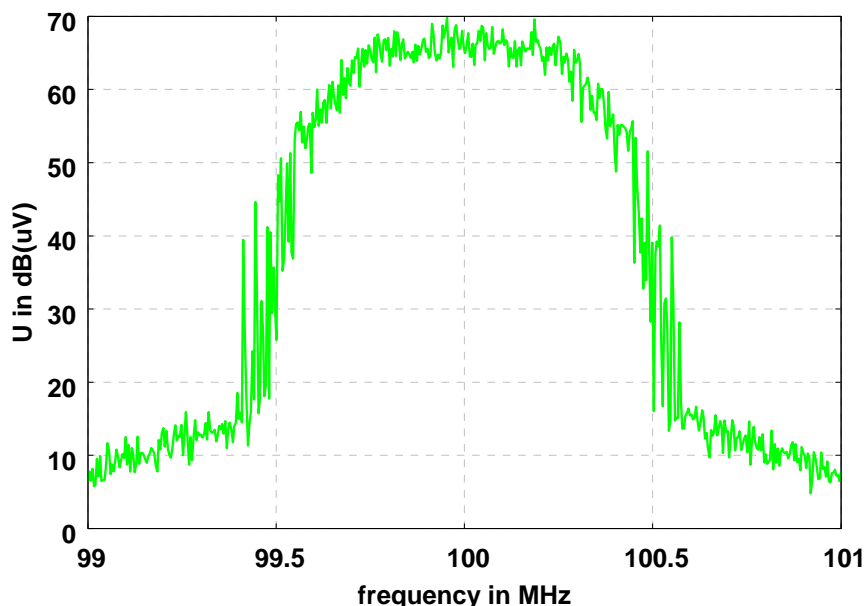


Figure 8: Output Spectrum obtained with the SMY Generator (frequency modulated with noise) obtained with a Spectrum Analyzer at Resolution Bandwidth of 200 Hz in Clear-Write Modus

6.4.2 Verification and Calibration

Prior to the test, the disturbance signal has to be analyzed with a measurement receiver or spectrum analyzer to document the 3 dB bandwidth. As a first step, the amplification between the generator output level and the signal injected into the BNC-plug of the MIMO PLT coupler has to be determined. This is done by connecting the feed cable via an attenuator of 30 dB (protection of the measurement receiver) to the measurement receiver input.

Setting of the measurement receiver:

Detector:	Average
Bandwidth:	120 kHz for measurement frequency above 30 MHz
Attenuation:	Auto
Measurement time:	1 000 ms

Feeding level of signal generator is U_{max_feed} .

6.4.3 Measurement Procedure

After the calibration of the amplification has been done, the measurement can be performed. The output of the RF generator is connected via a step attenuator to the MIMO PLT coupler (see figure 7).

In preparation a couple of radio stations, which can be received at the receiver's location, are selected.

At each frequency of a selected radio station the level of the RF generator is adjusted to a lower level where no disturbance at the radio receiver is recognized. (This could be performed easily by e.g. rotating the knobs of the step attenuator to Att_{SA} .) From that value, the generator level is increased until a disturbance can barely be recognized. After that the level of interference signal is verified by connecting

$$U_{gen} = U_{max_feed} - Att_{SA} \quad (\text{Eq. 2})$$

to the measurement receiver input to measure the signal level. The measured value U_{gen} (in dB(μ V)) is recorded in an Excel sheet.

This procedure is repeated for each:

- coupling type;
- selected frequency;

- feeding outlet (injection point);
- radio receiver;
- radio receiver location.

Furthermore the measurements have to be done when the radio receiver is battery driven and mains powered.

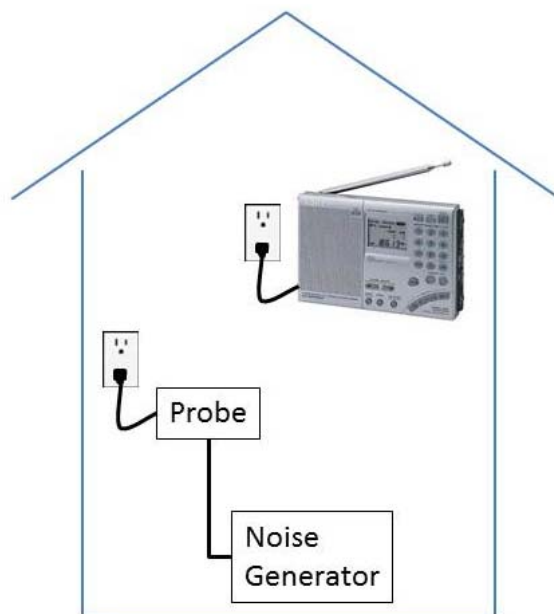


Figure 9: Radio Reception in a Building with Noise Feeding

6.5 General Equipment List

6.5.1 Coaxial Cables

The coaxial cables used to record k -factor_{10m} measurements are doubly shielded (e.g. RG214 are recommended due to their low attenuation). To avoid signal ingress to the cable going back from the antenna or the PLT coupler to the NWA, the cable has to be surrounded by ferrites. Axial Ferrite Beads are attached to the coaxial cable every 0,15 m. For years experts claimed that NWA k -factor measurements using coaxial cables to connect the couplers were unacceptable, because of the resulting "conducting" loop. Thus we validated the measurement setup described herein by comparative measurements with a setup using a fiber-optical link between the receiving coupler and the NWA. No difference could be detected. Thus, the optical link was not further used, because of its limited dynamic range, higher noise and more cumbersome installation.

Figure 10 shows a coaxial cable, Ecoflex 10 (double shielded and connected to the mains coupler), equipped every 0,15 m with attached Suppression Axial Ferrite Beads (Würth-Elektronik part number: 74270056). An RG214 cable (black colour) is also visible.



Figure 10: Cable with Ferrites

6.5.2 Network Analyzer

See [i.5] for the list of NWA used for the EMI measurements.

6.5.3 Probes to Connect to the LVDN

The MIMO PLC couplers for feeding and receiving signals are specified in [i.9].

6.5.4 Amplifier

The Amplifier used to increase the measurement dynamic is:

- 50WD1000 (DC - 1 GHz, AR);
- Bonn Elektronik BLWA 0310-1.



NOTE: Bonn Elektronik BLWA 0310-1 is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.

Figure 11: Amplifier

6.5.5 Filter to Isolate Measurement Devices from Mains

Filter as specified in clauses 6.4 and 6.5 (Mains Filter) of [i.5] is used.

7 Statistical Evaluation of Results

7.1 k-Factor

STF 410 measured the k-factor at 15 locations in Spain, France and Germany.

A typical sweep from 1 MHz to 100 MHz of any k-factor measurement is shown in figure 12. Fading characterizes the shape of a k-factor sweep. In total 1,294 such sweeps were recorded by STF 410.

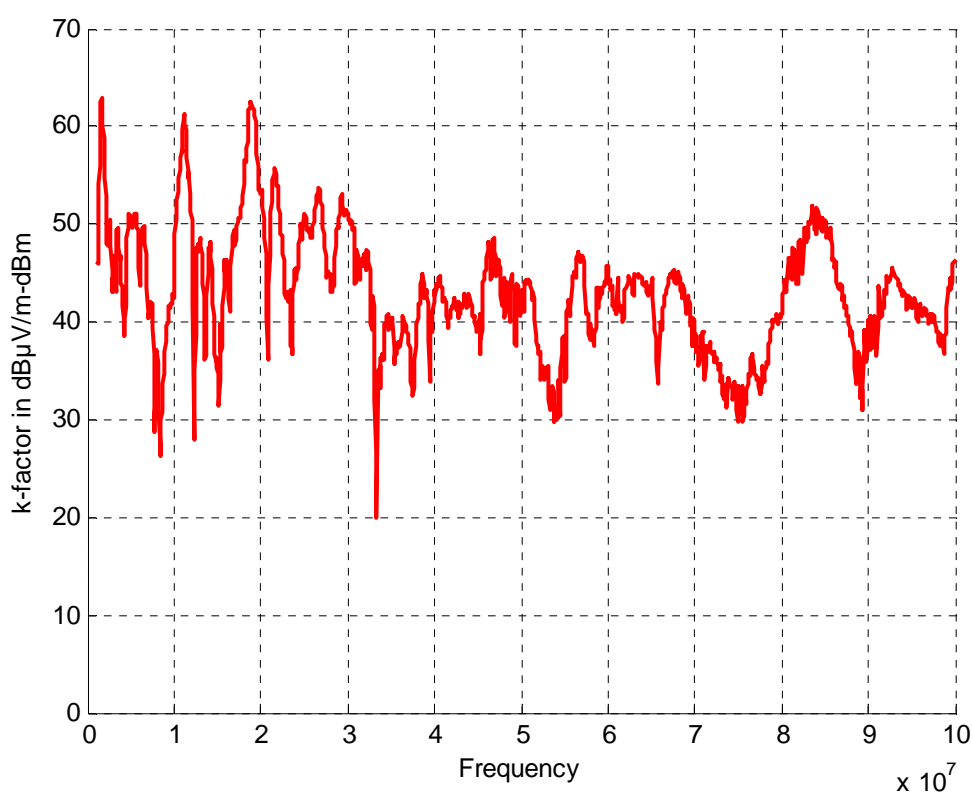


Figure 12: Typical Sweep of a k-Factor Measurement Outdoors at 10 m Distance

Figure 13 shows the median of all data separated into the individual feeding possibilities. The median value for each measured frequency and feeding style is calculated individually.

NOTE: This median value is derived from data received from all antenna locations: indoors, outdoors in 3 m and 10 m distance from the building.

Figure 13 shows no tendency of the k-factor over frequency for all symmetrical feeding possibilities.

The attenuation, caused by terminations of the coupler feeding ports, is not considered in the present document. In all the following graphs the symmetrical feedings have individual terminations, as described in [i.5]. E.g. when feeding EPNT, NENT and PNNT the unused MIMO feeding interfaces are not terminated. When feeding EP, NE and PN the 2 unused feeding possibilities at the PLT coupler are terminated with 50 Ω. At EP-NET and NE-EPT one of the two unused feeding possibility is terminated and the other one is not. The purpose of this presentation is to allow a comparison of the SISO style (PNNT) which is used by conventional PLT modems. The energy feed into the mains after the PLT coupler is 1,3 dB less in the 3-port termination (PN, EP and NE) compared to 1-port termination (EPNT, NENT and PNNT).

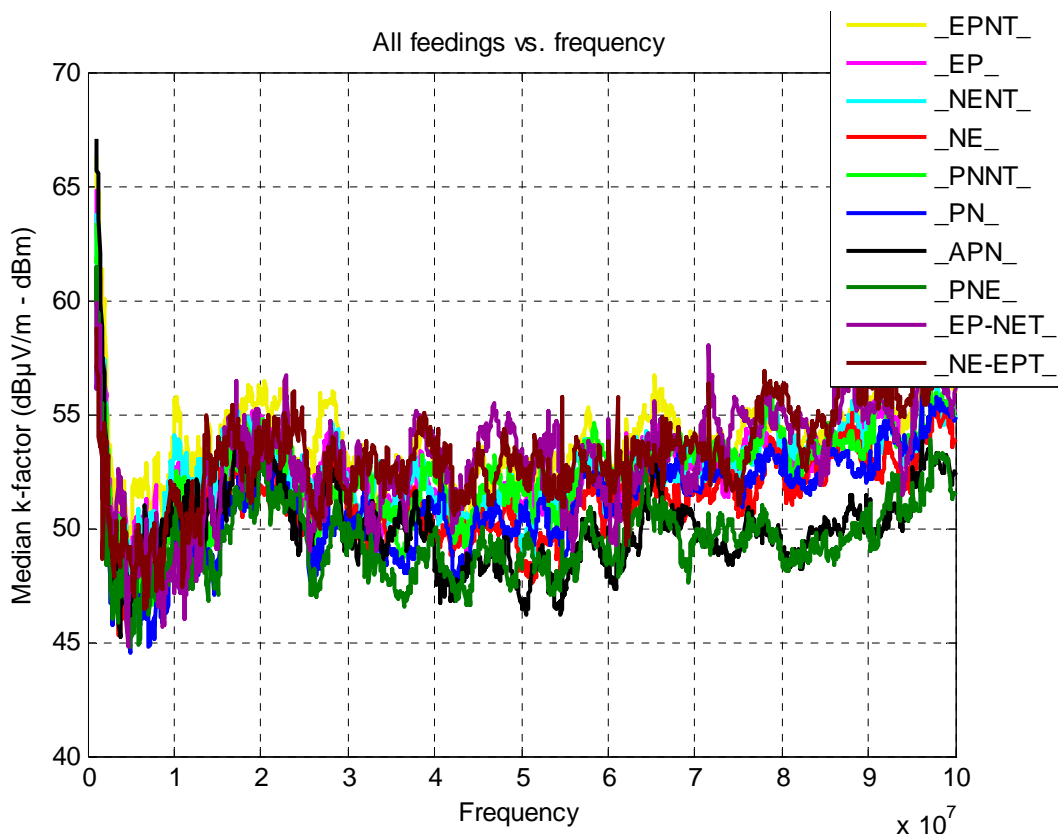


Figure 13: Median Values for Each Feeding Possibility Over Frequency

The legend for figure 13 shows the feeding possibilities according to figure 6. Table 4 wraps up the abbreviations as a reminder.

Table 4: Legend of plots

EPNT	Signal feed mode: DELTA (differential) between E and P, PN and NE not terminated
EP	Signal feed mode: DELTA (differential) between E and P, PN and NE terminated
NENT	Signal feed mode: DELTA (differential) between N and E, PN and EP not terminated
NE	Signal feed mode: DELTA (differential) between N and E, PN and EP terminated
PNNT	Signal feed mode: DELTA (differential) between P and N, NE and EP not terminated (SISO)
PN	Signal feed mode: DELTA (differential) between P and N, NE and EP terminated
APN	Signal feed mode: Dual wire feed (version C in [i.5]) to input P N E in figure 28 of [i.5]
PNE	Signal feed mode: Dual wire feed (version C in [i.5]) to input PN in figure 28 of [i.5]
EP-NET	Signal feed mode: Differential between E and P, only NE terminated
NE-EPT	Signal feed mode: Differential between N and E, only EP terminated

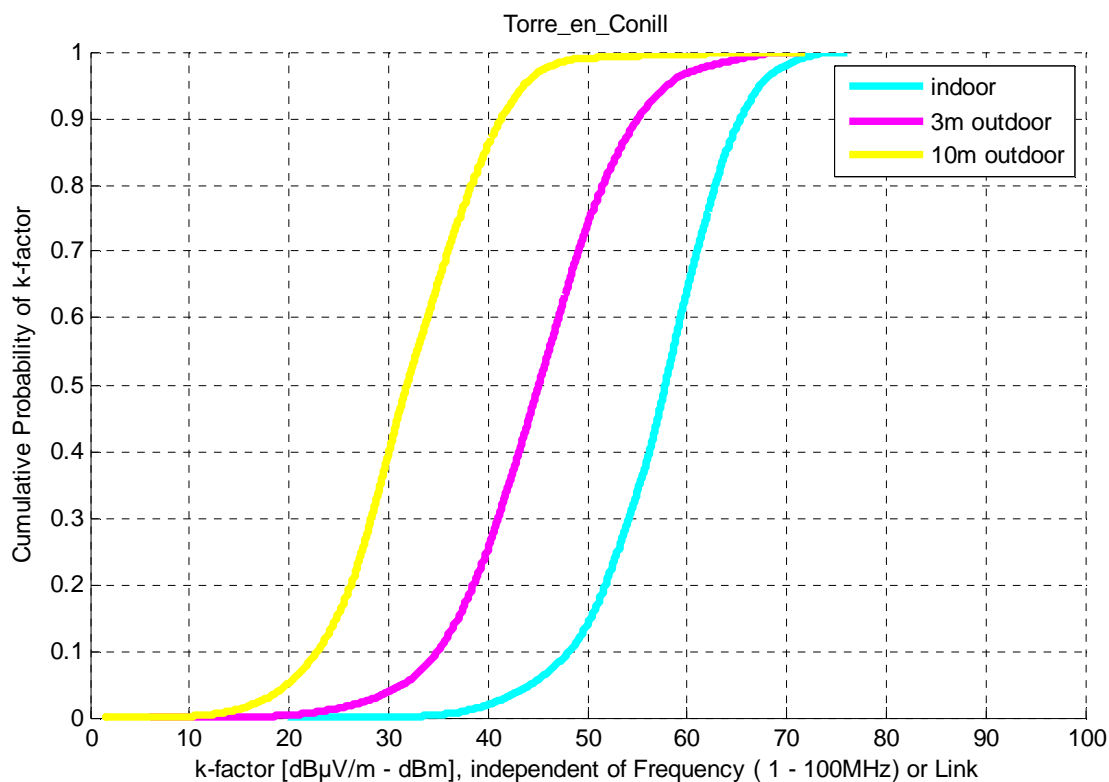
The median k-factor value of each location is given in table 5 for all Antenna positions indoors, at 3 m distance and at 10 m distance from the outside wall of the building.

Table 5: Median Coupling Factors of Each Location

Location	Country	Median k-factor indoor in dB μ V/m - dBm	Median k-factor from 3 m distance in dB μ V/m - dBm	Median k-factor from 10 m distance in dB μ V/m - dBm
Duerrbachstr	Germany	72,60	not measured	45,63
ImGeiger	Germany	69,17	not measured	44,77
Nauheimerstr	Germany	73,48	not measured	43,24
Rothaldenweg	Germany	73,60	not measured	51,54
Schlossbergstr	Germany	68,46	57,10	44,74
VickiBaumWeg	Germany	61,19	not measured	47,70
Boenen	Germany	71,88	62,38	not measured
Universitaet	Germany	not measured	55,58	49,84
Voerde	Germany	not measured	69,53	59,76
El_Puig	Spain	55,89	40,04	not measured
Sant_Sperit	Spain	not measured	49,51	44,87
Torre_en_Conill	Spain	57,83	45,12	31,87
Guingamp	France	72,92	59,52	54,22
RueBunuel	France	69,61	not measured	52,67
RueDepasse	France	70,67	62,89	50,69
All locations		67,98	51,3	46,96

Due to the high variance of the results between the individual locations and the low number of locations surveyed, a statistical evaluation of the k-factor for each country has not calculated. Furthermore, the number of records at each location is unique. The number of antenna positions was selected according to the size of the location, size of the garden and accessibility to each location. In total, in all frequencies and feeding possibilities: 771,682 values (482 sweeps) have been recorded from a 10 m distance; 650,006 values (406 sweeps) from 3 m; and 441,876 values (276 sweeps) from indoors. An explanation why there is such a high spread in the median values might be due to the local conditions surrounding the building and inside the flat. In most measurements conducted the area around the building was flat and the outdoor antenna positions were located on the same level as the ground floor. If the residential unit was e.g. a flat located in the 2nd floor of a building or a multi level house some of the feeding outlets have an additional vertical distance to the antenna. For example, the k-factor measurements in France and Voerde were recorded where all feeding outlets were located on the ground floor and the area around the building is flat land. This is why the outdoor k-factors in these locations tend to be higher than at others.

The cumulative distribution of the k-factor at a location where all 3 antenna positions were recorded with a high number of sweeps is depicted in figure 14.



NOTE: No. of sweeps indoor: 30, in 3 m: 60, in 10 m: 30.

Figure 14: Cumulative Distribution of k-Factor of a Location

For MIMO feedings the potential of interference relative to the SISO case is of interest. Figure 15 and figure 16 show the change in k-factor when using the SISO style and other feeding possibilities. The SISO case is the feeding style used by conventional (non MIMO) PLT modems. Figure 16 is a zoom into figure 15 at the median value (50 % point). The lines presented in figure 15 are calculated by subtracting the k-factor of the PNNT from all other k-factor measurements. For the PNNT feeding this subtraction has to result in zero. This is why the PNNT line is presented as a vertical line here. This calculation was performed only where feeding was done at the identical outlet and the signals were received at identical antenna positions for both records. The signals feed in PN and PNE style show a high correlation to PNNT.

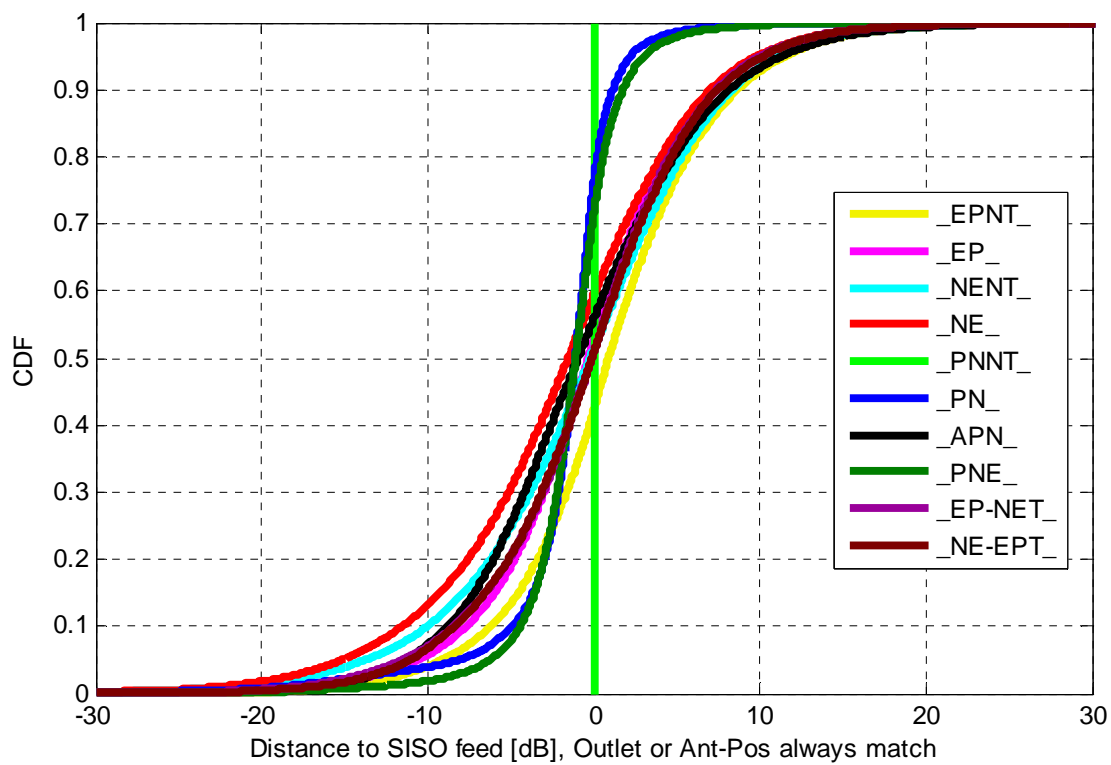


Figure 15: Relative Difference of MIMO Feeding Possibilities to SISO Feeding (PN and Others Non Terminated)

The zoom in figure 16 and table 6 show that only the EPNT feeding style tends to display a higher radiation than the traditional SISO feeding. All other differential feeding possibilities radiate less.

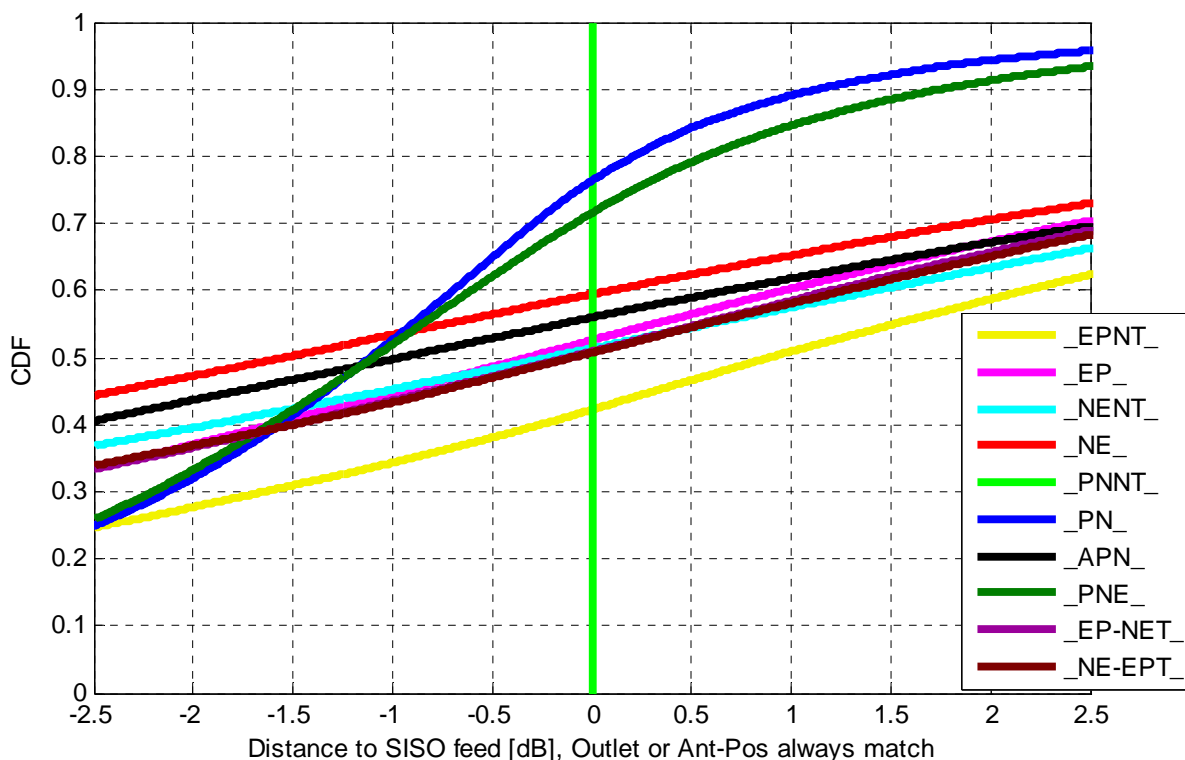


Figure 16: Zoom Showing the Difference between SISO and MIMO Feedings

Table 6 presents the median values of figure 15 and figure 16 in numbers.

Table 6: Median Difference at k-Factor of Feeding Style to SISO

Feeding Style	Difference to SISO feed in dB
EPNT	0,89
EP	-0,32
NENT	-0,21
NE	-1,54
PNNT	0,00
PN	-1,11
APN	-0,96
PNE	-1,09
EP-NET	-0,11
NE-EPT	-0,10

Comparisons between the magnetic field (H-field) and electric field (E-field) were recorded at the location in Voerde, Germany. Radiation measurements were recorded from the building using an E-field biconical antenna [i.8] and H-field ring antenna [i.10], from 3 m and 10 m away, with the antennae in the same fixed position for each reading. In order to compare H-field and E-field values, the magnetic fields - recorded in $\text{dB}\mu\text{A}/\text{m}$ - need to be converted into electric fields with a free space wave impedance of $377 \Omega = 51,5 \text{ dB}\Omega$. Figure 17 and figure 18 show some correlation between H- and E-field at 3 m distance. Obviously, a distance of 3 m may still be in the near field, where the free space wave impedance of 377Ω cannot be applied. From 10 m away from the building, the E- and H- fields display a similar pattern, as expected in the far field (see figure 19 and figure 20). The graphs stop at 30 MHz because the loop antenna [i.10] is only specified up to this frequency. At frequencies above 30 MHz it is expected that far field radiation conditions from a building are valid at closer distances or even indoors.

The k-factor records in the present document were obtained using an E-field antenna, because magnetic EMC antennae are not available frequency ranges up to 100 MHz. Furthermore, consumer electronic devices in private homes use an E-field antenna (stick or whip) in the HF and VHF bands.

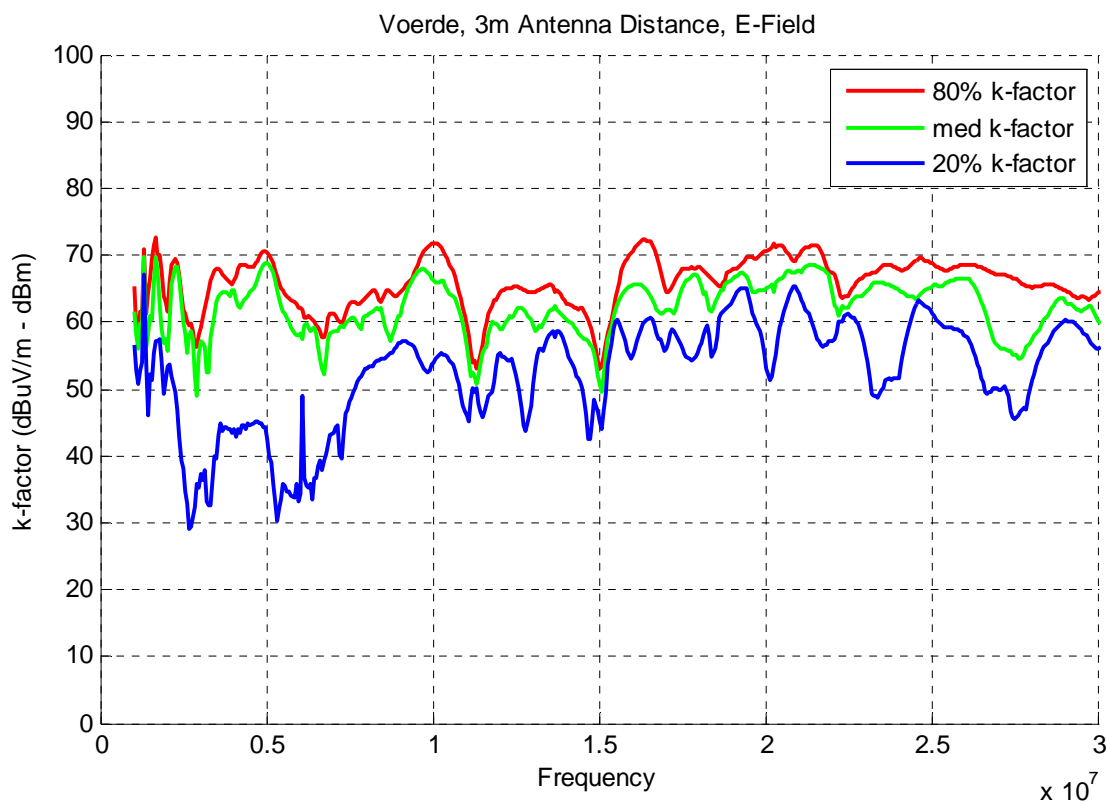


Figure 17: k-Factor Measured with Biconical Antenna at 3 m Distance

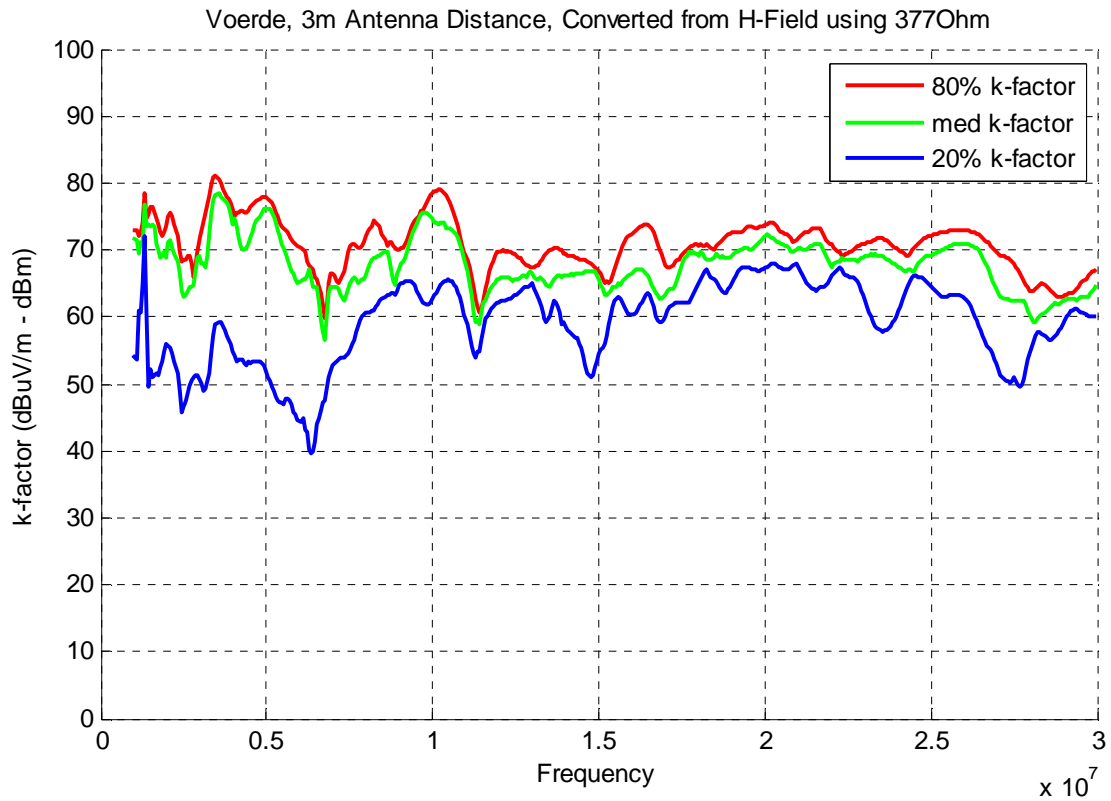


Figure 18: k-Factor Measured with Loop Antenna in 3 m Distance and Converted to E-field

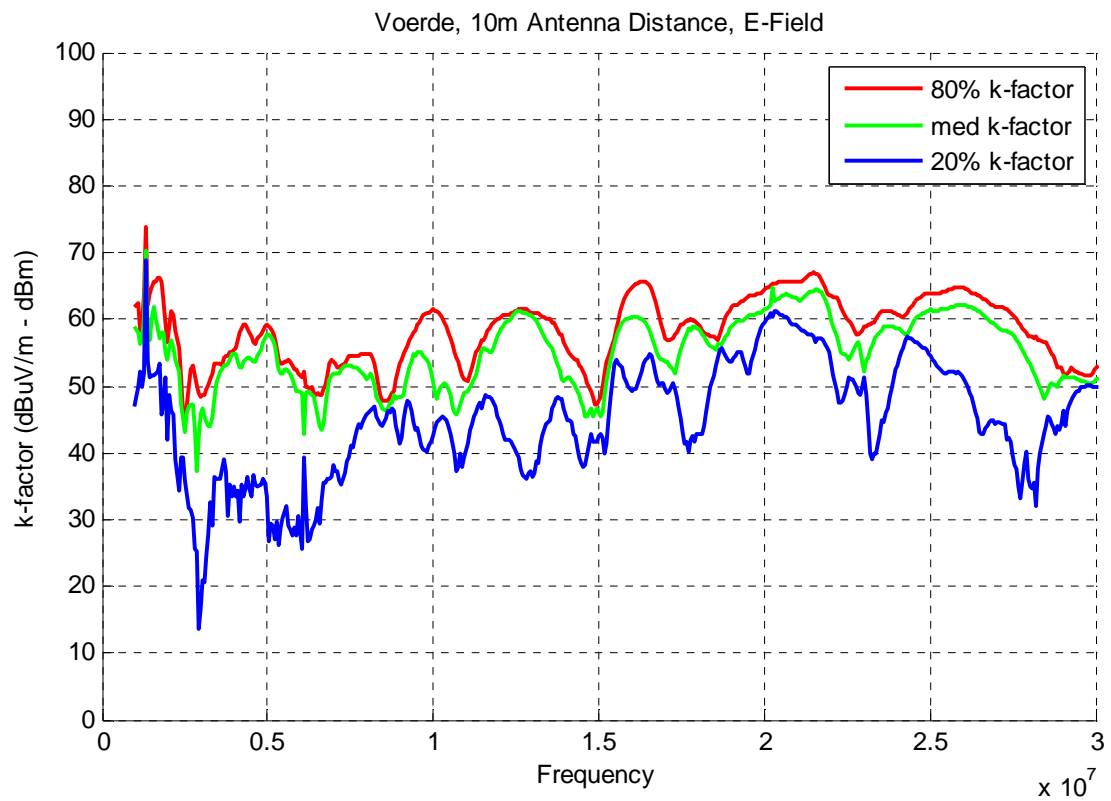


Figure 19: k-Factor Measured with Biconical Antenna at 10 m Distance

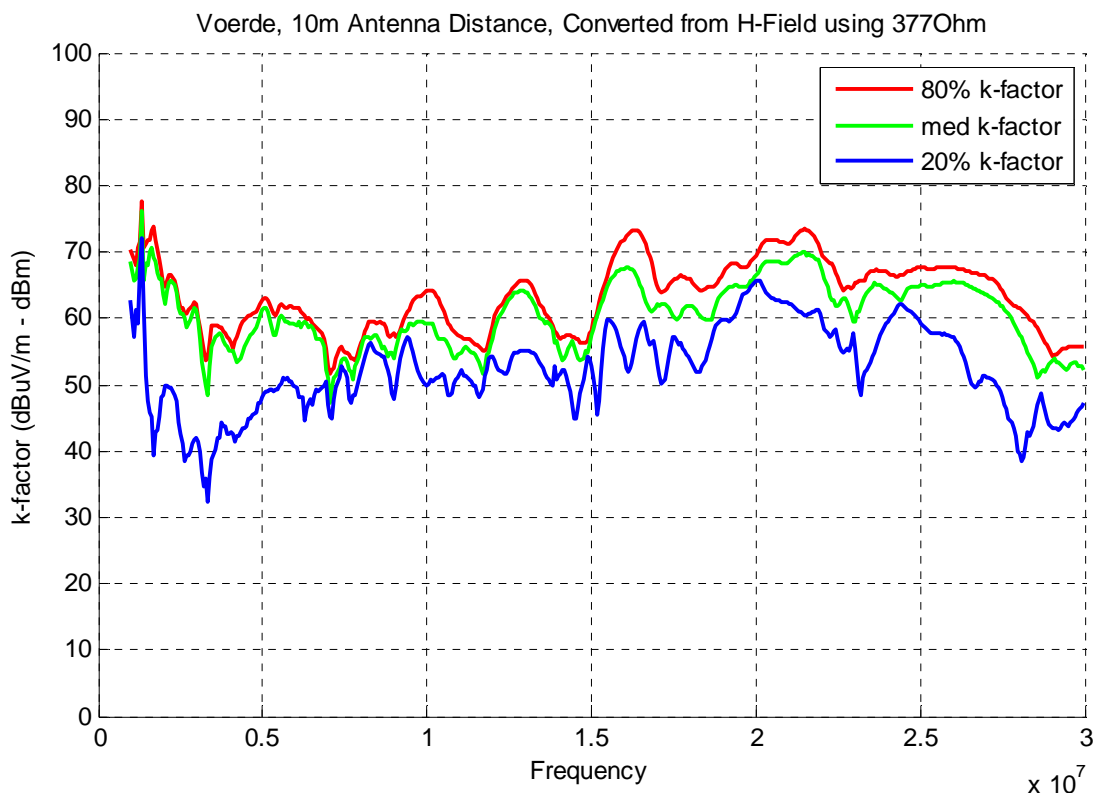


Figure 20: k-Factor Measured with Loop Antenna at 10 m Distance and Converted to E-Field

An influence in earthing variations (e.g. described in [i.5] clause 6.1) or operator differences was not found when analyzing the EMI results.

7.2 Interference Threshold of FM Radio Broadcasts

The level of interference in FM radio broadcasts was tested at 10 different locations. In total, 1,179 subjective evaluations of PLT noise, which can be detected by human ears, in FM radio were conducted. This includes 9 feeding styles times 131 radio stations with various radio devices in a range of different positions.

An example of a measurement protocol produced at one location can be seen in table 7. Several radio stations were disturbed with noise signal feeds in various styles through one or more outlets. Various radio devices, battery driven and plugged into a power supply, were monitored. The threshold at which human ears are able to detect interference is noted in the protocol below.

Usually, sensitive radio stations, which are difficult to receive, are affected by even the lowest PLT levels.

Table 7: Measurement Protocol of FM Interference Threshold in a Home

Frequency in MHz	Radio station	Receiver location	Injection Point	Threshold							
				PNNT	EPNT	NENT	PN	EP	NE	APN	PNE
92,2	SWR 3	Bose System	P42	-4,5	-23,5	-31,5	-4,5	-30,5	-19,5	-30,5	-3,5
107,7	Die neue 107,7	Bose System	P42	-31,5	-43,5	-39,5	-25,5	-43,5	-40,5	-37,5	-25,5
101,3	Antenne1	Sony Radio	P42	1,5	-6,5	-4,5	0,5	-4,5	-5,5	-17,5	-7,5
92,2	SWR 3	Sony Radio	P42	-6,5	-19,5	-16,5	-3,5	-18,5	-10,5	-9,5	-0,5
107,7	Die neue 107,7	Sony Radio	P42	-22,5	-33,5	-33,5	-33,5	-28,5	-24,5	-29,5	-28,5
101,3	Antenne1	Sony Radio Bat	P42	4,5	-4,5	-1,5	5,5	-3,5	-0,5	4,5	5,5
92,2	SWR 3	Sony Radio Bat	P42	-4,5	-16,5	-13,5	1,5	-16,5	-16,5	-3,5	1,5
107,7	Die neue 107,7	Sony Radio Bat	P42	-18,5	-20,5	-18,5	-13,5	-16,5	-17,5	-27,5	-22,5
107,7	Die neue 107,7	Bose System	P42	1,5	-10,5	-5,5	4,5	-9,5	-7,5	-9,5	-8,5

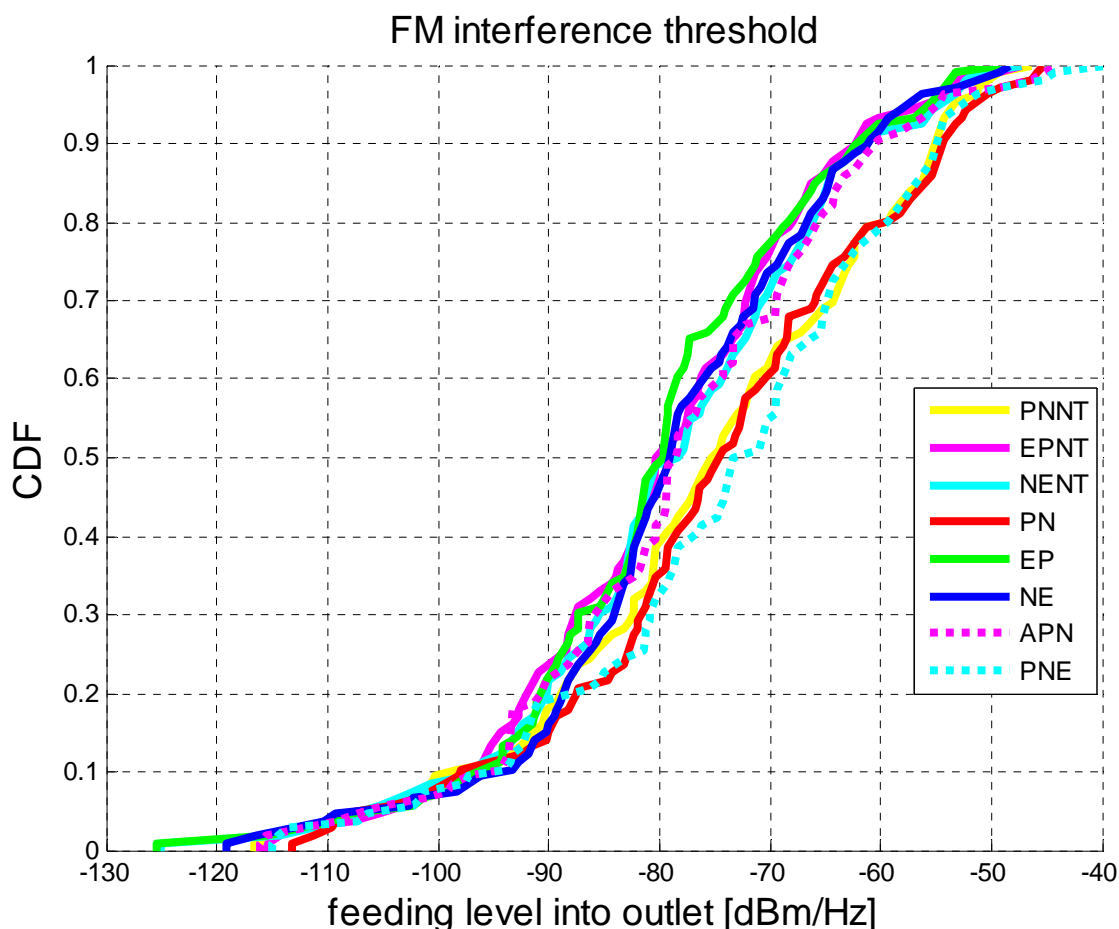


Figure 21: Cumulative Distribution Function of Threshold when Interference is Noticeable by Human Ears

Figure 21 shows the cumulative distribution of the threshold of all radio services at all locations independent of the radio device or power supply used. The individual lines represent the individual feeding styles. The x-axis is the feeding PSD injected to a power outlet. Table 8 lists the values of the 80 %, 90 %, 99 % and 100 % threshold of when FM radio becomes disturbed.

Table 8: CDF Values of Interference Threshold for FM Radio

	50 % value in dBm/Hz	80 % value in dBm/Hz	90 % value in dBm/Hz	99 % value in dBm/Hz	100 % value in dBm/Hz
PNNT	-78	-93	-105	-114	-117
EPNT	-81	-95	-103	-114	-115
NENT	-81	-96	-105	-114	-125
PN	-77	-91	-104	-111	-113
EP	-82	-94	-102	-115	-125
NE	-79	-92	-102	-116	-119
APN	-79	-94	-101	-115	-116
PNE	-78	-93	-106	-114	-115

Figure 22 and figure 23 show the influence on a particular radio device (Sony® ICF-SW1000T, see note) when the device is battery driven or power is supplied from the mains. The location of the radio device during both tests was identical. If the radio receiver is battery powered, there is only a radiated coupling path from the mains to receiver. When the radio receiver is mains powered, radiation as well as conductive coupling paths exist.

NOTE: Sony® ICF-SW1000T is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.

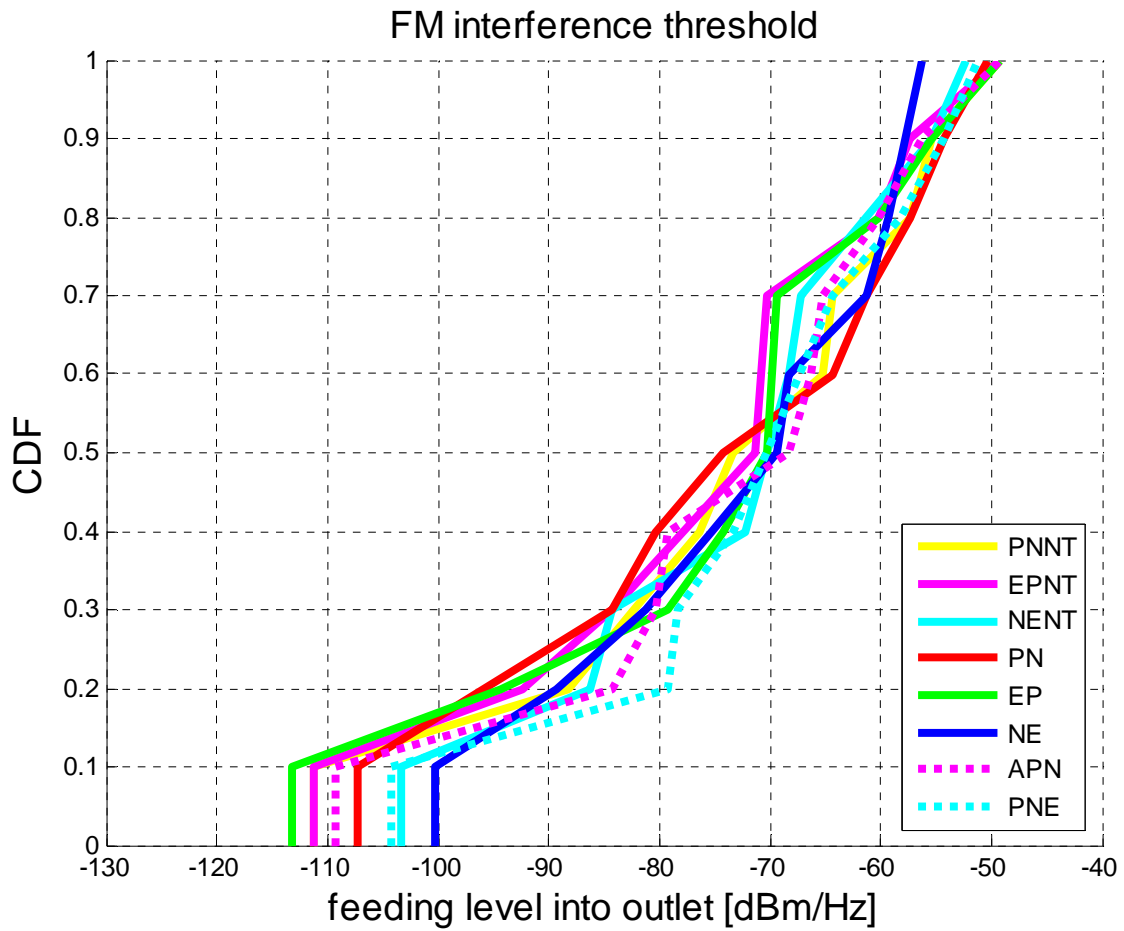


Figure 22: CDF of Interference threshold for Sony® ICF-SW1000T with Power Supply

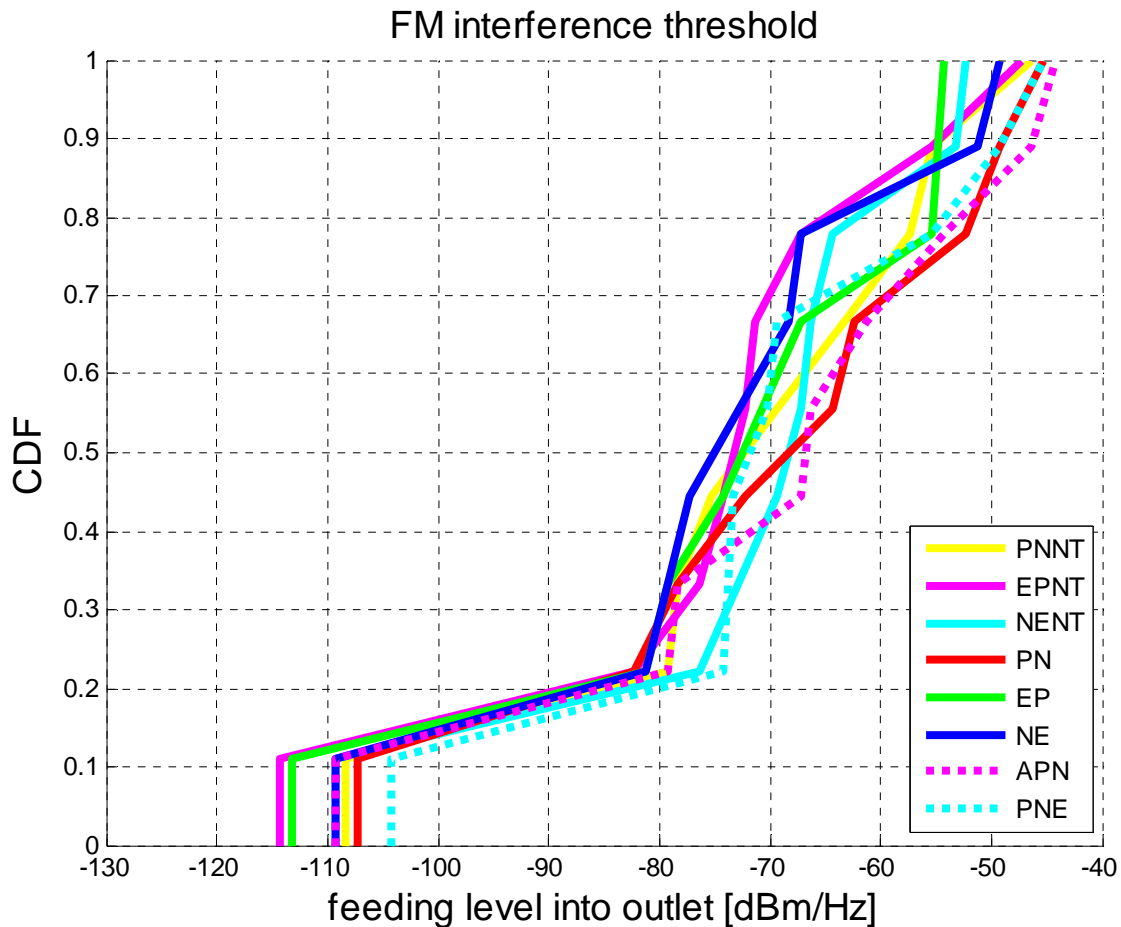


Figure 23: CDF of Interference Threshold for Sony® ICF-SW1000T Battery Driven

The graphs in figure 22 and figure 23 are pretty much identical. The conductive coupling path from mains interference to the radio device seems not to be dominant in the VHF range. Or in other words, the FM radio used in this test is sufficiently isolated from the mains interferer. This phenomenon is different compared to the HF range [i.3].

The STF 410 FM radio immunity field tests were performed using the Sony® ICF-SW1000T device and the radio device was owned by the habitant of the flat. The immunity of all radio devices was pretty much identical. No dependency among device manufacturers or HIFI radio systems versus kitchen radios could be found.

Annex A: Alternative Procedure for NWA Calibration if Amplifier Output Power is too high for NWA Input

If the output power of the amplifier is too high for the NWA input, an attenuator (of sufficient power) can be inserted between amplifier output and NWA input during calibration (see figure A.1). An attenuation of 30 dB is recommended.

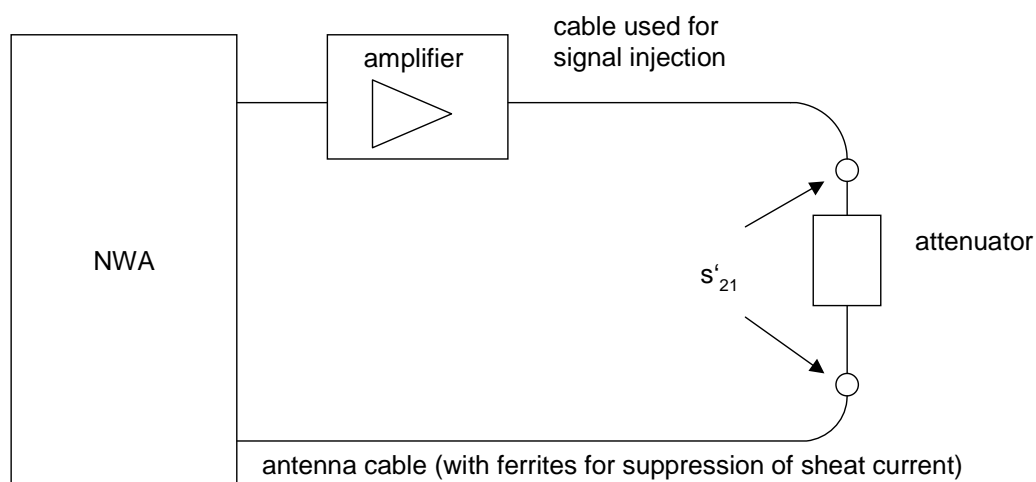


Figure A.1: Alternative NWA Calibration

The "through" calibration is made in the usual way.

During measurements, the attenuator is removed. The setup is shown in figure 5. The operator has to correct the measured data before archiving them in the STF 410 database. The true s_{21} value is derived from the measured s'_{21} values by subtracting the attenuation of the attenuator.

Annex B: Software for Automatic File Naming

B.1 General

According to experience collected from other measurement campaigns, a structured procedure for acquiring the wanted data is sometimes critical. In [i.9], clause A.2 a scheme based on a page that should be completed during tests is used for this structured approach. Here software has been developed in order to avoid different file naming, typographical errors in file naming and similar errors, which at the end would lead to manual corrections for the statistical evaluation. Although the software is equipped with an interface to readout the NWA and store the data in the correct file, it can also be used for managing just the measurements. All data is stored in an ASCII-form so it can be read with a large number of software tools for further investigations. The software is available to all STF 410 members as a resource.

B.2 Main Dialog

Main dialog box after opening the software.

The screenshot shows the 'Site Description' dialog box with the following data:

No	Feed-ID
1	Feed1

No	Location-ID
1	Innen_3m_Bi
2	Innen_3m_Loop
3	aussen_3m_Bikon
4	aussen_10m_Bikon
5	aussen_10m_Loop
6	aussen_3m_Loop

No	File	Comment

Figure B.1: STF 410 Software, Site Description

The first step is to assign an appropriate file folder for the site specific data and measurement results. The folder has to be created in advance. After selecting the Menu "Workspace" a dialog box will show up, with which the folder can be assigned.

After that, the user should fill in the general information associated with the measurement site, i.e. Country, City, Zip, Street, Building No (if applicable), GPS Coordinates, Date and Time of the Measurements, Persons, who performed the measurements. The general descriptions can be completed with arbitrary comments. To allow better interpretation of results obtained from the specific measurement site, some photos including remarks on what is shown on the photos are helpful. This information is stored with "Save".

After the general information, the associated antenna locations and feed locations (plugs) need to be defined. This is easily done by placing a unique ID for the location in the text box below the tables for feed files and antenna locations. A click on the "Add" button will put the ID into the corresponding list.

B.3 Antenna Location Description Dialog

A pre-defined antenna location can be edited by double clicking on an entry in the antenna locations table. The following dialog appears.

The screenshot shows the 'Antenna location' dialog box with the following details:

- Antenna-Location-ID:** Aussen_Stirnseite_3m (1)
- Description:** Measurement with biconical antenna
ground: green
- Antenna type:** Loop, Biconical
- Noise:**
 - y / horizontal: EQ_A01h
 - z / vertical: EQ_A01v
- Buttons:** Set Filenames, Measure, View
- Geometric antenna data:**
 - Height (Phase centre, loop centre) above ground: 1 m
 - Shortest distance to wall/ceiling: 3 m
- Maps and photos table:**

No	File	Comment
1	C:\WBASIC\STF410\example\photo\Halle_auße	Halle aussen
- Bottom section:** File: [text box] ... Comment: [text box] Add, Delete, View buttons. Save and Exit buttons are on the right.

Figure B.2: STF 410 Software, Antenna Location

Again some general information can be given to describe this special antenna location. Also some photos showing the antenna and its relation to the building are helpful. Loop antenna or biconical antenna are the possible antenna types. The antenna height and distance information is needed for an automatic evaluation and statistics.

When "Set Filenames" is pressed the text boxes in the frame Noise are filled. Since these files are not yet present, the background is set to a red color. If the files exist it will be green. If a recognized measurement receiver is connected to the PC a click on the button "Measure" will perform the measurement and store the data in the selected file. In the version on the FTP-site the receiver ESIB from Rohde&Schwarz is supported. Support of other receivers may be available upon request.

B.4 Feed Point Description Dialog

A pre-defined feed file can be edited by double clicking on an entry in the antenna locations table. The following dialog appears.

The 'Feed' dialog box contains the following information:

- Antenna-Location-ID:** Living_base (1)
- Floor:** 0
- Description:** Internal wall in the living room. About 1m from front wall of the building
- Files:**

	y / horizontal		z / vertical	
Other plugs open				
P-N	<input type="radio"/>	EP01_A01_C01h	<input type="radio"/>	EP01_A01_C01v
P-E	<input type="radio"/>	EP01_A01_C02h	<input type="radio"/>	EP01_A01_C02v
N-E	<input type="radio"/>	EP01_A01_C03h	<input type="radio"/>	EP01_A01_C03v
Other plugs terminated				
P-N	<input type="radio"/>	EP01_A01_C04h	<input type="radio"/>	EP01_A01_C04v
P-E	<input type="radio"/>	EP01_A01_C05h	<input type="radio"/>	EP01_A01_C05v
N-E	<input type="radio"/>	EP01_A01_C06h	<input type="radio"/>	EP01_A01_C06v
N-E resp. P-E terminated				
P-E	<input type="radio"/>	EP01_A01_C07h	<input type="radio"/>	EP01_A01_C07v
N-E	<input type="radio"/>	EP01_A01_C08h	<input type="radio"/>	EP01_A01_C08v
CM	<input type="radio"/>	EP01_A01_C09h	<input type="radio"/>	EP01_A01_C09v
Dual wire mode				
P N-E	<input type="radio"/>	EP01_A01_C31h	<input type="radio"/>	EP01_A01_C31v
P-N (E tap)	<input type="radio"/>	EP01_A01_C32h	<input type="radio"/>	EP01_A01_C32v
- Antenna location:** Living_room
- Correction:** 0 dB
- Buttons:** Set filenames, Measure, View, View All, Exit
- Maps and photos:**

No	File	Comment
1	C:\WBasic\STF410\example\boenen\photo\IMI	Box used for feeding
2	C:\WBasic\STF410\example\boenen\photo\IMI	Box used for measuremer

Figure B.3: STF 410 Software, Feeding Settings

Again some general information can be given to describe this special feed location. Also some photos showing the plug with the attached adapter and its relation to the structure of the building are helpful.

The injection of signals to the mains causes variations in field strength at certain antenna locations. This can be documented by selecting one of the predefined antenna locations in the software. A press of the "Set filenames" button defines all the necessary file names and measurements. If a NWA is connected to a PC, the measurements can be directly started by selecting a certain permutation and pressing the "Measure" button. NWA ZVRE from Rohde & Schwarz is supported by the version on the FTP-site. Support of other NWA may be available upon request. The file is marked green upon completion to indicate that the measurement has been done. Pressing the "View" button calls the graphic tool Gnuplot (public domain tool) for graphical representation of the measured data.

Besides the pure EMI-measurement the software also manages Noise, S_{11} and Transfer Function measurements by selecting the corresponding tabulator.

B.5 Help for Injection Types

A help function can be called from the main dialog (menu entry Help - Coupling Types) or by double clicking on the coupling type (e.g. P-E) in the feed file dialog to assist with setting switches of the box correctly.

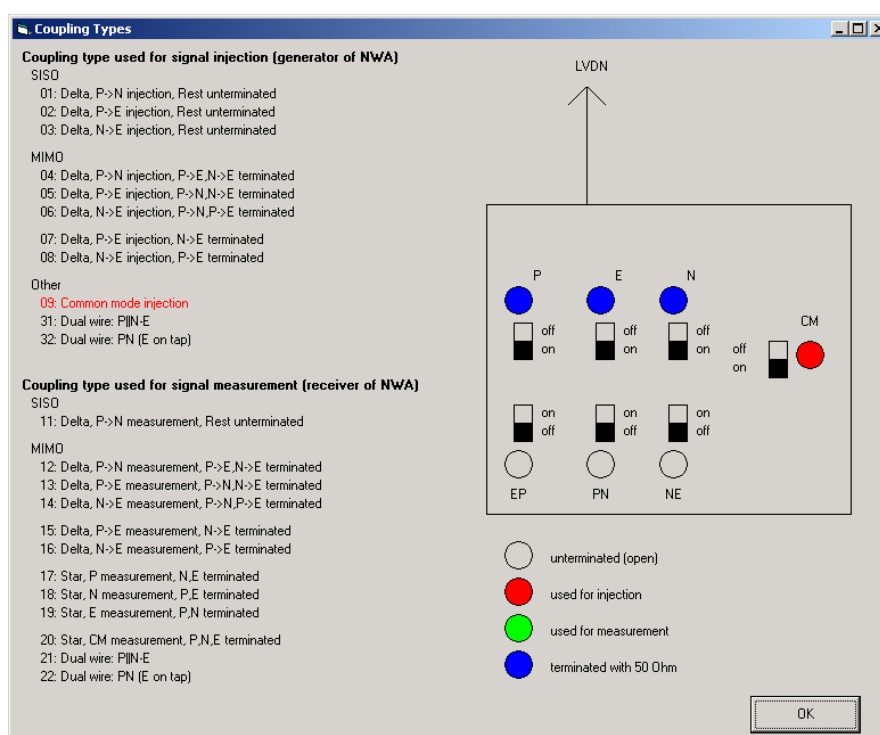


Figure B.4: STF 410 Software, Coupling Types

This dialog shows how to adjust the switches, which BNC plugs will be terminated and how the measurement instruments are connected. The different permutations can be shown in this dialog simply by clicking on the coupling type on the left side.

B.6 File Formats

For better exchange a simple ASCII-Format is used for data storage.

For data measured with the network analyzer, there should be one header line indicating the number of points and some settings, followed by a table with the measurement results.

Its form looks like:

```
Number of points: 1601, Startfrequency: 1e+006, Stopfrequency: 1e+008, Label:'XFR:POW:S12'
1e+006 -0.000272393 -0.000801793 0.0008468 -1.89829 -61.4444
1.06188e+006 -0.000102707 -0.000721605 0.000728877 -1.71218 -62.7469
1.12375e+006 -0.000300805 -0.000974474 0.00101985 -1.8702 -59.8293
...
```

The values in the table are:

frequency in Hz, s12 real part, s12 imaginary part, s12 magnitude (linear), s12 phase, s12 magnitude (in dB)

For data from a measurement receiver there is no header. The data is just stored as a table, which looks like this:

```
1000000      23.5484161376953      9.04364013671875
1005000      21.0335845947266      14.4008636474609
1010000      22.5505752563477      14.3177490234375
...
```

The values in the table are:

- frequency in Hz;
- peak detector reading in dB(μ V);
- average detector reading in dB(μ V).

B.7 Creation of Data for the FTP Server

Since the software uses an internal file naming scheme, the file names and file formats need to be converted into the format defined in clause 6.3.1. This can be done by selecting "rename files to WI28 and WI29" from the "Tools" menu of the main dialog.

Annex C: Bibliography

Terms of Reference for Specialist Task Force STF 410 (TC PLT) on "Measurements to Verify Feasibility of MIMO PLT", version: 1.1, 6 May 2010.

History

Document history		
V1.1.1	August 2011	Publication
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