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PowerLine Telecommunications (PLT);
MIMO PLT;
Part 1: Measurement Methods of MIMO PLT

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Contents

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Foreword

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

The present document is part 1 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

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

1 Scope

Convential PLT modems (SISO) use only the phase and neutral wire of the mains grid. MIMO PLT utilizes additionally the protective earth wire.

The present document is an overview of the prevalence of the third wire in private homes and a description of the measurement setup and equipment used to perform EMI, channel and noise measurements.

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; Zeddam, 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] Housing Statistics in the European Union 2010; The Hague: Ministry of the Interior and Kingdom Relations; Edited by Kees Dol and Marietta Haffner, OTB Research Institute for the Built Environment, Delft University of Technology; September 2010.

NOTE: Available at http://abonneren.rijksoverheid.nl/article/kennisplein-wwi/nieuwsbrief-kennisplein-wwi-december-2010/housing-statistics-in-the-european-union-2010/428/3384?mode=html-mail.

[i.6] How we are housed: Results from the 1999 American Housing Survey; Summary of U.S. housing market conditions (30 Aug. 2011).

NOTE: Available at http://www.huduser.org/periodicals/ushmc/fall00/summary-2.html.

[i.7] Canadian Housing Observer 2006; CMHC, ISBN 0-662-44559-7, adapted from Statistics Canada (Census of Canada) (30 Aug. 2011).

NOTE: Available at http://www.cmhc-schl.gc.ca/odpub/pdf/65102.pdf.

[i.8] Wikipedia, free encyclopedia; 2010/2011.

NOTE: Available at http://en.wikipedia.org.

[i.9] ETSI TR 101 562-2 (V1.2.1): "Powerline Telecommunications (PLT); MIMO PLT; Part 2: Setup and Statistical Results of MIMO PLT EMI Measurements".

[i.10] 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.11] IEC 60906-1: "IEC system of plugs and socket-outlets for household and similar purposes - Part 1: Plugs and socket-outlets 16 A 250 V a.c.".

[i.12] Directive 2006/95/EC of the European Parliament and of the Council of 12 December 2006 on the harmonisation of the laws of Member States relating to electrical equipment designed for use within certain voltage limits.

[i.13] IEC 60364-1: "Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions".

3 Symbols and abbreviations

3.1 Symbols

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

dB	decibel (logarithmic unit)
dBm	10 * $\log_{10}$ (P / 1 mW)
Hz	Hertz
L	Inductance
m	meter
MHz	Mega Hz
nF	nanoFarads
nH	nanoHenry
R	Resistor
Ω	Ohm
Z	Impedance

3.2 Abbreviations

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

AC	Alternating Current
AMN	Artificial Mains Network
BCA	Building & Construction Authority
BNC	Bayonet Nut Connector
BS	British Standard
BSI	British Standards International
C	"Center point" of the Coupler
CEE	Conformity certification of Electrical Equipment
CIS	Commonwealth of Independent States
CM	Common Mode
DC	Direct Current
DM	Differential Mode
E	Protective Earth Contact

EC	European Commission
EMI	Electro Magnetic Interference
EP	Connection E to P
EU	European Union
GFCI	Ground-Fault Circuit Interrupters
HSE	Health and Safety Executive
IEC	International Electrotechnical Commission
IF	Intermediate frequency
IS	International Standard
LISN	Line Impedance Stabilization Network
LVDN	Low Voltage Distribution Network
MEN	Multiple Earthed Neutral
MIMO	Multiple Input Multiple Output
N	Neutral
NE	Connection N to E
NEC	National Electric Code
NWA	Network Analyzer
P	Phase
PE	Protective Earth
PLC	PowerLine Communication
PLT	PowerLine Telecommunications
PME	Protective Multiple Earthing
PN	Connection P to N
PVC	PolyVinyl Chloride
RCD	Residual Current Device
Rx	Receive
S	Switch
SABS	South African Bureau of Standardization
SI	International System of Units
SISO	Single Input Single Output
STF	Special Task Force
T	Transformer
t	Turns
TTL	Transverse Transfer Loss
Tx	Transmit
USSR	Union of Soviet Socialist Republics

3.2.1 Abbreviations Used for Feeding Styles

APN	Signal feed mode: Dual wire feed (version C of clause 7.1.4.5) to input P||N E in figure 28
CM	Signal feed mode: Common mode, P, N, E terminated to ground
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) to input PN in figure 28
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	1st 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 1st 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 2nd TR on EMI results	ETSI PLT #60
10	Oct. 2010 to August 2011	Evaluation of the presence of PE wire worldwide	
11	June to August 2011	Drafting and STF 410 review and approval process	
12	Sept. 2011	Presentation of Channel and Noise readings to ETSI PLT plenary	ETSI PLT #61
13	Oct 2011	Content of the 3 TR parts is revised and rearranged.	
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], [i.3] describe up to 8 transmission paths that might be used simultaneously.

Channel measurements, as described in these publications, are verified by STF410. New electricity installations in many countries of the world use 3 wires for connecting a single plug. Clause 6 provides information about the presence of the PE wire.

All flats protected with RCD (residual current devices) must have a separate protective earth wire installed. In Germany, for example, the protective earth has been mandatory for all new installations since the early 1970's. As MIMO PLT modems also utilize the protective earth, they are able to alternately feed from phase to neutral (P - N), phase to protective earth (P - PE) and neutral to protective earth (N - PE). The protective earth may be grounded inside (e.g. at the foundations) or outside (at the transformer station) the building and provides low impedance for the 50 Hz AC power. However, high frequency signal measurements show the PE wire to be a rather excellent communication path which by no means represents a ground. This is due to the inductivity of the grounding wires.

If the differentially fed signals are converted to common mode, they propagate over the network, as well. For each pair of outlets, the DM (Differential Mode) and the TTL (Transverse Transfer Loss) [i.4] attenuation is measured and statistical comparisons are provided.

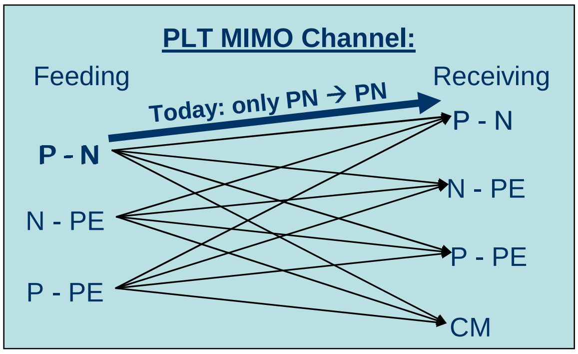


Figure 1: MIMO PLT Channel Matrix

Figure 1 shows the individual physical paths in a MIMO PLC channel. The DM path P-N at transmitter to P-N at receiver is the traditional channel between two SISO modems. All other paths contribute to multiple input and multiple output.

6 Worldwide Evaluation of the Presence of the Protective Earth (PE) Wire in Residential Dwellings

Before evaluating the properties of the protective earth wire in private homes, it is important to consider where and with which probability the third wire is likely to be found in a given country. Unfortunately this information is not available in a harmonized way for all countries, so several different approaches were employed to collect this information:

- Study of individual grounding systems and investigations into which grounding systems are used in which countries
- Creation of a list of AC wall socket types and where which one is used
- Researches when the regulation for the installation of the protective earth went into effect and produced an estimate of how many electrical installations have taken place since then
- Searches for secondary information, e.g. worldwide sales numbers of RCDs
- Worldwide survey of data from electrical standardization committees and engineering clubs for each country

A map is presented at the end of this clause, which summarizes the presence of the PE wire in each country based on the research mentioned above. It has to be noted that the results here do not reflect a complete, comprehensive and comparable overview of the probability of PE wire installations.

The information collected in this clause was frequently derived from [i.8]. This reference is not given at all locations where it is used.

6.1 Grounding Systems

In electricity supply systems, a "grounding system" defines the electrical potential of the conductors relative to that of the Earth's conductive surface. The choice of grounding system has implications for the safety and electromagnetic compatibility of the power supply. Note that regulations for grounding systems vary considerably among different countries.

A *protective earth* connection ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth, to avoid the risk of electric shock if a person touches a device in which an insulation fault has occurred. It ensures, that in the case of an insulation fault (a "short circuit"), a very high current will surge, which will trigger an over-current protection device (fuse, circuit breaker) that disconnects the power supply.

A *functional earth* connection may carry a current during the normal operation of a device. Examples of such devices are surge suppression and electromagnetic interference filters, some types of antennas and various measurement instruments. Generally the protective earth is also used as a functional earth, though this requires care in some situations.

International Standard IEC 60364-1 [i.13] distinguishes three families of grounding arrangements, using the two-letter codes **TN**, **TT** and **IT**.

The first letter indicates the connection between earth and the power-supply equipment (generator or transformer):

T Direct connection of a point with earth (Latin: terra);

I No point is connected with earth (isolation), except perhaps via high impedance.

The second letter indicates the connection between earth and the electrical device being supplied:

T Direct connection of a point with earth;

N Direct connection to neutral at the origin of installation, which is connected to the earth.

6.1.1 TN Networks

In a **TN** earthing system, one of the points in the generator or transformer is connected with earth, usually at the star point in a three-phase system. The body of the electrical device is connected with earth via this earth connection at the transformer.

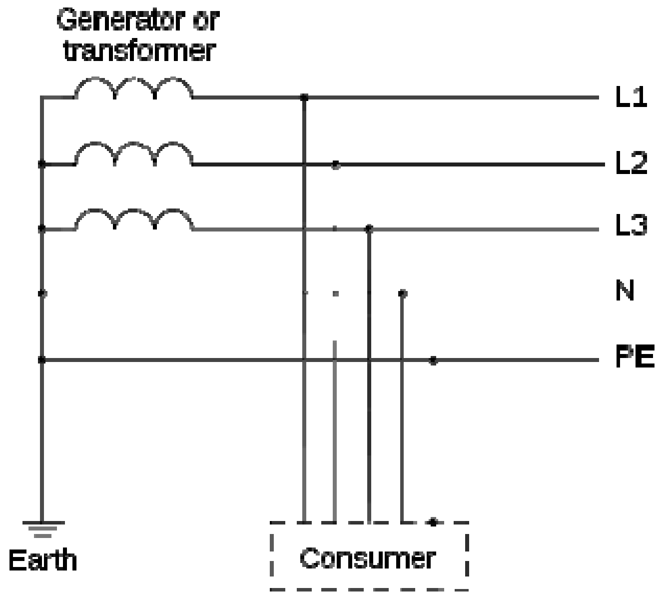


Figure 2: TN Networks

The protective earth (PE) is the conductor that connects the exposed metal parts of the consumer. The neutral (N) conductor connects to the star point in a three phase system, or carries the return current in a single phase system. There are three variants of TN systems:

TN-S, TN-C, TN-CS

6.1.1.1 TN−S

PE and N are separate conductors that are only connected together near the power source.

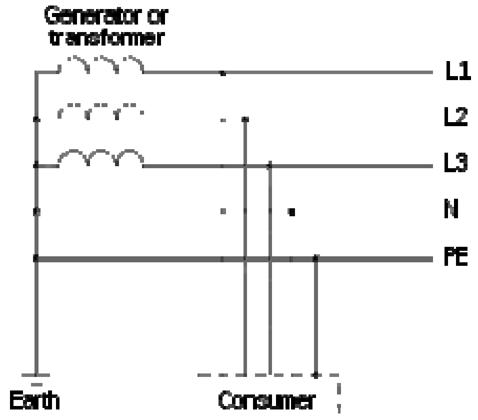


Figure 3: TN-S Network

Separate protective earth (PE) and neutral (N) conductors from transformer to consumer device, which do not connect after the building distribution point.

6.1.1.2 TN−C

A combined PEN conductor fulfils the functions of both a PE and an N conductor, but this type of installation is rarely used.

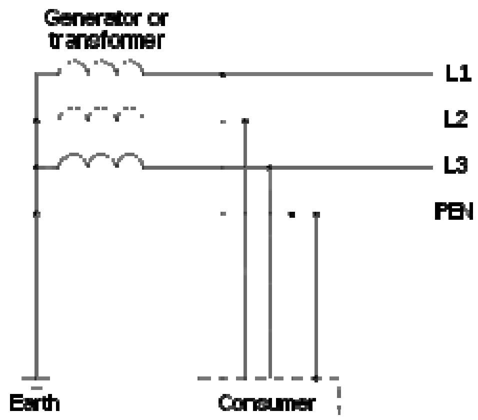


Figure 4: TN-C Networks

The combined PE and N conductor are connected all the way from the transformer to the consuming device.

6.1.1.3 TN−C−S

Part of the TN-C-S system uses a combined PEN conductor, which splits into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, and separates in the service head. This system, which connects the combined neutral-and-earth conductor to real earth at many locations to reduce the risk of broken neutrals, is also known as "protective multiple earthing" (PME) in the UK and "multiple earthed neutral" (MEN) is the designation of Australia's system.

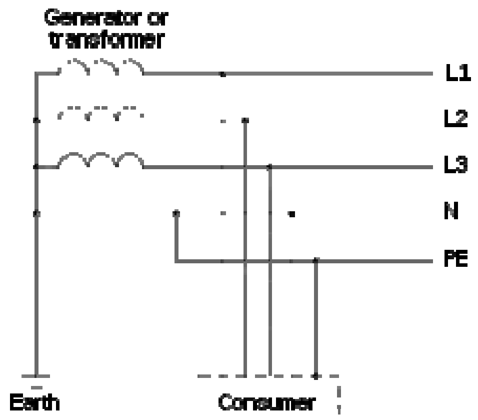


Figure 5: TN-C-S Networks

Combined PEN conductor from transformer to building distribution point, but PE and N conductors separate in the fixed indoor wiring and have flexible power cords.

6.1.2 TT Network

In a **TT** earthing system, consumer PE connections are provided by a local connection to earth, which is independent from any earth connection at the generator. An advantage of a TT network is that there is no risk of a broken neutral.

In locations where power is distributed overhead and TT is used, installation earth conductors are not at risk should any overhead distribution conductor be fractured by, say, a fallen tree or branch.

TT earthing systems were unattractive for general use, before RCD times, due to their lesser ability to accept high currents in the event of a live-to-PE short circuit (in comparison to TN systems).However, residual current devices mitigate this disadvantage, making the TT earthing system attractive for premises where all AC power circuits are RCD-protected.

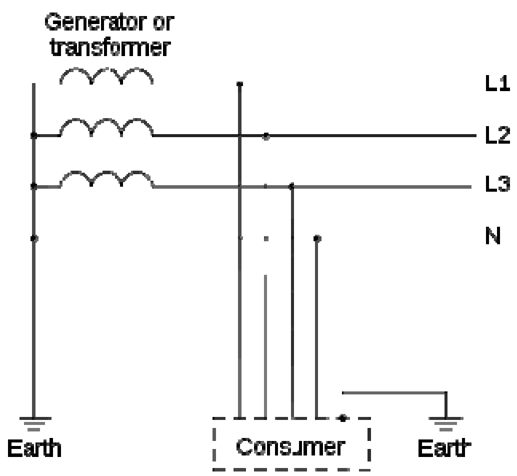


Figure 6: TT Network

6.1.3 IT Network

In an **IT** network, the distribution system has no connection to earth at all, or it has a high impedance connection which is monitored by an insulation monitoring device. Environments supplied via engine-generators, e.g. laboratory rooms, medical facilities, construction sites, repair workshops, mobile electrical installations, etc., where there is an increased risk of insulation faults, often use an IT earthing arrangement supplied by insulation transformers. In order to mitigate the two-fault issues with IT systems, isolation transformers should either supply only a small number of loads each and/or be protected with an insulation monitoring device (generally used only by medical, railway or military IT systems, due to cost).

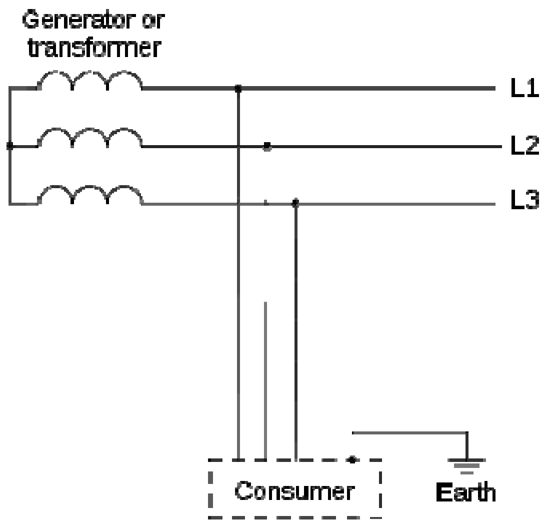


Figure 7: IT Network

When an isolation problem occurs, the power is not cut, but the monitoring system detects the current leakage through the high impedance and a warning light comes on to indicate that there is a problem. An assigned technician has to then solve the problem. It is mandatory that he be available 24/7 as implied this grounding standard.

If a second problem occurs with a stronger current leak to earth, where both Phase & Neutral conductors in short-circuit, then the power will be cut by another protection device, e.g. a fuse or circuit breaker.

6.1.4 Regulations of Earthing Networks

- According to the United States National Electrical Code and Canadian Electrical Code, the feed from the distribution transformer uses a combined neutral and grounding conductor, but within the structure separate neutral and protective earth conductors are used (TN-C-S). The neutral must be connected to the earth (ground) conductor only on the supply side of the customer's disconnecting switch. Additional connections of neutral to ground within the customer's wiring are prohibited.

- Japan is governed by PSE law, and uses TT earthing in most installations.

Most modern homes in Europe have a TN-C-S earthing system with a combined neutral and earth between the nearest transformer substation and the service cut out (the fuse before the meter); and separate earth and neutral cores thereafter in all internal wiring.

- Urban and suburban homes in the UK tend to have TN-S supplies, where the earth connection is delivered through the lead sheath of the underground lead-and-paper cable.

- Older homes, worldwide, especially those built before the invention of residual-current circuit breakers and wired home area networks, use an in-house TN-C arrangement. Today, this is no longer recommended practice.

- In remote areas, where the cost of an additional PE conductor outweighs the cost of a local earth connection, TT networks are commonly used in some countries, especially in older properties or in rural areas, where safety might otherwise be threatened by the fracture of an overhead PE conductor(e.g. by a fallen tree branch). Within areas that mainly utilize TN-C-S systems, individual properties can be seen to have a TT supply, if the property is considered unsuitable for TN-C-S.

- Australia and Israel both use the TN-C-S systems. However, additional wiring rules require that each customer have separate connections to earth via a water pipe bond (where metallic water pipes enter the consumer's premises) and a dedicated earth electrode. In Australia, new installations must also be bonded to the concrete in the foundation in order to reinforce the connection to the earth conductor (AS3000) under areas of the premises which might become wet, such as bathrooms; typically, this increases the earthing size and creates an equipotential plane. It is not uncommon to only find the water pipe bond in older installations, which is allowed to remain as such, until upgrade and renovation work is done, in which case the additional earth electrode must be installed. Protective earth and neutral conductors are combined up until the consumer's neutral link (located on the customer's side of the electricity meter's neutral connection) - beyond this point, the protective earth and neutral conductors are separate.

6.2 Wall Socket Types Used in Various Countries

AC power plugs and **sockets** are devices for connecting removable, electrically operated consumer devices to a power supply.

A plug connects mechanically to a matching socket. Plugs are mostly or completely male, while sockets are mostly or completely female; the plug has protruding prongs or pins that fit into matching slots or holes in the socket. Generally, a plug is the movable connector attached to the power cord of an electrically operated device, and the socket is a fixture on equipment or a building structure. Wall-mounted sockets are also called receptacles, outlets, or power points.

To reduce the risk of electric shock, plug and socket systems can incorporate a variety of safety features. For example, sockets can be designed to accept only compatible plugs and reject all others, whereas others are designed so that a dangerous voltage is never present on an exposed contact. Exposed contacts in some sockets are used for grounding.

Every commonly-used power outlet has two or three wired contacts. The contacts may be steel or brass, and may be plated with zinc, tin, or nickel. Both *live* and *neutral* contacts typically carry current from the source to the load and from the load to the source, changing direction 50-60 times per second, since alternating current (AC) is predominantly used in energy distribution networks vs. direct current (DC = unidirectional). However only the *neutral* contact remains at or very near the voltage potential of the earth, while the potential of the *live* contact changes sinusoidally, for example -320 V to +320 V (peak-to-peak). Many outlets and plugs also have a third contact for a connection to earth ground, intended to protect against insulation failure of the connected device. A common approach is for electrical sockets to have three holes, which can accommodate either 3-pin earthed or 2-pin non-earthed plugs.

6.2.1 3 Pin Type Sockets

The types **B, H, I, J, K** and **L** use PE third pin (type B accepts type A plugs and types H, J, K and L accept type C). The "Europlug" (type C) will fit type E and F sockets, and the earthed type E/F 2-pin plugs will fit type C (and certain hybrid) sockets, without making earthing contact. Types **D, G** and **M** plugs are exclusively 3-pin, used for both earthed and non-earthed appliances.

Table 2: Comparison of Sockets

Type	Socket standard	Power rating	Grounded	Polarised	Fused	Insulated pins
A	NEMA 1-15 unpolarised	15 A/125 V	No	No	No	No
	NEMA 1-15 polarised	15 A/125 V	No	Yes	No	No
	JIS C 8303, Class II	15 A/100 V	No	No	No	No
B	NEMA 5-15	15 A/125 V	Yes (Note 1)	Yes	No	No
	NEMA 5-20	20 A/125 V	Yes (Note 1)	Yes	No	No
	JIS C 8303, Class I	15 A/100 V	Yes (Note 1)	Yes	No	No
C	CEE 7/16 (Europlug)	2.5 A/250 V	No	No	No	Yes
	CEE 7/17	16 A/250 V	No	No (Note 1)	No	No
	GOST 7396 C 1	6 A/250 V 16 A/250 V	No	No	No	No
D	BS 546 (2 pin)	2 A/250 V 5 A/250 V = BS 4573	No	No	No	No
	BS 546 (3 pin)	2 A/250 V 5 A/250 V 15 A/250 V = SABS 164 30 A/250 V	Yes	Yes	No	No
E	CEE 7/5	16 A/250 V	Yes (Note 1)	Yes	No	No (Note 1)
F	CEE 7/4 (Schuko)	16 A/250 V	Yes (Note 1)	No	No	No (Note 1)
E+F	CEE 7/7	16 A/250 V	Yes (Note 1)	Yes (Note 3)	No	No (Note 1)
G	BS 1363, IS 401 & 411, MS 589, SS 145	13 A/230-240 V	Yes	Yes	Yes	Yes
H	SI 32	16 A/250 V	Yes (Note 3)	Yes	No	No
	TIS 166-2549	16 A/250 V	Yes	Yes	No	Yes
I	AS/NZS 3112	10 A/240 V 15 A/240 V 20 A/240 V 25 A/240 V 32 A/240 V	Yes (Note 1)	Yes	No	Yes
	CPCS-CCC	10 A/250 V	Yes	Yes	No	No
	IRAM 2073	10 A/250 V	Yes	Yes	No	No
J	SEV 1011	10 A/250 V 16 A/250 V	Yes (Note 1)	Yes	No	No
K	Section 107-2-D1	13 A/250 V	Yes (Note 1)	Yes	No	No
L	CEI 23-16/VII	10 A/250 V 16 A/250 V	Yes (Note 1)	No	No	Yes
-	IEC 60906-1 [i.11] (2 pin)	10 A and 20 A/250 V	No	No	No	Yes
	IEC 60906-1 [i.11] (3 pin)	10 A and 20 A/250 V	Yes (Note 1)	Yes	No	Yes

NOTE 1: There are common ungrounded plugs that work with the grounded sockets of this type.
NOTE 2: Deep-wall socket prevents human contact with pins.
NOTE 3: Plug can only be inserted one way with French socket of type E, but lack of wiring convention means that the type is not polarized in practice.
NOTE 4: There are some CEE 7/17 plugs with a special shape which are polarized when used with the French socket of type E (mechanically only).
NOTE 5: Newer sockets can accept ungrounded Type C Europlugs.

Information regarding the use of PE in each country is included in the table above, alongside the type of sockets used. For more information, please view links below.

http://www.interpower.com/icl2/guide.htm

http://en.wikipedia.org/wiki/AC_power_plugs_and_sockets

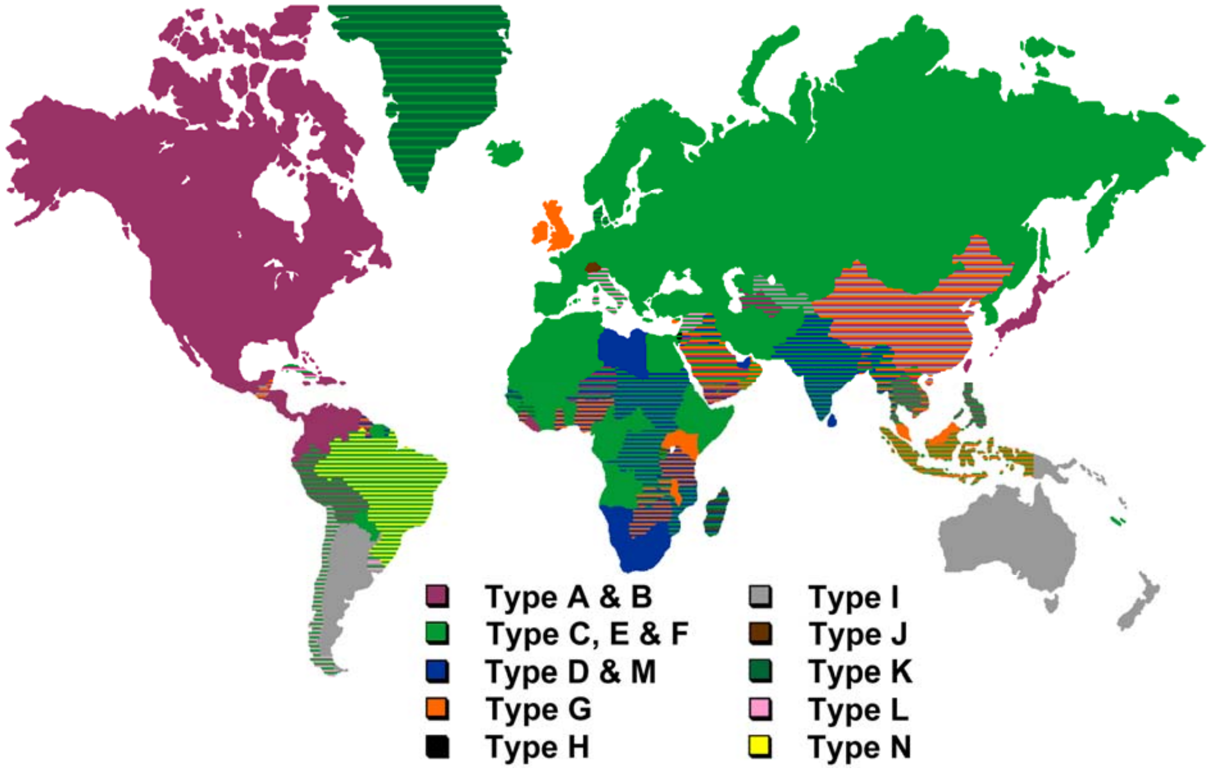


Figure 8: Socket Types World Map

6.2.2 Countries in which PE Grounding is Not in Use

According to the available information on the different socket types in use, it can be concluded that PE is most likely not used in the following countries:

- Angola
- Egypt
- Eritrea
- Gabon
- Georgia
- Guinea-Bissau
- Mauritania
- North Korea
- Paraguay
- Somalia
- Togo

6.2.3 Countries where PE Type Sockets are Exclusively Used

It can also be concluded that PE should be exclusively used in the following countries which use D, I, G and J type sockets:

Australia, Bahrain, Bhutan, Botswana, Brunei, Chad, Cook Islands, Cyprus, Dominica, Falkland Islands, Fiji, Gambia, Ghana, Gibraltar, Grenada, Hong Kong, Ireland, Isle of Man, Kenya, Kiribati, Kuwait, Lesotho, Libya, Macau (China), Malawi, Malta, Mauritius, Namibia, Nauru, New Caledonia, New Zealand, Nigeria, Papua New Guinea, Qatar, Reunion Island (France), St Lucia, St Pierre and Miquelon (France), Samoa, Seychelles islands, Sierra Leone, Sri Lanka, Swaziland, Tanzania, Tonga, Turkmenistan, Uganda, United Kingdom, Vanuatu, Zimbabwe.

For these countries, it can be assumed that the percentage of dwellings equipped with Protective Earth wire is high (around 100 %).

6.3 Regulation Approach to Estimate Presence of Protective Earth

In the following clause information from some countries are collected in a harmonized way. Further information on a few countries is given later by STF 410 experts, who have had access to more in depth information. Please see the individual sources for this information.

6.3.1 European Countries

Table 3 lists the total number of dwellings for several European countries from census data sourced from *Housing Statistics in the European Union 2010* [i.5].

Table 3: Number of Private Households (x 1 000) for a few European Countries

	1980	1990	2000	2005	2007	2008	2009
Austria	2 669	2 973	3 276	3 475	3 537	3 567	3 598
Belgium	3 608	389	4 237	4 439	4 523	4 569	na
Bulgaria							
Cyprus	na	172	224				
Czech Republic	3 791	3 984	4 216				
Denmark	2 062	2 265	2 434	2 488	2 517	2 530	2 548
Estonia	na	na	575	567	584	584	
Finland	1 782	2 037	2 295	243	2 477	2 499	2 517
France	19 044	21 478	2 424	25 876	26 633	27 005	
Germany	24 811	34 681	38 124	39 178	39 722	40 076	
Greece	2 974	3 203	3 674				
Hungary	3 719	389	3 863	3 837	381		
Ireland	880	1 015	1 251				
Italy	18 632	19 909	21 811	236	24 282	24 641	
Latvia	na	na	929	905	899	899	889
Lithuania	na	na	1 354				
Luxembourg	128	144	171	178	189		
Malta	na	na	128	140	141	142	na
Netherlands	5 006	6 061	6 801	7 091	7 191	7 242	7 313
Poland	10 948	1 197	13 337				
Portugal	2 924	3 147	3 651				
Romania				7 365	7 381	7 384	
Slovak Republic	166	1 832	2 072	na	na	Na	na
Slovenia	595	632	685				
Spain	10 025	11 299	13 086	14 865	1 628	16 741	na
Sweden	3 498	383	4 363	4 441	4 477	4 555	na
United Kingdom	199	2 214	24 121	24 200			25 200
Private household: The usual definitions concern the "same address" or sharing common arrangements such as meals and rent.							

Distribution of housing stock, organized by age of residences for each country [i.5].

Table 4: Age Distribution of Housing Stock

	Age distribution of housing stock (%)							
	Year	**< 1919**	**1919-1945**	**1946-1970**	**1971-1980**	**1981-1990**	**1991-2000**	**> 2000**
Austria	2009	15,2	8,2	28	15,2	11,5	13,6	8,3
Belgium	2009	17,1	24,2	24,2	13,7	20,8		
Bulgaria								
Cyprus	2001	na	7,4	16,9	20,7	27,4	27,1	-
Czech Republic	2005	10,5	14,2	25,4	21,8	15,8	7,9	3,4
Denmark	2009	19,7	16,1	26,4	16,6	9,1	5,4	6,7
Estonia	2009	9,4	14,2	30	21,5	19,6	2	3,3
Finland	2009	1,5	8,1	27,6	21,5	18,5	11,5	9,8
France	2006	17	13,2	17,4	25,2	10,2	8,5	8,5
Germany	2006	14,4	13,6	46,3	13,2	9,2	3,3	
Greece	2001	3,1	7,2	31,8	24,5	19,1	14,4	na
Hungary	2005	-	20,8	27,2	23,1	17,8	7,9	3,2
Ireland	2002	9,4	8	15,9	14,2	13,2	19,5	19,8
Italy	2001	14,2	9,9	36,8	18,8	12,2	7,9	-
Latvia	2008	13,8	13,1	22,1	19,4	20,2	7	4,4
Lithuania	2002	6,2	23,3	33,1	17,6	13,5	6,3	-
Luxembourg	2008	21,8	25,6	29,2	11,6	5,1	4,5	2,2
Malta	2005	12,2	10	22,1	16,2	19,1	17	3,4
Netherlands	2009	6,9	13,9	27	17	15,4	12	7,9
Poland	2002	10,1	13,1	26,9	18,3	18,7	12,9	-
Portugal	2008	7,4	10	21,9	16,1	18,8	17,7	8,1
Romania	2002	3,9	11,5	37,3	23,8	14,8	7,3	1,4
Slovak Republic	2001	3,4	6,6	35,1	25,6	21	6,2	0,6
Slovenia	2004	15,1	7,8	27,7	23,2	16	6,9	3,4
Spain	2001	8,9	4,2	33,5	24,1	13,6	15,7	-
Sweden	2008	12	14,7	37	16,8	9,4	5,5	4,6
United Kingdom	2004/5	17	17	21	21,8	20	na	na

Furthermore, the regulation enforcement date (when known) was added to get figures about the number of dwellings built after the Protective Earth requirement was passed into law, which "normally" should be in compliance with the actual Safety Regulation.

The results of a survey which organized by the Forum for European Electrical Domestic Safety held in 2004 was also taken into account [i.5].

This interesting survey presents information about the particular situation found in some countries (especially former Eastern Europe Block countries). An estimate of PE equipped households, based on this survey and additional data from other sources, e.g. local contacts and authorities, is compiled below.

Table 5: Date when PE became Mandatory and Estimate of PE equipped Dwellings

	PE mandatory date	Estimated percentage of dwellings equipped with PE
Austria		
Belgium	1981	25 %
Bulgaria		
Cyprus		
Czech Republic	1997	7 %
Denmark	1994	10 %
Estonia		
Finland	1990	25 %
France	1966-1972	60 %
Germany	1970	70 %
Greece		
Hungary		
Ireland	< 1960	100 %
Italy		
Latvia	Not mandatory	< 15 %
Lithuania		
Luxembourg		
Malta	1940	100 %
Netherlands		
Poland	1995	15 %
Portugal		
Romania		
Slovak Republic	2000	2 %
Slovenia	2004	2 %
Spain	1973	55 %
Sweden	1994	5 %
United Kingdom	1947	97 %

6.3.2 United States

The same approach was used to estimate the housing stock in the US, as for Europe. See [i.6] for source information regarding the age of housing stock in the US.

Table 6: Age of Housing in U.S.

Year Structure Built*	Total Housing Units	Percentage of Total
1995–1999	8,360,000	7.3
1990–1994	7,203,000	6.3
1985–1989	8,873,000	7.7
1980–1984	7,684,000	6.7
1975–1979	11,757,000	10.2
1970–1974	11,423,000	9.9
1960–1969	15,810,000	13.7
1950–1959	13,574,000	11.8
1940–1949	8,334,000	7.2
1930–1939	6,548,000	5.7
1920–1929	5,564,000	4.8
1919 or earlier	10,124,000	8.8

Presence of Protective Earth has been mandatory in the US since 1962, thus it is estimated that the actual percentage of properly grounded dwellings is above 64 %.

6.3.3 Canada

The same approach was used to estimate the status in Canada. Source: [i.7].

Table 7: Number and Age of Housing in Canada

Tenure and Period of construction	# of households	% by age	Built after 1960
1945 or before	1 661 635	14,3	
1946-1960	1 819 730	15,7	PE mandatory after 1960
1961-1970	1 833 290	15,9	15,9
1971-1980	2 460 455	21,3	21,3
1981-1985	1 001 665	8,7	8,7
1986-1990	1 079 075	9,3	9,3
1991-1995	887 255	7,7	7,7
1996-2001	819 865	7,1	7,1
	11 562 970	100	69,9

Presence of Protective Earth has been mandatory since around 1960 (depending on provinces), thus we have estimated the actual percentage of properly grounded dwellings to be above 70 %.

6.3.4 More Detailed Information about a few Countries

6.3.4.1 Presence of PE Wire in Belgium

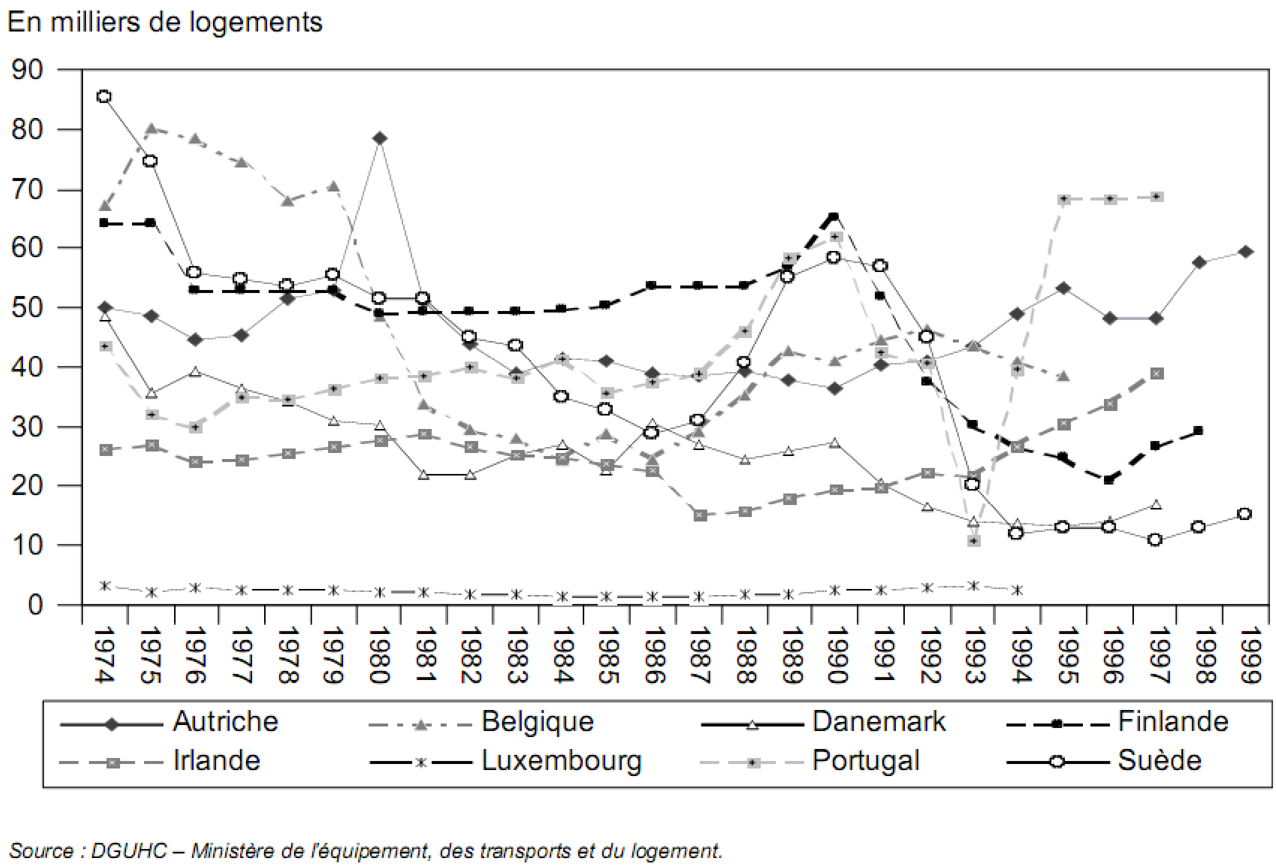


Figure 9: Number of dwellings erected over time in some European countries

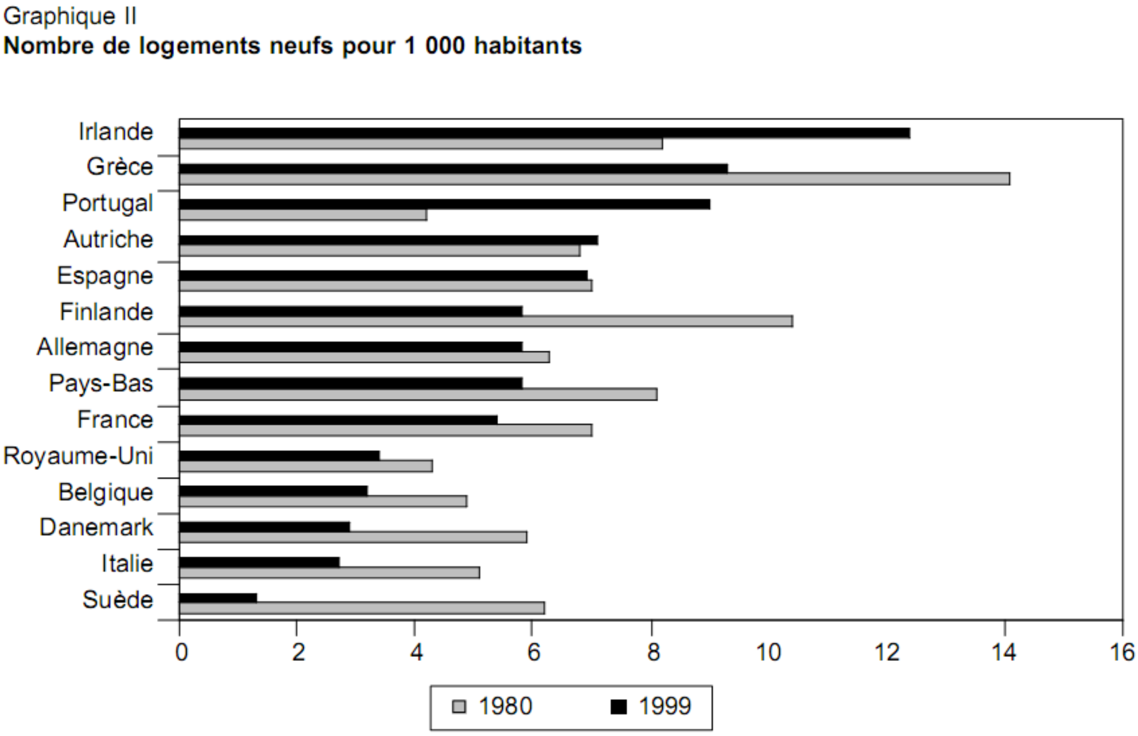


Figure 10: Number of New Dwellings per 1 000 Inhabitants

In Belgium, electrical installations fall under the national regulation of the so called **AREI** (Algemeen reglement op de Elektrische Installaties). The present document describes the electrical installation including transport of high voltage, distribution, industrial and household installation and is available in Dutch and French only (**RGIE**).

The present document also outlines the PE and its requirements, how it should behave and how it should be installed (maximum earth resistance, materials, wire sections and colors, installation practices, etc.).

Additional and specific PE requirements may exist according to the "machine directive" in industrial environments.

From 1982 on, a PE has been mandatory for all new installations, but old, and (non-renovated private) houses are exempt (it is estimated that 1,5 million houses in Belgium still do not have a PE, or at least no PE which is "state of the art" and in compliance with AREI regulations).

6.3.4.2 Presence of PE Wire in France

6.3.4.2.1 Historical PE relative standards

This clause presents the main standards related to PE over the past years in France.

Table 8: Historical Development of Standards Requesting Earthing in France

Year	Standard	Comments
1935	4th August 1935 decree	This decree introduces the fact that, due to possible lack of isolation, equipment ground shall be connected to earth. No details regarding earth connector, earth connection. Earthing is not associated to circuit breaker. Not applicable decree due to lack of technical and mechanical information.
1962	Decree 62-1454 November 14th 1962	Main decree that introduced protective earth concept with protection circuit (circuit breaker) and clearly identified PE wire. This decree only applied to electricians working on power supply installation.
1966	Minute 66-32 August 17th 1966	Application of decree 62-1454 for new building: PE wire is mandatory.
1971	SEC/EL n°14 March 10th 1971	Technical note given rules regarding PE installation on new building
1972	UTE 5-120 February 10th 1972	UTE (Electro-technical French standardization) published practical guide of wiring PE wire inside new building. This guide is the technical and practical aspects of the Minute 66-32. PE wire is mandatory and shall be installed according to this guide.
1972	NF C15-120 June 21st 1972	Technical note that give recommendation regarding reinforced concrete that shall be connected to Earth.

From this historical data, we can sum up that the PE wire has been mandatory since 1966, but it is not technically applicable due to lack of recommendations and technical information.

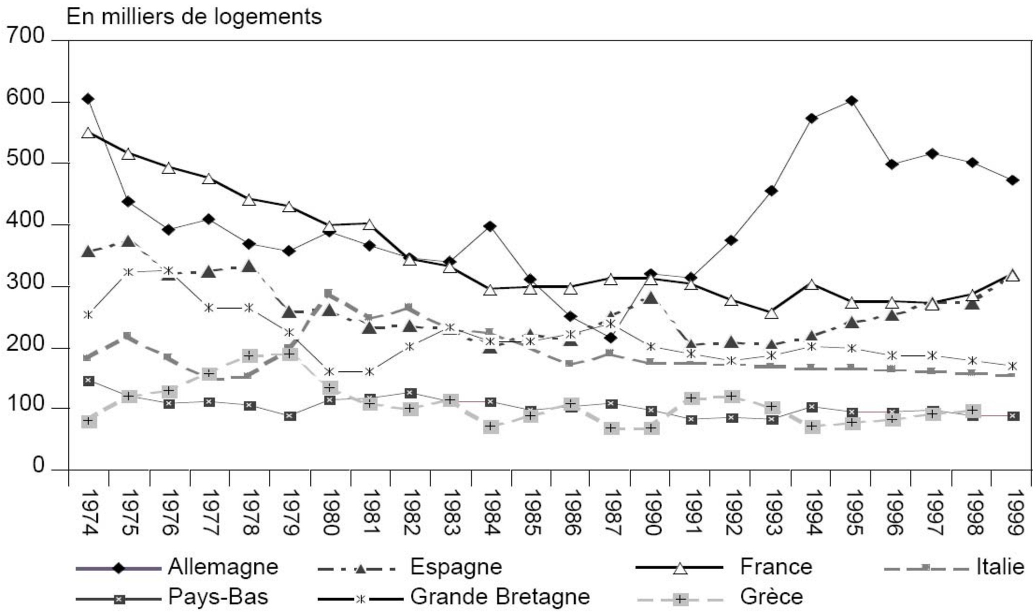
Since 1972 and publication of technical information, new buildings are equipped with common rules for PE wire installations.

6.3.4.2.2 Statistical Data

Now, based on statistical data, we will try to calculate the number of premises equipped with PE wire.

6.3.4.2.2.1 New Housing since 1972

The INSEE (French statistical institute) provides relevant information regarding the number of new residences since 1974 for various countries in Europe. (http://www.insee.fr/fr/ffc/docs_ffc/es343b.pdf)



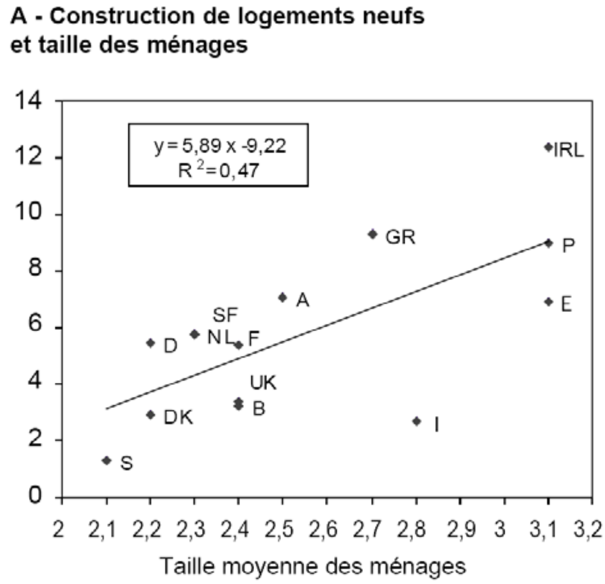
NOTE: **X-axis:** Year; **Y-axis:** Thousands of new housing for different countries.

Figure 11: Number of Dwellings Erected over Time in some European Countries

We can assume an average number of 350 k new residences per year. That means that about 13,3 million residences equipped with PE wiring have been built since 1972.

6.3.4.2.2.2 Average people per housing

The same document from INSEE (http://www.insee.fr/fr/ffc/docs_ffc/es343b.pdf) claims about 2,4 people (average) per new housing.



NOTE: **X-axis**: Number of People per Household; **Y-axis:** Number of New Residences per one thousand People.

Figure 12: Number of People per Household vs. Number of New Residences in some European Countries

Based on these figures we can estimate that 2,4*13,3=31,92 million French people live in a PE equipped home.

6.3.4.2.2.3 French Population

According to INSEE (http://www.insee.fr/fr/themes/tableau.asp?reg_id=0&ref_id=NATTEF02133) the French population is about 64 million.

6.3.4.2.2.4 Premises Renovation

We could not find any statistical information related to the renovation of older, privately owned buildings (built before 1972). We only found that roughly 1 % of social premises are renewed per year (http://www.insee.fr/fr/themes/tableau.asp?ref_id=NATnon11413&id=0).

If we suppose that only 0,25 % of the private premises are renewed per year, then, about 10 % of old premises (before 1972) are now equipped with PE wire.

6.3.4.2.2.5 Conclusion of French Wiring Practices

According to the number of new housing since 1972, about 50 % of the French population is equipped with the PE wire.

According to the estimated figure of renovation, 20 % of the French population is living in an old but renewed premise with a PE wire.

So we can estimate that 60 % of the French population is equipped with the PE wire.

6.3.4.3 Presence of PE Wire in Switzerland

Following information given by Electrosuisse:

- Separate wiring of protective earth is mandatory in Switzerland since the 1960's.
- It is believed that more than 90 % (likely more than 95 %) of the apartments are wired this way today.

6.3.4.4 Presence of PE Wire in the US

Following figures (table 9) on housing building permits in the US was found on the web.

Table 9: New Houses in the US According to the Census Bureau (source http://www.census.gov)

New Privately Owned Housing Units Authorized by Building Permits in Permit-Issuing Places

Annual Data

(Components may not add to total because of rounding. Number of housing units in thousands.)

Universe	Year	Total	In structures with--			Region							
			1 unit	2 to 4 units[1]	5 units or more	Northeast		Midwest		South		West	
						Total	1 unit	Total	1 unit	Total	1 unit	Total	1 unit
10,000 Place Series	1959	1,208.3	938.3	77.1	192.9	222.4	.	285.8	.	355.8	.	344.3	.
	1960	998.0	746.1	64.6	187.4	199.0	130.0	228.3	186.0	283.0	238.0	287.7	192.0
	1961	1,064.2	722.8	67.6	273.8	229.4	125.0	226.1	172.0	299.4	236.0	309.4	190.0
	1962	1,186.6	716.2	87.1	383.3	242.5	126.0	238.3	164.0	342.8	232.0	363.0	195.0
12,000 Place Series	1963	1,334.7	750.2	118.9	465.6	239.4	129.0	268.8	174.0	403.2	245.0	423.3	202.0
	1964	1,285.8	720.1	100.8	464.9	243.4	130.0	286.9	176.0	401.4	241.0	354.2	173.0
	1965	1,240.6	709.9	84.8	445.9	252.7	137.4	310.5	181.7	408.3	236.5	269.1	154.3
	1966	971.9	563.2	61.0	347.7	209.8	113.9	250.9	148.6	331.1	186.0	180.2	114.7
13,000 Place Series	1967	1,141.0	650.6	73.0	417.5	222.6	119.6	309.8	176.0	390.8	225.0	217.8	130.0
	1968	1,353.4	694.7	84.3	574.4	234.8	119.2	350.1	182.1	477.3	233.9	291.1	159.5
	1969	1,322.3	624.8	85.2	612.4	215.8	104.7	317.0	149.9	470.5	215.6	319.0	154.6
	1970	1,351.5	646.8	88.1	616.7	218.3	93.1	287.4	148.1	502.9	246.5	342.9	159.1
	1971	1,924.6	906.1	132.9	885.7	303.6	127.3	421.1	208.1	725.4	338.6	474.6	232.1
14,000 Place Series	1972	2,218.9	1,033.1	148.6	1,037.2	333.3	147.3	440.8	230.1	905.4	391.5	539.3	264.3
	1973	1,819.5	882.1	117.0	820.5	271.9	141.6	361.4	197.5	763.2	323.9	423.1	219.0
	1974	1,074.4	643.8	64.3	366.2	165.4	97.2	241.3	154.5	390.1	223.7	277.6	168.4
	1975	939.2	675.5	63.9	199.8	129.5	92.6	241.5	169.3	292.7	222.8	275.5	190.8
	1976	1,296.2	893.6	93.1	309.5	152.4	111.2	326.1	219.4	401.7	292.6	416.0	270.5
	1977	1,690.0	1,126.1	121.3	442.7	181.9	126.8	402.4	269.3	561.1	370.1	544.6	359.9
16,000 Place Series	1978	1,800.5	1,182.6	130.6	487.3	194.4	132.9	388.0	260.8	667.6	439.3	550.5	349.6
	1979	1,551.8	981.5	125.4	444.8	166.9	110.2	289.1	182.4	628.0	392.1	467.7	296.7
	1980	1,190.6	710.4	114.5	365.7	117.9	75.7	192.0	107.9	561.9	333.0	318.9	193.7
	1981	985.5	564.3	101.8	319.4	109.8	65.7	133.3	78.3	491.1	270.7	251.3	149.5
	1982	1,000.5	546.4	88.3	365.8	106.7	65.7	126.3	67.6	543.5	281.1	224.1	132.0
	1983	1,605.2	901.5	133.6	570.1	164.1	112.3	187.8	117.4	862.9	443.0	390.4	228.6
17,000 Place Series	1984	1,681.8	922.4	142.6	616.8	200.8	141.2	211.7	121.5	812.1	432.3	457.3	227.4
	1985	1,733.3	956.6	120.1	656.6	259.7	173.5	237.0	128.6	752.6	428.9	483.9	225.7
	1986	1,769.4	1,077.6	108.4	583.5	283.3	203.8	290.0	167.5	686.5	443.2	509.7	263.1
	1987	1,534.8	1,024.4	89.3	421.1	271.8	194.0	282.3	180.3	574.7	413.1	406.0	236.9
	1988	1,455.6	993.8	75.7	386.1	230.2	166.0	266.3	177.8	543.5	391.6	415.6	258.3
	1989	1,338.4	931.7	67.0	339.8	179.0	129.7	252.1	172.1	505.3	361.5	402.1	268.4
	1990	1,110.8	793.9	54.3	262.6	125.8	96.5	233.8	165.7	426.2	318.1	324.9	213.7
	1991	948.8	753.5	43.1	152.1	109.8	91.8	215.4	168.1	375.7	308.4	247.9	185.2
	1992	1,094.9	910.7	45.8	138.4	124.8	108.5	259.0	204.4	442.5	382.2	268.6	215.6
	1993	1,199.1	986.5	52.3	160.2	133.5	113.7	276.6	218.4	500.7	419.5	288.2	235.0
19,000 Place Series	1994	1,371.6	1,068.5	62.2	241.0	138.5	119.1	305.2	233.6	585.5	453.0	342.4	262.8
	1995	1,332.5	997.3	63.7	271.5	124.2	104.5	296.6	220.5	583.2	430.3	328.5	241.9
	1996	1,425.6	1,069.5	65.8	290.3	136.9	108.8	317.8	236.6	623.4	468.5	347.4	255.6
	1997	1,441.1	1,062.4	68.5	310.3	141.9	111.2	299.8	220.0	635.9	464.2	363.5	267.1
	1998	1,612.3	1,187.6	69.2	355.5	159.4	124.1	327.2	247.8	724.5	521.9	401.2	293.8
	1999	1,663.5	1,246.7	65.8	351.1	164.9	127.1	345.4	262.1	748.9	550.4	404.3	307.1
	2000	1,592.3	1,198.1	64.9	329.3	165.1	122.3	323.8	245.4	701.9	529.7	401.5	300.7
	2001	1,636.7	1,235.6	66.0	335.2	159.8	117.7	333.6	252.5	730.3	556.9	413.0	308.5
	2002	1,747.7	1,332.6	73.7	341.4	173.7	126.6	352.4	263.4	790.7	606.5	430.9	336.2
	2003	1,889.2	1,460.9	82.5	345.8	182.4	124.4	371.0	287.3	849.3	670.1	486.5	379.0
	2004	2,052.1	1,596.4	90.0	365.6	196.5	131.4	365.4	290.6	949.7	745.5	540.5	429.0
20,000 Place Series	2004	2,070.1	1,613.4	90.4	366.2	197.0	131.8	370.5	295.5	960.8	756.1	541.9	430.0
	2005	2,155.3	1,682.0	84.0	389.3	203.8	126.6	353.9	278.7	1,039.0	826.8	558.6	450.0
	2006	1,838.9	1,378.2	76.6	384.1	174.6	103.4	279.4	209.3	929.7	726.2	455.2	339.3
	2007	1,398.4	979.9	59.6	359.0	150.6	83.7	211.7	153.8	692.2	507.5	343.9	234.9
	2008	905.4	575.6	34.4	295.4	119.0	58.0	137.7	93.2	451.9	304.3	196.7	120.0
	2009	583.0	441.1	20.7	121.1	68.5	45.8	100.3	74.9	297.4	231.8	116.7	88.7

[1]Through 1962, 2 units includes 3 and 4 units.

Furthermore:

- In 2011, there were 130 M households in total, in the US [i.8]
- NEC (National Electric Code) requires a ground wire outlet since 1962 [i.8]

Therefore, the number of residences supplied with protective earth is provided in table 9 from the census bureau.

6.3.4.5 Presence of PE Wire in Spain

6.3.4.5.1 Electrical Regulations Data for Spain

The low voltage installations in Spain are regulated by the "Reglamento Electrotécnico para Baja Tensión" (RBT) (Low Voltage Electrotechnical Regulation).

The regulation of internal electrical installations (see note 1) was published on 5th July 1933. This regulation was in effect until 1955 and no further investigation has been done as this regulation does not require the installation of a PE wire inside residences.

In 1955 (see note 2) the RBT was published, effectively overriding the regulation of 1933, and mandatory until 1973. The 1955 version of RBT does not make explicit mention of PE installations inside housing, but states that the metallic parts of several appliances must be earthed: "*it is advisable that all the frequently used electrical appliances and placed on tile or cement floor, like kitchen, stove, water boilers, etc., must have its metallic parts earthed.*"

In 1973 the RBT was revised (see note 3) to include the mandatory installation of PE in low voltage installations for all new housing constructed, as well as for renovated housing where a low voltage installation is present.

As mentioned above, the first regulation requiring the installation of PE appeared in 1973 and was not enforced until the end of December that same year. For this reason, we will take into account that buildings began to have PE installations in new constructions starting in 1974.

NOTE 1: R. 983 y Diccionario 7049 (Regulation 983 and Diccionary 7049).

NOTE 2: Approved by decree of 3rd June of 1955.

NOTE 3: Approved by decree 2413/1973 of 20th September (published in the B.O.E. number 242 of 9th October 1973).

6.3.4.5.2 Spanish Housing Data

The following data has been obtained from the Bank of Spain (www.bde.es) (see note), the Statistics National Institute of Spain (www.ine.es) and the Ministry of Housing of Spain (www.mviv.es).

16 165 923 houses were constructed in the time frame from January 1971 until December 2009.

The total number of houses in Spain at the end of 2009 was 26 768 715.

The average number of houses built per year is 414 511.

NOTE: Except for the figures for 1950 and 1960, these figures have been obtained from the Wikipedia's link: http://es.wikipedia.org/wiki/Anexo:Vivienda_en_España.

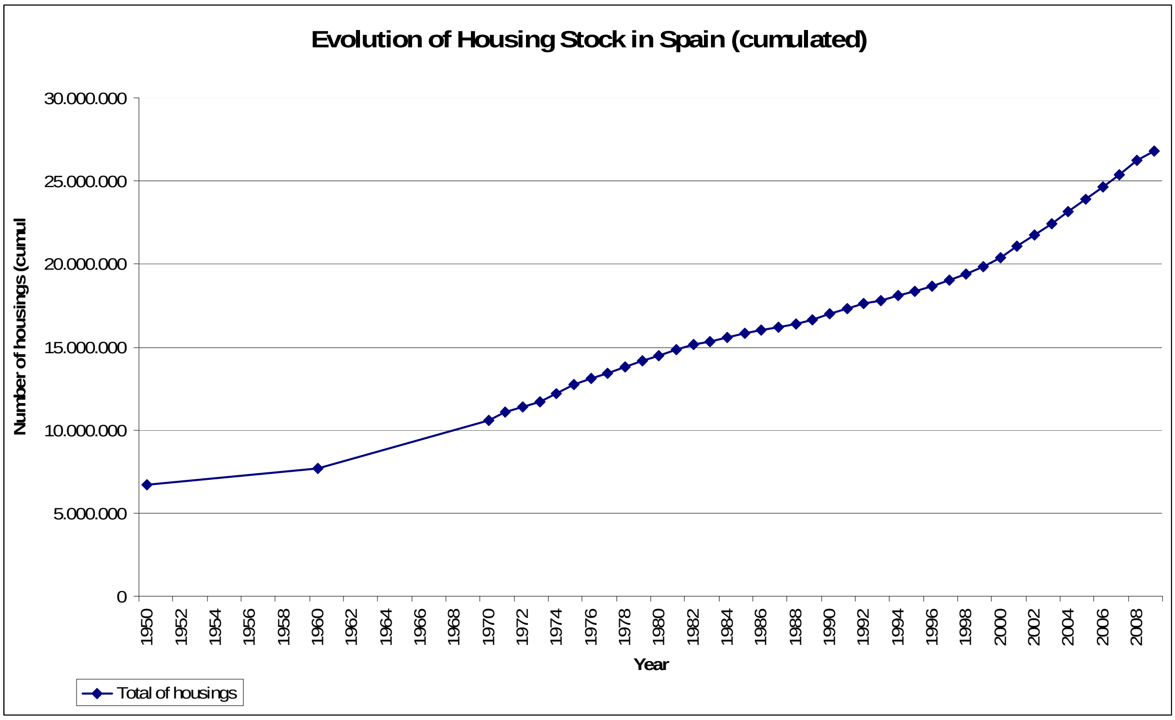


Figure 13: Cumulated Number of New Housing in Spain

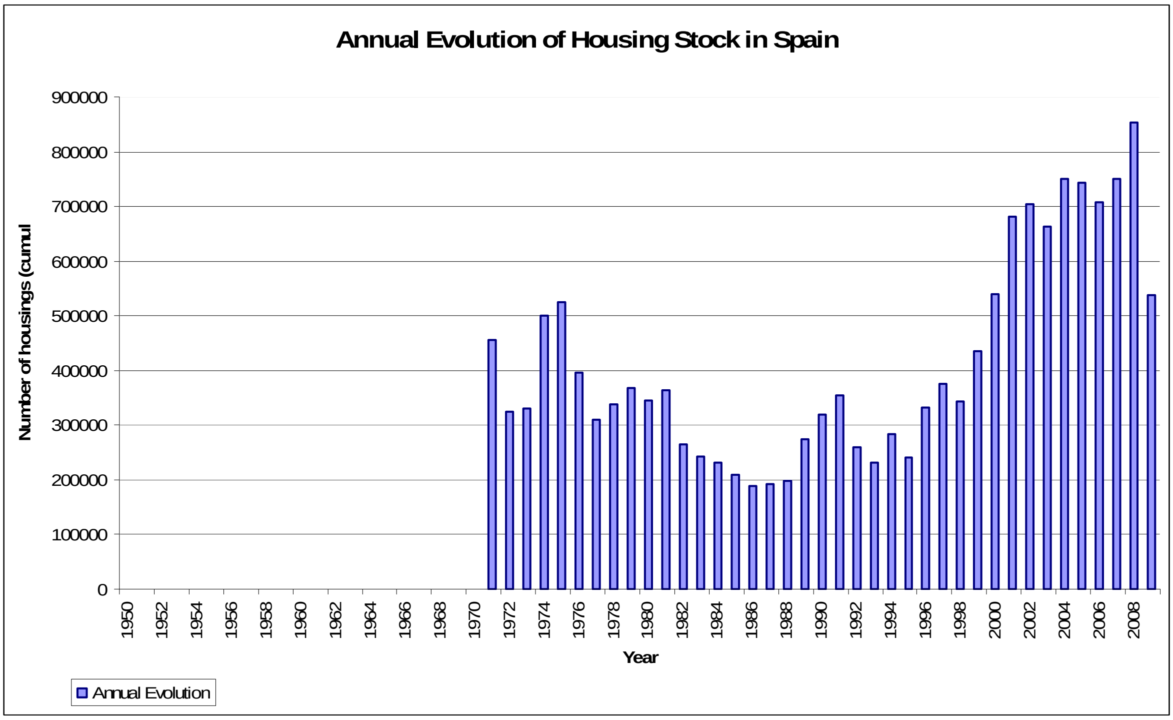


Figure 14: Annual Increase of New Houses in Spain

6.3.4.5.3 New Housing built in Spain Since 1974

Using the reference data of the annual increase of new houses, we have determined the number of houses constructed from January 1974 until December 2009 to be 14 553 529.

The total number of houses at the end of 2009 was 26 768 715.

We can conclude from these figures that the percentage of houses with a PE installation is around 54,37 %.

6.3.4.5.4 Data on Housing Renovations

The data obtained regarding housing renewal and renovation (see note) is more difficult to interpret because the source does not specify whether the electrical wiring was included in the renovation or if the premise already had a PE installation.

NOTE: Data about renewal (housings and buildings) was taken from the statistical information of Ministry of Promotion of Spain (Ministerio de Fomento: www.fomento.es) and Ministry of Housing of Spain (Ministerio de la Vivienda: http://www.mviv.es/).

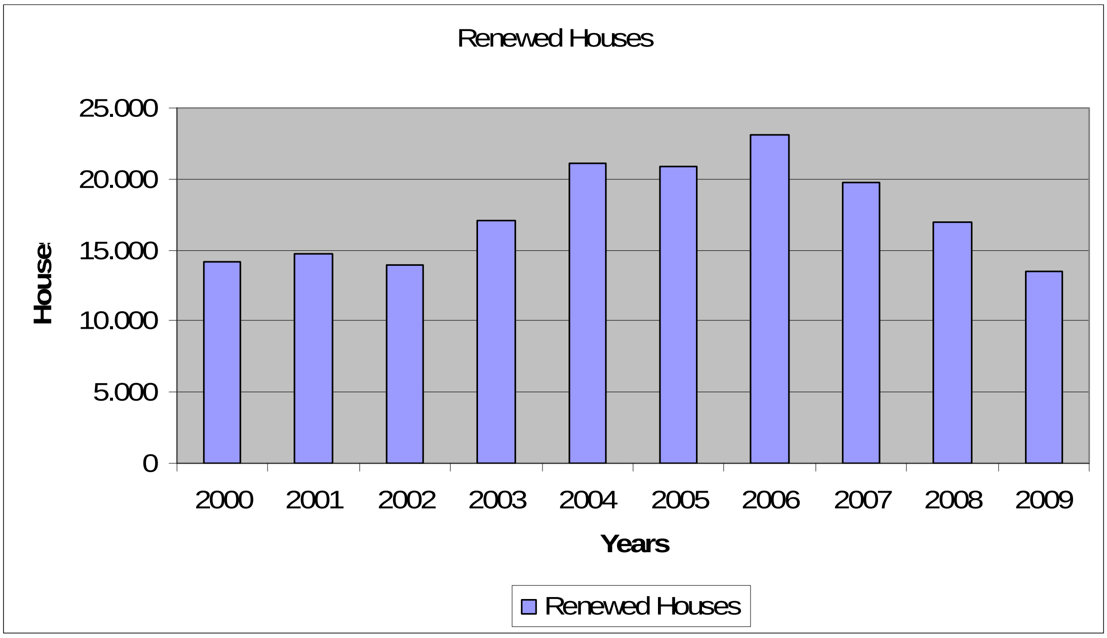


Figure 15: Renewed Houses in Spain from 2000 to 2009

Data involving building renewal and renovation, although unspecific, is also presented here as it is reasonable to assume, that a percentage of those renewals involve changes to the electrical wiring and PE circuit installations.

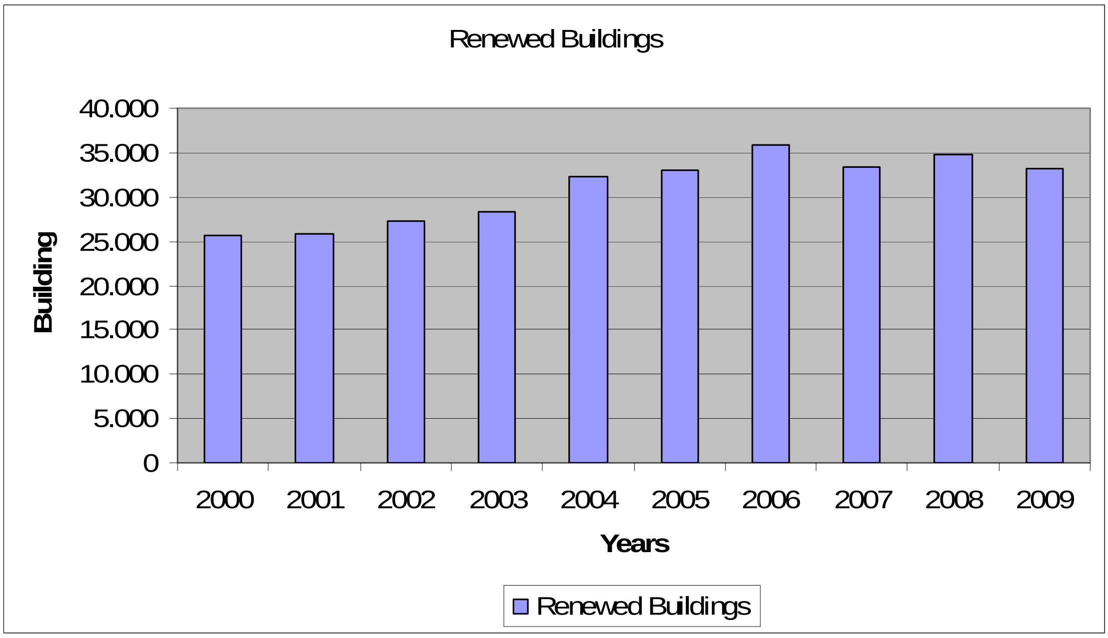


Figure 16: Renewed Buildings in Spain from 2000 to 2009

6.3.4.5.5 Summary Figures: Housing, Renewals and PE Installations

Table 9a: Summary of Figures of Housing in Spain

Total Residences in Spain (Dec.'09) =	26 768 715
Total Residences **without** PE =	12 215 186
Total Residences **with** PE =	14 553 529
Total Renewals (Residence + Building) =	485 106

For the analysis of the presence of the PE wire in Spain we will use different approaches and we will see in the final figures the impact of each approach.

6.3.4.5.6 Variation in the Rate of PE Installations in Renovated Housing

Due to the unspecific data available regarding electrical wiring modifications and PE installations in renovated or renewed homes, we have compiled table 9b to demonstrate the shift in total PE wired housing in Spain for different rates of electrical renewal. On the left can be viewed a hypothetical rate of electrical modification expressed in a percentage, followed by the actual number and finally the new total percentages of people with a PE installation.

Table 9b: Variation of PE in Renovated Homes

% of Total Renewals that Incorporate New PE Installations	Qty. With New PE	% Housing with PE in Spain
0 %	0	54,37 %
10 %	48 511	54,55 %
25 %	121 277	54,82 %
50 %	242 553	55,27 %
75 %	363 830	55,73 %
100 %	485 106	56,18 %

6.3.4.5.7 Conclusion: Electrical Installation Practices in Spain

Based on the assumptions detailed above and in light of the data obtained, we estimate the percentage of housing in Spain with PE installations to be **54-56 %**.

6.4 Secondary Information for Estimating the Presence of PE

Several marketing institutes and customer research institutes were contacted in regards to:

- Sales numbers of RCD
- Sales volume of NYM-J/NYM-O - PVC Installation Cables
    - Share of 3 and 5 wire cables

Unfortunately no useful information was found here. Public reports were not available and manufacturers of such equipment do not openly share their data.

6.5 Survey of Worldwide Electrical Standardization Committees and Engineering Clubs

6.5.1 Information Collection Methodology

A survey was conducted in order to collect information regarding the grounding situation in each country.

The following methodology was used:

- Find information regarding the Socket types in use for each country

- Cross-check and verify the above data with socket manufacturer's
- Identify countries that exclusively use "3 pin socket types" (probable that the grounding proportion in these countries will be high)
- Identify countries where only "2 pin socket types" are used (No grounding is used)
- Contact member representatives of IEC countries and request them to provide information where available. Following items are requested:
- Is Protective Earth mandatory for new dwellings built in countries worldwide (as of today)?
- Since when? (When was the PE requirement stated into law for each country?)
- What is the proportion (percentage) of dwellings equipped with PE in each country?
- Any statistics regarding the number of older dwellings which do not comply with the grounding requirements.

Table 10 shows who was contacted and the reply status.

Color key:

Red: Replied, but no information available.

Orange: Incomplete information was given.

Green: Useful information was provided.

White: Reply Pending.

Table 10: Worldwide Survey of Electrical Standardization Committees and Engineering Clubs

Contact	Reply
IEC	Requested to contact country representatives.
FIEEC	
AFPI68	
CEB-BEC (Belgium)	
OVE (Austria)	
SCC (Canada)	
DS -(Denmark)	
Sesko (Finland)	
UTE (France)	They have no information. Requested to contact "Promotelec".
DKE (Germany)	
Standards (Australia)	
UNMZ (CZ Republic)	
MSZT (Hungary)	
ETCI (Ireland)	Protective earthing is an essential component of all electrical installations in Ireland, which must comply with the National Rules for Electrical Installations ET 101:2008 This publication is available from ETCI. Protective earthing in electrical installations has been standard in Ireland since before 1960. In Ireland it is compulsory to build new installations or adapt existing installations in accordance with the national rules. For new electrical installations an electrical contractor and an inspection authority (RECI & ECSSA) have to take care of the inspection.
CEI (Italy)	
Italy	In Italy, most houses are reported to have RCDs installed as there is no protective earth conductor. In 1990 Italy made inspection - and renovation where required - statutory for all dwellings built before 1999. An initial verification for new build properties is compulsory.
JISC (Japan)	
NEN (Netherlands)	
OSS (Norway)	
IPQ (Portugal)	
SEK (Sweden)	According to Swedish Standard, it is a requirement to connect exposed-conductive-parts to a protective earthing conductor when the protective measure "Automatic disconnection of supply" is used. It is not stated in a law, but in a standard. However, the standard's requirements are presumed to fulfil the law, but you are allowed to use an equally safe method, if any. The requirement for protective earthing has been in force since 1 January 1994. It is probably that a majority of the dwellings' electrical installations are without protective earthing in socket-outlets, according to older wiring rules. We have no such information. Maybe the government agency Boverket has. http://www.boverket.se/Om-Boverket/About-Boverket/.
AENOR (Spain)	Contact with the Spanish Administration which is the organization in charge of Spanish mandatory regulations (Ministerio de Industria, Turismo y Comercio).
ANSI (united States)	
BSI (UK)	Please be advised that I have forwarded your enquiry to KnowledgeCentre@bsigroup.com to check if they are able to help with your enquiry.
Electrosuisse (CH)	
TISI (Thailand)	
Stadlar (Iceland)	All socket outlets in dwellings and buildings of similar use (schools, day care, hotels, public buildings, etc.) in Iceland shall have connection to PE-conductor in accordance with Regulation for Electrical Installations, (no. 678/2009). These requirements were first issued in 2007. This regulation, set according to Act on the Safety of Electrical Installations, Consumer Apparatus and Electrical Materials, no. 146/1996. Despite the requirements first being presented in 2007, it has been going on for decades (last 30 years) in Iceland to connect the PE-conductor in all socket outlets in dwellings. I would estimate that about 70 % to 80 % of all dwellings in Iceland have such an arrangement.
KATS (Korea)	
ILNAS (Luxembourg)	
GOST (Russia)	
BIS (India)	
SUTN (Slovakia)	

Contact	Reply
Boverket (Sweden)	
Standards (NZ)	PE is mandatory in NZ since 1935. More than 95 % of dwellings are properly grounded. The number of houses in 1935 was approximately 350 000. The total number at the last census in 2006 was 1 478 709. A number (unknown) of the 1935 houses will have been demolished and a much larger number would have been upgraded. Houses constructed prior to 1935 would have had a limited number of socket-outlets installed and almost all of those homes would have had additional outlets installed to cope with the increased use of electrical appliances, at which time protective earths would have been fitted.
IANOR (Algeria)	
DPS (Albania)	
BELST (Belarus)	
STAND (Bosnia & Herzegovina)	
COBEI (Bresil)	
BDS (Bulgaria)	
HZN (Croatia)	
AEACEA (Argentina)	
ICONTEC (Colombia)	
CYS (Cyprus)	
EVS (Estonia)	
ELOT (Greece)	
BSN (Indonesia)	
SII (Israel)	
TCVN (Vietnam)	
DSSU (Ukraine)	
SABS (South Africa)	
SIST (Slovenia)	In our country, this area is regulated by European legislation - Council Directive 2006/95/EC [i.12] of the Low Voltage Equipment and harmonized European standards (hEN). This is mandatory for us since 2004 when we became full members of the EU. Unfortunately we do not have statistics regarding the total number of households and the newly built ones since the PE requirement is mandatory until now.
spring (Singapore)	Transferred to Building & Construction Authority (BCA).
SASO (Saudi Arabia)	
snima (Morocco)	
lst (Lithuania)	
msa (Malta)	100 % (Stated in law since 1940. TT system used). Malta follows the S.L. 423.01 - Electricity Supply Regulations - 21st May, 1940 and use a TT grounding system. Thus 100 % of households are properly grounded.
isme (Montenegro)	
lvs (Latvia)	PE is not mandatory in Latvia, nevertheless there is a practice during the last 5-7 years that for new or reconstructed buildings the neutral feeding line should be additionally earthed at the entrance to the building. The number of such buildings with protective earthing is hard to evaluate, but they think that it is less than 15 % of total number of residential buildings. There is no law or regulation in Latvia to request erection of protective earthing at the input of power to the existing or newly built residential buildings or dwelling houses with several flats. Nevertheless there is a practice during the last 5-7 years that for new or reconstructed buildings the neutral feeding line should be additionally earthed at the entrance to the building.
(Malaysia)	
SCC (Canada)	The Canadian Electrical Code, CE code, or CSA C22.1.
Canada	Historically, we have identified the relevant part 2 of the Canadian Electrical Code CSA C22.2 No.42 Construction and Test - Receptacles, Plugs and Similar Wiring Devices published in 1959. In this standard, we do find a section dedicated to grounding (section 4.12.7). How this was enforced in Canada through the provinces, you will need to consult with the Canadian provinces. Also for Ground-Fault Circuit Interrupters (GFCI) requirements according to CSA C22.2 No.144.1, this was introduced in the early 1970s. Again, how this was introduced and enforced in Canada, the information would need to be gathered from the provinces.

Contact	Reply
HSE (UK)	The Health and Safety Executive (HSE) are a government body that enforces UK health and safety legislation in the workplace and are concerned with the control of risks to people's health and safety arising from work activities in the UK. The Health and Safety Executive (HSE) has no direct involvement with any requirement for protective earth in domestic properties and so would not hold the information you require.
Inspectapedia (US)	
NFPA (US)	NFPA statistics focuses on FIRE. They do not have stats related to the equipment of households.
Consuel (France)	Consuel has no statistics about the situation in France.
sgs (certification in many countries)	
EnergieNed (Netherlands)	No information (requested to contact NEN).
ZVEH (Germany)	
ESFI (US/Canada) Worldwide?	
GRESEL (France)	Redirected to Promotelec.
France	NFC 15.100 is the French standard. GRESEL & Consuel are important organisations for electrical safety. In France, all houses and flats are required to have RCDs of 500 mA at entry to the installation to protect against fires. French national wiring codes recommend that all properties in France should have a 30 mA RCD installed to protect against the risk of electrocution in bathrooms. Since 1991, it has been obligatory for new electrical installations to be protected against overload and earth leakage currents. It has been estimated that at least one million new homes in France have this type of protection. An initial verification for new build properties is compulsory. Mandatory inspection at change of ownership of electrical installations older than 15 years by law (2010).
Promotelec (France)	
Italy	The installation of a protection system has become mandatory in Italy since 1990 (that is, with the entry into force of Law 46/90 on the safety of electrical installations, later replaced by Decree 37/08, which has enlarged the scope of application). With regard to the percentage of non-compliant plants, the available data show that 60 % of homes built before 1990 are not in accordance with (unless of successive restoration) and that currently the properties with non-compliant implants are estimated around 12 million. Difficult to give an exact percentage of total homes since not all properties are intended for residential use, but an estimate could be around 30 %. The earth system used in Italy is TT type. The inspection checks have been provided since 1990, but in reality, due to various reasons, primarily those related to economic aspects, a true check campaign on national basis has never been made.
Spain	Complete information provided (see above).
Finland	See Tukes (Finland).
Denmark	10 %.
Netherlands	
Poland	Found information that the TN-S earthing system is mandatory since beginning of 1995. So all buildings built after that date have additional wire. Before that there was TN-C earthing system with grounding pin bridged to neutral wire in each wall socket. I have also attached the statistics of residential buildings from 1991-2010 period. According to it more than 1,7 M new buildings were built with new system.
Czeck Rep	1) Yes PE is mandatory for new households. It is given by Czech technical standard CSN 332000. 2) Partly it is in force from 1997, the latest update is from 2009. 3) Any official data on proportion are not available, currently it seems that 80 % of dwellings are not equipped with PE.
Hungary	
Turkey	
Austria	
Belgium	
Sweden	SEK is responsible for standardisation in Sweden in the field of electricity. The organisation also co-ordinates Swedish participation in European and other international standardisation work as a member of the IEC and CENELEC.

Contact	Reply
Tukes (Finland)	It is compulsory now in Finland, and has been from the mid-90's. (Before that it was required only in places with conducting floor and similar, but not in common living rooms or bedrooms.) Old installations can still be repaired and even modified using unearthed (class 0) socket-outlets. No statistics exist on the proportions. A lifetime of a dwelling building is very long, so I would assume that at least more than 50 % are still without protective contact in socket-outlets. Perhaps 70-80 %, as a very rough personal guess. Standardized type used in Finland is the Schuko-type.
dsb (Norway)	
sik (Denmark)	Earthing mandatory for new buildings since April 1st 1994.
BCA (Singapore)	
SGS (Belgium)	No stats available about dwellings situation.
CEBEC (Belgium)	
FEEDS contact of the "Towards improved electrical installations in European homes" survey	
China	The outlet is either C/A type or I type and the power level is 220V/50Hz. The ratio between2-wire and 3-wire is about 1:1 according to statistics collected from our employee in China office - most houses have these two types of outlets at the same time. Please be advised that, since the number of surveyed houses is quite limited, this ratio in China can only serve as a rough reference only. Unfortunately, there are no official documents at hand for your further reference. In China, the 2-wire and 3-wire outlets always come in pair. In other words, a C/A type and an I type outlet could be found on the same panel. In such circumstances, should we say 50 % or 100 % in China? It depends on interpretation of availability of 3-wire outlet. The Chinese Standard "Design code for residential buildings; GB 50096-1999" specifies how many outlets (incl. the outlet contacts) are mandatory for each room in private homes.
Taiwan	In Taiwan, all outlets in a family home are either 2-wire (A type) for 110V home appliances or 3-wire (H type) for 220V home appliances. The 220V home appliances include refrigerator and air conditioner (i.e. heavy power consumption devices/equipments). All other home appliances use 110V power (i.e. 2-wire) by default. The (A type) is the majority in Taiwan. Note: some 110V power output might use H type as well, depending on request by the family host, for certain purposes. 10 % or less should be fair enough for Taiwan as a statistical probability of meeting a PE wire.
Russia	In Russia and former USSR (and CIS), the country's situation is very unclear and difficult. The Rules of Exploitation of Electro installations (published in 1988, last edited in 1998) said that one of protective countermeasures allowed: x.x.x.x. This document was edited in 1999 and now it includes the clear recommendation to have TN-S or TN-C-S system (even during reconstruction of building). At the same time allowed combining N and PE in five-wires system (in four-wired it is prohibited to combine N and PE). The general idea - we have to increase the degree of harmonization of national situation with worldwide requirements. In the past - (until 1990-th) there was no ground at all. All houses had two-wired mains. Currently - all new buildings (and old ones - during reconstruction) must have four or five-wires mains.

6.6 Worldwide Earthing Situation by Country - an Estimation Table

Table 11 shows the estimated situation regarding the presence of the PE in countries worldwide (based on the available information).

Color key:

Red: Replied, but no information available.

Orange: Incomplete information was given.

Green: Useful information was provided.

White: Reply Pending.

Blue: This country uses three pronged plugs only. The earthing rate is assumed to be 100 %.

Table 11: Worldwide Evaluation of Pug Types, Voltage, Frequency, Earthing, etc.

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Afghanistan	C, D, F	240 V	50 Hz					
Albania	C, F, L	220 V	50 Hz	CEI 23-16				
Algeria	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
American Samoa	A, B, F, I	120 V	60 Hz					
Andorra	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Angola	C	220 V	50 Hz		NO			
Anguilla	A, B	110 V	60 Hz	NEMA				
Antigua	A, B	230 V	60 Hz	NEMA				
Argentina	C, I	220 V	50 Hz	IRAM 2073				
Armenia	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Aruba	A, B, F	127 V	60 Hz					
Australia	I	230 V	50 Hz	AS 3112	Only			
Austria	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Azerbaijan	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Azores	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Bahamas	A, B	120 V	60 Hz	NEMA				
Bahrain	G	230 V	50 Hz	BS1363	Only			
Balearic Islands	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Bangladesh	A, C, D, G, K	220 V	50 Hz					
Barbados	A, B	115 V	50 Hz	NEMA				
Belarus	C, F	220 V	50 Hz			Very low	1999	Same as Russia

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Belgium	C, E	230 V	50 Hz	CEE 7/5 CEE 7/7		25 %	1981	An initial verification for newly built properties is compulsory + 25 years "Periodic Inspection" + mandatory inspection of electrical installations in dwellings at change of ownership from 01.01.07
Belize	A, B, G	110 V and 220 V	60 Hz					
Benin	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Bermuda	A, B	120 V	60 Hz	NEMA				
Bhutan	D, F, G, M	230 V	50 Hz		Only			
Bolivia	A, C	220 V	50 Hz					
Bonaire		127 V	50 Hz					
Bosnia	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Botswana	D, G, M	230 V	50 Hz		Only			
Brazil	A, B, C, I - Older C, NBR14136:2002/ IEC 60906-1 [i.11] - Newer devices	127 V and 220 V	60 Hz	NBR 14136			2002 ?	
Brunei	G	240 V	50 Hz	BS1363	Only			
Bulgaria	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Burkina Faso	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Burundi	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Cambodia	A, C, G	230 V	50 Hz					
Cameroon	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Canada	A, B	120 V	60 Hz	NEMA		> 70 %	1959 ? Tbc	
Canary Islands	C, E, F, L	220 V	50 Hz					
Cape Verde	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Cayman Islands	A, B	120 V	60 Hz	NEMA				

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Central African Republic	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Chad	D, E, F	220 V	50 Hz		Only			
Channel Islands	C, G	230 V	50 Hz					
Chile	C, L	220 V	50 Hz	CEI 23-16				
China, People's Republic of	A, C, I	220 V	50 Hz	GB1002, GB2099				
China, Republic of Taiwan	A, B	110 V	60 Hz	NEMA				
Colombia	A, B	120 V	60 Hz	NEMA				
Comoros	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Congo-Brazzaville	C, E	230 V	50 Hz	CEE 7/5 CEE 7/7				
Congo-Kinshasa	C, D	220 V	50 Hz	BS 546				
Cook Islands	I	240 V	50 Hz	AS 3112	Only			
Costa Rica	A, B	120 V	60 Hz	NEMA				
Côte d'Ivoire	C, E	230 V	50 Hz	CEE 7/5 CEE 7/7				
Croatia	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Cuba	A, B	110 V	60 Hz	NEMA				
Cyprus	G	240 V	50 Hz	BS 1363	Only	High (Same as UK ?)		
Czech Republic	C, E	230 V	50 Hz	CEE 7/5 CEE 7/7		20 %	1997	
Denmark	C, E, K	230 V	50 Hz	AFSNIT 107-2-D1			April 1st 1994 (For kitchens and bath-rooms since April 1975)	
Djibouti	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Dominica	D, G	230 V	50 Hz	BS546 BS1363	Only			
Dominican Republic	A, B	110 V	60 Hz	NEMA				
East Timor	C, E, F, I	220 V	50 Hz					
Ecuador	A, B	120 V	60 Hz	NEMA				
Egypt	C	220 V	50 Hz		NO			

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
El Salvador	A, B	115 V	60 Hz	NEMA				
Equatorial Guinea	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Eritrea	C	230 V	50 Hz		NO			
Estonia	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Ethiopia	C, E, F, L	220 V	50 Hz	CEI 23-16				
Faroe Islands	C, K	220 V	50 Hz	AFSNIT 107-2-D1				
Falkland Islands	G	240 V	50 Hz	BS1363	Only			
Fiji	I	240 V	50 Hz	AS 3112	Only			
Finland	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7		> 25 %	Mid 1990	
France	C, E	230 V (formerly 220 V)	50 Hz	CEE 7/5 CEE 7/7		>60 %	Between 1966-1972	
French Guiana	C, D, E	220 V	50 Hz					
Gaza Strip	C, H	230 V	50 Hz					
Gabon	C	220 V	50 Hz		No			
Gambia	G	230 V	50 Hz	BS1363	Only			
Georgia	C	220 V	50 Hz		NO			
Germany	C, F	230 V (formerly 220 V)	50 Hz	CEE 7/4 CEE 7/7		70 %	1970	
Ghana	D, G	230 V	50 Hz	BS546 BS1363	Only			
Gibraltar	G, K	240 V	50 Hz		Only	High (Same as UK ?)		
Greece	C, F, (older)"Tripoliko" similar to type J and post-1989 type H	230 V (formerly 220 V)	50 Hz					
Greenland	C, K	220 V	50 Hz	AFSNIT 107-2-D1				
Grenada	G	230 V	50 Hz	BS1363	Only	High (Same as UK ?)		
Guadeloupe	C, D, E	230 V	50 Hz	CEE 7/5 CEE 7/7				
Guam	A, B	110 V	60 Hz	NEMA				
Guatemala	A, B	120 V	60 Hz	NEMA				
Guinea	C, F, K	220 V	50 Hz					
Guinea-Bissau	C	220 V	50 Hz		NO			

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Guyana	A, B, D, G	240 V	60 Hz					
Haiti	A, B	110 V	60 Hz	NEMA				
Honduras	A, B	110 V	60 Hz	NEMA				
Hong Kong	G is used in almost all products, while M is (rarely) used when required current rating is between 13~15A. D is now obsolete in Hong Kong.	220 V	50 Hz	BS 1363	Only	High (Same as UK ?)		
Hungary	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Iceland	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7		70 %to 80 %	2007	
India	C, D, M	230 V	50 Hz	IS 1293 BS546 BS1363				
Indonesia	C, F, G	220 V	50 Hz					
Iran	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Iraq	C, D, G	230 V	50 Hz					
Ireland	G (obsolete or specialist installations may be D and M (as in the UK) or F)	230 V (formerly 220 V)	50 Hz	BS 1363	Only	100 %	< 1960	
Isle of Man	G	240 V	50 Hz	BS1363	Only			
Israel	C, H, M	230 V	50 Hz	SI32				
Italy	C, F, L	230 V (formerly 220 V)	50 Hz	CEI 23-16				
Jamaica	A, B	110 V and 220 V	50 Hz	NEMA				
Japan	A, B	100 V	50 Hz and 60 Hz	JIS C 8303		Low		
Jordan	B, C, D, F, G, J	230 V	50 Hz					

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Kazakhstan	C, E, F	220 V	50 Hz			Very low	1999	Same as Russia
Kenya	G	240 V	50 Hz	BS1363	Only			
Kiribati	I	240 V	50 Hz		Only			
Kuwait	C, G	240 V	50 Hz		Only			
Kyrgyzstan	C	220 V	50 Hz					
Laos	A, B, C, E, F	230 V	50 Hz					
Latvia	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7		< 15 %	Not mandatory	
Lebanon	A, B, C, D, G	240 V	50 Hz					
Lesotho	M	220 V	50 Hz	BS 546	Only			
Liberia	A, B, C, E, F	120 V and 240 V	50 Hz					
Libya	D, L	127 V	50 Hz		Only			
Lithuania	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Liechtenstein	C, J	230 V	50 Hz	SEV 1011				
Luxembourg	C, F	230 V (formerly 220 V)	50 Hz	CEE 7/4 CEE 7/7				
Macau, China	D, M, G, a small number of F	220 V	50 Hz		Only			
Macedonia	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Madagascar	C, D, E, J, K	127 V and 220 V	50 Hz					
Madeira	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Malawi	G	230 V	50 Hz	BS1363	Only			
Malaysia	C, G (but M for air conditioners and clothes dryers)	240 V (although officially ratified as 230 V)	50 Hz	BS 1363 PSB Spring		High (Same as UK ?)		
Maldives	A, D, G, J, K, L	230 V	50 Hz					
Mali	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Malta	G	230 V	50 Hz	BS1363	Only	100 %	1940	

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Martinique	C, D, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Mauritania	C	220 V	50 Hz		NO			
Mauritius	C, G	230 V	50 Hz	BS1363	Only	High (Same as UK ?)		
Mexico	A, B	127 V	60 Hz	NEMA				
Micronesia	A, B	120 V	60 Hz	NEMA				
Moldova	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Monaco	C, D, E, F	127 V and 220 V	50 Hz	CEE 7/4 CEE 7/5 CEE 7/7				
Mongolia	C, E	220 V	50 Hz	CEE 7/5 CEE 7/7				
Montenegro	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Montserrat (Leeward Is.)	A, B	230 V	60 Hz	NEMA				
Morocco	C, E	127 V and 220 V	50 Hz	CEE 7/5 CEE 7/7				
Mozambique	C, F, M	220 V	50 Hz					
Myanmar/Burma	C, D, F, G	230 V	50 Hz					
Namibia	D, M	220 V	50 Hz		Only			
Nauru	I	240 V	50 Hz	AS 3112	Only			
Nepal	C, D, M	230 V	50 Hz					
Netherlands	C, F	230 V (formerly 220 V)	50 Hz	CEE 7/4 CEE 7/7			1962 ?	Should comply with NEN1010 norm (1st issue 1940, maybe applied from 1962)
Netherlands Antilles	A, B, F	127 V and 220 V	50 Hz					
New Caledonia	E	220 V	50 Hz	CEE 7/5 CEE 7/7	Only			
New Zealand	I	230 V	50 Hz	AS 3112	Only	> 95 %	1935	
Nicaragua	A, B	120 V	60 Hz	NEMA				
Niger	A, B, C, D, E, F	220 V	50 Hz					
Nigeria	D, G	240 V	50 Hz	BS546 BS1363	Only			
North Korea	C	220 V	60 Hz		NO			
Norway	C, F	230 V	50 Hz	CEE 7/4				

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
				CEE 7/7				
Okinawa	A, B	100 V	60 Hz	NEMA				
Oman	C, G	240 V	50 Hz	BS1363				
Pakistan	C, D, G, M	230 V	50 Hz					
Panama	A, B	110 V	60 Hz	NEMA				
Papua New Guinea	I	240 V	50 Hz	AS 3112	Only			
Paraguay	C	220 V	50 Hz		NO			
Peru	A, B, C	220 V	60 Hz	NEMA				
Philippines	A, B, C	220 V	60 Hz	NEMA	-			
Poland	C, E	230 V (formerly 220 V)	50 Hz	CEE 7/5 CEE 7/7		**Around 15 %** > 1,7 M buildings were constructed since 1995 with a total of 12 M in 2010	1995	TN-S earthing system is mandatory since beginning of 1995. So all buildings built after that date have additional wire. Before that there was TN-C earthing system with grounding pin bridged to neutral wire in each wall socket.
Portugal	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				An initial verification for newly built properties is compulsory.
Puerto Rico	A, B	120 V	60 Hz	NEMA				
Qatar	D, G	240 V	50 Hz		Only			
Réunion	E	220 V	50 Hz	CEE 7/5 CEE 7/7	Only			
Romania	C, F	230 V (formerly 220 V)	50 Hz	CEE 7/4 CEE 7/7				

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Russian Federation	C, F	220 V	50 Hz	GOST 7396		Around 10 % (only new buildings since 1999 and renewed ones if owner wants to add PE)	1999	
Rwanda	C, J	230 V	50 Hz	SEV 1011				
St. Kitts and Nevis	A, B, D, G	110 V and 230 V	60 Hz					
St. Lucia (Windward Is.)	G	240 V	50 Hz	BS1363	Only	High (Same as UK ?)		
Saint Pierre and Miquelon	E	230 V	50 Hz	CEE 7/5 CEE 7/7	Only			
St. Vincent (Windward Is.)	A, C, E, G, I, K	230 V	50 Hz			High (Same as UK ?)		
Samoa	I	230 V	50 Hz	AS 3112	Only			
São Tomé and Príncipe	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Saudi Arabia	A, B, F, G	127 V and 220 V	60 Hz	SASO 2203				
Senegal	C, D, E, K	230 V	50 Hz					
Serbia	C, F	220 V	50 Hz	CEE 7/4 CEE 7/7				
Seychelles	G	240 V	50 Hz	BS1363	Only			
Sierra Leone	D, G	230 V	50 Hz		Only	High (Same as UK ?)		
Singapore	C, G	230 V	50 Hz	BS 1363 PSB Spring		High (Same as UK ?)		Buildings including residential developments must comply with the Singapore Standard SS 555: 2010 - Code of Practice for Protection Against Lightning. I got no information about sockets grounding, so far.

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Slovakia	C, E	230 V	50 Hz	CEE 7/5 CEE 7/7		Very low	1st sept 2000	Protective Earth is mandatory in Slovakia since 1 Sept 2000 by implementation of harmonization document HD 384.4.41 S2: 1996 into Slovak national standard STN 33 2000-4-41 which require TN-S or TN-C-S system, i.e. separated PE conductor in residential installations. Due to fact, that Slovak Standards Institute does not perform any certification or approval of installation we do not possess any statistical data related to your other questions.
Slovenia	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7		Very low	2004	In Slovenia, this area is regulated by European legislation - Council Directive 2006/95/EC [i.12] of the Low Voltage Equipment and harmonized European standards (hEN) . This is mandatory since 2004 when Slovenia became full members of the EU. Unfortunately we do not have statistics regarding the total number of households and the newly built ones since the PE requirement is mandatory until now.
Somalia	C	220 V	50 Hz		NO			
South Africa	C, M, IEC 60906-1 [i.11]	220 V	50 Hz	SABS 164-1, BS546				

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
South Korea	A, B, C, F (Types A & B are used for 110-volt installations and/or found in very old buildings. Types C & F are used for 220 Volts.)	220 V	60 Hz	KS C 8305				
Spain	C, F	230 V (formerly 220 V)	50 Hz	CEE 7/4 CEE 7/7		> 55 %	1973	PE is mandatory in Spain since technical instructions published by the Spanish government at the end of 1973 "Instrucciones RBT 1973". Electrical installations are regulated in the Reglamento Electrotécnico de Baja Tensión (REBT), approved by Real Decreto of august 2 of 2002, and its Complementary Technical Instructions (ITC-BT). PRIE - Platform For Periodic Inspection of Electrical Installations - Draft guide for periodic inspections of electrical installations. An initial verification for newly built properties is compulsory.
Sri Lanka	D, M, G	230 V	50 Hz		Only	High (Same as UK ?)		
Sudan	C, D	230 V	50 Hz					
Suriname	C, F	127 V	60 Hz	CEE 7/4 CEE 7/7				
Swaziland	M	230 V	50 Hz		Only			

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Sweden	C, F	230 V (formerly 220 V)	50 Hz	CEE 7/4 CEE 7/7		> 5 %	1994	According to Swedish Standard it is a requirement to connect exposed-conductive-parts to a protective earthing conductor when the protective measure "Automatic disconnection of supply" is used. It is not stated in a law, but in a standard. However, the standard's requirements are presumed to fulfil the law, but you are allowed to use an equally safe method, if any. The requirement for protective earthing has been in force since 1 January 1994. It is probably that a majority of the dwellings' electrical installations are without protective earthing for socket-outlets, according to older wiring rules. We have no such information. Maybe the government agency Boverket has. http://www.boverket.se/Om-Boverket/About-Boverket/
Switzerland	C, J	230 V	50 Hz	SEV 1011		90 % - 95 %	1960	Mandatory inspection every 20 years of electrical installations in dwellings by law. An initial verification for newly built properties is compulsory.
Syria	C, E, L	220 V	50 Hz					

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Tahiti	A, B, E	110 V and 220 V	60 Hz/ 50 Hz					
Tajikistan	C, I	220 V	50 Hz					
Tanzania	D, G	230 V	50 Hz		Only			
Thailand	A, B, C, F, Unearthed I	220 V	50 Hz					
Togo	C	220 V	50 Hz		NO			
Tonga	I	240 V	50 Hz	AS 3112	Only			
Trinidad & Tobago	A, B	115 V	60 Hz	NEMA				
Tunisia	C, E	230 V	50 Hz	CEE 7/5 CEE 7/7				
Turkey	C, F	230 V	50 Hz	CEE 7/4 CEE 7/7				
Turkmenistan	B, F	220 V	50 Hz		Only			
Uganda	G	240 V	50 Hz	BS1363	Only	High (Same as UK ?)		
Ukraine	C, F	220 V	50 Hz					
United Arab Emirates	C, D, G	220 V	50 Hz					

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
United Kingdom	G (D and M seen in very old installs and specialist applications)	230 V (formerly 240 V in mainland Britain and 220 V in Northern Ireland)	50 Hz	BS 1363	Only	> 97 %	1947 ?	**(From the 2008 "English Housing Survey")** The vast majority of the dwellings (98 %) had modern PVC sheathed wiring and **90,6 % had modern earthing wires (Yellow/green), 4,9 % had unsheathed or Green cover earthing wiring, 1,6 % had mixed earthing wiring.** However a significant minority of dwellings lacked modern electrical safety features such as RCDs (residual current devices) (41 %) and MCBs (miniature circuit breakers) (31 %). Households aged 60 or over were far more likely to live in dwellings that lacked these features. Recommendation for periodic inspection at change of ownership or tenancy and every 10 years, with particular requirements for special situations
United States of America	A, B	120 V	60 Hz	NEMA		**Estimated to > 64 %** (100 % of dwellings built after 1962 or renovated)	1962	
Uruguay	C, F, L (I only in very old installs)	230 V (formerly 220 V)	50 Hz					
Uzbekistan	C, I	220 V	50 Hz					
Vanuatu	I	230 V	50 Hz	AS 3112	Only			
Venezuela	A, B	120 V	60 Hz	NEMA				

Region	Type(s) of plug/socket	Voltage	Frequency	Standard	Earthed ?	Earthing ratio	Earthing mandatory since	Source/Comment
Vietnam	A, C, G	220 V	50 Hz					
Virgin Islands	A, B	110 V	60 Hz	NEMA				
Yemen	A, D, G	230 V	50 Hz					
Zambia	C, D, G	230 V	50 Hz	BS546 BS1363				
Zimbabwe	D, G	220 V	50 Hz	BS546 BS1363	Only			

Figure 17 shows the probability of PE wire installations. Countries which exclusively use three pronged plugs (and shaded blue in table 11) are assumed to have 100 % of the outlets equipped with the 3rd wire. Unfortunately, STF410 could not collect any data on countries presented with a white background.

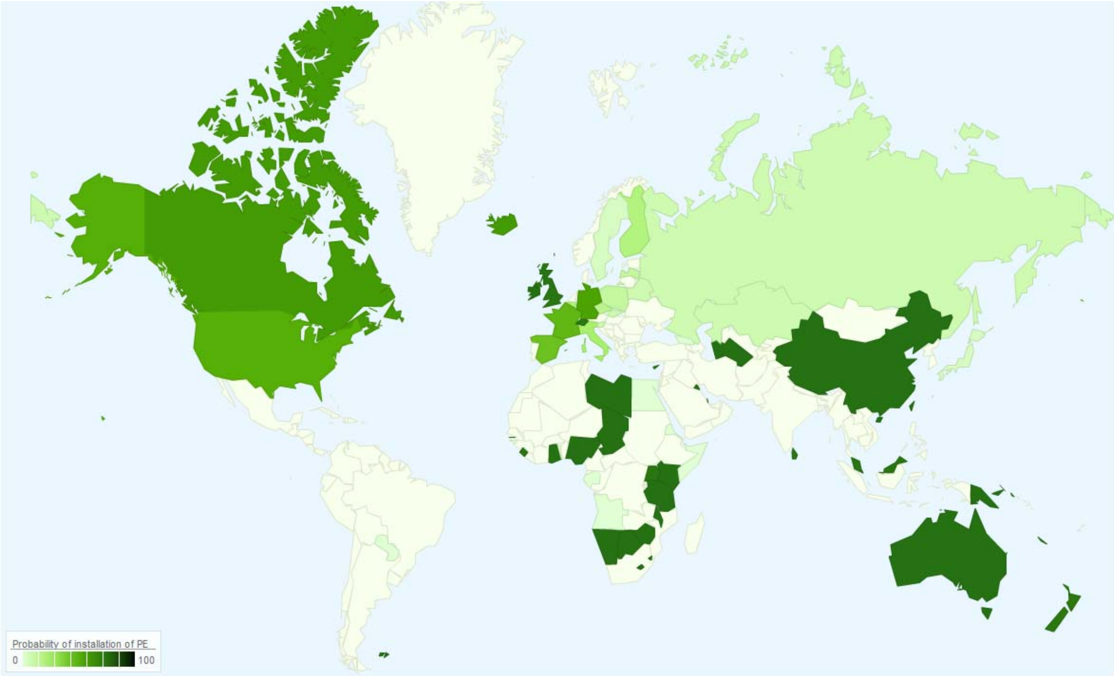


Figure 17: Map showing the Probability of PE Wire Installations

7 Measurement Description of Joint Equipment from Channel, Noise and EMI Measurements

This clause describes the measurement equipment used for all STF410 activities including the channel, Noise and EMI measurements. The special description of the EMI records, how to setup the equipment, how to perform the measurements and the statistical evaluation of the results can be found in TR 101 562-2 [i.9]. A detailed description of the channel and noise records, how to set up the equipment, how to perform the measurements and the statistical evaluation of the results can be found in TR 101 562-3 [i.10].

7.1 MIMO PLT Universal Coupler

Figure 18: Photograph of Coupler from Top

Figure 19: Photograph of Coupler, Case Opened

Figure 18 and figure 19 show photographs of the STF410 coupler from top and with opened case.

7.1.1 Safety Note

- STF 410 MIMO couplers are designed and built with great care.
- STF 410 couplers have to be used exclusively for tests carried out by instructed personnel.
- It is recognized that the connection of the Protective Earth of the STF 410 MIMO couplers does not comply with safety standards for commercial products.
- For best protection of the connected instruments, it is recommended:
  - to first switch off all interfaces;
  - then to connect the instruments;

- then to connect the coupler to the mains; and
- then switch on whatever is required for the operation.

7.1.2 Objectives of the MIMO PLT (STF 410) Design

General Requirements:

- Safety for field use by instructed personnel (but no formal safety test).
- Safety for connected test equipment (50 Hz level, surge protection).
- Well defined electrical characteristics to get reproducible measurement results (namely well defined impedance matching conditions for sender and receiver).

Following objectives were defined by STF 410:

- The frequency range should be extended to 100 MHz.
- The coupler(s) should allow the measurement of:
  - Transfer function
  - Noise level
  - Symmetrical input impedances
  - k-factor (i.e. strength of the radiated field at a distance of 10 m with an available source power of 0 dBm)
- If possible, one single type coupler for all functions.

7.1.3 Technical Data of Couplers

7.1.3.1 Impedance Conditions

Impedance conditions are defined at the center point C (see schematic diagram clause 7.1.6).

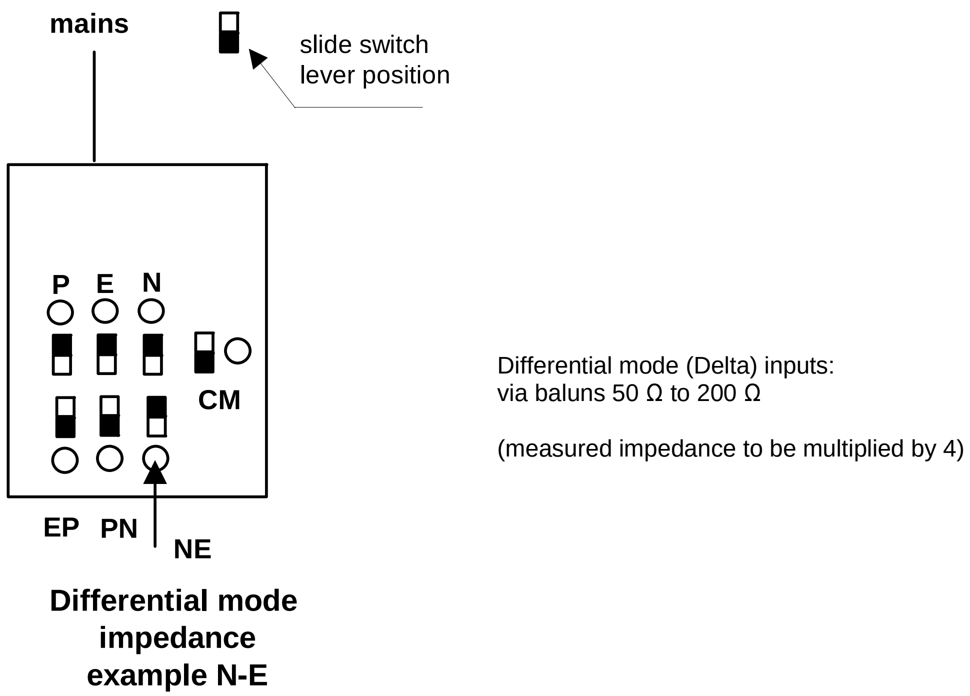


Figure 20: Coupler in Impedance Measurement Mode

Common Mode (CM) inputs:

- via balun 50 Ω to 200 Ω.

Star inputs (P, N, E):

- direct 50 Ω in each leg.

Characteristic impedance of mains cable, third conductor open circuited:

- approximately 80 Ω.

Characteristic impedance of common mode transformer windings:

- third conductor open circuited:
  - approximately 80 Ω.

Test pad: A test or calibration pad was realized to verify impedances of the probes.

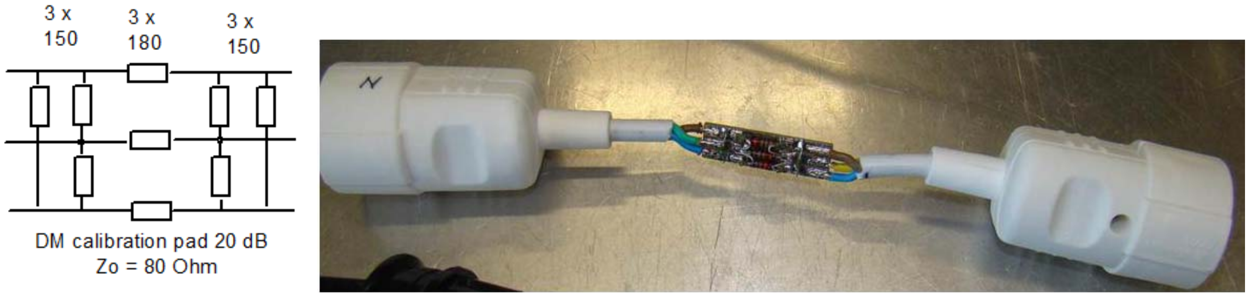


Figure 21: Test pad: Schematic and Photo

Characteristic impedance of test pad, (without cables and Schuko connectors):

- third connection open circuited:
  - 80 Ω.

7.1.3.2 Insertion Loss

See measurement results in clause 7.1.6.

7.1.4 Operation

The following figures show the connections to MIMO sender and receiver and the position of the slide switches for the different operation modes.

7.1.4.1 SISO Transmit and SISO Receive (Example P-N to P-N)

The setup to connect two couplers in SISO mode is shown below.

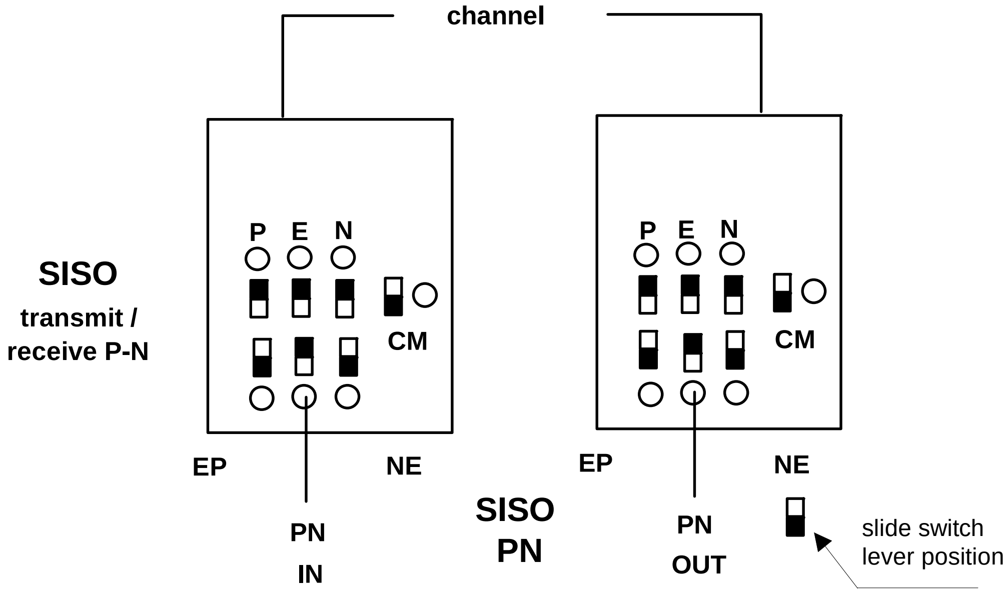


Figure 22: Coupler in SISO Attenuation Measurement Mode

7.1.4.2 MIMO Symmetric Transmit (Example N-E), MIMO Receive Star Plus CM

Figure 23 shows the setup to connect two couplers in a MIMO example mode.

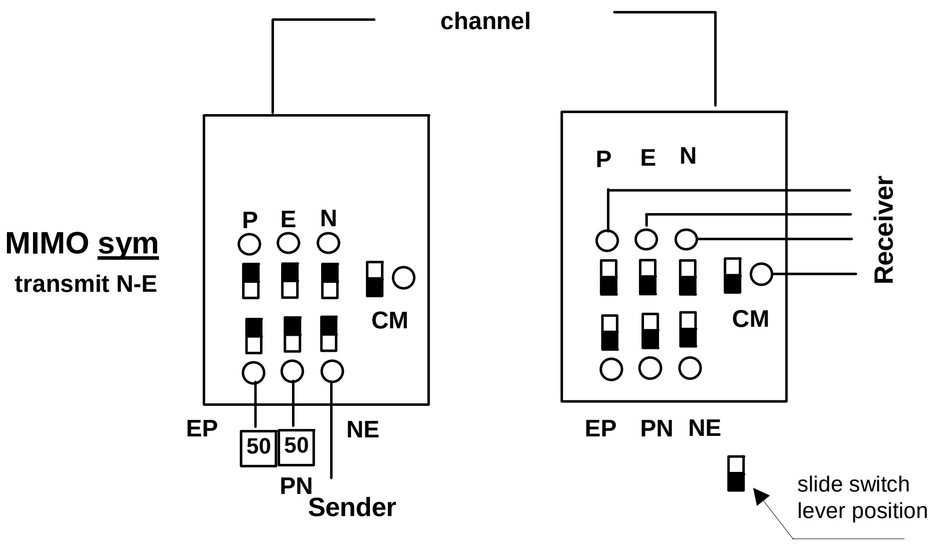


Figure 23: Coupler in MIMO Symmetric Transmit and MIMO Receive (Star Plus CM) Mode

7.1.4.3 MIMO Asymmetric Transmit (Example N-E), MIMO Receive Star Plus CM

Figure 24 shows the setup to connect two couplers in a MIMO example mode where one port is not terminated.

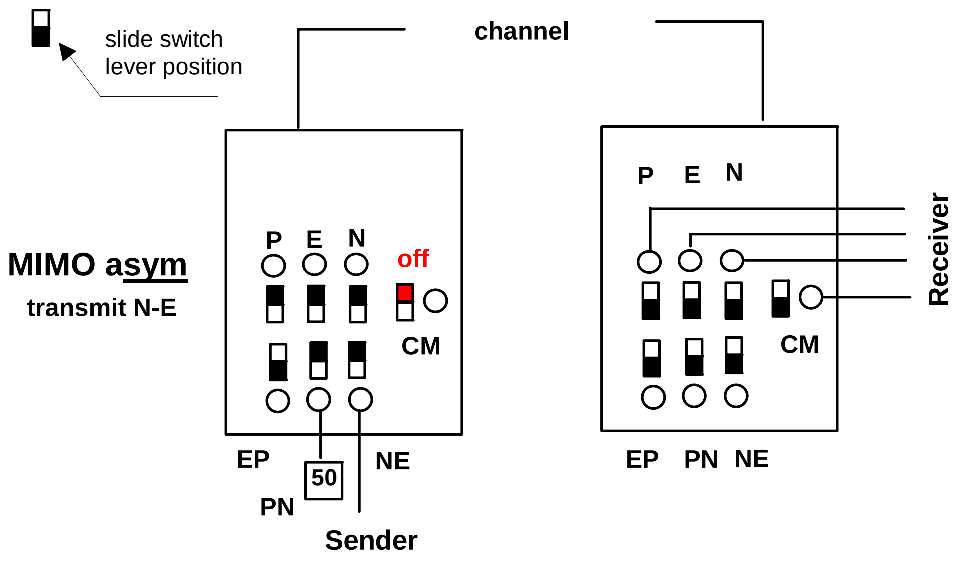


Figure 24: Coupler in MIMO Asymmetric Transmit and MIMO Receive (Star Plus CM) Mode

7.1.4.4 SISO Common Mode Transmit and SISO Common Mode Receive

Figure 25 shows the setup to connect two couplers in CM-CM mode. (It is not a proposal for practical deployment.)

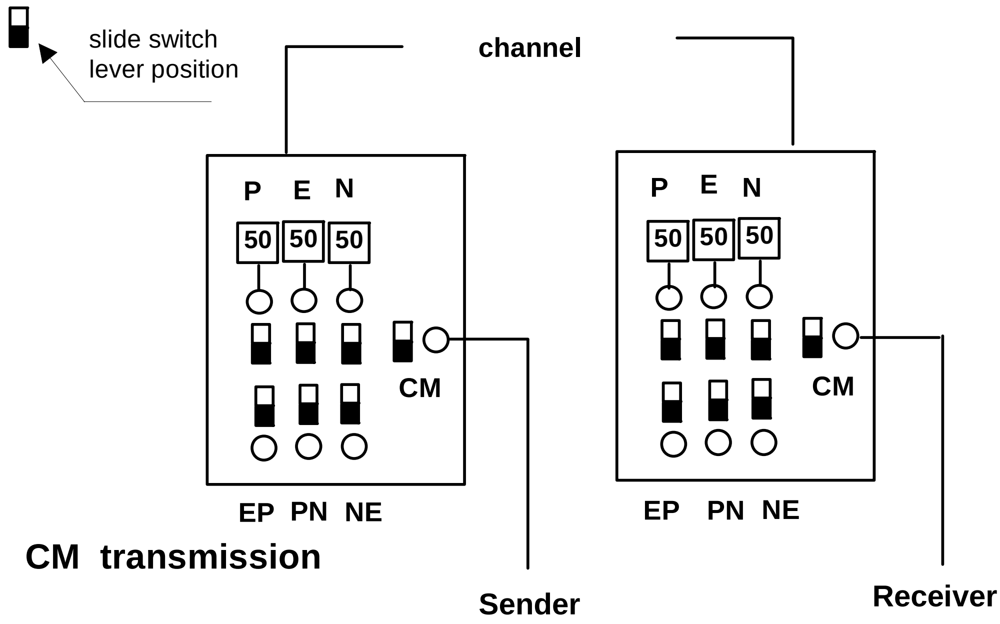


Figure 25: Coupler in SISO Common Mode Transmit and Receive Mode

7.1.4.5 Alternative MIMO Mode Using Dual Wire Feed

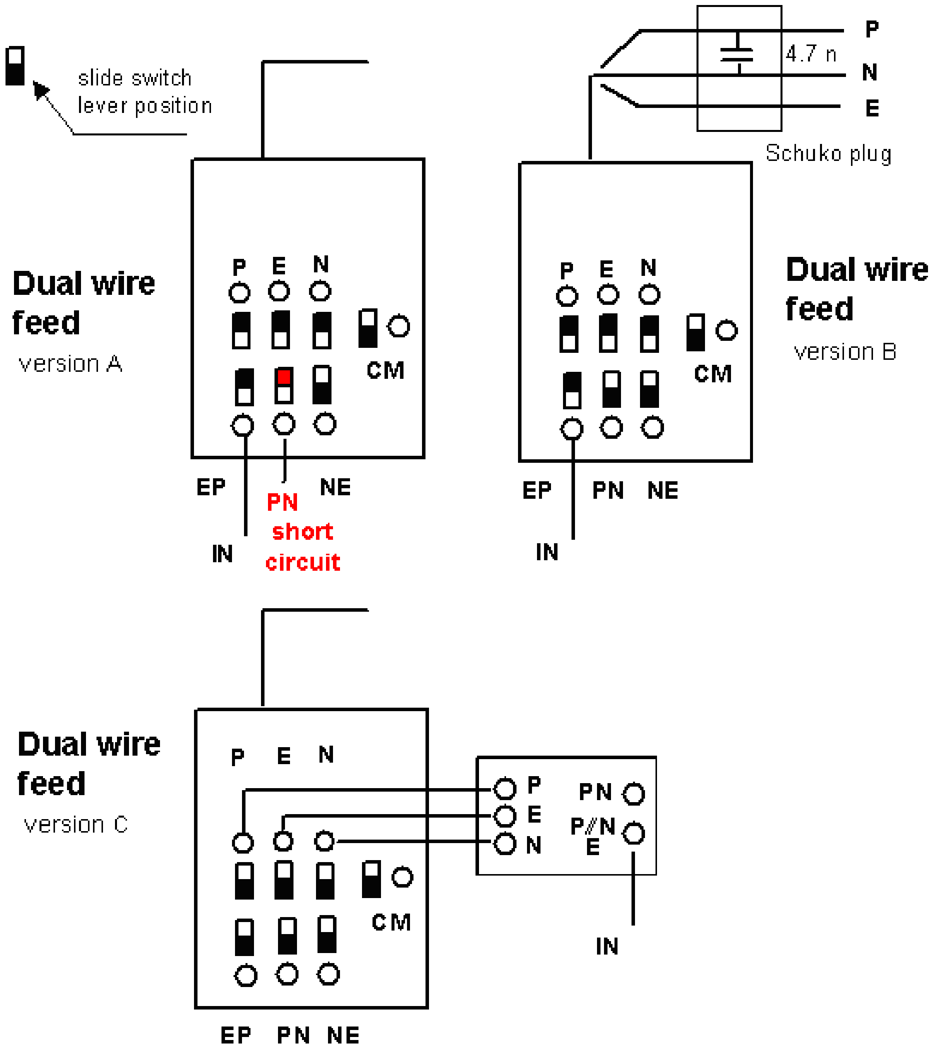


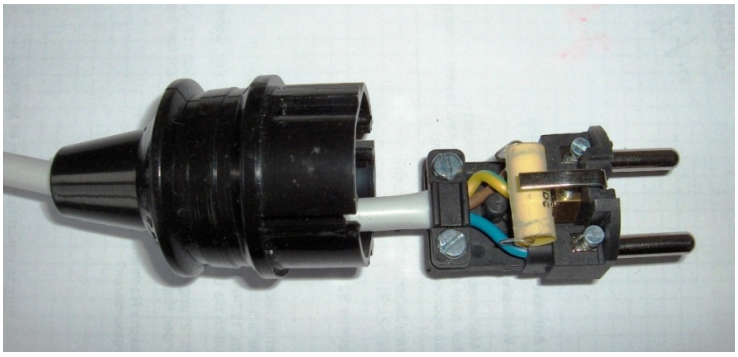
Figure 26: Coupler in Dual Wire Feed Mode

Version A:

- The short circuit between P and N is not perfect, because the balun represents a transmission line of about 34 cm of electrical length and Zo = 200 Ω at the secondary. At 30 MHz P and N are "shorted" with about j 43 Ω, at 80 MHz with j 115 Ω.

Version B:

- There is enough space inside the Schuko plug of the coupler, to mount a 4,7 nF capacitor inside. For frequencies above 5 MHz this type of short circuit is more effective. The internal coupling to the open third wire is small due to the symmetric construction of the coupler. It should be negligible.



NOTE: 4,7 nF 1 000 V polypropylene capacitor mounted into the Schuko plug.

Figure 27: Coupler in Dual Wire Feed Version B Mode

Version C:

- Using a differential choke to feed into P and N wires in common mode ensures a very symmetric dual feed injection for all the frequency range of interest. This is implemented in an additional extension box to avoid the need of modifying the original couplers. This box contains not only this choke, but both 50 Ω to 200 Ω baluns for the dual-wire (P//N E) and the classical differential (PN) injection modes. In this way, both modes (as well as the CM) can be used at the same time to create an alternative set of MIMO modes. This type of coupler is called the T-style coupler.

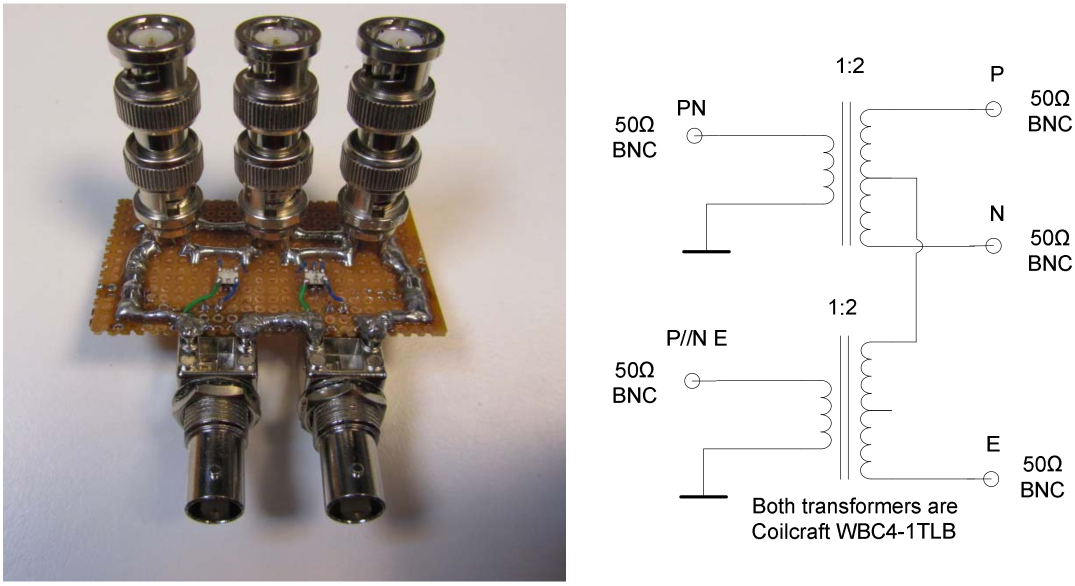


Figure 28: Coupler Extension in Dual Wire Feed Version C Mode

7.1.5 Circuit Diagram

The center point C in the schematic diagram in figure 29 is the heart of the coupler. It is built in a very compact form in order to reduce spurious inductances and capacitances for proper operation in excess of 100 MHz.

All baluns are of the same type (Guanella transformers 1 : 4). They are of very low loss.

The common mode transformer is magnetically coupled (Faraday type). Its loss is not negligible.

If the CM switch is on (open position) and the CM interface is open then the CM transformer acts as an effective CM choke.

If the CM switch is off (closed position) then the impedance of the common mode transformer is decreased. The instruments connected to the coupler are protected in several ways:

- gas discharge and varistor between P and N;
- surge protection diodes on P, N and PE;
- switches S1 to S7 that allow the instruments to disconnect.

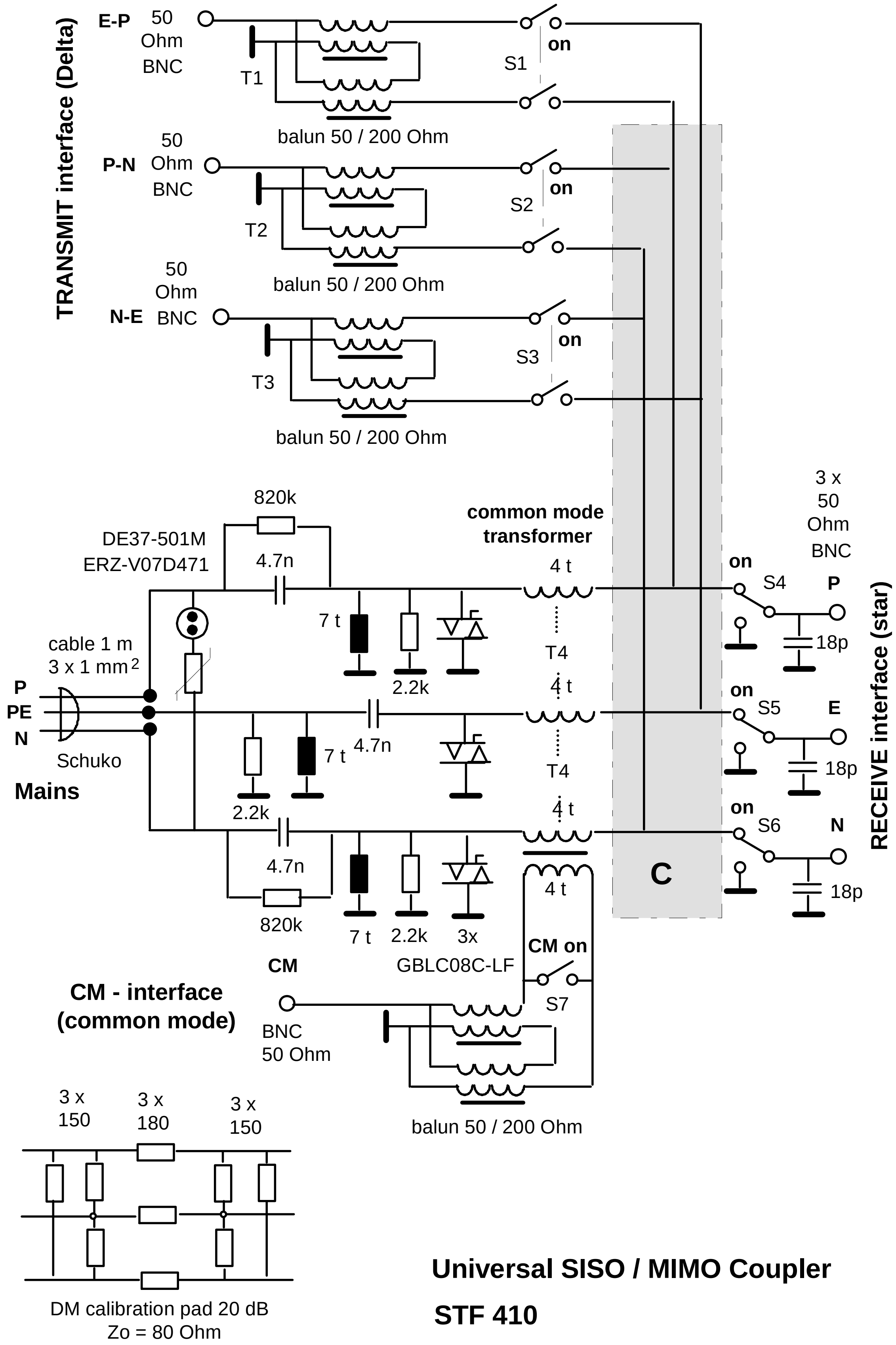
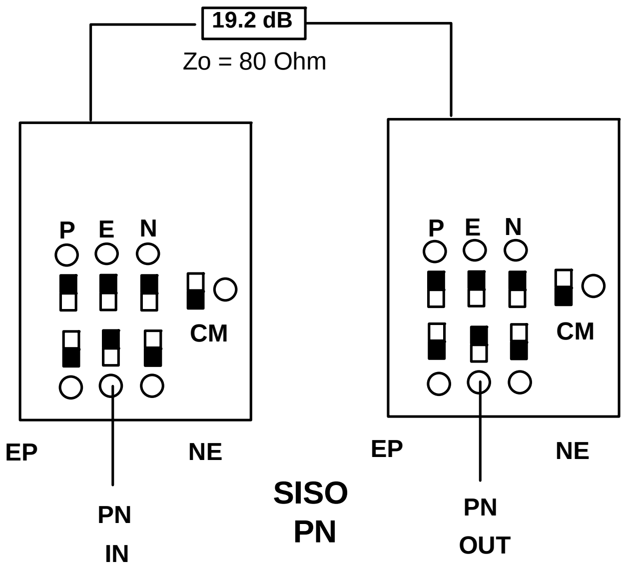


Figure 29: Coupler Schematic

7.1.6 Measurement Results of STF410 Coupler Verification

7.1.6.1 SISO

Figure 30 shows the coupler's verification setup for SISO.



Insertion loss with ideal coupler:

total: a = 21,0 dB

Excess insertion loss per coupler:

3 MHz < 0,4 dB

30 MHz < 0,3 dB

60 MHz < 0,5 dB

80 MHz < 0,7 dB

100 MHz < 2,4 dB

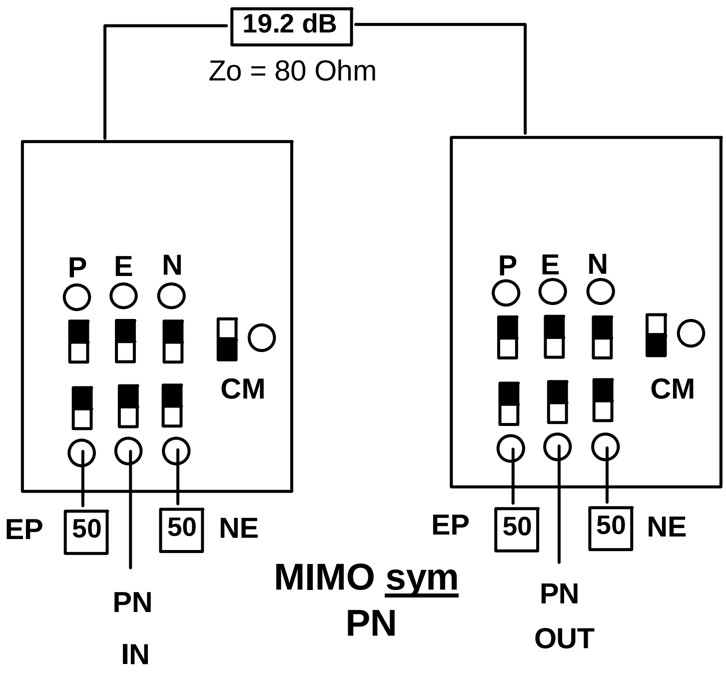
Figure 30: Coupler Settings: SISO

Table 12

Coupler Pad	MHz	3	10	30	60	80	100
01 to 02	-S21 PN-PN (dB)	21,7	21,7	21,4	21,8	23,5	25,2
A	-S21 NE-NE (dB)	21,7	21,8	21,5	21,7	22,6	24,1
	-S21 EP-EP (dB)	21,8	21,8	21,6	21,8	22,6	24,2
03 to 04	-S21 PN-PN (dB)	21,7	21,7	21,5	21,9	23,3	25,3
B	-S21 NE-NE (dB)	21,8	21,8	21,5	21,6	22,6	24,2
	-S21 EP-EP (dB)	21,8	21,8	21,6	21,7	22,4	24,1
05 to 06	-S21 PN-PN (dB)	21,8	21,8	21,5	21,9	23,6	25,7
C	-S21 NE-NE (dB)	21,8	21,8	21,6	21,8	22,8	24,4
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,9	22,7	24,1
07 to 08	-S21 PN-PN (dB)	21,7	21,7	21,4	21,7	23,0	24,9
D	-S21 NE-NE (dB)	21,7	21,8	21,5	21,5	22,3	23,8
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,8	22,3	23,6
09 to 10	-S21 PN-PN (dB)	21,7	21,7	21,4	21,9	23,3	24,3
E	-S21 NE-NE (dB)	21,8	21,7	21,5	21,4	22,1	23,5
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,7	22,3	23,7
11 to 12	-S21 PN-PN (dB)	21,7	21,7	21,4	21,9	23,3	25,3
F	-S21 NE-NE (dB)	21,8	217	21,5	21,4	22,1	23,5
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,8	22,3	23,7
13 to 14	-S21 PN-PN (dB)	21,8	21,8	21,5	21,9	23,3	25,2
G	-S21 NE-NE (dB)	21,8	218	21,6	21,6	22,2	23,6
	-S21 EP-EP (dB)	21,8	21,8	21,7	21,9	22,6	24,0

7.1.6.2 MIMO Symmetric

Figure 31 shows the coupler's verification setup for MIMO.



Insertion loss with ideal coupler:

total: a = 23,3 dB

Excess insertion loss per coupler:

3 MHz < 0,9 dB

30 MHz < 0,6 dB

60 MHz < 0,8 dB

80 MHz < 1,2 dB

100 MHz < 2,1 dB

Figure 31: Coupler Settings: MIMO Symmetric

Table 13

Coupler pad	MHz	3	10	30	60	80	100
01 to 02	-S21 PN-PN (dB)	24,8	24,7	24,5	24,8	25,4	26,5
A	-S21 NE-NE (dB)	24,8	24,7	24,5	24,6	24,7	25,3
	-S21 EP-EP (dB)	24,8	24,7	24,5	24,7	24,8	25,5
03 to 04	-S21 PN-PN (dB)	24,6	24,5	24,4	24,8	25,8	27,4
B	-S21 NE-NE (dB)	24,6	24,5	24,3	24,5	25,2	26,4
	-S21 EP-EP (dB)	24,6	24,5	24,3	24,4	25,1	26,4
05 to 06	-S21 PN-PN (dB)	24,6	24,6	24,3	24,8	25,7	27,1
C	-S21 NE-NE (dB)	24,6	24,5	24,3	24,6	25,2	26,6
	-S21 EP-EP (dB)	24,7	24,5	24,4	24,3	25,1	26,3
07 to 08	-S21 PN-PN (dB)	24,7	24,6	24,3	24,9	25,9	27,5
D	-S21 NE-NE (dB)	24,7	24,6	24,4	24,7	25,3	26,6
	-S21 EP-EP (dB)	24,7	24,6	24,4	24,7	25,2	26,3
09 to 10	-S21 PN-PN (dB)	24,6	24,5	24,3	24,7	25,4	26,8
E	-S21 NE-NE (dB)	24,7	24,5	24,3	24,5	25,0	26,4
	-S21 EP-EP (dB)	24,6	24,5	24,4	24,6	24,9	25,9
11 to 12	-S21 PN-PN (dB)	24,6	24,5	24,3	24,8	25,6	27,2
F	-S21 NE-NE (dB)	24,6	24,5	24,3	24,5	24,9	25,9
	-S21 EP-EP (dB)	24,6	24,5	24,3	24,6	25,0	26,1
13 to 14	-S21 PN-PN (dB)	24,7	24,6	24,4	24,8	25,7	27,1
G	-S21 NE-NE (dB)	24,7	24,6	24,4	24,6	24,9	26,0
	-S21 EP-EP (dB)	24,7	24,5	24,4	24,7	25,1	26,2

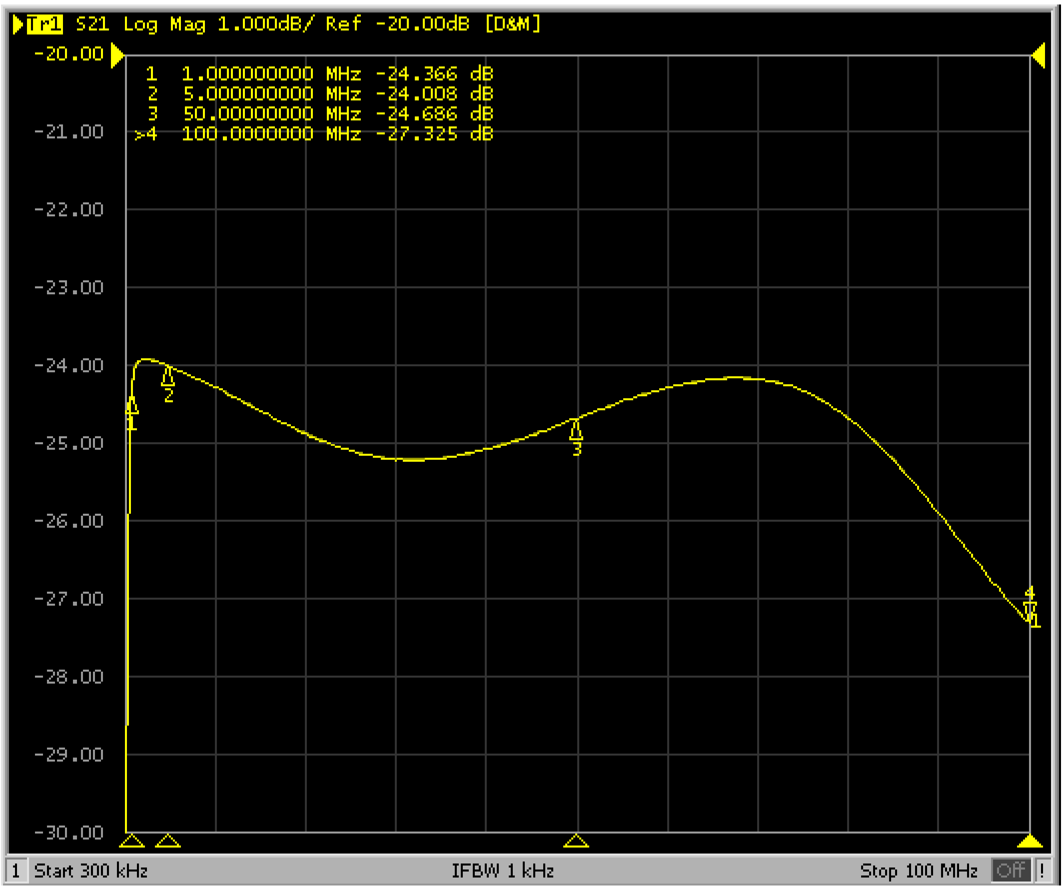
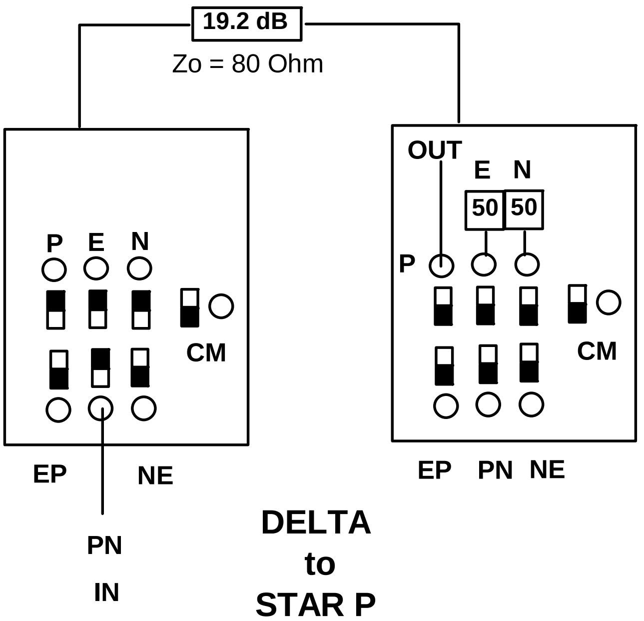


Figure 32: Frequency Sweep MIMO Symmetric

7.1.6.3 MIMO Delta Transmit to Star Receive

Figure 33 shows the coupler's verification setup for MIMO delta to star mode.



Insertion loss with ideal coupler:
total: a = 23,2 dB

Excess insertion loss per coupler:

(ex prototypes)

3 MHz	< 0,4 dB
30 MHz	< 0,3 dB
60 MHz	< 0,5 dB
80 MHz	< 0,7 dB
100 MHz	< 2,1 dB

For **symmetric** MIMO feed the insertion loss increases by 1,5 dB
For **asymmetric** MIMO feed the insertion loss increases by 0,5 dB

Figure 33: Coupler Settings: MIMO Delta Tx to Star Rx

Table 14

Coupler pad	MHz	3	10	30	60	80	100
01 to 02	-S21 PN to P (dB)	25,4	25,2	25,3	25,5	26,7	27,3
A	-S21 PN to N (dB)	25,4	25,3	25,3	25,2	26,3	26,8
prototype	-S21 PN to E (dB)	69	67	63	59	58	56
03 to 04	-S21 PN to P (dB)	23,7	23,7	23,5	24,5	25,6	27,2
B	-S21 PN to N (dB)	23,9	23,9	23,5	24,3	25,6	27,3
	-S21 PN to E (dB)	58	57	51	44	43	42
05 to 06	-S21 PN to P (dB)	23,7	23,7	23,6	24,5	25,3	26,8
C	-S21 PN to N (dB)	23,9	23,9	23,6	24,3	25,4	26,9
	-S21 PN to E (dB)	58	59	54	44	43	44
07 to 08	-S21 PN to P (dB)	23,8	23,7	23,7	24,5	25,8	27,4
D	-S21 PN to N (dB)	24,0	23,9	23,6	24,4	25,4	27,0
	-S21 PN to E (dB)	59	63	67	53	52	50
09 to 10	-S21 PN to P (dB)	23,7	23,7	23,7	24,6	25,5	27,3
E	-S21 PN to N (dB)	23,9	23,9	23,6	23,9	24,2	25,4
	-S21 PN to E (dB)	58	61	57	49	45	42
11 to 12	-S21 PN to P (dB)	23,7	23,7	23,6	24,7	25,8	27,4
F	-S21 PN to N (dB)	24,0	23,9	23,6	24,3	24,3	26,9
	-S21 PN to E (dB)	62	61	59	65	55	51
13 to 14	-S21 PN to P (dB)	23,7	23,7	23,6	24,6	25,7	27,3
G	-S21 PN to N (dB)	24,0	24,0	23,7	24,2	25,0	26,4
	-S21 PN to E (dB)	61	74	64	59	67	60

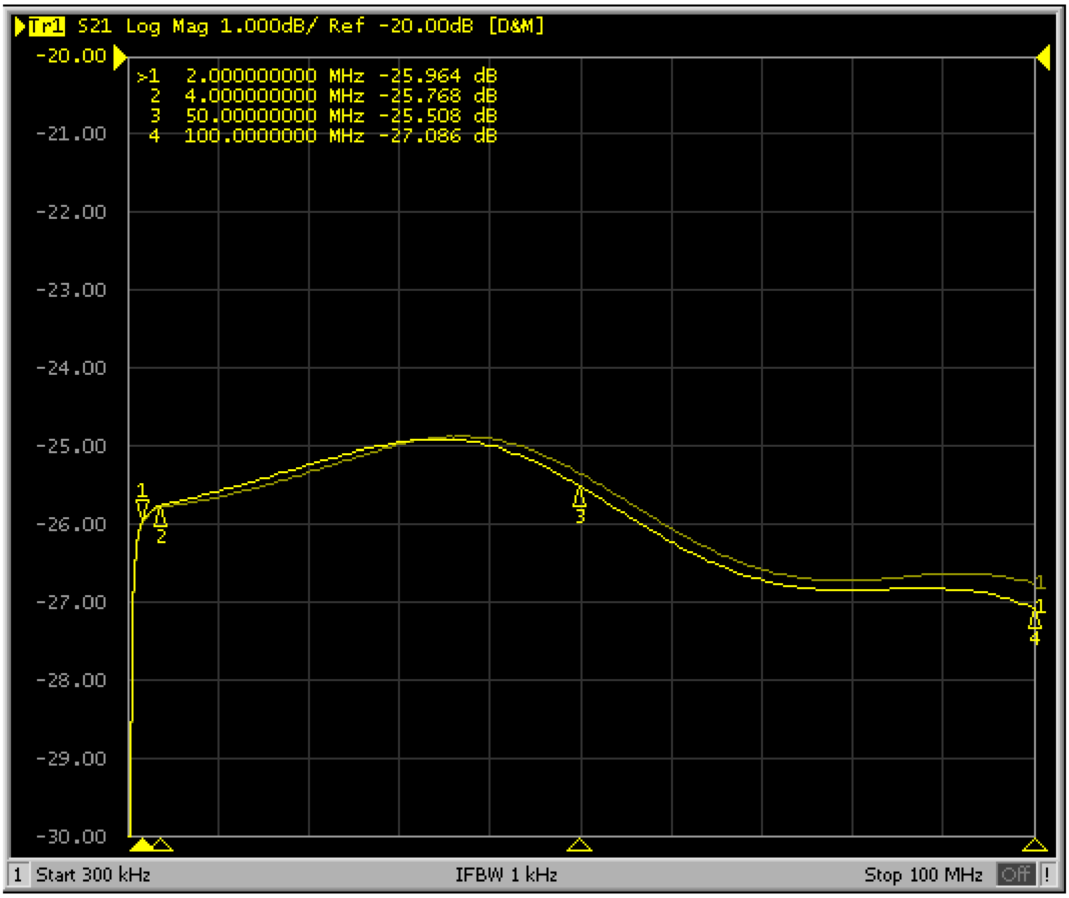


Figure 34: Frequency Sweep MIMO Delta Tx to Star Rx

7.1.6.4 Common Mode Reception

Figure 35 shows the coupler's verification setup for CM reception.

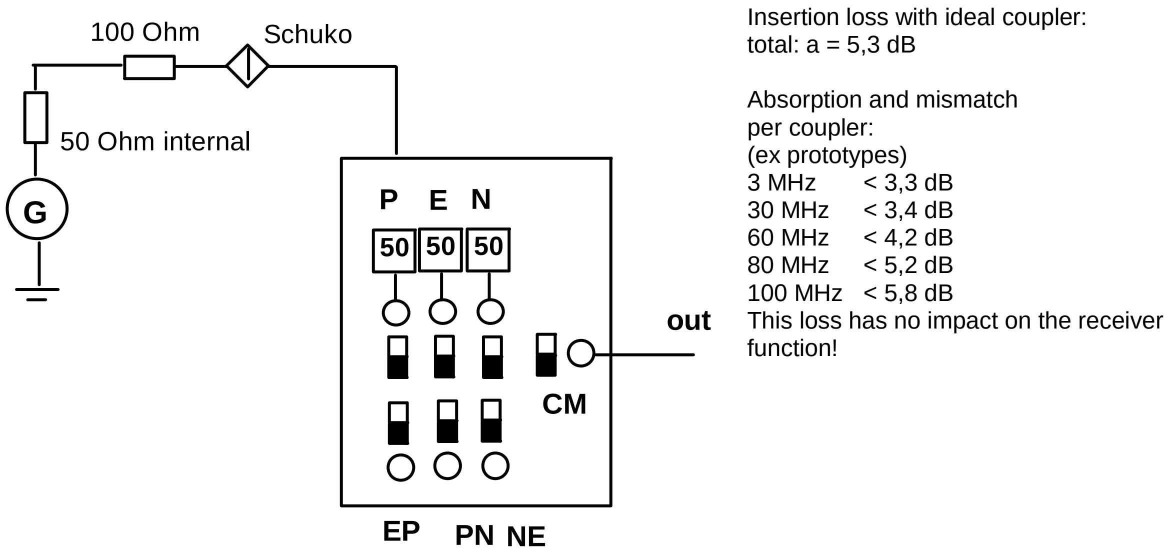


Figure 35: Coupler Settings: CM Reception

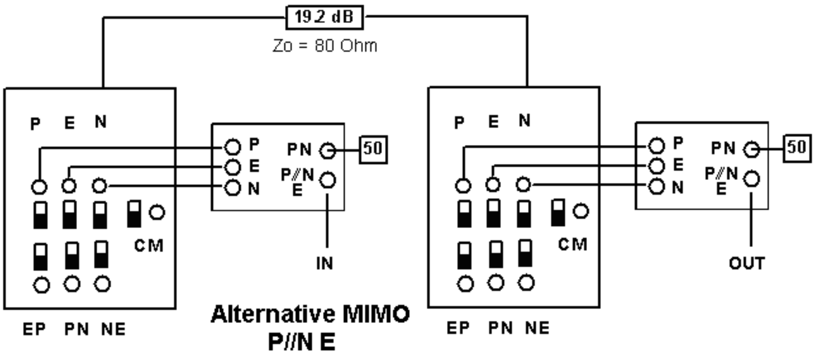
Table 15

Coupler	MHz	3	10	30	60	80	100
01	-S21	9,2	8,7	9,2	9,7	10,5	11,0
02	-S21	9,2	8,7	9,2	9,9	10,8	11,4
03	-S21	8,6	8,1	8,7	9,4	10,4	11,0
04	-S21	8,6	8,1	8,6	9,4	10,4	10,9
05	-S21	8,6	8,1	8,6	9,4	10,2	10,8
06	-S21	8,6	8,1	8,6	9,4	10,4	11,0
07	-S21	8,6	8,1	8,6	9,3	10,1	10,7
08	-S21	8,6	8,1	8,6	9,4	10,2	10,9
09	-S21	8,6	8,1	8,6	9,2	10,1	10,6
10	-S21	8,6	8,1	8,6	9,5	10,5	11,1
11	-S21	8,6	8,1	8,6	9,4	10,2	10,8
12	-S21	8,6	8,1	8,7	9,3	10,2	10,8
13	-S21	8,6	8,1	8,6	9,5	10,5	11,1
14	-S21	8,6	8,1	8,6	9,4	10,3	10,9

Figure 36: Probe in CM Reception Mode

7.1.6.5 Alternative MIMO Modes (Dual Wire Feed)

Figure 37 shows the coupler's verification setup for MIMO using the alternative (T-style) mode.



Comparative losses with respect to previous MIMO symmetric injection (point 12.2) in PN-PN mode (coupler/pad - 11 to 12/F):
3 MHz -1,6 dB
30 MHz -1,3 dB
60MHz -0,2 dB
80 MHz +1 dB (see note)
100 MHz +2,1 dB (see note)

NOTE: The attenuation increment at higher frequencies comes from the 18pF capacitors at P, E, N ports of the coupler.

Figure 37: Coupler Settings: MIMO Symmetric

Table 16

Coupler pad	MHz	3	10	30	60	80	100
11 to 12	-S21 PN -PN (dB)	23,0	22,8	23	24,6	26,6	29,3
F	-S21 P//N E-P//N E (dB)	23,9	23,8	24,0	24,9	26,6	29,6

7.2 Coaxial Cables

The coaxial cables used to conduct the measurements have to enable results of a dynamic range of up to 120 dB. Therefore doubled shielded cables are required. Of course, due to long distances inside the buildings, low attenuation cables are preferred. RG214 or Ecoflex 10 cables fulfil these requirements.

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 several ferrites and CMADs.

A Suppression Axial Ferrite Bead (Würth-Elektronik part number: 74270056) is attached to the coaxial cable every 0,15 m.

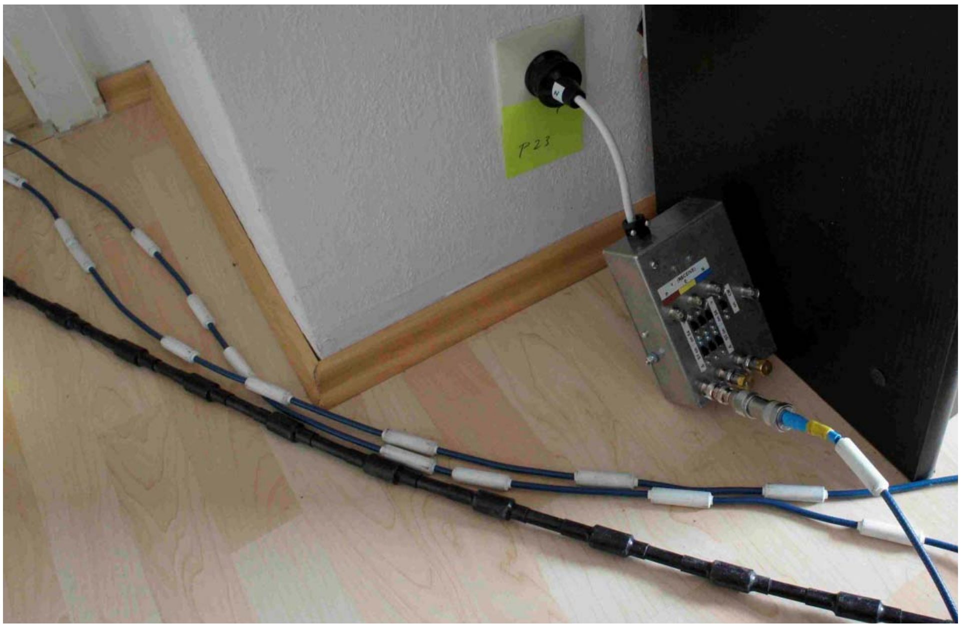


Figure 38: Cable with Ferrites

7.3 Network Analyzer

The following NWA were used by the measurement teams.

7.3.1 Agilent E5071B

The team Germany used an Agilent E5071B.

NOTE: Agilent E5071B 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 39: Agilent E5071B

Table 17: Technical Properties of Agilent E5071B

Property	Value	Comment
Type	E5071B ENA	
Manufacturer	Agilent	
Output power	+12 dBm	in the frequency domain; into 50 Ω
Out-/Input impedance	50 Ω	
Frequency range	300 kHz to 8,5 GHz	
Max Dynamic Range	125dB	

7.3.2 Agilent E5071C

The teams Belgium and France, Lannion used an Agilent E5071C ENA Network Analyzer.

NOTE: Agilent E5071C 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 40: Agilent E5071C

Table 18: Technical Properties of Agilent E5071C

Property	Value	Comment
Type	E5071C ENA	
Manufacturer	Agilent	
Output power	+10 dBm	in the frequency domain; into 50 Ω
Out-/Input impedance	50 Ω	
Frequency range	9 kHz to 6,5 GHz	
Max Dynamic Range	123 dB	

7.3.3 Rohde & Schwarz ZVB4

The team in Spain used a Rohde & Schwarz ZVB4 Network Analyzer.

NOTE: Rohde & Schwarz ZVB4 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 41: Rohde & Schwarz ZVB4

Table 19: Technical Properties of R&S ZVB4

Property	Value	Comment
Type	ZVB4	
Manufacturer	Rohde & Schwarz	
Output power	-40 dBm to + 13 dBm	
Out/Input Impedance	50 Ω	
Frequency Range	300 kHz to 4 GHz	
Max Dynamic Range	> 123 dB	at 10 Hz IF bandwidth
Number of ports	4	
Number of measurement points	1 to 60 001	

7.4 LISN or Filter to Isolate Measurement Devices from Mains

Figure 42: AMN

Table 20: Technical Properties of AMN

Property	Value	Comment
Type	ESH3-Z5	
Manufacturer	Rohde & Schwarz	
PE connection	50 µH "on"	

For isolation of the PE wire, an additional mains filter as described in the following clause should be inserted in series to the LISN.

7.5 Mains Filter

If the test instruments (namely the network analyzer) are connected to the mains section for EMI, channel impedance and transfer measurements, the instruments represent an additional load and may cause measurement errors. Whenever possible the power supply for the measurement equipment should be used from a neighboring flat or building via a mains extension cable, to provide maximum isolation between the flat under measurement and the power supply. When this is not possible, the MIMO mains filter described herein can be used to minimize the influence.

Even with the filter, one should avoid mains outlets immediately beside the feeding and the reception points. The filter has to be inserted between measurement equipment and the LISN.

This filter was manufactured by STF410 several times and distributed to all measurement teams.

7.5.1 Schematic Diagram

A mains filter also attenuating the PE wire is shown below.

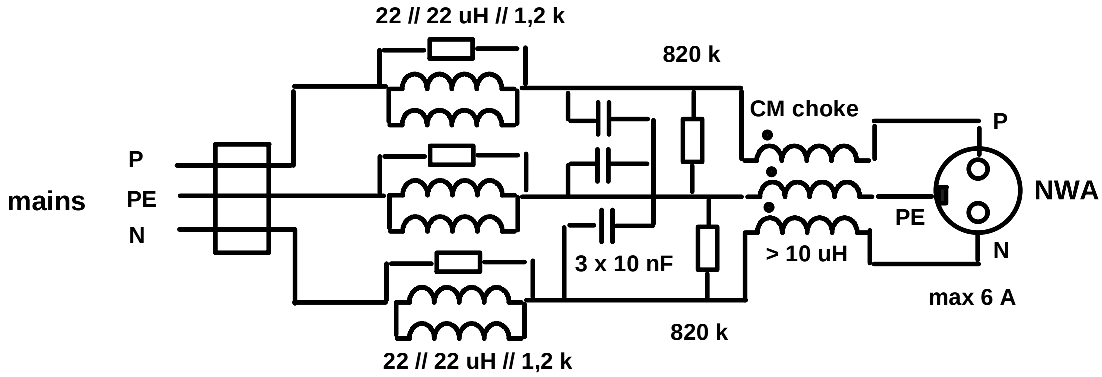


Figure 43: Schematic of Mains Filter

7.5.2 Typical Impedances of Decoupling Components

7.5.2.1 R/L Combinations - Mains Side

Table 21: Impedance R, L Circuit on Mains Side of STF410 Mains Filter

MHz	1,59	3	10	30	60	80	100	
$\lvert Z \rvert$	79	135	450	1 100	650	440	340	**Ω**
φ	58	58	64	- 4	- 50	- 60	- 60	**degree**

7.5.2.2 Common Mode Choke - Instrument (NWA) Side (4 turns)

Table 22: Impedance of CM Choke in STF410 Mains Filter

MHz	1,59	3	10	30	60	80	100	
$\lvert Z \rvert$	110	240	610	850	580	400	310	**Ω**
φ	89	82	42	- 16	- 51	- 62	- 64	**degree**

7.5.3 Figures of Mains Filter

Figure 44: Mains Filter with Closed Lid

Figure 45: Filter View Inside

7.6 Ground Plane

To achieve a low impedance or high capacity connection to ground, a huge ground plane is necessary. Especially for reproducibility of the received CM signal; the ground plane is essential. The size of the ground plane is sufficiently large when human contact no longer influences measurement results.

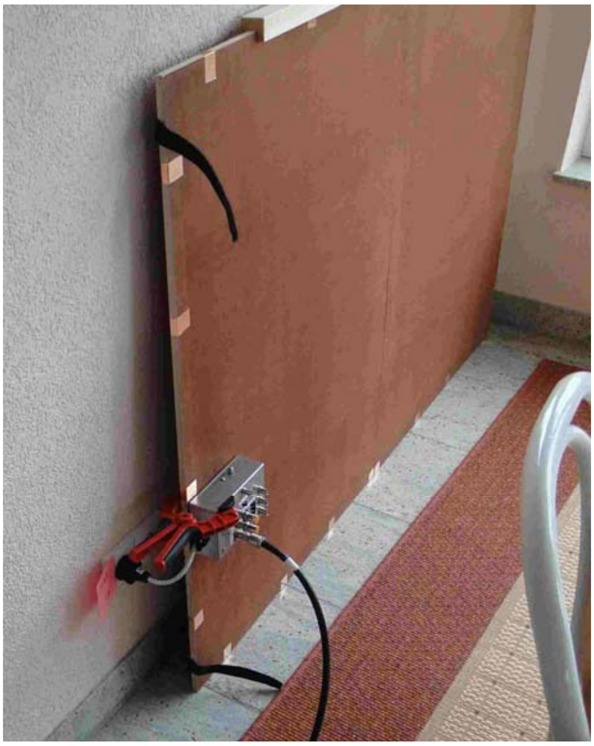


Figure 46: Ground Plane with PLC Coupler Connected Tight

Annex A: 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	May 2011	Publication as TR 101 562 (Historical)
V1.2.1	August 2011	Publication
V1.3.1	February 2012	Publication