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ITER Electrical Design Handbook Electromagnetic Compatibility (EMC)

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ITER Electrical Design Handbook

Electromagnetic Compatibility (EMC)

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Introduction

Abstract

This manual is provided for the use of all Departments of the ITER Organization and is addressed to system specifiers, designers and users of electrical components in otherwise non-electrical plant systems.

This is an initial version of this document that has been reviewed in accordance with the ITER MQP. Review comments have in part been addressed and others will be considered in detail and addressed at the next revision.

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1 Introduction

This document will be published in the Baseline documentation folder of the ITER Document Management (IDM) System and will be the subject of continual review and revision throughout the lifetime of the ITER project.

This handbook is provided for the use of all Departments of the ITER Organization and is addressed primarily to system specifiers, designers and users of electrical components in otherwise non-electrical plant systems, rather than to designers of the power supply systems. The latter shall in addition comply with many other standards, instructions and industrial practices that are beyond the scope of this handbook.

Standardisation Guides

All electrical components and plant systems used or installed at ITER shall comply with the requirements set out in this EDH.

In particular, voltage and current ratings must be selected for connection to the ITER standard nominal system voltages that have been selected from the IEC standards as given in the Section on Standard Voltages.

The related test voltages are given in the Section on Standard Test Voltages.

1.1 Standard Voltages

1.1.1 Applicable IEC standards

IEC 60038 IEC Standard Voltages

International Standard **IEC 60038** defines a set of standard voltages for use in low voltage and high voltage AC electricity supply systems.

The definition of voltage levels is as follows:

IEC voltage range	AC	DC	defining risk
Extra-low voltage	< 50 V_{rms}	< 120 V	low risk
Low voltage	50–1000 V_{rms}	120–1500 V	electrical shock
High voltage	> 1000 V_{rms}	> 1500 V	electrical arcing

Table 1.1 IEC Definition of Voltage Levels

1.1.2 Low Voltage, single & 3 phase, 50Hz

The 230V/400V level (in bold text) is that adopted for use by ITER:

	rms voltage between a phase and the neutral connector	Corresponding rms voltage between two phases. Four-wire (with neutral) or three-wire (without neutral) systems
LV	**230 V**	**400 V**
	400V	690V
	1000V	-

Table 1.2 Low Voltage (LV) used at ITER

1.1.3 High Voltage, 3 phase, 50 Hz

Whilst defined by IEC as being **High Voltage**, i.e. > 1000 V_{rms}, the following voltage levels shall be referred to within ITER as **Medium Voltage (MV)**, i.e. 1 kV < $V_r \leq$ 35 kV, **Intermediate Voltage (IV)**, i.e. 35 kV < $V_r \leq$ 230 kV or as **High Voltage (HV)**, i.e. 230 kV < $V_r \leq$ 800 kV.

The levels in bold are those adopted for use by ITER:

	Highest voltage for equipment *V_m kV	Nominal system voltage ⊠V_r kV (± 10%)
MV	3.6	3.3
	7.2	**6.6**
	12	11
	17.5	-
	24	**22**
IV	**72.5**	**66**
	123	110
	145	132
HV	245	220
	420	**400**

Table 1.3 Medium Voltages (MV), Intermediate Voltage (IV) and High Voltage (HV) used at ITER

1.2 Standard Test Voltages

1.2.1 Applicable IEC standards

IEC 60060 High-Voltage Test Techniques

International Standard **IEC 60060** defines a set of tests on equipment having its highest voltage for equipment V_m above 1kV, i.e. in the case of components and plant systems used or installed at ITER, any that are to be connected to a supply voltage higher than that classed as low voltage, must be subjected to testing.

This standard is applicable to:

- dielectric tests with direct voltage;
- dielectric tests with alternating voltage;
- dielectric tests with impulse voltage;

* V_m represents the dielectric strength of an equipment, device or system for which it is designated
⊠ V_r represents the nominal or rated system voltage at which an equipment, device or system shall usually operate

- tests with impulse current;
- tests with combinations of the above.

Highest voltage for equipment V_m kV	Standard short-duration power frequency withstand voltage kV (rms value)	Standard lightning impulse withstand voltage
7.2	**20**	**40/60**
24	**50**	**95/125/145**
36	70	145/170
72.5	**140**	**325**
245	(275)/(325)/360/395/460	(650)/850/950/1050

Note: If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltage are met, additional tests are needed.

Table 1.4 Test Voltages

1.3 Voltage Classes

The voltage class of a power circuit defines the degree of availability of the power delivery. The following classification of the power delivery circuits have been adopted at ITER:

Class I	Uninterruptible DC (up to 250 V)	DC battery supplies; batteries charging when AC supply is available. AC supply may be Class III or Class IV depending on Safety Level
Class II	Uninterruptible AC (230/400 V)	Provided from UPS systems, will switch to alternate supply. Alternate AC supply may be Class III or Class IV depending on Safety Level
Class III	Temporarily interruptible AC (230/400 V and 6.6 kV)	Provided from diesel motor generators, interruption for 30 s while generators start up
Class IV	Indefinitely interruptible AC (230/400 V and 6.6 kV).	Directly provided from the electrical supply network

Table 1.5 Voltage Classes

1.4 Insulation Coordination

1.4.1 Applicable IEC standards

IEC 60071 IEC Insulation Coordination

The following table shows standard insulation levels for range I (1kV < V_m = 245 kV)

Highest voltage for equipment (V_m) kV (rms value)	Standard rated short- duration power-frequency withstand voltage kV (rms value)	Standard rated lightning impulse withstand voltage kV (peak value)
7.2	20	40 60
24	50	95 125 145
36	70	145 170
72.5	140	325
245	(275) (325) 360 395 460	(650) (750) 850 950 1050

Note: If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltage are met, additional tests are needed.

Table 1.6 Insulation Withstand Voltages

1.5 Standard Current Ratings

1.5.1 Applicable IEC standards

IEC 60059 IEC Standard Current Ratings

This standard specifies standard current ratings for electrical devices, apparatus, instruments and equipment and should be applied to the designing or utilisation of systems or equipment as well as to operating characteristics. This standard does not apply to current ratings of components and parts used within electrical devices or items of equipment.

Standard current ratings in amperes have been fixed by the IEC as follows:

1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
10	12.5	16	20	25	31.5	40	50	63	80
100	125	160	200	250	315	400	500	630	800
1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
10000	12500	16000	20000	25000	31500	40000	50000	63000	80000
100000	125000	160000	200000						

Table 1.7 IEC Standard Current Ratings

Terminology & Acronyms

Abstract

This part lists all terms, definitions and acronyms that may be referenced when specifying an electrical component, device or system for use by the ITER Organization.

This is an initial version of this document that has been reviewed in accordance with the ITER MQP. Review comments have in part been addressed and others will be considered in detail and addressed at the next revision.

Contents

1 Terminology

This part of EDH (Electrical Design Handbook) outlines the terminology adopted by the ITER Organization for specific electrical components, devices or systems.

For components, devices and systems not covered by this document, the following references shall be considered to identify the proper terminology:

1. IEC dictionaries and glossaries (http://www.electropedia.org)

2. Electrical Installations Handbook, Executive Editor: Gunter G. Seip, John Wiley and Sons, ISBN 0-471-40435-6

In case of inconsistency between the above documents, requests for clarification shall be submitted to the ITER Electrical Implementation Division.

The ITER Organization has adopted the International System of Units, universally known as the **SI** (from the French *Système International d'Unités*), see http://www.bipm.org/en/si/si_brochure. The SI prefixes are given in the table below:

Factor	Name	Symbol		Factor	Name	Symbol
10^{1}	deca	da		10^{-1}	deci	d
10^{2}	hecto	h		10^{-2}	centi	c
10^{3}	kilo	k		10^{-3}	milli	m
10^{6}	mega	M		10^{-6}	micro	µ
10^{9}	giga	G		10^{-9}	nano	n
10^{12}	tera	T		10^{-12}	pico	p
10^{15}	peta	P		10^{-15}	femto	f
10^{18}	exa	E		10^{-18}	atto	a
10^{21}	zetta	Z		10^{-21}	zepto	z
10^{24}	yotta	Y		10^{-24}	yocto	y

Table 1.1 SI Prefixes

1.1 Main Definitions from IEC Standards

1.1.1 Nominal System Voltage

The voltage by which a system is designated.

1.1.2 Rated Voltage/Current of Equipment

The voltage/current assigned generally by a manufacturer, for a specified operating condition of a component, device or equipment.

1.1.3 Highest System Voltage

The highest value of voltage which occurs under normal operating conditions at any time and any point on the system. It excludes voltage transients, such as those due to system switching, and temporary voltage variations.

1.1.4 Highest Voltage for Equipment

The highest rms value of phase-to-phase voltage for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards.

The highest voltage for equipment is the maximum value of the "highest system voltage" (see above) for which the equipment may be used.

1.1.5 Insulation Coordination

The selection of the dielectric strength of equipment in relation to the voltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available protective devices. The process is determined from the known characteristics of voltage surges and the characteristics of surge arresters.

1.1.6 The Standard Short-Duration Power Frequency Voltage

A sinusoidal voltage with frequency between 48 Hz and 52 Hz, and duration of 60 s. The voltage level is determined for specific tests.

1.1.7 The Lightning Impulse Voltage

An impulse voltage having a front time of 12 μs and a time to half-value of 50 μs. The voltage level is determined for specific tests.

2 Common Definitions Adopted for ITER

2.1.1 AC/DC Charger

A battery cahgher converting alternating current (AC) power into DC power, being the converter section of a UPS which charges batteries and supplies DC to the inverter.

2.1.2 Batteries

One or more cells fitted with devices necessary for use, for example case, terminals, marking and protective devices. A battery stores and supplies electrical energy to an electrical circuit when the normal power supply of that electrical circuit is interrupted.

2.1.3 *Busbar*

Conductors fabricated from thick strips of copper or aluminium to conduct electricity within a switchboard, distribution board, substation, or other electrical apparatus.

2.1.4 *Bus Coupler*

Inbuilt mechanical interlocking which connects busbar systems, where position change is via the OFF position, ensuring downstream distribution in case of failure of upstream lines. In a substation a circuit-breaker located between two busbars and which permits the busbars to be coupled; it may be associated with selectors in case of more than two busbars

2.1.5 *Cable*

Assembly of one or more conductors and/or optical fibres, with a protective covering and possibly filling, insulating and protective material

2.1.6 *Cable Tray*

a unit or assembly of units or sections and associated fittings forming a rigid structural system used to securely fasten or support cables and raceways. Cable trays are used to support and distribute cables.

2.1.7 *Circuit Breaker*

A switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and carrying for a specified time during abnormal circuit conditions such as a short circuit.

2.1.8 *Converter*

A functional unit which changes the representation of information. Examples of converters are: analog-digital converter, digital-analog converter, code converter, parallel-serial converter, serial-parallel converter.

2.1.9 *Current Transformer*

A device that reduces current values at a point in a network where they are connected, to proportional and manageable values, whilst separating measuring instruments, meters, relays, etc. from the medium or low voltage circuit.

2.1.10 *Diesel Generator*

A diesel generator is the combination of a diesel engine with an electrical generator (often called an alternator) to generate electrical energy. Diesel generating sets are used as emergency power-supply if the grid fails. There are four 6.6kV diesel generator sets, two seismic qualified to feed SR loads and two non-seismic qualified for IP loads.

2.1.11 *Disconnector*

A mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements. A Mechanical switching device which, in the open position, disconnects all the poles of an electrical circuit and is equipped with a reliable contact position indicator. A closed disconnector is capable of carrying currents under normal circuit conditions and carrying for a specified time currents under abnormal conditions such as those of short circuit.

2.1.12 *Earth Switch*

Mechanical switching device for earthing parts of an electrical circuit, capable of withstanding for a specified duration, electric currents under abnormal conditions such as those of a short-circuit, but not required to carry electric current under normal conditions of the electrical circuit

2.1.13 *Electrical Interlock*

Type of circuit in which the auxiliary contacts of various devices are switched in such a ways that the circuit states are interdependent. This makes it impossible to switch on one switching device if another is already switched on.

2.1.14 *Insulators*

A device designed to support and insulate a conductive element. A device intended for electrical insulation and mechanical fixing of equipment or conductors which are subject to potential differences.

2.1.15 *Inverter*

Electrical energy converter that changes direct current to single-phase or polyphase alternating current

2.1.16 *Load Centre*

The load voltage load centres are connected to the secondary 22 kV distribution switchgear through the MV/LV transformers.

They are mainly used at the load level. They are used for:

- Protecting persons and property
- Protecting electrical loads
- Protecting cables and electric lines
- Overvoltage protection
- Safety disconnection
- Monitoring and signalling
- Open and closed-loop control
- Metering, measuring and display purposes

This load centres are composed of:

- Incoming circuit breakers and coupler circuit breaker (interlocked function)
- 400V copper strip semi-busbars.
- Outgoing draw-out circuit breakers to the Local Panels and MCC.

2.1.17 *Load Tap Changer*

The on-load tap changer is used to change the tapping connection of the transformer winding while the transformer is energized. A connection made at some intermediate point in a winding. It is used to control the voltage over the SSEN

2.1.18 *Main Busbar*

The busbar is an assembly necessary to make a common connection for several circuits. A low-impedance conductor, to which several electric circuits can be connected

2.1.19 *Main Distribution Board*

Assembly containing different types of switchgear and control gear associated with one or more outgoing electric circuits fed from one or more incoming electric circuits, together with terminals for the neutral and protective conductors.

They are used for up 6300 A. They are used first and foremost for:

- Safety disconnection
- Coupling busbar sections
- Protecting busbars
- Selectivity vis-à-vis upstream protection equipment

They are primarily equipped with:

- Circuit-breakers and non-automatic circuit-breakers
- Tie circuit-breakers
- Fuses

2.1.20 *Motor Control Centre*

MCC is a low-voltage withdrawable-unit-type switchgear station for motor feeders with a main switch and door interlock. The MCC will consist of individual cubicles housed in the correspondent switchgear placed as close as possible of the LV motors zone. The MCC shall include:

- Motor protection systems.
- Monitoring & Control devices.
- Starter devices if applicable.

2.1.21 *Outlet/Connector*

Device which provides connection and disconnection to a suitable mating component. Conductor of electricity used for carrying current between components in an electric circuit

2.1.22 *Penetration*

A cable transit assembly designed to implement safely the passage of cables lines through walls , floors or ceilings of areas with various environmental conditions, maintaining their integrity

2.1.23 *Soft Starters*

The combination of the switching means necessary to start and stop a motor in combination with suitable overload protection.

2.1.24 *Raceway*

An enclosed channel of metallic or nonmetallic materials designed expressly for holding wires, cables or busbars. Examples are electrical metallic tubing (EMT), flexible metallic tubing and nonmetallic rigid conduit.

2.1.25 *Relay*

Switching device which brings about sudden predetermined changes in one or more electric output circuits when specific conditions that control the device arise in the electric input circuit.

2.1.26 *Sockets*

Connector attached to an apparatus or to a constructional element or the like. Contact members of a socket may be socket contacts, pin contacts or both.

2.1.27 *Static Transfer Switch*

Device which transfers load automatically and without disturbance between inverter and utility power

2.1.28 *Sub-Distribution Board*

Part of an electrical installation for distributing energy to downstream loads or groups of loads

They are used up for 2500 A. They are used for:

- Safety disconnection
- Switching electrical loads, e.g. lighting systems and motors
- Protecting cables, electric lines and loads
- Back-up protection and selectivity vis-à-vis upstream and downstream protection equipment
- Overvoltage protection
- Control, metering and measuring purposes

The following devices are integrated in order to carry out these functions:

- Circuit-breakers, switch-disconnectors and fuse switch-disconnectors.
- Miniature circuit-breakers
- Fuses
- Modular built-in equipment for control, metering and measuring purposes

2.1.29 *Surge Arrester*

A protective device designed primarily for connection between a conductor of an electrical system and earth to limit the magnitude of transient overvoltages on equipment.

2.1.30 *Switchgear*

Electrical equipment switching devices for the purpose of carrying out one or more of the following functions: protection, control, isolation, switching and their combination with associated control, measuring, protective and regulating equipment Also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for use in connection with generation, transmission, distribution and conversion of electric energy.

2.1.31 *Transformers*

A device that is used to change the voltage in an alternating current (AC) circuit. Three kinds of transformers are identified taking into account the voltage level: The four main step down transformers which transform from HV (400 kV) to MV (22 kV) Oil transformers, which transform from MV (22 kV) to MV (6.6 kV) and located outside of buildings and dry transformers which transform from MV (6.6 kV) to LV (0.4 kV) and located inside buildings.

2.1.32 *UPS*

An uninterruptible power supply (UPS) system is designed to provide conditioned power which offsets the effects of adverse normal power. A static UPS consists of:

- a battery to provide continuous source of electrical power;
- a rectifier/charger to maintain battery charge and to provide input to inverter when utility power is available;

- an inverter to provide power to load during normal operation;
- a static switch ,to transfer load automatically and without disturbance between inverter and utility power,
- a manual switch to bypass the static switch for maintenance;
- input and output isolation transformers and filters to provide appropriate isolation and disturbance attenuation; and monitors, sensors, and control circuits.

2.1.33 Voltage Transformers

These reduce the voltage values from the point in the network where they are connected to proportional and manageable values, whilst separating measuring instruments, meters, relays etc. from the medium or low voltage circuit.

3 Acronyms

A complete list of Acronyme used within ITER Organization is available at ITER Abbreviations (ITER_D_2MU6W5), here follows a list of those frequently used in EDH:

AC	Alternating Current
BO	Blackout
CB	Circuit Breaker
CC	Control Cubicle
CD	Current Drive
CMF	Common Mode Failure
CT	Current Transformer
CWS	Cooling Water System
D/G	Diesel Generator
DC	Direct Current
DDD	Design Description Document
DP	Distribution Panel for 400 V loads located within buildings
EDG	Emergency Diesel Motor Generator
EDH	Electrical Design Handbook
EHV	Extra High Voltage, > 275 kV, not used at ITER
ELV	Extra Low Voltage, <50 V_{rms} or < 120 V DC (IEC Definition)
EM	Electromagnetic
EPS	Emergency Power Supply
EPSS	Emergency Power Supply System

FDS	Fire Detection and alarm System
FFS	Fire Fighting System
FO	Fibre Optic
FPS	Fire Protection System
FSS	Fire Suppression System
H&CD	Heating & Current Drive
HV	High Voltage, > 1000 V_{rms} or > 1500 V (IEC Definition), 400 kV level on ITER
HVAC	Heating, Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
ICD	Interface Control Document
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
IO	ITER Organization
IP	Investment Protection
IPEG	Integrated Plant Earth Grid
IV	Intermediate Voltage, 66 kV level on ITER
LC	Load Centre
LCC	Local Control Cubicle
LEP	Local Electrical Panel
LOSP	Loss of Off-Site Power
LTM	Construction/Long Term Maintenance
LV	Low Voltage, 5 – 1000 V_{rms} or 120 – 1500 V DC, 400 V level on ITER
MCC	Motor Control Centre
MP	Main 400V Distribution Panel located in LC
MPCB	Magnet Power Conversion Building
MPSSN	Magnet Power Supply Switching Network
MV	Medium Voltage, 6.6 kV and 22 kV levels on ITER

NBI	Neutral Beam Injection
NBPS	Neutral Beam Power Supply
OL	Ordinary Load
P&ID	Process and Instrumentation Diagram
PA	Procurement Arrangement
PBS	Plant Breakdown Structure
PEC	Prefabricated Electric Centre
PF	Power Factor
PHTS	Primary Heat Transport System
PID	Proportional, Integral and Differential Control
PID	Project Integration Document
PINI	Positive Ion Neutral Injector
PLC	Programmable Logic Controller
POS	Pulse Operation State
PP	Procurement Package
PPEN	Pulsed Power Electrical Network
PS	Power Supply
PSH	Plant System Host
QA	Quality Assurance
RCC-E	Règles de Conception et de Construction des matériels Electriques des îlots nucléaires
RF	Radio Frequency
RPC	Reactive Power Compensation
RPC&HF	Reactive Power Compensation and Harmonic Filtering system
RTE	Réseau de Transport d'Electricité (French Transmission Grid Operator)
SCADA	Supervisory Control And Data Acquisition
SCS	Supervisory Control System
SF6	Sulphur Hexafluoride
SIC	Safety Important Component
SIC	Safety Important Classification
S-ICD	System Interface Control Document

SR	Safety Relevant
SRD	System Requirements Document
SSEN	Steady State Electrical Network
SSPD	Steady State Power Distribution
SSS	Steady State 400 kV Substation
STM	Short term Maintenance
STS	Short Term Standby
TBC	To Be Confirmed
TBD	To Be Defined
TCR	Thyristor Controlled Reactor
TCS	Test and Conditioning State
UPS	Uninterruptible Power Supply
VT	Voltage Transformer
WBS	Work Breakdown Structure

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Electromagnetic Compatibility (EMC)

Contents

1 Purpose

This part of the Electrical Design Handbook provides the guidelines for the earthing and cabling of electrical and electronic systems and installations aimed at ensuring electromagnetic compatibility (EMC) among electrical and electronic apparatus or systems in the ITER side.

This technical document describes the minimum immunity of all the equipment to electrical noise and the maximum allowed emissions of electrical noise from the various types of equipment employed. The design of the electrical common bonding network is also provided.

2 Scope

This part of the Electrical Design Handbook is intended for use by installers and users, and to some extent, manufacturers of sensitive electrical or electronic devices and systems, and equipment with emission levels that could degrade the overall electromagnetic (EM) environment.

3 Definitions

AFNOR	L’Association Française de Normalisation
CEA	Commissariat à l’Énergie Atomique
CBN	Common Bonding Network
DA	Domestic Agency
ECH	Electron cyclotron Heating and Current Drive
EDH	Electrical Design Handbook
EED	Electrical Engineering Division
IDM	ITER Document Management
IEC	International Electrotechnical Commission
ICH	Ion cyclotron Heating and Current Drive
IO	ITER Organisation
ISO	The International Organisation for Standarization
LCZ	Loop Controlled Zone
NBI	Neutral Beam Injection
PA	Procurement Arrangement
PBS	Plant Breakdown Structure
PEC	Parallel Earthing Conductor
POP	Directorate for Plasma Operation
QA	Quality Assurance
RCC-E	Règles de Conception et de Construction des Matériels électriques des Centrales Nucléaires
SIC	Safety Important Class
SPD	Surge Protection Device
SRPP	System Reference Potential Plane
ZBBP	Zone Boundary Bonding Plate

For a complete list of ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations.

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[21] "EMC for Systems and Installations", Tim Williams and Keith Armstrong, Newnes 2000, ISBN: 0-7506-4167-3.

5 ITER Electromagnetic Compatibility (EMC)

The Electromagnetic Compatibility is the capacity of equipment or a system to be operated in their intended operational environment, within designed levels of efficiency, without causing degradation due to unintentional electromagnetic interference (electrical, magnetic or electromagnetic phenomena, either radiated or conducted).

Three main areas can be considered with regard to EMC:

- Emitters: the source of the disturbance, influenced by design of the device
- Coupling paths: influenced by the design of the earthing system layout and by geometry
- Victims: the sensitive equipment, influenced by design of the device

In order to assure EMC, three steps should be applied:

- At the source of disturbances: reduction of emissions
- At the coupling: reduction of couplings
- At the victim: increase of immunity.

This section specifies the necessary standards that are applicable to ensure reliable operation of the equipment when it is installed in the ITER environment. Then it describes the design of the bonding network.

The hazard presented in ITER and that should be minimized or mitigated by the earthing system include:

- Short circuits and earth faults originating in power supplies
- Induced currents from changing magnetic fields and plasma disruption
- Coupling from RF sources (mainly the ICH&CD) and Neutral Beam injection.
- VFD (Variable Frequency drive), large power rectifiers and large UPS (Uninterruptible Power supplies), mainly for currents higher than 100 A.
- Lightning effects.
- Dry-contact arcing for inductive loads.
- Failures in high, medium or low voltage systems.

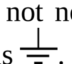
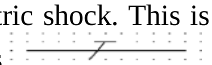
Important note:

The ITER Organization/EED will always be the final arbiter in any situation where justifications are offered for a failure to comply with any of the requirements of this document.

If ITER Organization/EED does not agree with a supplier that his justifications are sufficient, the supplier shall do whatever is required to comply with the requirements of this document.

5.1 Definitions and symbols

ITER Organization has adopted IEC Standards for electro-technical. This section contains the terms most commonly used in this document which are defined in the IEC 60050 (International Electro-technical Vocabulary, IEV) and their associated symbols:

- Earth: part of the Earth, which is in electric contact with an earth electrode and the electric potential of which is not necessarily equal to zero (IEC 60050-195-01-03). The IEC symbol (IEC 60617 S00200) is .
- Protective conductor (PE): conductor provided for purposes of safety, for example protection against electric shock. This is for example the green/yellow cable (IEC 60050-195-02-09) and its symbol is .
- Common bonding network (CBN): equipotential bonding system providing both protective-equipotential-bonding and functional-equipotential-bonding (IEC 60050-195-02-25). It is a set of metallic components that are interconnected to form the bonding network of the building. These components include the structural steel or reinforcement, metallic plumbing, AC power conduit, PE conductors, cable racks and bonding conductors. The CBN always has a mesh

topology and is connected to the earth. The IEC symbol (IEC 60617 S00203) is used for the CBN.

- Signal Reference Subsystem (SRS): A conductive sheet or cable network/mesh providing an equipotential reference for equipment (MIL-HDBK-419A). The IEC 60050-195-01-16 symbol is used: .This symbol will be used to represent the ‘0 V’. It maybe floating or not.

The following figure shows the correct use of the ITER symbols.

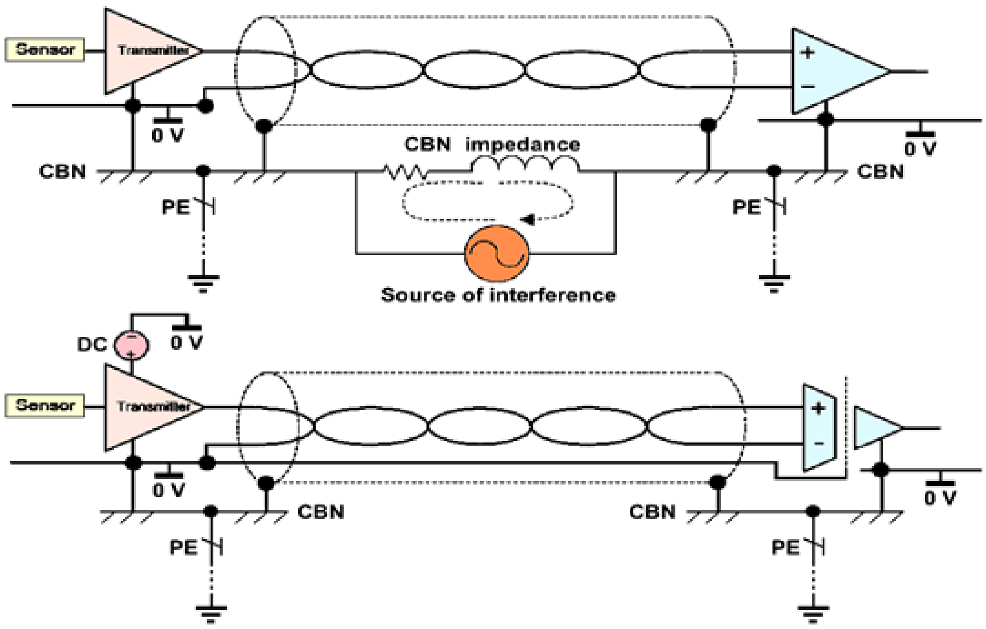


Figure 5-1 Correct use of ITER symbols: Earth, CBN, PE and Signal Reference.

5.2 Norms and Standards

This section lists the standards and norms that are applied in the design of the ITER Common bonding network.

- RCC-E: Design and construction rules for electrical equipment of nuclear islands.
- IEC 61000-5-2 Ed 1.0 (1997): EMC-Installation and mitigation guidelines - Earthing and cabling
- IEC 62305-1 to 4 Ed 1.0 (2006): Protection against lightning
- IEC 60364-5-54 Ed 3.0 (2011): Electrical installations of buildings. Selection and erection of electrical equipment- Earthing arrangements, protective conductors and protective bonding conductors[1].
- IEC 61000-6-2 Ed 2.0 (2005): EMC-Generic standards - Immunity for industrial environments.
- IEC 61000-4-16 Ed 1.1 (2002): EMC-Testing and measurement techniques - Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz
- IEC 61000-6-4 Ed 2.1 (2011): EMC-Generic standards - Emission standard for industrial environments.
- ITER test specification for conducted emissions in the frequency range 30 Hz to 30 MHz (ITER_D_43QDHR).
- ITER test specification for Magnetic field compatibility tests (ITER_D_47SBRU).

[1] In case of conflict between the IEC 62305-x and IEC 60364-5-54, the 62305 will be applied.

5.3 Summary of the EMC methods used

This section lists the summary of EMC methods to be used applied in the design of the ITER facility.

- Building re-bars are bonded to create a mesh in all concrete walls and floors in the technical areas of the Tokamak complex, with fixed bonding terminals provided on the ceiling and walls every 5 m. (see Section 8.2).
- The common bonding network (CBN) is meshed (cross-bonded) to create a MESH-CBN (in the in-air part, not in the vessel nor the cryostat, see Section 8.1) with the largest distance between bonds being 5 metres (see Section 8.2) at the Tokamak complex. This creates very many, very small loops in the MESH-CBN.
- EM Zoning is used for interference control within the Tokamak Complex (see Section 9).
- Galvanic isolation will be only used when absolutely necessary. In this case, no floating voltage reference (floating 0 V) will be common to several cables (see Section 8.2.1).
- Cable shields are all electrically bonded to equipment connector panels at both ends, and also to the MESH-CBN when crossing an EM Zone boundary (see Sections 5.4, 9 and 11.1).
- All instrumentation & control cables are all routed in conduits, ducts or sheet-metal cable trays, which are reliably electrically bonded at all joints and to the equipment connector panels at both ends, and also bonded to the MESH-CBN when crossing an EM Zone boundary (see Sections 5.4, 8.2, 9 and 11.1).
- Cables and other conductors are all segregated and routed according to the rules in Section 13.
- “In-vacuum devices” are shielded against high frequency fields (see Section 11.1)
- Wherever the signal connection permits, sensors shall use differential cables and differential (balanced) amplifiers (see Section 11.1).
- The CBN is never used as a return path for signal or power currents, it is only a path for stray (common mode) and fault currents. All signal and power conductors are provided with their own, independent, dedicated return conductors (see Section 8.2).
- Equipment immunity and emissions are controlled to specifications (see Sections 6 and 7 respectively).

5.4 Construction and installation issues regarding EMC

All the signal, instrumentation and control cables in the ITER facility outside of the bioshield (i.e. cable Classes S1, S2 and N1, as defined in Section 13) shall run inside covered metallic containments, either shielding metal conduits or covered sheet-metal cable trays that are electrically bonded to the equipment connector-plates at both ends of the cables, for example as shown in Figure 5-2 and Figure 5-3, and also bonded at all joints along their lengths, for example as shown in Figure 5-4.

Where shielded flexible conduit is not practical as a means of connecting cable trays to connector plates, the trays shall bond directly to the connector plates using the jointing techniques shown in Figure 5-4.

Electrical bonding shall be reliable and corrosion-free over the lifetime of the ITER installation, with no paint or any other insulating surface coating on bonded metal surfaces.

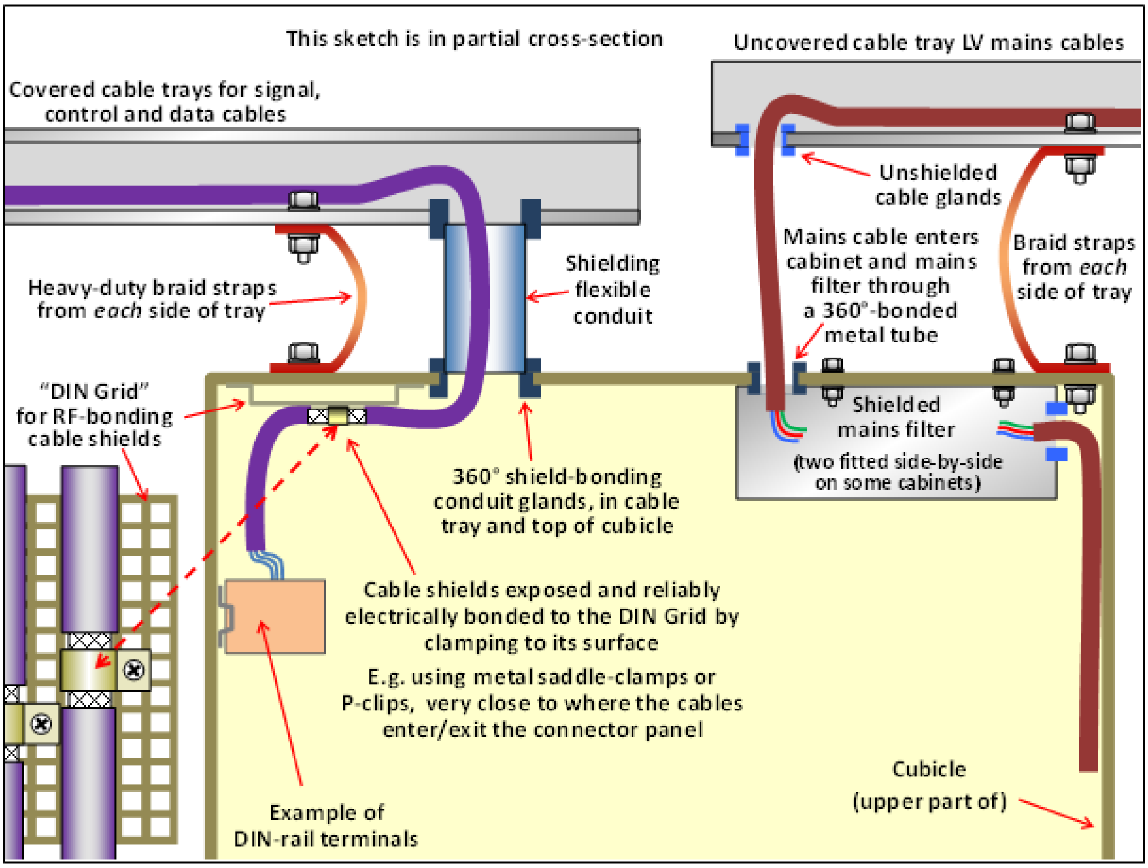


Figure 5-2 Electrically bonding all cable trays and terminating all cable shields to the equipment connection panels at both ends

The trays shall also be bonded to the MESH-CBN (see Section 8.2) at no more than 5 m (preferably less) spacing all along their lengths, using direct metal-to-metal bonding wherever possible, otherwise using short (< 0.5 m), wide (>25mm) braid straps from both sides of each tray.

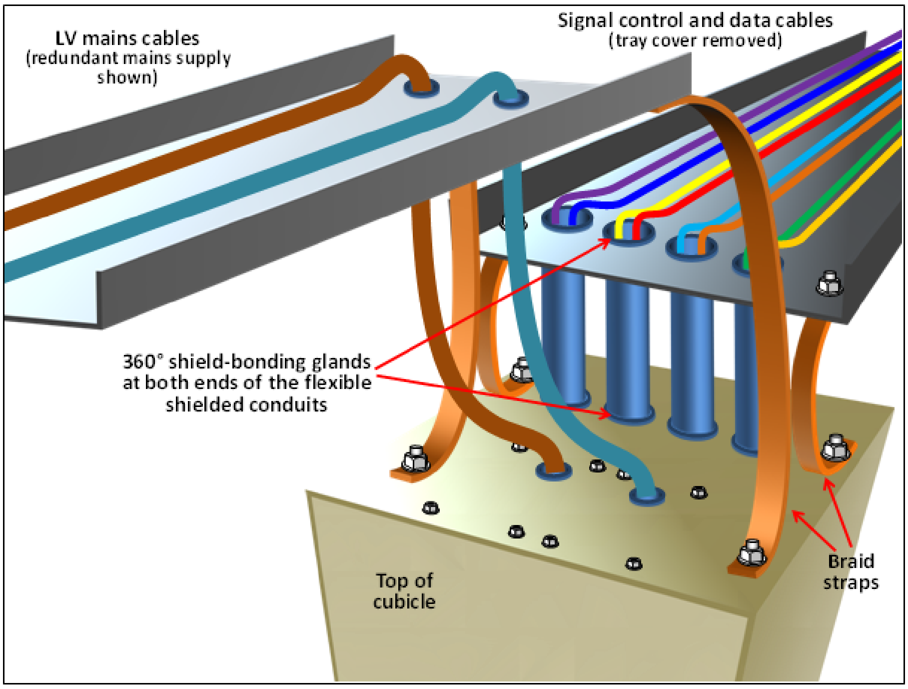


Figure 5-3 More details on electrically bonding all cable trays and terminating all cable shields to the equipment connection panels at both ends.

The trays' metal covers shall be screw-fixed directly metal-to-metal to their trays, to make reliable electrical bonds along both of their sides, every 500 mm (or less) directly metal-to-metal. Along each joint in a cover there shall be bonds every 50 mm (or less), with a minimum of two bonds.

Bright acid tin-plated or electrolytic zinc-plated (not galvanized) solid steel cable trays or ducts shall be used, with a highly-conductive surface (no polymer or other non-conductive passivation). Unfortunately Zincor, Zintec, and similar steels supplied already zinc-plated are unsuitable, because they use polymer passivation over their zinc-plating. Conductive trivalent chromium passivation treatments for electrodeposited zinc-base coatings are recommended (according to British Defence Standard 03-41 - Issue 1 – 2008).

Perforated trays or ducts shall be acceptable when they are sheet metal with circular perforations up to 10 mm diameter on a pitch of twice their diameter. Where the perforations are not circular, they shall run lengthways, be no wider than 10 mm, no longer than 50 mm, and the metal between perforations shall be at least 10 mm wide. Ladder and basket types of trays are only allowed for power distribution.

The surface conductivity shall be checked on every piece of cable tray or duct, including their covers and other accessories, using a low-contact-pressure conductivity probe, to check they are suitably conductive without requiring very high contact pressures.

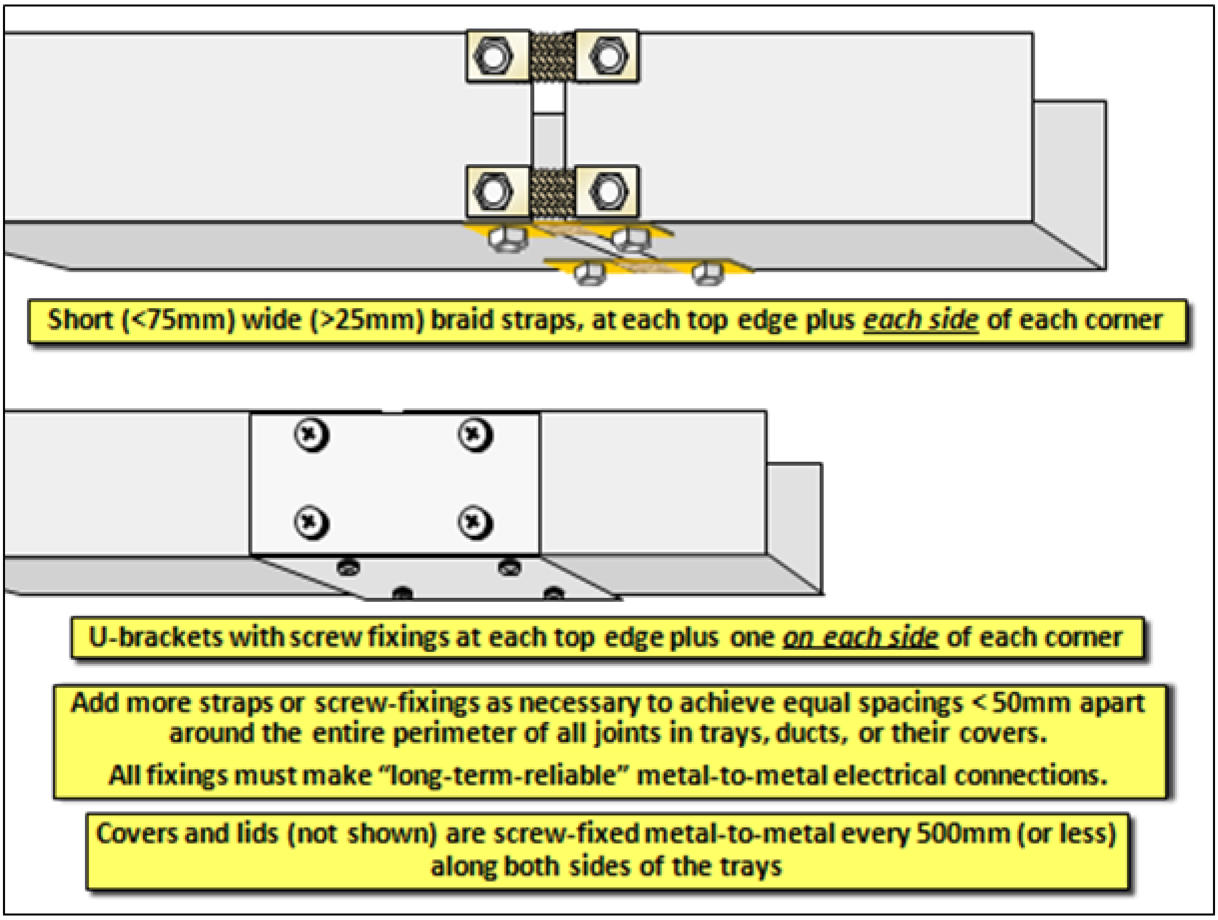


Figure 5-4 Bonding cable trays and their covers at joints. The U-bracket connection is preferred.

All signal cables shall also use shielded cables (e.g. braided, solid wall, semi-rigid, etc. not foil-wrapped) with the braid bonded circumferentially (sometimes called 360° bonding) directly to the cubicle grid at both ends, for example by using the saddle-clamps or P-clips shown in Figure 5-2 and Figure 5-3.

A Common Mode (CM) noise reduction of more than 60dB at frequencies over 400 kHz has been measured in real-life installations of this type, see Section 6.

This reduction effect relies upon mutual inductance and so becomes ineffective below some frequency, maybe a few hundred Hz. At these low frequencies, protection is created by the very low resistance of the MESH-CBN, plus adequate common-mode rejection specifications for all the sensor amplifiers, down to DC.

In the very few cases where there is no cubicle for a cable shield to bond to, it shall be 360° bonded directly to the MESH-CBN at a fixed bonding terminal (see Section 6.2) as near to that end of the cable as possible, with the shield continuing from that point to as near to the end of the cable as practical.

5.5 Evaluation of signal noise voltages caused by magnetic field variations

The loops in the MESH-CBN that are created outside of the bioshield will have a loop induced voltage due to the magnetic field variation (the document ITER_D_3BQBVY has the magnetic field simulation results). For a cable trays routed in the equatorial port cell, that create a loop with the MESH-CBN having a surface area ~50 m^2, the induced voltage due the magnetic flux variation is ~1 V_{peak}, having the magnetic field a time constant longer than 1 second.

The signal conductors and their shields and cable trays follow exactly the same routes, and so when there is a fluctuating magnetic field their induced voltages are the same to a high precision, and so the signal amplifiers see the same noise voltages on the signal conductors as they do on their local 0V references. This effectively means that induced differential-mode noise voltages are cancelled out at the amplifier inputs, the induced voltages all appear as common-mode.

The induced voltage during a plasma disruption for a cable running from the vessel ports into the cubicles area in the diagnostics building, with a length of more than 200 m is just 4.4 V. The differential signal amplifiers shall be able to withstand such common-mode voltages without harm or erroneous outputs, and this will be tested using IEC61000-4-16 Level 3 (which tests at 10 V common-mode, see Section 7). We would like to stress that the voltage difference between two cubicles cannot be computed as electrostatic signals.

The loops between parts of the CBN outside of the cryostat will have induced voltages during the magnetic field variations, resulting in eddy currents flowing in closed loops in the CBN’s structure. Those currents will produce a heating of less than 0.1 degree Celsius in the cable trays and cable shields, which could be considered negligible (see ITER_D_3TCLEB).

The effect of heating in the building structures has been evaluated (in table 4.2-4 of ITER_D_2FGN9P,), with a temperatures increase below of 0.7 degrees in the bioshield and below 0.1 degrees in the other structures. So we could conclude that the heating due to eddy currents is insignificant.

6 Equipment immunity requirements

6.1 General requirements for immunity

This section specifies immunity standard tests that shall be performed to the electrical and electronic equipment that will be installed in the ITER facility with the application of common mode disturbances to power supply, control, signal and communication ports. Those tests shall be performed on one sample device of the series delivered, those all have exactly the same design, components, software and build standard.

Immunity tests will be undertaken with a setup according to those guidelines. In case of contest, ITER’s Electrical Division will specify the actual setup and the relevant working conditions and criteria.

If any of the delivered devices in a series of a particular type differ in any way, however small in their design, components, software or build standard (including "minor" modifications, so-called "form, fit and function" replacement parts, "bug fixes", cable routing changes, etc.), then they shall be identified as Version 2, 3, etc. and the relevant series of tests (all that may be affected by the modification) shall be repeated on the new version.

Where a manufacturer believes that the changes do not warrant repeat of these tests, they shall provide ITER with comprehensive descriptions of the changes and technical justifications for not redoing some/all of the tests. If ITER does not agree, the full series of immunity tests shall be repeated on the new version.

All tests shall be carried out by independent test laboratories that have been assessed and accredited by a government-appointed National Accreditation Body as complying both with the current version of ISO 17025 and the test standards listed in this document. The test laboratory does not have to be situated in the same country as the supplier.

A complete set of test reports and certificates shall be provided to ITER when any devices are delivered, along with the accreditation schedule of the test lab used. Where new Versions are tested, their full set of test reports shall also be provided to ITER. There is no need for all of the tests to be performed at one laboratory.

6.2 Electromagnetic requirements for immunity

The Table 6.2-1 specifies the test standards to be complied with for all the electronics equipment in general and the ITER Safety Important Class (SIC) as defined in ITER_D_347SF3.

Equipment	Standard
All	IEC 61000-6-2 IEC 61000-4-16 (level 3, performance criterion A) Low frequency magnetic field – see Section 6.3
SIC[2]	IEC 61000-4-9 (level 4)[3] IEC 61000-4-10 (level 5)

Table 6.2-1 Immunity requirements

Figure 6-1 shows the overall requirement for conducted immunity from 0 to 80 MHz, and the immunity against common mode disturbances. These tests employ common-mode signals to test the immunity of the equipment, because residual common-impedance noise coupling via the CBN's small but real impedance results in some common-mode noise voltage at the victim equipment.

[2] Applies to SIC and associated cables that are no closer than 4 m to the external walls or roof of the Tokamak Complex. SIC and/or associated cables that are closer than this might need to comply with higher levels on these tests

[3] This level comes from ITER_D_65BB9Y, which will be reviewed when the Architect Engineer has completed the simulation of the lightning protection system.

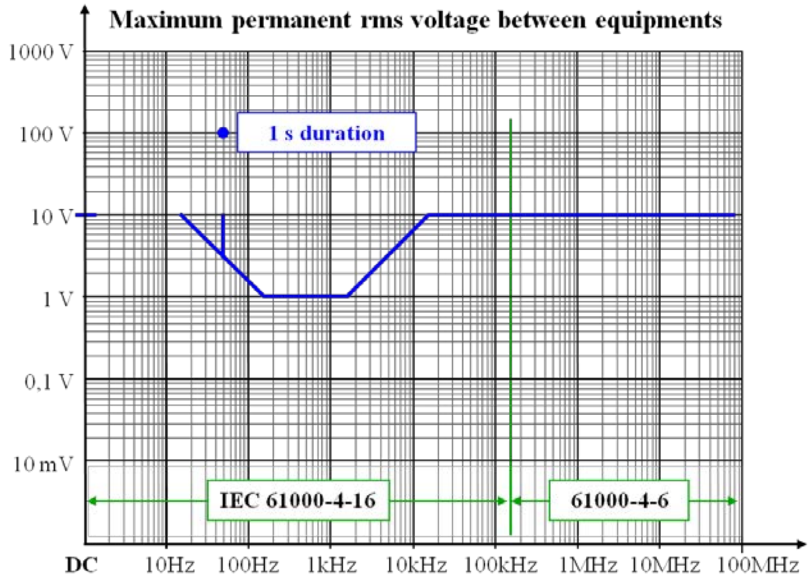


Figure 6-1 Immunity specification for the ports.

For short duration 50 Hz disturbances (1 second), the maximum common-mode voltage immunity requirement is 100 V (and a short-circuit current of 2 Amps). This test shall be performed for each port (a connector to mains, signal, data, etc.) of the equipment.

The IEC 61000-4-9 and IEC 61000-4-10 tests in Table 2.2-1 are not mandatory for ITER's non-SIC equipment, but equipment not certified with these standards at the test levels given, might not withstand the pulsed magnetic field generated by a lightning strike. It is left to the responsible of such equipment to decide whether to pass these tests, or suffer the consequences of the possible unreliability of their equipment.

All equipment, whether SIC or non-SIC, that – with their associated cables – will be located closer than 2 metres from the inner surfaces of the walls of the Tokamak Complex, might not be adequately protected from pulsed magnetic fields by the tests listed in Table 6.2-1. Where such equipment is SIC, or for other reasons the supplier wishes it to be reliably protected against pulsed magnetic fields caused by lightning strikes, the supplier shall contact IO/EED for its individual immunity specifications to be determined.

If an equipment does not fully comply with the specified standards, the manufacturer shall provide the actual immunity level and the corresponding performance criterion (for approval by ITER Organization), plus an explanation of the fundamental technical issue that prevents these tests from being passed.

Note that if there is no fundamental technical issue, then good EMC design and construction practices including EM mitigation such as shielding and filtering, and the use of good quality components for enclosures, connectors and cables, will always allow these tests to be passed, and this limits the excuses that a supplier can employ for not complying with these tests.

6.3 Low-frequency magnetic field immunity

The magnetic fields (both static and variable) to which equipment is subjected may influence the reliable operation of equipment and systems installed in the Tokamak building.

The tests described in this section are intended to demonstrate the immunity of the equipment when subjected to variable and static magnetic fields related to the specific location and installation condition of the equipment in the Tokamak building (during all plasma scenarios).

Table 6.3-1 below describes the immunity tests for **fluctuating magnetic field**, according to IEC 61000-4-8, which shall be passed at Performance Criterion A (i.e. full specification maintained during and after the test) by each item of electrical and/or electromechanical and/or electronic equipment, of whatever complexity or function, located in the Tokamak complex. The field strengths applied does not correspond with any of the specified levels in 61000-4-8, and are approximately double the maximum field strengths expected to be encountered in ITER. (The doubling is to provide some "engineering margin" to allow for degradation in immunity performance over years of use.)

Location	Continuous Duration	Short-duration (3 sec)
Port-cell	24 mT/s (H=60 A/m)	80 mT/s (H=200 A/m)
Tokamak building (except port cells)	2.4 mT/s (H=6 A/m)	8 mT/s (H=20 A/m)

Table 6.3-1 Immunity specification against magnetic field variation, for continuous and short duration. Magnetic field variation peak values are specified.

If an item of equipment does not meet this specification, the manufacturer shall provide evidence of passing the tests at a lower level of 50Hz magnetic field, for approval by ITER Organization. If approval is not granted, the equipment shall not be accepted until it has been shown to comply with the specified levels in the table above.

Where an item of electrical and/or electromechanical and/or electronic equipment includes anything with a time-constant of longer than 7 milliseconds[4], the above 50Hz tests will not be appropriate and the test frequency shall instead be a 1 Hz sine wave with the magnetic field test levels (H value) increased to 50 times the values in the above table (keeping the same magnetic field variation rate).

Regarding **static magnetic field**, no special requirement is needed for the equipment located in the diagnostics/tritium building, and for the equipment in the Tokamak building with magnetic field lower than 5 mT (see the maps from ITER roombook Magnetic Field Zoning).

The equipment located in areas where the static magnetic field is between 120 mT - 5 mT (port-cells to walls of Tokamak building), either the equipment is compliant with this field or a specific test has to be prepared to certify the correct operation of the equipment (the equipment has to be tested for a **field strength that is double** the values specified in the ITER roombook). The magnetic field compatibility tests are specified in the document ITER_D_98JL4W.

For equipment that is not electrical or electronic, and has parts that – when installed – can move relative to each other or to its mountings, or employs electrically conducting and/or magnetic fluids (including powders and dusts), a design analysis shall be provided concerning its susceptibility to the effects of the maximum levels of fluctuating and static magnetic fields up to 50Hz in the environment where it will be installed, according to maps from ITER roombook.

Each assessment shall predict whether the field strengths specified in maps from ITER roombook could have any significant effects on any of the equipment's characteristics or functional performances, and shall include a clear and easy-to-follow description of the reasons for each assumption, and detail each calculation.

ITER Electrical Division staff will audit each assessment, and if they are not convinced by a technical argument for "no significant effects" shall require specified design changes, and/or static and/or fluctuating magnetic field tests to be carried out on the equipment. Any such tests shall be passed without significant degradation in characteristics or performance.

[4] The 7 ms corresponds to a reduction in amplitude response of 3 dB at 50 Hz (for system with a single-pole frequency response).

7 Equipment emissions requirements

7.1 General requirements for emissions

This section specifies the emissions standard tests that shall be performed to all devices that will be installed in the ITER facility. The stability of the plasma makes it necessary to have an effective control of low frequency EMI; that is the reason why low frequency emissions are controlled from 50 Hz to 30 MHz (and not only in radio / TV bands above 150 kHz, as for usual civilian rules).

Those tests shall be performed on one sample device of the series delivered, which all have exactly the same design, components, software and build standard.

EMI emission measurements will be undertaken with a setup according to those guidelines. In case of contest, ITER's Electrical Division will specify the actual setup and the relevant working conditions.

If any of the delivered devices in a series of a particular type differ in any way, however small in their design, components, software or build standard (including "minor" modifications, so-called "form, fit and function" replacement parts, "bug fixes", cable routing changes, etc.), then they shall be identified as Version 2, 3, etc. and the relevant series of tests shall be repeated on the new version (all tests which may be affected by the modification).

Where a manufacturer believes that the changes do not warrant repeat of these tests, they shall provide ITER with comprehensive descriptions of the changes and technical justifications for not redoing some/all of the tests. If ITER does not agree, the full series of emissions tests shall be repeated on the new version.

All tests shall be carried out by independent test laboratories that have been assessed and accredited by a government-appointed National Accreditation Body as complying both with the current version of ISO 17025 and the test standards listed in this document. The test laboratory does not have to be situated in the same country as the supplier.

A complete set of test reports and certificates shall be provided to ITER when any devices are delivered, along with the accreditation schedule of the test lab used. Where new Versions are tested, their full set of test reports shall also be provided to ITER. There is no need for all of the tests to be performed at one laboratory.

7.2 Emissions requirements

If an equipment does not meet the complete standard required, the manufacturer shall provide the measurement of the emission levels (conducted and radiated), for approval by ITER Organization. If approval is not granted, the equipment shall not be accepted until it has been brought within the specified limits.

The tests methods to be employed when complying with the emission specifications described in this section are given by ITER_D_43QDHR. The emissions limits are given below, for the different types of equipment and their different types of cables. The emission limits are based on the following standards:

- MIL STD 461F, method CE 101-2
- IEC 61000-6-4

The other emissions tests and limits for ITER equipment are the Class A radiated limits according to CISPR 11 Edition 5.1 (2010) (or EN 55011 Edition 5.1, 2011).

7.3 Low Voltage equipment (V < 1 kV)

The emission limit for any equipment operating with an input current lower than 1 A at 50 Hz per phase is shown in figure below. This test shall be applied to the mains input and any signal or output cable, according to document ITER_D_43QDHR.

The limit from 50 Hz to 10 kHz decreases linearly with a slope of 20 dB per decade from 120 dBµA to 74 dBµA. From 10 kHz to 150 kHz, the limit decreases linearly in log-log from 74 dBµA at 10 kHz to 45 dBµA at 150 kHz. The limit from 150 kHz to 50 kHz is 45 dBµA, and from 150 kHz to 30 MHz is 39 dBµA.

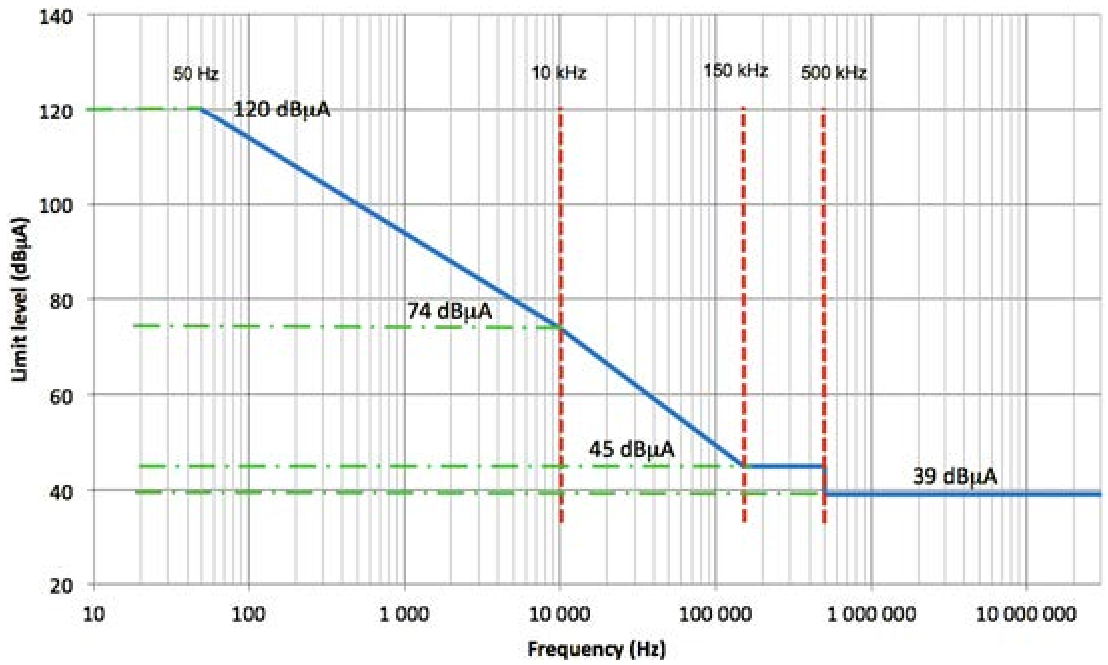


Figure 7-1 EMI current for LV equipment with an input current per phase at 50 Hz lower than 1 A and in common mode current for any other (signal or output) cable.

For equipment operating with an input current at the power frequency greater than 1 A, the limit for the mains input from 50 Hz to 10 kHz, as shown in Figure 7-1, will be relaxed by 20*log(I) (I = current at mains frequency). The limit between 10 kHz and 150 kHz decreases linearly in log-log from [74 + 20 log (I)] dBµA to 45 dBµA. The emission limits in the rest of the spectrum remain unchanged (from 150 kHz to 30 MHz). During the measurement, the relaxation will be adjusted at the actual 50 Hz current value (not the RMS value of the input current including all its harmonics and inter-harmonics).

The following figure shows the mains input emission limits for an equipment with input current at 50 Hz larger than 1 Amp (10 Amps in this example).

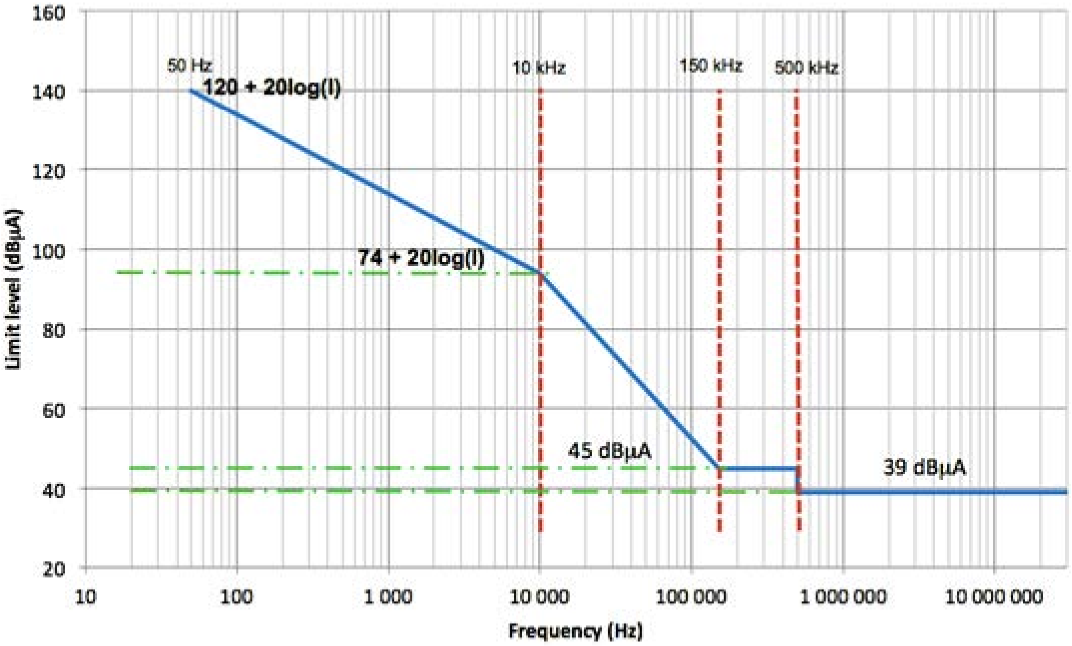


Figure 7-2 EMI current for mains input of LV equipment with an input current from 1 to 100 Amps (here 10 Amps)

The limit at 50 Hz is [120 + 20log (I)] dBµA decreasing to 10 kHz with a slope of -20 dB/decade. From 10 kHz to 150 kHz, the limit is a straight line in log-log. The emission limit from 150 kHz to 500 kHz is 45 dBµA, then 39 dBµA from 500 kHz to 30 MHz.

For equipment with a maximum input current larger than 100 A, the mains input emissions limit between 150 kHz and 30 MHz will be relaxed by 10 dB. The relaxation of 20*log (I) (I = current at mains frequency) between 50 Hz to 10 kHz is also applied. The following example shows the emission limits for equipment with an input current of 200 Amps.

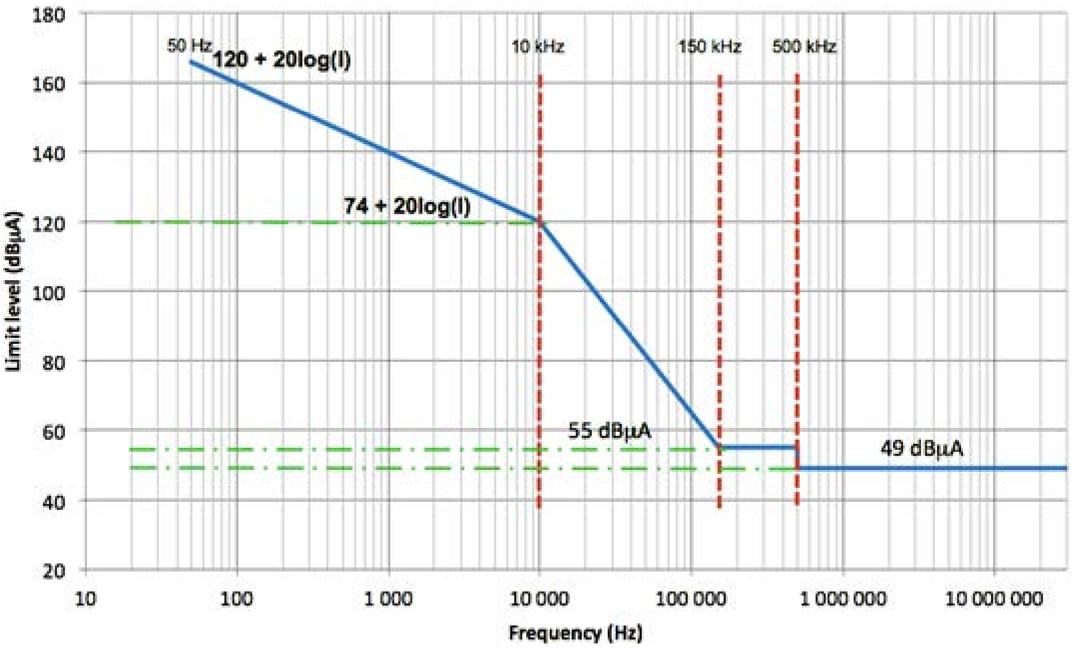


Figure 7-3 EMI current for mains input of LV equipment with an input current over 100 Amps (here 200 Amps).

The limit at 50 Hz is [120 + 20log (I)] dBµA, decreasing to 10 kHz with a slope of -20 dB/decade. From 10 kHz to 150 kHz, the limit is a straight line in log-log. The emission limit from 150 kHz to 500 kHz is 55 dBµA, and from 500 kHz to 30 MHz is 49 dBµA.

7.4 High Voltage (> 1 kV) equipment

The common mode current for any cable of a MV equipment is defined by figure below.

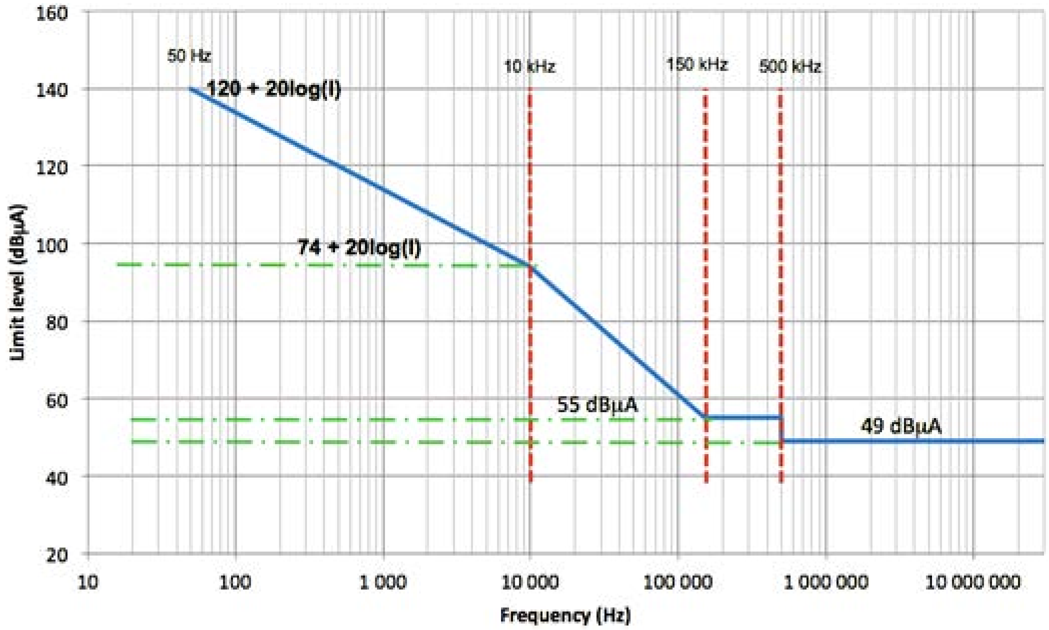


Figure 7-4 Emission limits of a MV equipment (here with 10 Amps per phase)

7.5 DC and 60 Hz equipment

Possible DC or 60 Hz equipment will follow the same EMI limits (as for 50 Hz equipment, with the same relaxations).

8 Earthing zones

The ITER facility is a very complex system, with very severe electromagnetic disturbances. For this purpose, two earthing topologies are implemented in the Tokamak complex:

- MESH-CBN: where a mesh-bonded CBN (Common Bonding Network) topology is implemented. This zone covers all Tokamak complex, except the vacuum vessel and the inside the cryostat: i.e. all of the in-air parts. The MESH CBN is described in Section 8.2.
- LCZ: where a single point earthing topology is implemented, and loops are controlled (Loop controlled Zone, LCZ). Large close loops in this area could generate high induced currents which could disturb the plasma and magnetic measurements, and they could damage some structures by joule effect. This area comprises the vacuum vessel and the inside of the cryostat: all the in-vacuum parts.

When conductors are connected to the boundary (cryostat or vessel ports), the interference current flowing on the conductor is transferred to the cryostat (or vessel port). This current will typically flow on the surface to which the conductor is connected, as long as the thickness of the metal is much larger than the material’s skin depth at that frequency. In this manner, currents flowing on external conductors may be diverted to the external surface of the cryostat. That layout is automatically implemented in ITER, using the vacuum feedthroughs which isolate the in-vacuum and in-air sides, transferring all interference currents to the cryostat.

The following figure shows the bonding zones for ITER.

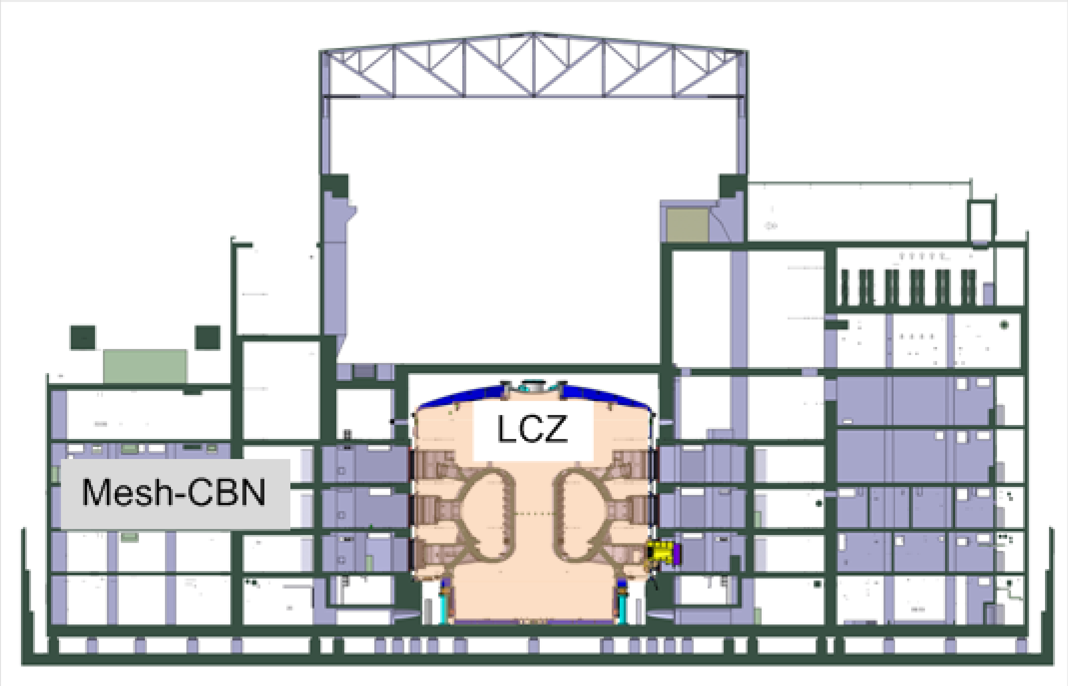


Figure 8-1 ITER earthing topologies

8.1 The Loop Controlled Zone (LCZ)

A "Loop Controlled Zone" (LCZ) is established in close proximity to the ITER tokamak where the electromagnetic environment is severe and where the presence of induced loop currents could interfere with plasma operations. This zone is defined to encompass the in-vacuum region inside the cryostat and the vessel ports.

Several aspects of tokamak operation create the potential for misoperation and/or damage to/from electrically conducting and/or ferromagnetic structures, objects, and apparatus inside this zone, including:

- high magnetic field;
- time-varying magnetic field due to plasma initiation, plasma scenario, plasma disruption, and fast discharge of superconducting magnets;
- time varying magnetic field and capacitive displacement currents driven by magnet AC/DC converter switching;
- high currents and/or voltages in case of faults in the magnet circuits;
- leakage from radio frequency heating systems.

Possible misoperation and damage effects include:

- excess current flow in and/or between conductors, conducting objects, or conducting structures causing localized arcing;
- excess force on conductors, conducting objects, or conducting structures due to current flow in magnetic field (Lorentz Force);
- excess force on objects with ferromagnetic content due to gradients of magnetic field;
- excess heating on conductors, conducting objects, or conducting structures causing damage and/or unanticipated heat load to cryogenic system;
- excess noise on diagnostic or instrumentation and control (I&C) systems;
- excess voltage imposed on diagnostic or I&C systems in fault modes;
- error in magnetic field at plasma prior to plasma initiation and/or during plasma operations.

To ensure proper operation of ITER, the design of all components installed or passing through the LCZ shall be reviewed and approved by the IO/POP to ensure conformance with the requirements given herein.

8.1.1 General Design Guidance

8.1.1.1 Earthing

All electrical conducting objects within the LCZ shall be electrically connected to earth via a low impedance connection which limits the potential to earth to < 50V. This level is well below the Paschen minimum breakdown voltage (~150V) which could exist inside the LCZ.

8.1.1.2 Earthing Reference

The cryostat is a thick wall axisymmetric cylindrical structure with top and bottom lids, constructed of stainless steel. It does not include any electrically insulating breaks and it will be bonded to the earthing grid of the tokamak building at multiple locations. As such it is will be nearly perfect equipotential surface under all foreseeable conditions. Therefore they shall serve as the earthing reference, or common earthing plane, for all equipment within the LCZ. Also, the cryostat will never significantly raise its potential voltage (< 1 V) regarding the MESH-CBN (see ITER_D_438TKG).

8.1.1.3 Ferromagnetic Effects

Materials which exhibit ferromagnetism will experience a force proportional to the gradient of the local magnetic field, and will cause a distortion of the magnetic field which could have a deleterious effect on plasma diagnostics and/or plasma operations. All materials (including welds) shall be tested for relative permeability μr. No materials with $\mu r > 1.03$ shall be permitted without approval by the IO/POP based on analysis of force and field error.

8.1.1.4 Induction Effects

The time-varying magnetic fields will generate an electromotive force (EMF) which will drive currents in conducting objects and structures. This includes eddy currents in solid objects as well as loop currents in conducting paths which link magnetic flux. The time-varying magnetic fields originate from the following events:

- plasma scenario (slow rate of change of poloidal field with full flux swing)
- plasma control (moderate rate of change of poloidal field with oscillating flux swing)
- plasma initiation (fast rate of change of poloidal field with partial flux swing)
- magnet fast discharge (fast rate of change or poloidal and/or toroidal field with full flux swing)
- plasma disruption (very fast rate of change of poloidal field with partial flux swing)

In addition to the above the harmonic content of the AC/DC converter voltage applied to the superconducting magnets could produce a small oscillating current and corresponding magnetic field oscillation at integer multiples of 300 Hz.

For any object or loop the induced current and consequential force, heating, and field error will depend on the location and geometry of same and which of the above events is the driver.

Induction of loop currents can be minimized by avoiding closed loops which link net flux. Note that flux linkages with the poloidal field are of prime importance due to the many related events and the extend of the poloidal field, but that flux linkages with the toroidal field must also be considered due to its variation during fast discharge and the fact that there is a finite region inside the LCZ which links the toroidal field which tends to extend beyond the bore of the Toroidal Field coils in the space between coils.

Induction of eddy currents in solid objects can be minimized by introducing breaks in the objects, e.g. slits in a plate.

The basic features of the tokamak at the boundary of the LCZ, namely the vacuum vessel, its ports, and cryostat, have been designed with induced currents taken into account. Also, the earthing of the Vacuum Vessel is implemented via the galvanic connection between its ports and the cryostat (the earthing reference).

Other features which need to be assessed in this regard include A single earthing path shall be provided in this area for each electrical circuit and structural or other metallic item, other than the cryostat itself, and the vacuum vessel. Parallel earthing paths creating low-resistance loops for induced currents must be avoided in this LCZ. The single-point-earthing concept implies that electrical insulation shall be provided between all metallic items earthed with different conductors. Occasional contacts between such items shall be detected before the operation starts.

The single-point-earthing concept implies that voltage differences may be present between nearby frames and structures.

Within the LCZ, double and multiple earth connections may be accepted with analysis provided on a case by case basis, and it shall be authorized by the Electrical Division. The main criteria shall be:

- To prevent excessive eddy currents flow in inadequate conductors,
- To prevent excessive electromagnetic forces,
- To limit eddy current losses in the cold structures,
- No impact on the magnetic measurements.
- No impact of error fields in plasma start-up and operation.

8.1.2 Isolation standoff voltages

Loop voltages created by changing magnetic fields from a plasma disruption or coil breakdown could result if ground loops are not properly isolated or prevented.

Any in-vacuum equipment, which has a metallic connection with the cryostat, the mechanical structure must be electrically isolated from any earth for 1 kV DC and 3 kV DC test voltage (short duration).

8.1.3 Diagnostic devices

All the diagnostic devices in-vacuum (mainly located in the vessel ports) shall be protected by an RF shielded enclosure, whenever possible (it is not possible for devices in direct contact with the plasma). This enclosure shall be electrically bonded to the vessel port. The cables connecting the device and the vacuum feedthrough shall have an overall shield or a flexible metallic conduit, which will be frequently bonded to the vessel port with clamps or similar connections, for both EMC and thermal relief, minimizing the surface between the cable and the port. The shields will be circumferentially bonded on both ends. See section 11 for more details.

In case of an earth fault involving a diagnostic sensor or cable, such a flash over from a poloidal coil connection to a sensor or to a cable, fault currents will flow via the vessel ports and the cryostat, as the cables are frequently bonded to the vessel port, and the resistance of a cable shield is several orders of magnitude higher.

8.1.4 Routing

The routing of cables and other conductors inside the cryostat, and in the vessel ports, shall be done in a radial-poloidal plane, as this orientation will cut the minimum magnetic flux, minimizing the induced currents and magnetic forces. Toroidal routing shall be avoided/minimised wherever possible. If a toroidal routing is necessary, it shall be routed as far away as possible from the center of the Tokamak.

All cables and conduits shall be routed as far away as possible from all noise sources (e.g. the plasma, ICH, ECH, magnet system, etc.) and shall also be routed as close to the outer wall of the cryostat as possible.

8.2 The Meshed Common Bonding Network (MESH-CBN)

A MESH-CBN [1], [9], [10] minimizes the common impedance coupling (due to the reduction of the common impedance between equipment), minimizes the field coupling (reduction of loop surfaces), and increases the immunity due to its low transfer impedance.

For these and other reasons, all items of "natural" metalwork such as metal cladding, cable trays, coil power supply busbar casings, pipes, ducts and conduits shall be electrically connected together ("bonded"). This bonding shall be direct metal-to-metal where practicable, but where this is not practical they shall be bonded using 50 mm wide (or wider) tinned copper braid straps or busbars, or round conductors, each having a minimum copper cross-sectional area of at least 25 mm^2, with lengths that are as short as is practicable in each instance, as shown in Figure 8-2.

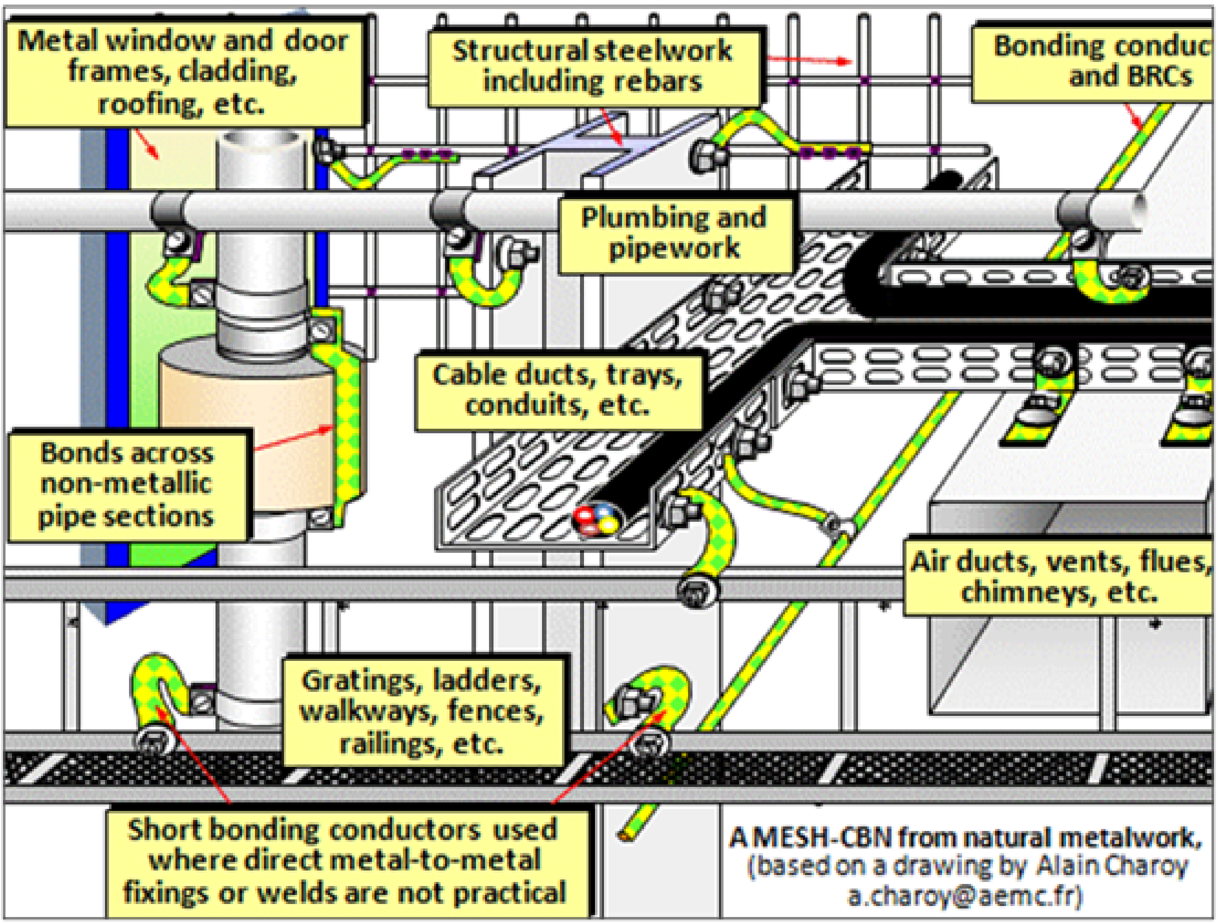


Figure 8-2 Three dimensional MESH-CBN using "natural" (i.e. existing) conductors.

These bonding conductors shall run both vertically and horizontally to create a complete conductively-meshed volume throughout each Technical Area in the Tokamak Building (outside of the vessel and the cryostat, i.e. outside of the LCZ, see 8.1).

Each meshed volume shall connect to as many of the fixed bonding terminals in the concrete walls and floors on all sides of its Technical Area as is possible.

The maximum vertical or horizontal spacing between bonding conductors anywhere in a meshed volume shall be 4 m, but wherever practicable the natural metalwork items shall be located and/or routed so as to permit smaller mesh sizes to be created between them.

The aim shall be to achieve a mesh size of no greater than 2 m everywhere, except where access requirements make this impractical. There is no minimum mesh spacing, but there is no point for the ITER project in going below a mesh size of 750 mm (e.g. bonding to each side of an 800 mm wide/deep cubicle).

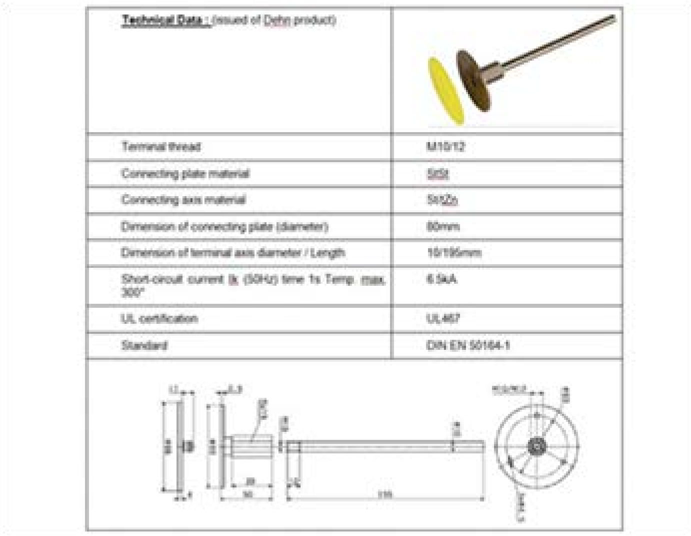
This MESH-CBN will provide the optimum return paths for the common mode EMI currents naturally circulating in cable shields and other metallic objects, thereby improving EMC.

Neither the MESH-CBN, nor any part of it, or anything described as an “earth” or “ground” shall ever be used as an electrical return path for any signals, control or instrumentation of any type; or as a return path for DC or AC power at any voltage or current level.

The building concrete re-bars will be bonded creating a grid of 1x1 m in the walls and floors of the Tokamak Port Cells and NeutralBeam Cell in the Tokamak building (see ITER_D_97ZQ3R) and 5x5 m for the rest. The Tokamak B2 floor has a 5x5 m grid.

Bonding between the rebar mesh in the concrete walls and floors, and everything else in the MESH-CBN, will be achieved by the following method:

- “**Fixed Bonding Terminals**” (see Figure 8-3) or similar[5], on a maximum 5 m square[6] spacing all over all of the walls and ceiling, in technical rooms[7].



Technical Data : (issued of Dehn product)	
Terminal thread	M10/12
Connecting plate material	StSt
Connecting axis material	SttZn
Dimension of connecting plate (diameter)	80mm
Dimension of terminal axis diameter / Length	10/195mm
Short-circuit current Ik (50Hz) time 1s Temp. max. 300°	6.5kA
UL certification	UL467
Standard	DIN EN 50164-1

Figure 8-3 Example of a proprietary “fixed bonding terminal”. A different “fixed bonding terminal” could be chosen without lightning requirements which could be easily welded into the re-bars.

The MESH-CBN and associated cable routing improves the common mode immunity by a considerable amount. Moreover, the Tokamak complex will be divided into different protected “EM Zones” (see Section 9), which require bonding and/or electromagnetic mitigation techniques to be applied to all conductors (whether carrying electrical or electronic signals or not (e.g. pipes for gases and fluids, structural steelwork, etc.) at the boundary of every Zone, as described in Section 9 “Site EM zoning for EMC” below.

A correctly-implemented MESH-CBN significantly reduces the amount of noise picked-up from induced currents in its loops, and also protects the electronics from damage due to any possible fault currents in the CBN.

5 The fixed bonding terminals do not need to withstand lightning currents.

6 The fixed bonding terminals could be replaced by embedded plates, only if the embedded plates are electrically connected to the concrete re-bar system.

7 The non-technical rooms shall have a raw of fixed bonding terminals spaced 10 m in the walls.

As described in Section 8, all instrumentation&control cables shall be routed in covered metal trays or covered ducts that are circumferentially bonded (using multi-point bonding with bond spacing < 100mm if necessary) at all joints and both ends as shown in Figure 5-2 through Figure 5-4. The metal trays and ducts will form part of the MESH-CBN, bonded together at least every 5 m and every 2 m or less where this is practicable, and the items of equipment at both ends of every cable shall have their metal chassis/frames/enclosures bonded to the MESH-CBN using fixed bonding terminals or embedded plates (Figure 8-3).

Also as described in Section 5.4, signal cables will all also have braid shields that are circumferentially bonded to the connector panels at both ends, with no breaks or gaps in their shields along their lengths.

With a MESH-CBN, even fault currents as high as, say, 100kA would spread widely amongst the various metal structures, and it would be surprising to find even 100 A in any one part of the CBN, such as a given cable tray (with the exception of the coil power supply busbar casings during a busbar double-earth-fault).

The MESH-CBN takes advantage of so-called “natural” metalwork (cable shields, structural steelwork, cable supports, the vacuum vessel, cable trays, etc.) and pipework. Figure 8-2 showed an example of three-dimensional mesh bonding in a typical industrial site’s CBN, and Figure 8-5 through Figure 8-7 show some examples of recommendations for bonding natural metalwork, during the improvement of an existing synchrotron installation.

In Figure 8-5 through Figure 8-7, the colour lines drawn onto the photograph of this part of the synchrotron are meant to represent where short braid straps are to be fixed to electrically bond the various metal parts together.

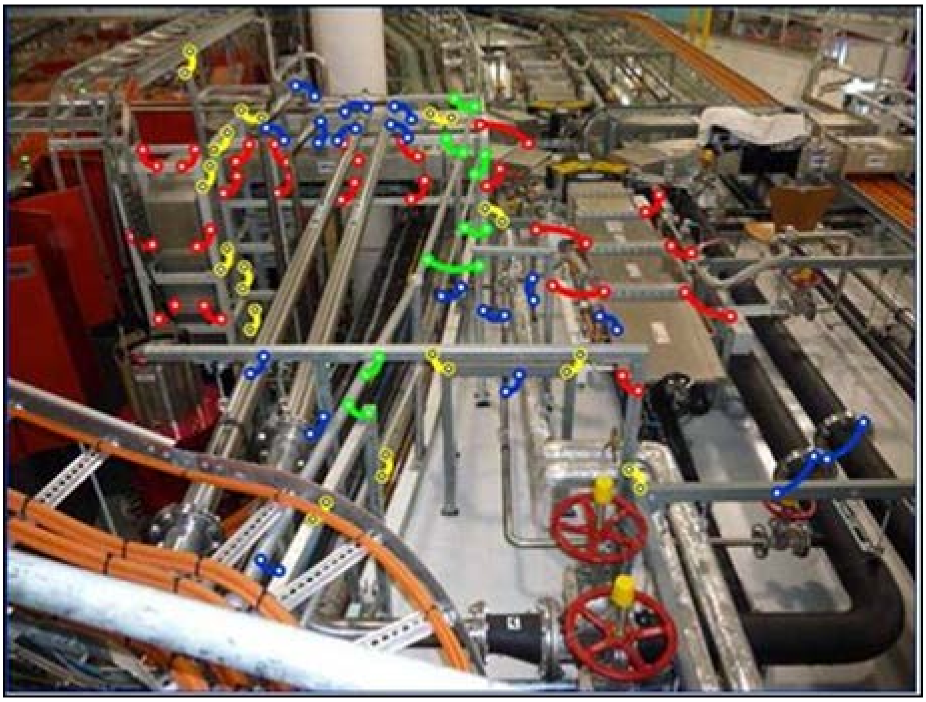


Figure 8-4 Examples of bonding natural metalwork, on an existing synchrotron, #1.

Figure 8-5 Examples of bonding natural metalwork, on an existing synchrotron, #2.

Figure 8-6 Examples of bonding natural metalwork, on an existing synchrotron, #3.

The cubicles (each 800 x 800 x 2000 mm) for the instrumentation and data acquisition are located in the Tokamak complex: ~620 cubicles in Tokamak building, ~250 cubicles in Tritium building and ~800 cubicles in diagnostics building. The diagnostics building is located on one wing of the Tokamak building, and the Tritium building is located on the opposite wing. The longer cables run from the port cells to the diagnostics building. A typical cable length from the vacuum vessel to a cubicle is ~150-250 m.

Cubicles require a very well-meshed floor across their entire area. Continuous sheet-metal flooring is the best method to use for this, but is considered impractical (at the moment), and a metal raised floor is not being considered (at this stage of the project) either. Instead, the building rebar mesh in the Tokamak complex walls and floors will be used as a reference potential plane, and as mentioned earlier, all the cubicles shall be electrically connected to it by the embedded plates they are mounted upon, see Figure 8-4.

A tinned copper braid strap having a width of at least 50mm and a copper cross-sectional area of at least 25 mm2 shall electrically connect one side of the cubicle's base frame to the nearest fixed bonding terminal, using the shortest practicable length of strap.

Where the length of the braid strap from a cubicle to the nearest fixed bonding terminal has to be longer than 500mm, two braid straps shall be used. They shall be connected to opposite sides of that cubicle's base, and each shall connected to its nearest fixed bonding terminal. Each strap shall, as before, be as short as practicable.

It may be practicable to use the metal support structure of the raised floor as part of the MESH-CBN. In this case the cubicles' bases would bond directly or via short braid straps to the raised floor's metalwork, and the raised floor's metal structure would in turn be bonded to fixed bonding terminals in the concrete below. Each such scheme shall be assessed for its suitability at the proposal stage by ITER's Electrical Division, before any implementation, and decision taken as to how best to achieve the required bonding.

As shown in Section 9, the Tokamak Complex is divided into a number of "EM Zones", and any/all conductors (e.g. cable trays or ducts, cable shields or armor, gas and liquid pipes, air ducts, structural steelwork, etc.) enter or exit an EM Zone shall be bonded to the MESH-CBN at the point where they cross its Zone Boundary, and then shall be bonded as often as practical (but not less than 2m apart) inside a Technical Zone.

Signal and power conductors cannot, of course, be directly bonded to the CBN, so instead shall all be indirectly bonded at every Zone Boundary using one or more EMC mitigation measures, including:

- Bonding of the cable's overall shield
- Filtering
- Surge suppression
- Galvanic isolation (e.g. transformers, fiber-optics)

Any metal framework or supports shall be electrically bonded to the MESH-CBN, and also electrically bonded to each other, following the general MESH-CBN principles for the site as a whole. Any metal panels in the walls or floors should be electrically bonded to the other side-panels, using screws or other metal fixings that have a conductive surface and make a reliable corrosion-protected electrical bond to the surfaces of both of the panels, every 1 m (or less) around their perimeters

All shielded cables entering reaching a cubicle shall have their outer shields "360° bonded" as described in Section 5.4 and shown in Figure 5-2 and Figure 5-3 to the cubicle's connector panel. Where possible, a cable's shield shall continue inside the cubicle past its first bonding point, to connect (ideally using "360° bonding") to an electronic module inside.

In addition, the low voltage power distribution cable shall be filtered at its entry via the connector panel, at each cubicle, using an effective filter that achieves >40 dB (or more) attenuation of CM (that filter manufacturers call "asymmetric") from 100 kHz to 30 MHz (or more) and DM (that filter manufacturers call "symmetric") over the frequency range from 100 kHz (or less) to 10 MHz (or more).

Special care shall be taken with the installation of this filter – it shall be reliably metal-to-metal bonded at two points at least to the cubicle's connector panel, at the first opportunity for the incoming power cable.

Special care shall also be taken with the routing of the un-filtered and filtered LV cables, in order to minimize the pickup noise or the coupling between both cables, by fully applying the cable classification and segregation rules in Section 13.

8.2.1 Exceptions

Insulating breaks should be avoided on ITER systems where possible. The installation of those insulating breaks shall be authorized by the Electrical Division. However, where the insulating breaks are necessary, methods of monitoring their integrity and measures to cope with safety issues will be required. Techniques developed and deployed on existing Tokamaks should be evaluated for applicability to ITER by the Division responsible for the sub-system. This Division will also be responsible for ensuring a consistent approach to isolation and earthing across the different Procurement Agreements with Domestic Agencies and any deviation from the approach required in the Electrical Design Handbook.

9 Site EM zoning for EMC

The Tokamak Complex is split into 2 zones for EMC, as shown in Figure 9-1. A complementary zoning could be established for lightning protection.

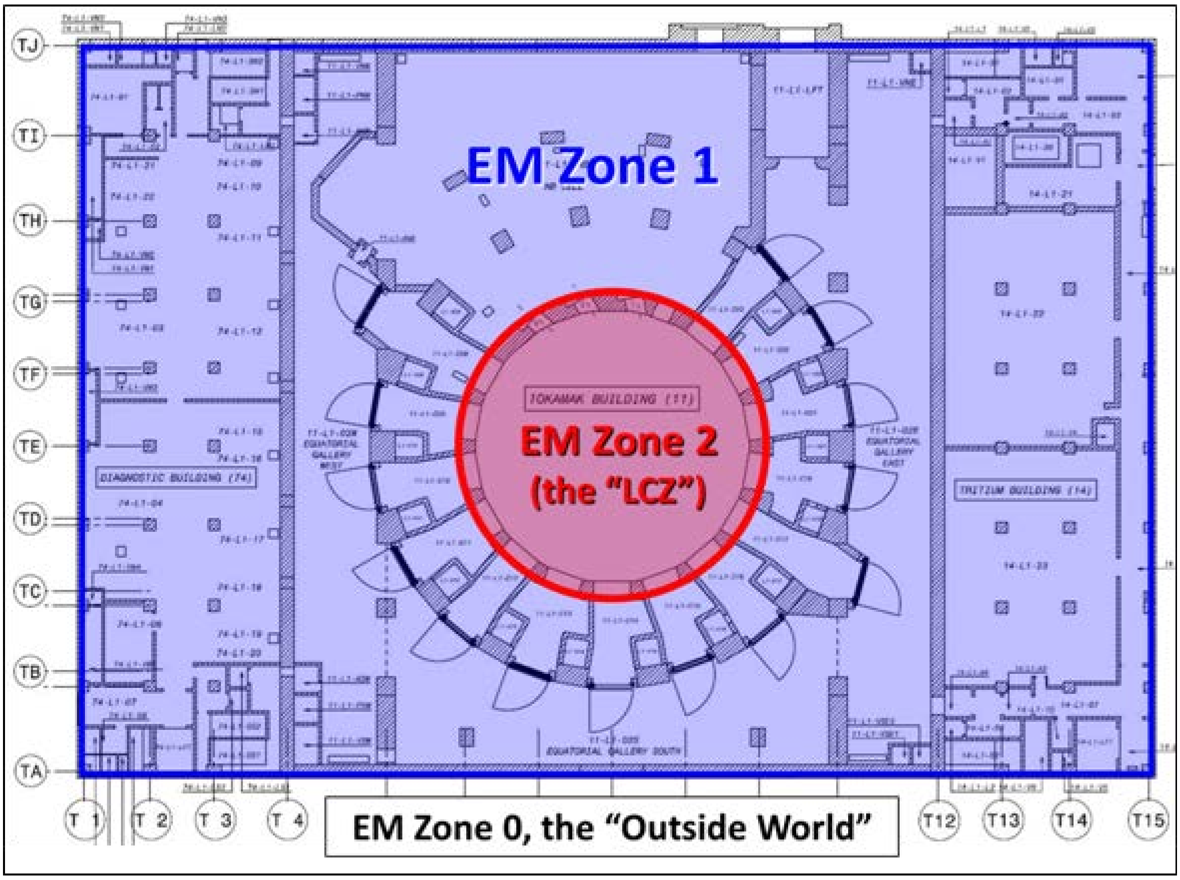


Figure 9-1 Plan view of the EM zoning of the site.

Each EMC Zone is treated as if it was a very large shielded box, obtaining its shielding effectiveness from the building meshed rebars and other meshed metal structures that form the walls, roofs and floors surrounding the entire volume of that Zone.

- Zone 0 is everything outside the Tokamak Complex, what Figure 9-1 calls the “outside world”.
- Zone 1 consists of the Diagnostic Building, Tritium Building, and Tokamak Building outside of the Cryostat and vessel ports (all in-air parts). Any electronic equipment exposed to more than 5 mT will be checked for compatibility with such high levels.
- Zone 2 is the inside of the Cryostat and vessel port (all in-vacuum), and corresponds to what Section 8.1 called the LCZ (where some/all of the conductor loops might need to be controlled, for example by using single-point bonding).

All conductors, whether used for electrical purposes or not (e.g. including pipes, tubes and ducts for air, gases or fluids) shall be bonded to the MESH-CBN at the point where they cross a Zone Boundary, i.e. at the point where the conductive item crosses from one Zone to the next. They shall also be bonded as often as practical (but not more than 4 m apart, ideally every 2m or less) to the MESH-CBN when inside any Zone.

No electrical cable shall be routed in the Tokamak complex without being supported and protected by a metal tray, duct or conduit, and – for the sake of removing any ambiguity – it is important to note that both the support/protection structures and the cables they support/protect shall be bonded to the MESH-CBN at the very point where they cross any/every EM Zone boundary.

The boundary between EM Zone 0 and EM Zone 1 (which we write as "the EMZ0/1 boundary") is also the boundary between Lightning Protection Zones 0 and 1 (the LPZ0/1 boundary). All of the EM and lightning mitigation measures that are required at this zone boundary – such as direct bonding, cable screen bonding, galvanic isolation, filtering, surge protection, etc. – are installed on a "Zone Boundary Bonding Plate" (ZBBP) that has at least two direct connections to fixed earthing terminals that connect to the rebar mesh in the outer wall of the Tokamak Complex. The EMZ/LPZ0/1 boundary ZBBPs are discussed in more detail in Section 10.

The EMZ1/2 boundary is where cables enter the Tokamak's LCZ (which is EM Zone 2, see Figure 9-1). For earthquake protection, they require flexible connections between their route in their covered cable trays/ducts and their connectors in the Tokamak ports, as shown in Figure 9-2.

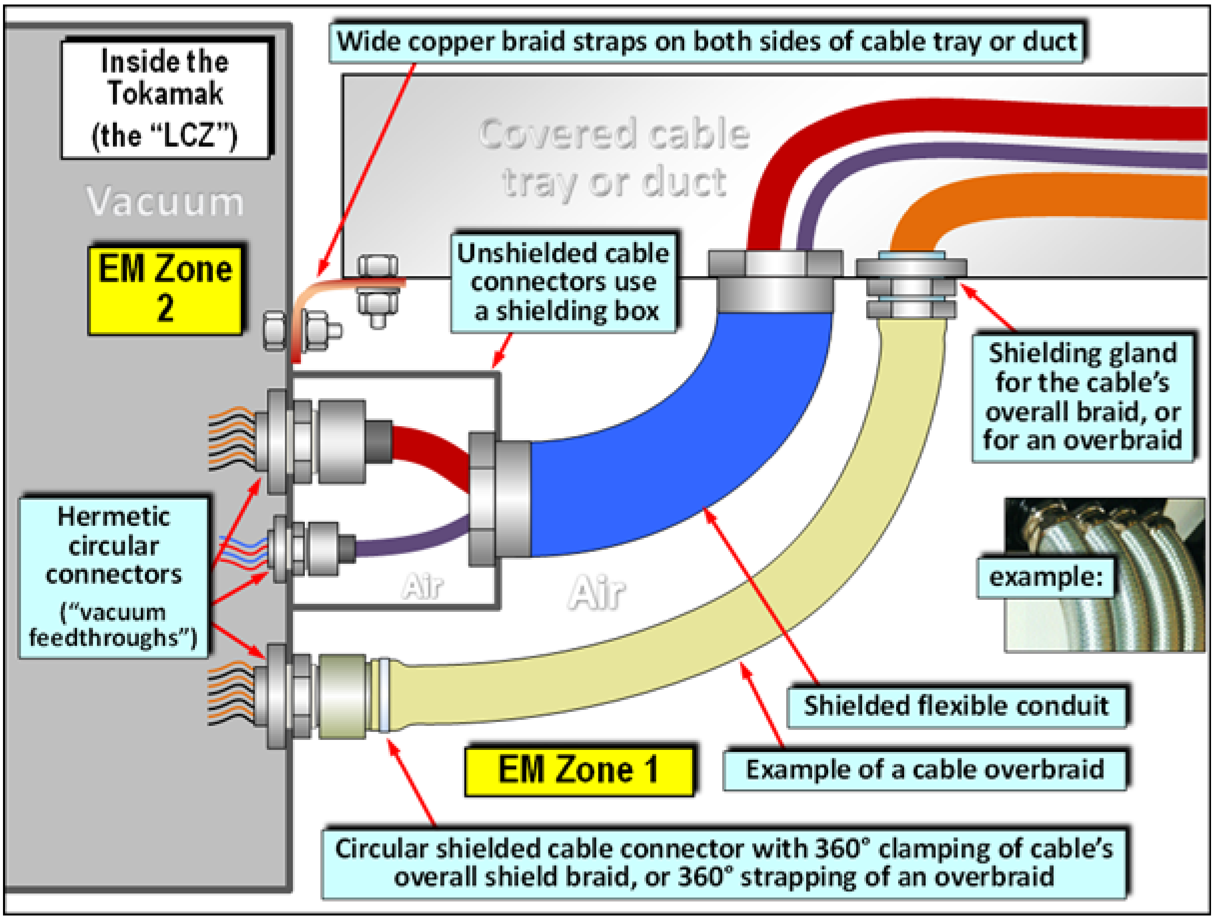


Figure 9-2 Cables entering the Tokamak LCZ via connectors of various types.

Although Figure 9-2 only shows two connectors, any number of connectors may be enclosed in a shielding box, and their cables routed inside one conduit. The only constraints are:

a) There is sufficient room inside the conduit for all the cables
b) All the cables have the same cable classification (see section 13).

The minimum required shielding effectiveness for any shielded cable – including its connectors – is 40 dB up to 100 MHz (at least). Such a performance requires at least a single braid shield and properly shielded connectors. Bright (stainless steel, bronze, titanium or nickel plated) circular shielded connectors are preferred (olive green connectors should be avoided). Screw connectors are recommended (bayonet connectors are not). For the braid connection, a metal gland is preferred (avoid a cable clamp). For the connector panel mounting, a Jam nut receptacle (or an integrated backshell) is preferred. Electromagnetic specifications are the same for hermetic and non-hermetic connectors.

Some connectors are accepted without testing:

- MIL-DTL 38999 Series 3 (all suppliers: Souriau, Glenair, Allen, Amphenol, ITT…)
- Hexashield for up to 6 shielded cables (from AMP/Tyco)
- Jaeger C27 industrial series with a metal gland (Capri for example)
- N connectors
- SMA connectors (non-isolated BNC are also accepted)
- All connectors with a specified transfer impedance lower than 10 mΩ + 0.5 nH

For other connectors, the maximum total transfer impedance (from braid to connector panel) is 10 mΩ + 0.5 nH (up to 100 MHz).

10 Site zoning for lightning protection

Lightning protection and lightning risk management are covered in detail in Part 5 of the EDH. This Chapter is a very brief summary of how the lightning protection system interacts with the EMC protection system described in this Part 4 of the EDH.

The lightning risk management will define several different lightning protection zones (LPZs), according to IEC 62305-2 to -4 standards. Any cable or pipe routed from one LPZ to another one will be protected by a ZBBP. In Figure 9-1, EM Zone 1 and EM Zone 2 are in the same lightning protected zone.

Compliance with the lightning protection standard, IEC 62305, requires any/all power, communication and signal cables entering any of the Tokamak Complex buildings from Zone 0 to be fitted with appropriate mitigation for the possible lightning effects, at their point of entry to the new Zone.

Lightning effects mitigation will generally employ Surge Protection Devices (SPDs) , which shall be fitted on Zone Boundary Bonding Plates (ZBBPs), an example of which is shown in Figure 10-1 and Figure 10-2.

ZBBPs are located exactly where conductive penetration of the EMZ/LPZ 0/1 boundary occurs, and shall carry all of the EMC and lightning mitigation devices required at that boundary.

In each case, a ZBBP’s size shall be sufficient to bond all of the conductors at that penetration point. It can be practical for an area of a cable tray to act as a ZBBP for the cables that it carries.

Each ZBBP will be directly and reliably connected to at least two fixed bonding terminals to the rebar mesh (see Section 8.2 and Figure 8-2) or to an embedded plate as described in Section 8.2 and shown in Figure 8-3 and Figure 8-4.

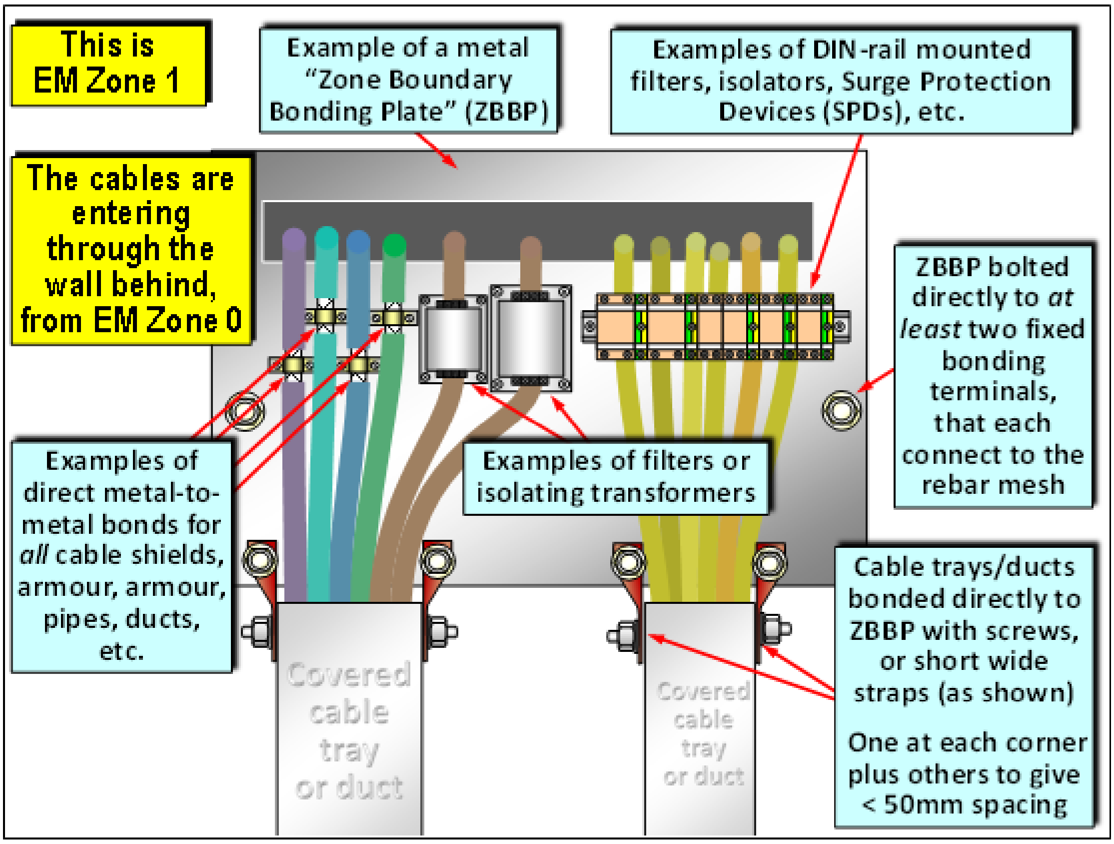


Figure 10-1 An example of a Zone Boundary Bonding Plate (ZBBP) at the Zone 0/1 boundary.

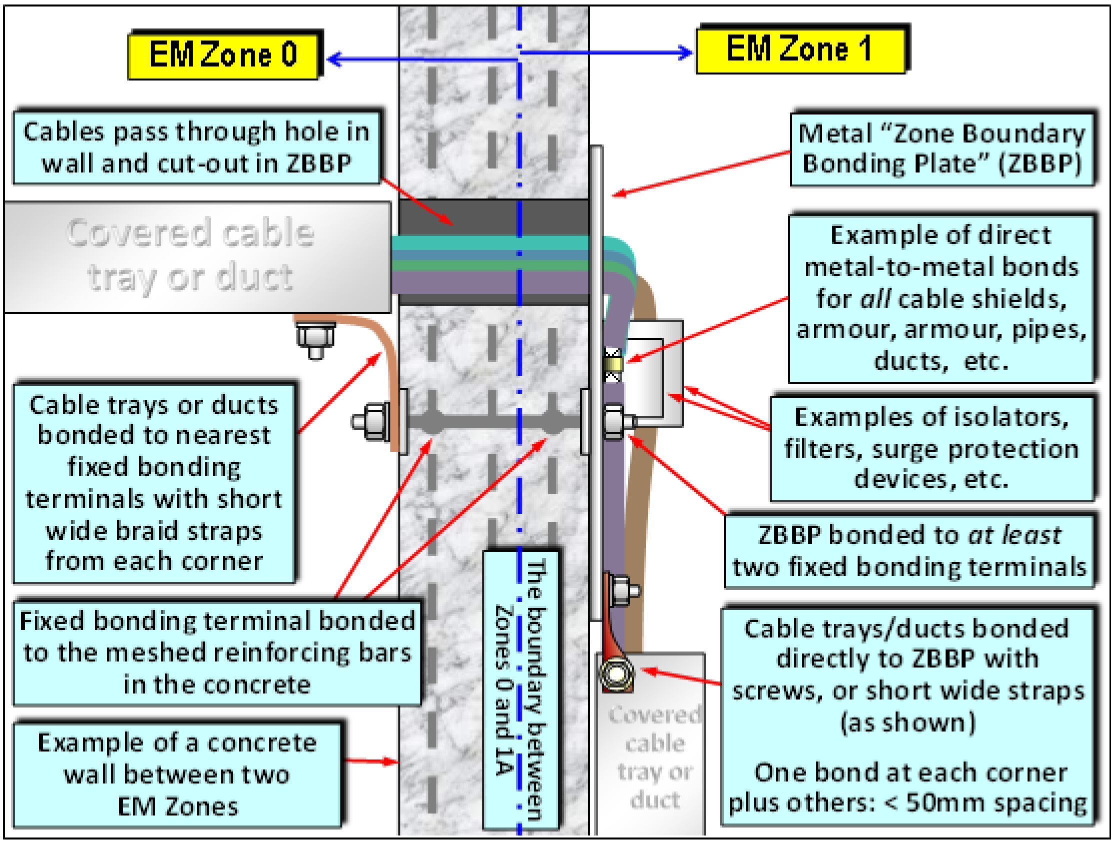


Figure 10-2 A cross-sectional view of the example ZBBP at the Zone 0/1 boundary.

As shown in Figure 10-2, all the EMC and lightning mitigation measures (cable screen bonds, filters, SPDs, etc.) necessary for EMC and lightning control at the Zone 0/1 boundary shall be arranged along a single line on each ZBBP. No conductors on one side of the line shall come any closer to conductors on the other side of the line than is necessary for connection to the bonds and mitigation measures. This is to help prevent radio-frequency noise from coupling from one conductor to another ("crosstalking") and thus bypassing (at least partially) the mitigation measures.

Sometimes two or more bonds and/or mitigation measures may need to be applied to the same conductor at a ZBBP, to provide mitigation for both EMC and Lightning. For example: shield-bonding plus filtering; filtering plus surge suppression, etc. The appropriate (optimal) protections shall be defined in a lightning protection report.

The SPDs divert lightning strike currents into the MESH-CBN at the Zone 0/1 boundary, and thence to electrodes in the soil below and/or near the Tokamak complex, to achieve personnel safety against "touch and step potentials" when people are stepping in or out of the buildings.

All other conductive elements (e.g. pipes, fiber-optic draw wires, cable armour, etc.) will be bonded directly to ZBBPs as they enter Zone 1 from Zone 0.

Other cables in Zone 0 entering or leaving the Tokamak complex are subject to very stringent requirements as regards lightning protection, and they are covered completely in the IEC 62305 series of standards. They all need SPDs (type 1, i.e. 10/350 µs current testing) at the Zone 0 boundary. Those zones will be clearly defined by the lightning management document.

Some SPDs may also be installed close to an earthing terminal (figure E.46 and E.47 from IEC 62305-3 in an electrical distribution cabinet (figure E.38 from IEC 62305-3) or in an electric power junction box (figure E.31 from IEC 62305-3).

The risk management will also define the coordination and the class of the SPDs (according to IEC 61643-12 and -22).

11 Sensors, signals and instrumentation cubicles

11.1 Sensors and signals

Neither the MESH-CBN, nor any part of it, or anything described as an "earth" or "ground" shall ever be used as an electrical return path for any signals, control or instrumentation of any type; or as a return path for DC or AC power at any voltage or current level.

Wherever the sensor technology permits, all sensors shall have a HF shield case (that provides more than 40 dB Electrical field shielding effectiveness from 1 MHz to > 100 MHz). Also all sensor cables shall be fitted with an HF shield (whether they are located in the vacuum or in the air), using a braid-shielded cable with a maximum transfer impedance of 20 mΩ/m + 1 nH/m (from DC to at least 100 MHz). Braid and foil (with the metal side of the foil in contact with the braid) would be better, and double-braid (braids in contact, not insulated) better still.

All the diagnostics equipment inside the vessel will have a RF shielded case (like an aluminum foil or a metallic grid). Those shields shall be designed not to reduce the magnetic field at frequencies below 100 kHz, by more than 2 dB. The cables inside the ports are frequently bonded to the vessel port with clamps or similar, for both EMC and thermal relief. In order to minimize the inductive crosstalk inside the connectors, some pins in the feedthroughs could be bonded to the vessel wall (i.e. the local reference potential). Also the pinout layout in the connectors could be optimized to minimize the crosstalk between signals.

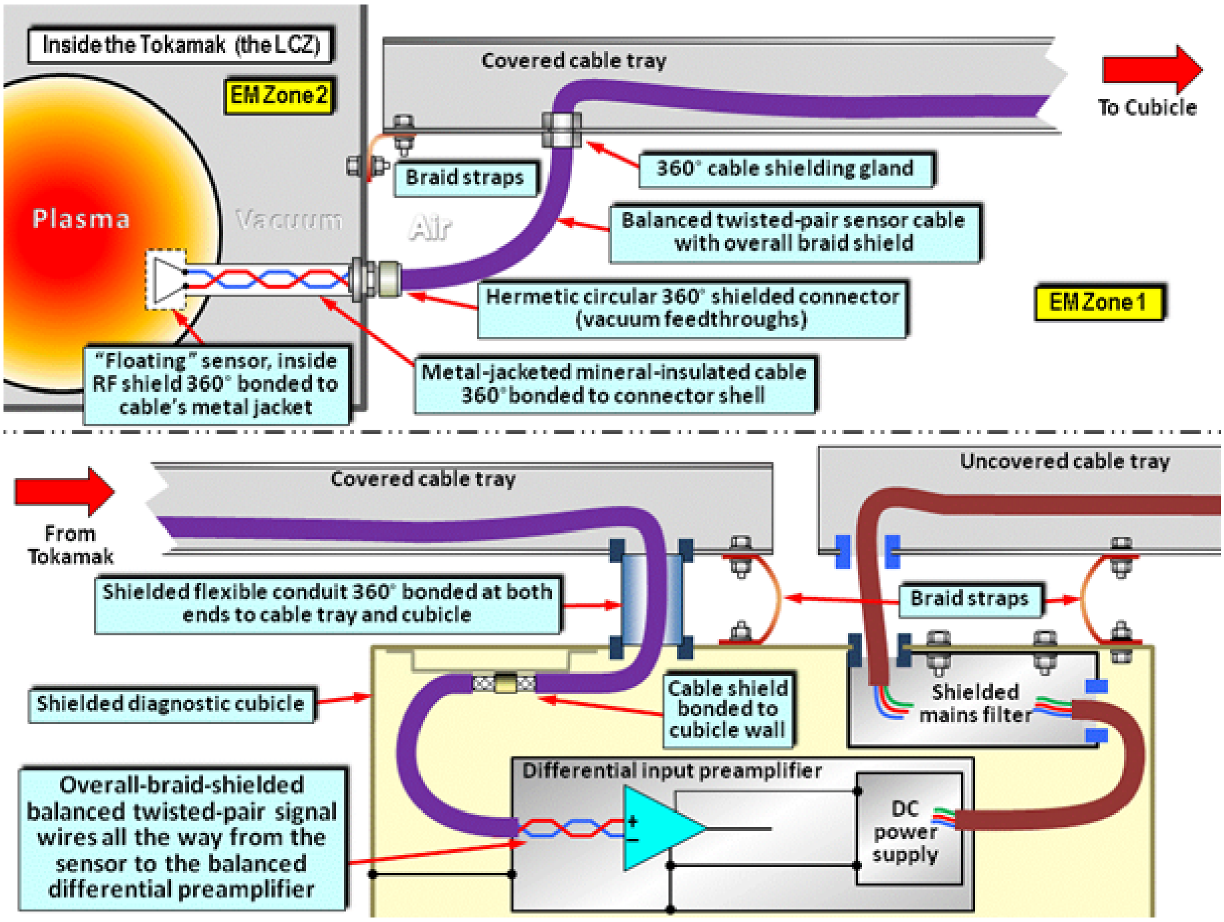


Figure 11-1 Cabling layout of a sensor in the vessel or port-plug, and the preamplifier located in the instrumentation cubicle.

All the signal cables shall have in addition to the cable shield, an additional electrical screen: a solid metal circular conduit, or a flexible shielding conduit (like Zero Ground or FLEXAgraff products), or an over-braid (with Zt < 20 mΩ/m + 1 nH/m, like a FederalMogul product), or a covered cable tray or duct, all of which shall be bonded at all joints and both ends (ideally 360°), as described in Section 5.4, to ensure a transfer impedance (Z_T) of no more than 20 mΩ + 1 nH/m from DC to 100 MHz (at least).

If this cannot be guaranteed, or for some reason a sensor cable cannot be shielded, the signal shall be filtered at the cubicle side, using a filter that achieves > 40 dB (or more) attenuation for both CM and DM over the frequency range from 100 kHz (or less) to 100 MHz (or more).

Any shielded cable shall be terminated on both sides with a shielded connector. A maximum transfer impedance of a shielded connector (cable braid to connector chassis) of 7 mΩ + 0.5 nH shall be achieved. This is the same acceptance limit for a hermetic shielded connector.

Figure 11-1 above shows the standard cabling layout of a sensor in the vessel or port-plug, and the preamplifier located in a cubicle in the port cell or in the diagnostics building.

11.2 Shielding effectiveness

In all cases, the shielding boxes, shielding connectors or glands, and cable overall shield braids, overbraids or shielded conduits shall be chosen as having been independently validated as achieving at least 40dB shielding effectiveness over the frequency range 1MHz - 100MHz from the metal of the cable tray or duct to the metal of the Tokamak port.

The bonding of the cable trays takes care of shielding frequencies below 1MHz.

Where such validation is not available, the parts shall instead be validated as achieving the following surface transfer impedance (Z_T) specifications using a recognized test method such as MIL-STD-810G, RTCA/DO-160F, IAW AS85049 or IEC M60096-1 Amendment 2:

a) 10 mΩ + 0.5 nH or less for connector shells or glands (between braid and metal plate)
b) 20 mΩ/m + 1 nH/m or less for the cable's overall shield braid, overbraid or shielded conduit.

The materials used for all the shielding boxes and parts shall be chosen to ensure that their shielding performance is maintained for at least 20 years in the ITER environment (shock, vibration, humidity, temperature, air quality, etc.).

11.3 Diagnostics and instrumentation cubicles

The shielding effectiveness achieved by a cubicle is related to the design of its metal enclosure, but is also related to the shielding of its cables and to the mitigation measures applied to any/all of the other conductors of any type that enter/exit the cubicle (even if they are not electrical, e.g. pipes for air, gases or liquids).

The approach to cabling cubicles that shall be used on ITER is shown in Figure 5-2 and Figure 5-3.

The shielding effectiveness of a cubicle after cabling installation[8] is completed shall be no less than 30 dB from 30 MHz to 100 MHz for Electrical fields. The measurements shall be done according to IEC 61587-3:2006.

12 Mechanical systems

All the mechanical parts inside the ITER building shall be bonded regularly to the MESH-CBN every 4 m (or less, and 2 m in average), for example through their supporting plates.

They shall be bonded to their supporting plates by a short wide braid strap or bracket, and the supporting plates shall in turn be bonded to their nearest fixed earthing terminal (see Section 8.2 and Figure 9-1).

Ideally, a supporting plate will be bolted directly to at least one fixed bonding terminal (Figure 9-1), or will itself be an embedded plate as shown in Figure 8-3 and Figure 8-4.

The overall DC resistance between the body of the mechanical item and the nearest fixed bonding terminal or embedded plate shall be less than 5 mΩ.

Metal structures having mechanical constraints during normal operation shall not be used as protective ("safety earthing") conductors (IEC 60364-5-54-3.2-3). All such metal structures shall be bonded to the MESH-CBN as described in Section 8.2.

Where the path of a protective ("safety earth") conductor includes a screwed or bolted connection, a conductor shall by-pass the joint. Such conductors shall be correctly sized for their maximum possible fault currents according to RCC-E and IEC 60364-5-54.

To improve the EMC performance of the facility, all metal mechanical structures shall be designed to achieve very low electrical resistances at all screwed or bolted junctions, protected from corrosion by oxidation or galvanic activity. This will require attention to conductive surface plating and finishing of the metal parts, and may require the use of special washers, paints, surface treatments, etc.

[8] The cabling inside the cubicles is out of the scope of this handbook. It is covered in document ITER_D_4H5DW6 - I&C cubicle internal configuration.

13 Cable classification, segregation and routing

Cables shall be divided into eight Classes with respect to their interference potential. There are 2 families for instrumentation and control (1 sensitive and 1 noisy) and 4 for power distribution (LV, 6.6 kV, 22 kV and 66 kV). The Medium and High voltage cables (6.6 kV, 22 kV and 66 kV) will follow the high voltage rules (IEC 60964).

These classes must be physically segregated from each other and preferably run in different trunkings (metal trays, ducts or conduit) along their entire lengths. Their trunkings shall be connected to the connector panels of the equipment at both ends, and bonded at all joints, as described in Section 8.2, to behave as what IEC 61000-5-2 [1] calls a “parallel earth conductor, or PEC”, that by virtue of its very low resistance diverts power-frequency currents away from the cable shields.

If cable classes must cross they shall only do so at right angles. Even so, crossing should be avoided, especially between S and N1 or LV. Classes M, MV and HV shall never come within 3 m of any S or N cables without a metal cover (bonded as described in Section 5.4) over the tray containing the S or N cables, and even then the distance from the M, MV or HV shall be maximized and no less than 500 mm.

Individual pairs of forward (send) and return wires for signals or power in multi-pair cables shall be twisted together ([1], sub-clause 7.3.b), although alternative constructions could be permitted by ITER Organization on a case-by-case basis if they feel that there is sufficient technical justification.

Where the bonds between sections of tray, duct or conduit are not considered to maintain a very reliable low resistance (i.e. < 1 mΩ at each bond), a 50mm wide 3mm thick copper busbar shall be routed along the entire length of the tray, duct or conduit, bonded directly to each section of tray either side of a joint, and finally bonded to the equipment at both of its ends. Taking good care over the bonding of the trays, ducts or conduit will therefore save a lot of money.

All signals and power conductors shall be bundled as twisted-pairs (i.e. never using a return conductor for more than one signal or power supply, DC or AC).

The cables, bus bars and any other current circulating items with their containments and supports in the Tokamak shall be properly sized for the magnetic forces created by the machine operation, according to the location of the item and its circulating current.

All cables shall be fire and flame retardant, low smoke, zero halogen, low toxicity and low corrosivity, according to IEC 60 or NF32070 C1.

13.1 S. Sensitive signals.

This cable Class is the most sensitive, and covers low-voltage or low-current signals such as those coming from sensors. This cable Class shall apply to all low level signals such as thermocouples, thermistors, RTDs, strain gauges, bolometers, vacuum gauges, pick-up coils, vacuum photodiode, temperature diode, scintillator, , etc.; and also all other sensor signals with full-scale range less than 1V or 1 mA. Also, the DC power supply lines for the low level sensors shall be included in this Class.

This cable Class also covers ordinary analogue (e.g. 4-20 mA, 0-10V) and digital signals (e.g. RS232, RS422, RS485, Profibus, and Ethernet). These signals should use screened cables (cat6 for Ethernet cables).

Flat ribbon cables must be screened either with flat shielding jackets or shielded "round and flat" (a flat cable is rolled up in a round cable with an overall braid shield). Round and flat is preferred, because it permits 360° shield termination, which is not possible with flat shielding jackets.

This class also covers less sensitive signals as digital (i.e. on/off) inputs and outputs such as limit switches, encoders, interlock signals from PLCs, etc., and telephone lines.

The cables for the signals in this Class shall use good quality highly-shielded twisted-pair (or similar) cables and shielded connectors with no breaks in 360° shielding and no screw terminals. Cable shields shall be terminated *without* pig-tails, for example by using the saddle-clamps or P-clips shown in Figure 5-2 and Figure 5-3 at both ends and all ZBBPs, ensuring that the cable shield remains unbroken over the entire signal path.

The cables in this Class shall be installed in solid metal trays or ducts forming part of the CBN, all fitted with metal covers that are bonded to the trays or ducts as discussed in Section 8. Circular solid conduit would be the best type of support for this cable class, 360° bonded at all joints and both ends, as seen in the example in Figure 13-1.

Figure 13-1 Example of a well-constructed system using solid circular conduit and covered ducts.

Green/yellow wire or braid straps are not suitable for bonding circular solid conduit to connector panels. Figure 9.1-2 shows one example of a type of circular conduit nut that should be used instead, to make a reliable, direct, multipoint metal-to-metal bond between panel and conduit.

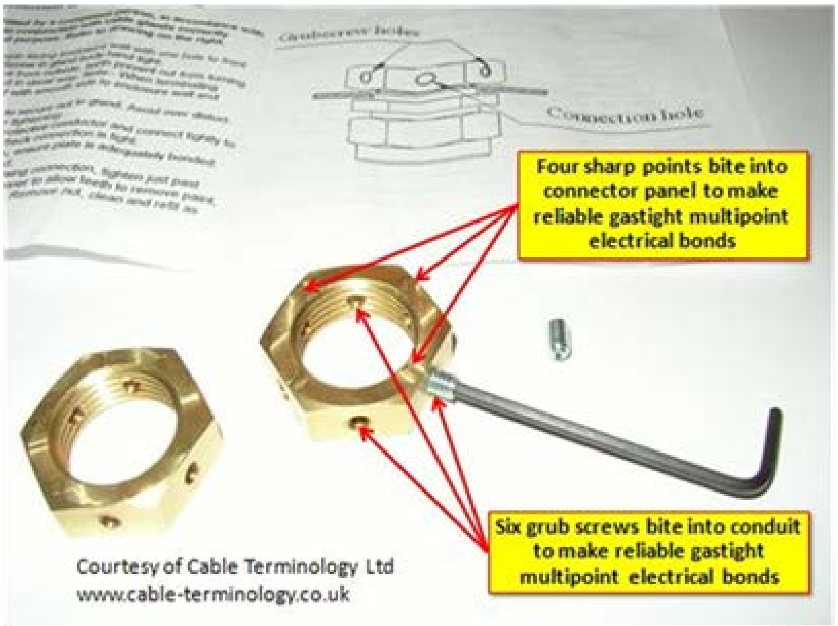


Figure 13-2 Example of a circular conduit nut designed for multipoint bonding to a connector panel.

13.2 N. Noisy signals

This cable Class covers cables associated with the power inputs and outputs and DC links of adjustable speed motor drives (DC, AC, steppers, servos, etc.), welding equipment, and similar electrically noisy equipment. Also AC and DC relay feed-line and leads to DC motors that use a brush collector, switched power lines, cables and earth wires in high-voltage switchyard, etc.

This cable class also covers control cables to inductive loads (relays, contactors, solenoids, etc.) or signals having high voltages or high currents: e.g. High voltage signals (30 kV) for magnet instrumentation, Fast discharge units (70 kA) for magnet coils, and Glow Discharge Cleaning (GDC) electrodes on the vessel (30 kV) for fuelling system.

All these cables are shielded and routed in covered cable trays and ducts (or circular solid conduit) in exactly the same way as for Class S are, except for Class N the aim is to keep the noises in, to reduce emissions, rather than to improve immunity by keeping noises out.

The cable trays, ducts and conduits used for Class N shall not be shared with any other cable Class, even when using metal dividers.

The minimum spacing from a Class N covered tray or duct to the covered tray or duct carrying Class S shall be 10 mm for each 1 m of parallel routing of these two Classes, with a minimum of 25 mm and a maximum of 250 mm (e.g. 25 mm for up to 2.5 m of parallel routing, 250 mm for more than 25 m of parallel routing).

It is permissible for the trays or ducts of these different cable classes to be close together at one end, and spread further apart as their route extends further, so instead of being parallel they in fact have a small angle between them.

There are no minimum spacing specified between S and/or N, providing that:

They are all contained within solid circular conduit with reliable 360° bonding at each joint and 360° bonds to the connector panels (or filter boxes mounted on connector panels) of the equipment at both ends of each conduit (see Figure 13-2 for an example of a suitable conduit-to-panel bonding nut).

The conduits are bonded to the MESH-CBN in every EM Zone they exist in, with bond spacing no more than 5m (preferably less) using circular clamps for their bonding. Also, the conduits shall not touch, except by being bonded to the same element of the MESH-CBN.

13.3 LV. Low Voltage Power distribution

This cable Class covers the AC distribution (240 V, 400 V) and DC power distribution.

It should be treated exactly as for cable Class N. The only difference is that this family does not require shielded cables (because they are properly filtered).

13.4 M6. 6.6 kV Power distribution

This class covers the distribution of Medium Voltage 6.6 kV Power.

13.5 MV. 22 kV Power distribution

This class covers the distribution of Medium Voltage 22 kV Power.

13.6 HV. 66 kV Power distribution

This class covers the distribution of High Voltage 6.6 kV Power.

13.7 Safety related cables

All the safety related cables with rated voltage below 1 kV (either supply or instrumentation & control of SIC loads) shall be fire resistant according to the IEC 60331 and NF32070 CR1, in addition to be fire retardant, low smoke, zero halogen, low toxicity and low corrosivity.

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

References

This ITER Technical Report may contain references to internal technical documents. These are accessible to ITER staff and External Collaborators included in the corresponding ITER Document Management (IDM) lists. If you are not included in these lists and need to access a specific technical document referenced in this report, please contact us at ITR.support@iter.org and your request will be considered, on a case by case basis, and in light of applicable ITER regulations.