

Guidance Document

G222 EMC best practice

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1 Purpose

- 1.1 The purpose of this Guidance is to describe the philosophy that must be adopted when designing, selecting, specifying, installing, commissioning and inspecting electrical installations on London Underground premises for the purpose of achieving electromagnetic compatibility in the final installations.
- 1.2 EMC best practice is essential to meeting the requirements of the relevant EU Directives, associated UK Statutory Instrument, safety and reliability.
- 1.3 The document is not intended as the definitive guide to all EMC issues, but to cover common issues.

2 Scope

- 2.1 This Guidance applies to :
 - a) defining and clarifying the key EMC requirements for all types of new, modified and 'off the shelf' Equipment into one document to ensure that the supplied Equipment meets the 'Essential Requirements';
 - b) providing guidance to Project Engineers on the applicable standards covering frequency limits of emissions and susceptibility;
 - c) defining the requirements for the EMC Control Plan, Test Plan, Test Reports and EMC evidence.
- 2.2 The requirements set out in this document are a means of providing assurance to LU that the 'Essential Requirements', which are explained further in Section 3, will be achieved when any Equipment or Apparatus is installed and operated on the London Underground infrastructure. This assurance will support the LU in its duty to comply with various statutory obligations particularly with regard to the acceptance and commissioning of assets.
- 2.3 Collating and updating the EMC requirements within one document will ensure that a correct and consistent approach is taken by all engineering disciplines, EMC is addressed at all stages of a Equipment life cycle and the risk of specifying redundant or inappropriate requirements is reduced. It is also important to ensure these requirements are addressed at the initial stage of a project/contract so that assurance can be demonstrated before the system is installed and commissioned. Waiting until the system is on line to consider EMC issues is not acceptable and is likely to lead to costly service delays and disruption. The project manager must ensure the requirements of this document are implemented and must contact a competent EMC Engineer to confirm the scope of requirements at an early stage. Section 3.14 defines the strategy and documentation required to demonstrate compliance.
- 2.4 This guidance replaces G-222, A1.

3 Guidance

3.1 Technical Background

- 3.1.1 All electrical or electronic Equipment generate electrical noise (some by design and others unintentionally). This characteristic is generally referred to as emissions.



All electrical or electronic Equipment has a tolerance level to electrical noise, beyond which it will malfunction. This characteristic is generally referred to as immunity.

Electromagnetic Compatibility (EMC) is ensuring that the generated emissions are smaller than Equipment immunity levels, ensuring that Equipment is compatible and continues to work as intended. This is generally referred to as the "Essential Requirements".

- 3.1.2 Any electrical or electronic Equipment has the potential to malfunction when exposed to EMI if not correctly designed, manufactured or installed. In the LU operational environment a large number of critical, emissive and sensitive systems are co-located in close proximity, including similar systems used by other rail operators and external organisations. This scenario results in one of the most difficult and challenging types of EMC environments in which a system must operate. The need to address and manage the EMC requirements throughout a system life cycle (e.g. from the initial ITT stage to the final system installation and ongoing maintenance) is of paramount importance if the total system EMC is to be achieved and maintained.
- 3.1.3 Achieving EMC for the wide range of LU Equipment and systems is interpreted as reducing the likelihood of unacceptable interference occurring between constituent parts and between LU installations and the outside world, including other rail operators. This must be achieved at an acceptable cost, commensurate with demanding safety and reliability requirements. The accepted method of achieving this is to impose design, analysis and testing constraints on Equipment and systems within a rigid framework of ongoing EMC management and quality control procedures.
- 3.1.4 The choice of test limits and installation constraints must in the first instant be based upon previous experience. Fortunately, the choice of tests, test limits and acceptance criteria present within current specifications are themselves derived from cost effective considerations. Careful selection of these criteria followed by careful monitoring of Equipment development, integration and installation, will reduce the risks of incompatibility.
- 3.1.5 Foremost of the special considerations imposed by railway systems must be the effects of interference on existing and new safety systems which also includes internal LU aspects. This is of particular concern when interference could, for example, lead to a wrongside failure of signalling Equipment and the opening of train doors whilst the train is in motion, with unacceptable safety implications. In this respect testing and analysis must be conducted within the framework of reliability and of Equipment failure modes which could give rise to unacceptable interference levels and margins.
- 3.1.6 Apart from direct considerations of the effects of interference on safety systems the approach, in general, is to consider interference as arising from the normal functioning of Equipment, and does not address failure modes explicitly.



- 3.1.7 Of paramount importance to the LU business perspective must be the possible impact of EMC on the Customer and the latter's perception of the service offered (e.g. Lost Customer Hours LCH). It is also important that normal consumer products, such as portable computers and games, which themselves are required to be tested for immunity to interference, are not adversely affected by LU facilities. Considerable care needs to be taken to ensure that such high profile Customer facilities as CCTV, PA and help points are of high quality. Any electrical or electronic Equipment has the potential to cause EMI and the risk should be determined on its design status and not on its proposed usage.

3.2 The Essential Requirements

- 3.2.1 The Essential Requirements are defined in the EMC legislation. They are:

- 3.2.2 Equipment shall be designed and manufactured, having regard to the state of the art, so as to ensure that—

(a) the electromagnetic disturbance it generates does not exceed a level above which radio and telecommunications Equipment or other Equipment cannot operate as intended; and

(b) it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.

- 3.2.3 There are also Essential Requirements that apply to “Fixed Installations”. A “fixed installation” means a particular combination of several types of apparatus and, where applicable, other devices, which are assembled, installed and intended to be used permanently at a pre-defined location;

3.2.4 Essential Requirements for Fixed Installations

A fixed installation shall be installed—

(a) applying good engineering practices; and

(b) respecting the information on the intended use of its components, with a view to meeting the essential requirements set out in 3.2.2.

- 3.2.5 Such good engineering practices shall be documented.

- 3.2.6 A fixed installation may contain “certain apparatus” which does not have a DoC and is not CE marked provided :

(a) the apparatus shall be incorporated into the fixed installation for which it was intended;

(b) such incorporation shall respect the intended use of the apparatus; and

(c) the incorporation shall comply with good engineering practice.

Certain apparatus is defined as :

(a) intended for incorporation into a given fixed installation; and

(b) is otherwise not commercially available.

- 3.2.7 The responsible person in relation to a fixed installation shall hold such documentation at the disposal of the enforcement authority for inspection purposes for as long as the fixed installation is in operation.



3.3 New Equipment

- 3.3.1 A system or Equipment that does not contain electrical or electronic devices will not need to meet all of the requirements. Further advice should be requested from the subject matter expert in such cases at lulemc@tfl.gov.uk.
- 3.3.2 Normally all Equipment and systems procured for LU should meet the requirements for a railway environment as defined in the BS EN 50121 series of Railway EMC Standards
- BS EN 50121-1, Railway applications - Electromagnetic Compatibility, Part 1: General. This part gives a description of the electromagnetic behaviour of a railway and specifies the performance criteria for the whole set of standards.
- BS EN 50121-2, Railway applications - Electromagnetic Compatibility, Part 2: Emission of the whole Railway to the outside world.
- BS EN 50121-3-1, Railway applications - Electromagnetic Compatibility, Part 3-1: Rolling Stock - Train and complete vehicle.
- BS EN 50121-3-2, Railway applications - Electromagnetic Compatibility, Part 3-2: Rolling Stock - Apparatus.
- BS EN 50121-4, Railway applications - Electromagnetic Compatibility, Part 4: Standard for the Emission and Immunity of the Signalling and Telecommunications apparatus.
- BS EN 50121-5, Railway applications Electromagnetic Compatibility, Part 5: Fixed power supply installations.

3.3.3 Off-the-Shelf and Previously Approved Systems

- 3.3.3.1 Procuring some systems for direct compliance with the new EMC Railway Standards may not be possible. For example, a proposed system may already satisfy a product or generic standard (e.g. BS EN 61000-6-2), or a previously approved system specified for a new installation could already meet many of the individual test requirements set out in the railway EMC standards. Expecting these systems to be revalidated would be expensive and not commercially viable.
- 3.3.3.2 Previous evidence of compliance may be acceptable provided it is possible to demonstrate and verify that the current approval status is equivalent to or exceeds the applicable worst case requirements set out in this document.
- 3.3.3.3 The Project Engineer should ensure that all such evidence is available and has been reviewed and validated by a competent person. The contractor will be required to supply all data requested by LU (e.g. previous test results, test reports, hardware or firmware changes between previously tested and supplied system) to verify the requirements detailed in this document have been met.
- 3.3.3.4 Any differences between the submitted evidence and these requirements may require additional analysis and test to resolve. The differences should be documented in a "Gap Analysis" report. Assurance must be given that the associated system satisfies the essential requirements. The Contractor should carry out any additional work required when previous tests or the content of any document are not considered adequate by LU. A concession may be required.
- 3.3.3.5 The project engineer must ensure that the contractor is made aware of the railway EMC environment to ensure a system, which may be 'CE' marked for a domestic environment, cannot be incorrectly specified for use by LU.



Note: A CE mark does not prove a product is suitable for use on a railway

3.3.4 Systems not Included in the EMC Railway Standards

3.3.4.1 Not all systems currently used by LU are included in the BS EN 50121 series of standards. These systems (e.g. lifts, escalators, fire, UPS, lights, UTS, computer networks and information systems) should meet the minimum requirements set out in the appropriate product standard and also the railway environment as defined by the tests and test levels in EN50121-4. However this may not always be commercially viable and certification to a current industrial based product standard may be considered to be compliant, subject to agreement with LU. The criticality of the Equipment is a consideration in accepting lesser requirements.

3.3.4.2 Any differences between the submitted evidence and these requirements may require additional analysis and test. Assurance must be given that any such system satisfies the 'Essential Requirements'. Further advice should be requested from the subject matter expert in such cases at lulemc@tfl.gov.uk.

3.3.5 Additional Requirements not included in BS EN 50121

3.3.5.1 All systems connected to a dc supply must also meet the requirements of the following standard.

- BS EN 61000-4-16, EMC, Test for Immunity to Conducted, Common Mode Disturbances in the Frequency Range 0-150 kHz.

3.3.5.2 All the standards listed below (as applicable. E.g. 61000-3-2, 61000-3-4 or 61000-3-12) apply to systems connected to a mains supply:

- BS EN 61000-3-2, EMC, Limits for harmonic current emissions (equipment input current ≤ 16 A per phase).
- BS EN 61000-3-3, EMC, Limitations of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current ≤ 16 A per phase.
- BS EN 61000-3-4, Limits for harmonic currents in low-voltage power systems for equipment with rated current > 16 A.
- BS EN 61000-3-11, Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 75 A per phase and subject to conditional connection.
- BS EN 61000-3-12, Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and $k \geq 75$ A per phase
- BS EN 61000-4-16, EMC, Test for Immunity to conducted common mode disturbances in the frequency range 0-150 kHz.
- BS EN 61000-4-11, EMC, Voltage dips, short interruptions and voltage variations immunity tests.
- G5/4, Planning levels for harmonic voltage distortion and the connection of non linear equipment to transmission systems and distribution networks in the UK. (See also LU Standard S1100)



- 3.3.5.3 Voltage harmonics on the mains supply can cause Equipment to malfunction and in extreme cases can cause overheating, potentially resulting in a fire. The 6 pulse traction rectifiers used on LU result in significant 11th and 13th harmonic voltages appearing on LU 400V AC supplies. The addition of escalators, lifts, UPS or any large inverter could significantly increase the existing harmonic voltage levels. This is a complex subject and advice should be sought from Power and EMC Engineers.
- 3.3.5.4 EN50121 does not require the ESD test to be undertaken if the Equipment is not accessible to the public. Given the high intensity service on LU, any disruption due to an ESD failure caused by maintenance staff would be unacceptable. This test should be applied to all LU Equipment.
- 3.3.5.5 EN50121-4 only applies the digital mobile phone test to within 3m of the track. In practice the threat from mobile phones exists in all public and staff areas where mobiles are permitted. This test should be applied to all LU Equipment.
- 3.3.6 **In House Design and Manufacture**
- 3.3.6.1 Some Equipment on the railway is designed and/or manufactured by LU departments. Provided these products are only used on LU infrastructure and not placed on the market, they do not require to be CE marked or have a DoC available.
- 3.3.6.2 Equipment designed and/or manufactured in house shall meet the essential requirements of the EMC Directive. To ensure this, they must be tested to the same requirements as other railway products. A test report shall be made available.

3.4 Modified Equipment or Systems

- 3.4.1 Assurance is required that the EMC Essential Requirements have been met when any existing Equipment or system is modified. This includes modifications due to failure, obsolescence or the introduction of new Equipment to an existing system (e.g. Station, train, room, etc).
- 3.4.2 As a minimum, an analysis must be performed (e.g. using the EMC test data for the new system or sub-system and the use of approved EMC installation practice) to demonstrate that the modification has not degraded the current level of EMC. Direct Equipment replacement may not need any significant analysis. The level of analysis will depend on the scope of the proposed modification as it is difficult to generalise on the assurance needed for all possible types and levels of modification that could occur. The degree of assurance required should be agreed at an early stage by the project by a competent person.
- 3.4.3 Any differences between the submitted evidence and these requirements may require additional analysis and test. The differences should be documented in a "Gap Analysis" report.
- 3.4.4 Changes to a system are considered to be changes to a "fixed installation" and therefore the essential requirements identified in section 3.2.4 apply.
- 3.4.5 Assurance must be given that any such system satisfies the Essential Requirements and the EMC best practice shall be documented.



3.5 Installation

- 3.5.1 Any installation work is by definition a change to a “fixed installation” and therefore the essential requirements identified in section 3.2.4 apply.
- 3.5.2 Installation technique is very important if the system EMC is to be achieved and this must be devised and approved at an early stage of any project (not just before the installation process is scheduled to start). Any system or Equipment, which has met a set of type test requirements has a level of immunity which can be exceeded if incorrectly installed or maintained, potentially exposing it to high levels of interference. For example, if a sensitive cable is routed adjacent to a power or radiating cable or if a VDU is located near a power transformer, problems are likely to occur.
- 3.5.3 The following documents contain many examples of good installation technique that will promote EMC of the system.
- a) IEE wiring regulations (BS 7671);
 - b) BS EN 61000-5-1, Part 5 Installation and mitigation guidelines, Section 1 - General considerations;
 - c) BS EN 61000-5-2, Part 5 Installation and mitigation guidelines, Section 2 - Earthing and cabling.
 - d) BS EN 50174-2, Information Technology. Cabling Installation, Part 2. Installation Planning and practices inside buildings.
- 3.5.4 The main source of radiation from, or coupling mechanism into, any system is caused by external cabling which, due to their lengths, provide an efficient mechanism to cause EMI problems. The coupling of interference between cables can be reduced significantly by observing certain rules, during installation, which will reduce the inductive and capacitive coupling between them.
- 3.5.5 In general, cables are classified according to whether they are likely to radiate interference, or are connected to susceptible Equipment, and also by the levels of interference or signal which they are carrying. The rules specify the required segregation distances between cables of the various classes.
- 3.5.6 The separation of sensitive cabling (e.g. signalling and communications) from the many potential sources of EMI is essential if EMC is to be achieved. In practice, it may be difficult, and in some instances impossible, to maintain the separation distances over the entire cable run (e.g. at cable entries into voids or cabinets). Additional protection may be required (e.g. trunking or re-routing). In addition, all cable 'cross over points' should be at right angles and parallel lengths should be minimised wherever possible.
- 3.5.7 Various methods of classifying cables can be employed, depending on the degree of complexity which is required for a particular type of system. The following example is a fairly simple classification and is intended to give a general ideal of the concept. The exact separation distances must be appropriate for each job.
- 3.5.8 The minimum separation distances required by the ITU, Fire regulations and the IEE wiring regulations must also be considered when such a system is devised, particularly where these are applied for electrical safety reasons.



3.5.9 The cables are divided into three main categories:

Radiators:

Category - R1

- a) Power cables up to 80 A < 415V;
- b) Transmitter output cables (systems operating below 100 kHz);
- c) Transceiver cables.

Category - R2

Power cables (50 Hz) more than 80 A > 415V.

Susceptors:

Category - S1

Receiver input cables, systems operating below 100 kHz, signals less than 100 μ V.

Category - S2

Receiver input cables, systems operating below 100 kHz, signals in the range 100 μ V to 100 mV.

Category - S3

- a) Cables that carry low level voltage and current signals (e.g. Signalling Cabling);
- b) Coaxial cables to receivers and video systems operating above 100 kHz.

Category - General

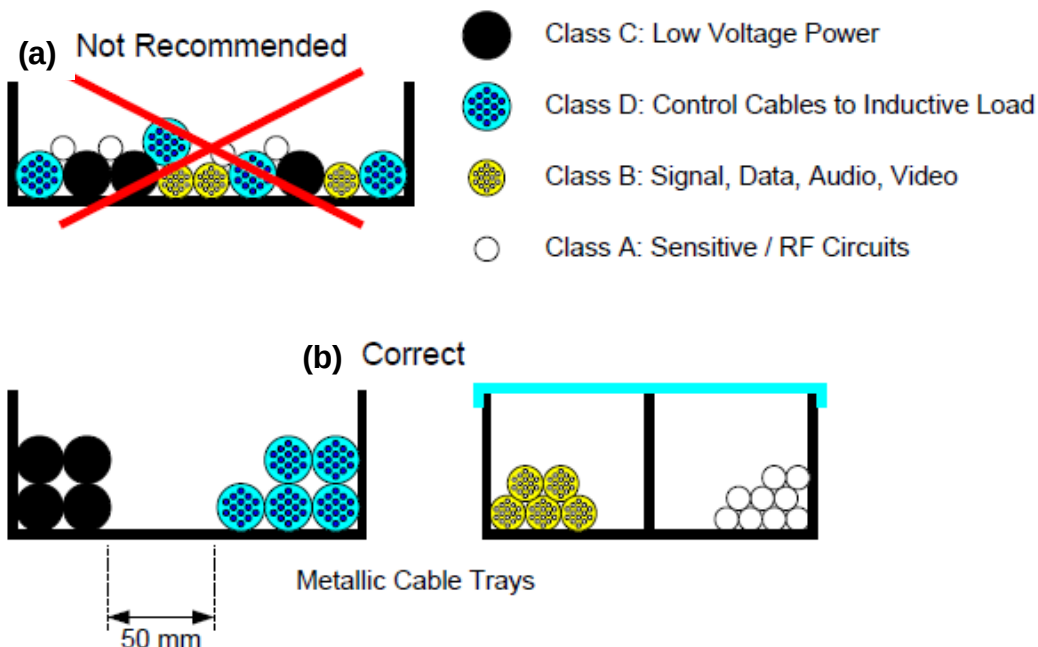
- a) Coaxial cables to transmitters operating above 100 kHz;
- b) Cables carrying low frequency signals above 0.1 V.

3.5.10 Segregation Distances

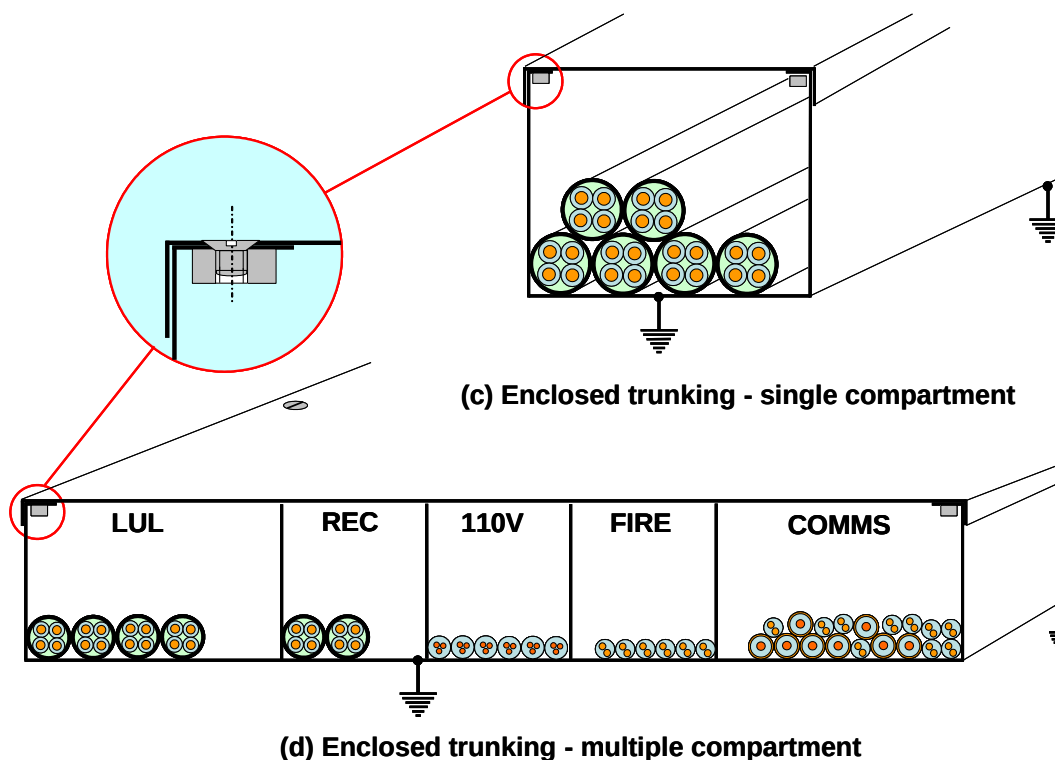
For example, the classification system given above could require the following minimum separation distances:

S1 to	G	100 mm *Example only*
	R1	100 mm *Example only*
or	R2	150 mm *Example only*
S2 to	G	75 mm*Example only*
or	R1	100 mm *Example only*
S2 to	R2	100 mm (increase by 75 mm per 50 A above 160 A) *Example only*
S3	R2	200 mm (increase by 75 mm per 50 A above 160 A) *Example only*
G to	R1	75 mm *Example only*
or	R2	100 mm (increase by 75 mm per 50 A above 160 A) *Example only*

3.5.11 The use of screened cable, cable tray, metal trunking and conduits will also reduce the cable emissions and provide some protection for system cabling. This would allow the separation distance to be reduced. (a) & (b) are examples of good and bad practice.



(c) & (d) are examples of containment typically used on LU. (d) shows carrying strongly interfering signals far as possible from the most sensitive carrying signal cables, that is, LUL – REC – 110V/230V – FIRE – COMMS.

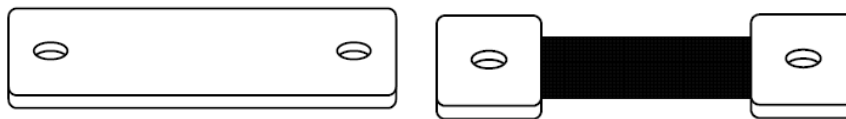




- 3.5.12 The placement of any Equipment into an operational railway must be carefully considered before the installation process begins. This should ensure that any EMC problems, which could be caused by both intentional (e.g. radio base stations) and unintentional Equipment emissions, are avoided. This issue is particularly important when a diverse range of systems are co-located (e.g. station platform area) or when a new system is proposed to be installed adjacent to a system of unknown EMC status.
- 3.5.13 Equipment considered potentially sensitive (e.g. communication receivers, VDUs, low level signalling systems and components) should not be co-located close to potentially emissive Equipment (e.g. power transformers and cables, electric motors). Additional analysis and protection measures may be needed where separation cannot be achieved, which should be identified and resolved at the initial stage of a project.
- 3.5.14 The availability of a good earthing system, installation methodology and the practice of ensuring that Equipment enclosures and cable screens are earthed by a low impedance bond are essential if the system EMC is to be achieved.

One of the main objectives for EMC earthing is:

- a) Ensure that the 'earth' at each of the system Equipment is at the same potential to minimise coupling between systems and Equipment that share the same earth;
 - b) Divert unwanted interference currents from cable screens, Equipment filters and transient protection devices back to earth and not to other systems.
- 3.5.15 The ideal EMC earthing would be a combination of a single point system for low frequency systems and a multi-point system, where voltage differentials must be minimised, for high frequency systems.
- 3.5.16 Reference should be made to:
- 1-106 - Earthing and Bonding of LU Electrical Networks
 - BS 7671 - IEE wiring regulations.
 - BS 7430 - Earthing.
 - BS EN 61000-5-1, Part 5 Installation and mitigation guidelines, Section 1 - General considerations.
 - BS EN 61000-5-2, Part 5 Installation and mitigation guidelines, Section 2 - Earthing and cabling.
- 3.5.17 The chosen earthing must also consider systems issues and failure conditions. System Safety must be the overriding concern. E.g. bonds installed for electrical safety can also introduce stray currents which may have the potential to affect signalling safety.
- 3.5.18 Bonding is the establishment of a low impedance connection between two metal surfaces. The following list is considered good EMC bonding practice:
- a) Use the same metal or metals close together in the electrochemical series;
 - b) Bonds should be correctly tightened and coated to prevent moisture ingress;
 - c) Bonds should be short, wide and flat to minimise impedance (braids should be avoided where possible). See examples below.



Example of poor EMC installation. Bonds are long and the coil creates a significant impedance which provides a poor earth with high frequency interference.

3.5.19 Where trunking or cable tray is used it is essential to provide a good bond across the joint. Below are examples of good and bad practice.

