Scottish Health Technical Memorandum 2014

(Part 2 of 4)

Design considerations

Abatement of electrical interference

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Contents

1. Scope

General

1.1 Medical-electrical equipment in healthcare premises is liable to be susceptible to electrical interference from:

a. alternating magnetic fields;

b. alternating electric fields;

c. transient voltage changes.

Although distinct types, these inter-relate and are generally known as Electromagnetic Interference (EMI). Electromagnetic Compatibility (EMC) is achieved when this interference is eliminated.

1.2 Earlier statutory regulations and British Standards Institution publications dealing with EMI were primarily concerned with preventing various types of electrical equipment (including medical-electrical equipment) from interfering with radio telecommunication services.

1.3 A requirement is in place for all electrical products, systems and installations not to cause, or be unduly affected by, EMI. The requirement is in the form of an EC Directive on EMC 89/336/EEC as amended by 91/263/EEC and 92/31/EEC. This Directive has been implemented in UK law by the Electromagnetic Compatibility Regulations 1992 (SI 2372) and amended by SI 3080: 1994 and SI 3180: 1995. Transitional arrangements, until 31 December 1995, were in situ so that member states could continue to allow to be placed on the market, or to be taken into service, apparatus which conforms to the national regulations in force in their territory on 30 June 1992.

1.4 The EMC Directive is not, however, all-inclusive. Apparatus wholly covered by other Directives (for example Telecommunication Terminal Equipment, which has its own specific Directive) is excluded, while medical devices, active implantable medical devices and in vitro diagnostic devices are covered by three specific Directives as follows:

a. Active Implantable Medical Devices - 90/385/EEC, UK legislation Active Implantable Medical Devices Regulations 1992 (SI 3146), effective 1 January 1993 and amended by the Active Implantable Medical Devices (Amendment and Transitional Provisions) Regulations 1995 (SI 1671).

b. Medical Devices Regulations 1994 (SI 3017) implements Council Directive 93/42/EEC concerning medical devices. It lays down essential safety requirements which medical devices must satisfy.

c. The In Vitro Diagnostic Medical Devices Regulations 2000 (SI 1315) implements council directive 98/79/EC on in vitro diagnostic medical devices.

Definitions

1.5 The following definitions apply throughout this document:

1.6 **Management:** is the owner, occupier, employer, general manager, chief executive, or other person who is accountable for the premises and is responsible for issuing or implementing a general policy statement under the Health and Safety at Work etc. Act 1974.

1.7 **Employer:** any person or body who:

a. employs one or more individuals under a contract of employment or apprenticeship;

b. provides training under the schemes to which the Health and Safety (Training for Employment) Regulations 1990 (SI 1380) apply.

1.8 **Department:** an abbreviation of the term “Scottish Executive Health Department”.

1.9 **Duty holder:** a person on whom the Electricity at Work Regulations 1989 impose a duty in connection with safety.

1.10 **Electrical/electronic equipment:** includes anything used, intended to be used or installed for use to generate, provide, transmit, transform, conduct, distribute, control, measure or use electrical energy.

1.11 **Equipment:** abbreviation of electrical/electronic equipment.

1.12 **System:** a system in which all the electrical equipment is, or may be, electrically connected to a common source of electrical energy, including such source and such equipment.

1.13 **High voltage (HV):** the existence of a potential difference (rms value for ac) normally exceeding 1000 volts ac between circuit conductors or 600 volts between circuit conductors and earth.

1.14 **Low voltage (LV):** the existence of a potential difference (rms value for ac) not exceeding 1000 volts ac or 1500 volts dc between circuit conductors or 600 volts ac or 900 volts dc between circuit conductors and earth.

1.15 **Ambient level:** those levels of radiated and conducted signal noise existing at a specified test location and time when the test sample is inoperative. Atmospherics, interference from other sources, circuit noise, or other interference generated within the measuring set comprise the “ambient level”.

1.16 **Antenna-induced voltage:** the voltage that is measured or calculated to exist across the open-circuited antenna terminals.

1.17 **Broadband emission:** emission which has a spectral energy distribution sufficiently broad, uniform and continuous so that the response of the measuring receiver in use does not vary significantly when tuned over a specified number of receiver impulse bandwidths.

1.8 **Conducted emission:** desired or undesired electromagnetic energy which is propagated along a conductor. Such an emission is called "conducted interference" if it is undesired.

1.9 **Cross coupling:** the coupling of a signal from one channel, circuit or conductor to another, where it becomes an undesired signal.

1.20 **Cross modulation:** modulation of a desired signal by an undesired signal. This is a special case of intermodulation.

1.21 **Crosstalk:** an electromagnetic disturbance introduced by cross coupling.

1.22 **Electromagnetic compatibility:** capability of electronic equipment or systems to be operated with a defined margin of safety, in the intended operational environment, at designed levels of efficiency, without degradation due to interference.

1.23 **Emission:** electromagnetic energy propagated from a source by radiation or conduction. This may be an intentional or unintentional emission.

1.24 **Field strength:** the term "field strength" shall be applied only to measurements made in the far field. The measurement may be of either the electric or the magnetic component of the field, and may be expressed as volts per metre, amperes per metre, or watts per square metre; any one of these may be mathematically converted to the others.

1.25 **Earth plane:** a metal sheet or plate used as a common reference point for circuit returns and electrical or signal potentials.

1.26 **Impulse:** an electromagnetic pulse of short duration relative to a cycle at the highest frequency being considered. Regularly repeated impulses of uniform level will generate a uniform spectrum of discrete frequencies (Fourier components), separated in frequency by an amount equal to the repetition frequency.

1.27 **Impulse bandwidth:** the peak value divided by the area of the impulse response envelope.

1.28 **Impulse emission:** emission produced by impulses having a repetition frequency not exceeding the impulse bandwidth of the receiver in use.

1.29 **Interference emission:** any undesirable electromagnetic emission.

1.30 **Intermodulation:** mixing of two or more signals in a non-linear element, producing signals at frequencies equal to the sums and differences of integral multiples of the original signals.

1.31 **Narrowband emission:** that which has its principal spectral energy lying within the bandpass of the measuring receiver in use.

1.32 **NAMAS:** a specialist NPL test executive approved under the auspices of the National Measurement Accreditation Scheme to accredit test laboratories to undertake EMC testing.

1.33 **Open area:** a site for radiated electromagnetic interference measurements which consists of open flat terrain at a distance far enough away from buildings, electric lines, fences, trees, underground cables and pipelines so that effects due to these are negligible. This site should have a sufficiently low level of ambient interference to permit testing to the required limits.

1.34 **Radiated emission:** radiation and induction field components in space.

1.35 **Spurious emission:** any electromagnetic emission from the intended output terminal of an electronic device, but outside the designed emission bandwidth.

1.36 **Spurious response:** any response of an electronic device to energy outside its designed reception bandwidth through its intended input terminal.

1.37 **Standard reference output:** a condition for a particular test sample that defines normal operation and is used in measuring any deviation from standard performance that occurs during susceptibility testing. This value should be indicated in the individual equipment specification.

1.38 **Susceptibility:** the characteristic of electronic equipment that permits undesirable responses when subjected to electromagnetic energy.

1.39 **Test antenna:** an antenna of specified characteristics designed for use under specified conditions in performing tests.

Figures

1.40 A list of Figures included in this volume:

Figure 1: The Electromagnetic Environment

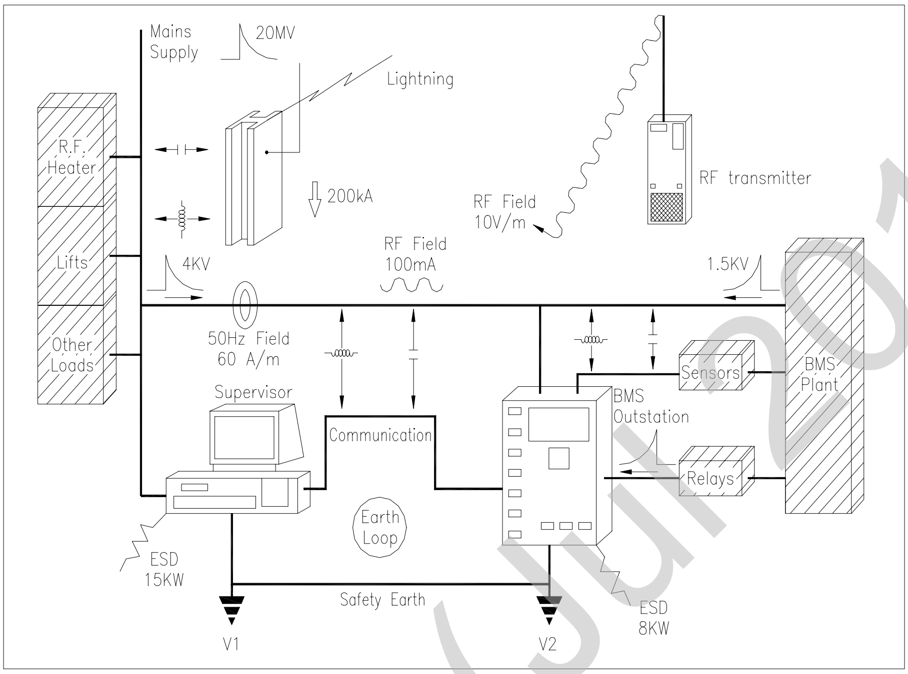


Figure 2: Main Disturbances

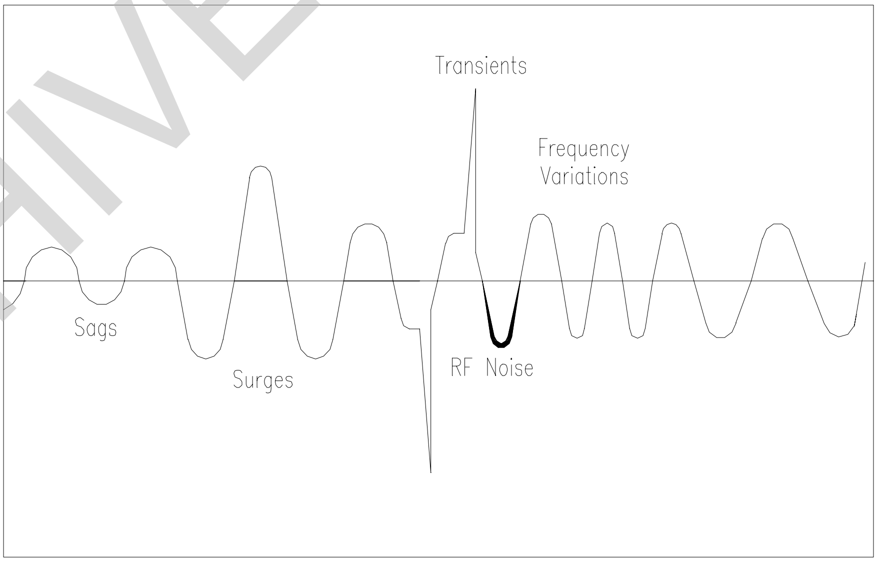


Figure 3: Typical interference waveforms

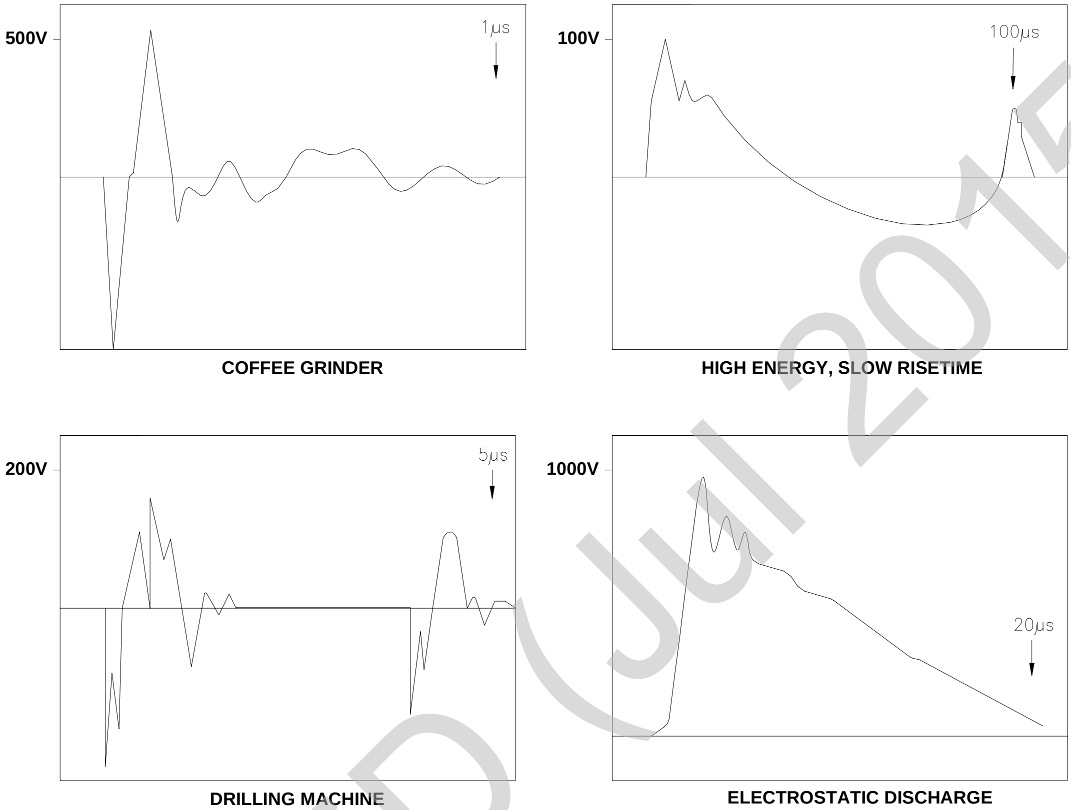


Figure 4: Enclosures limit radiation coupling

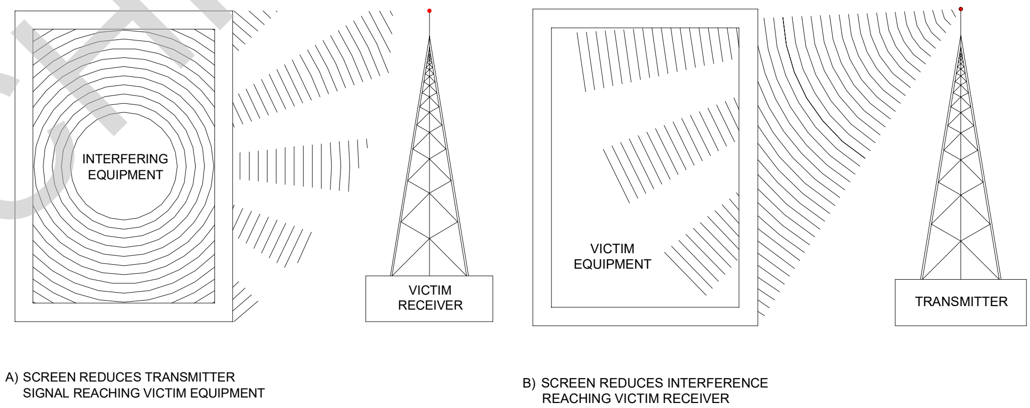


Figure 5: Electromagnetic wave hits metallic barrier

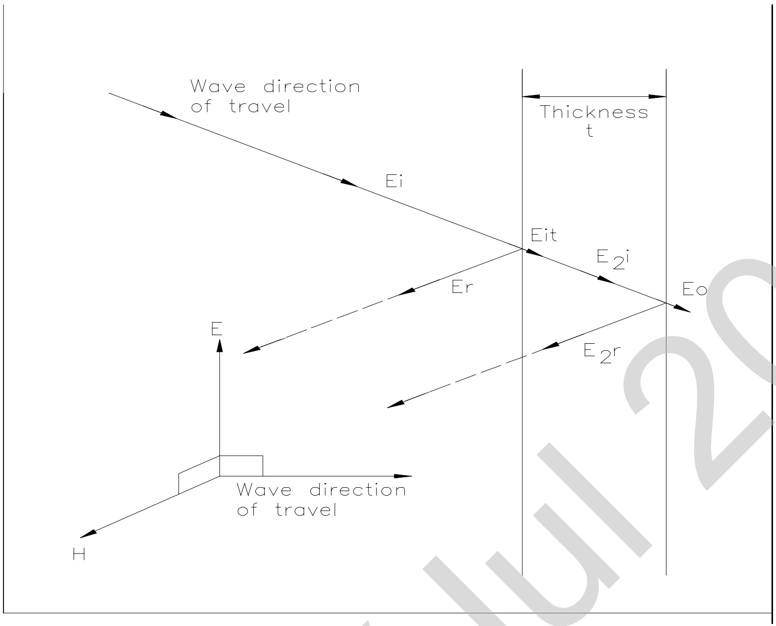


Figure 6: Absorption loss for steel and copper

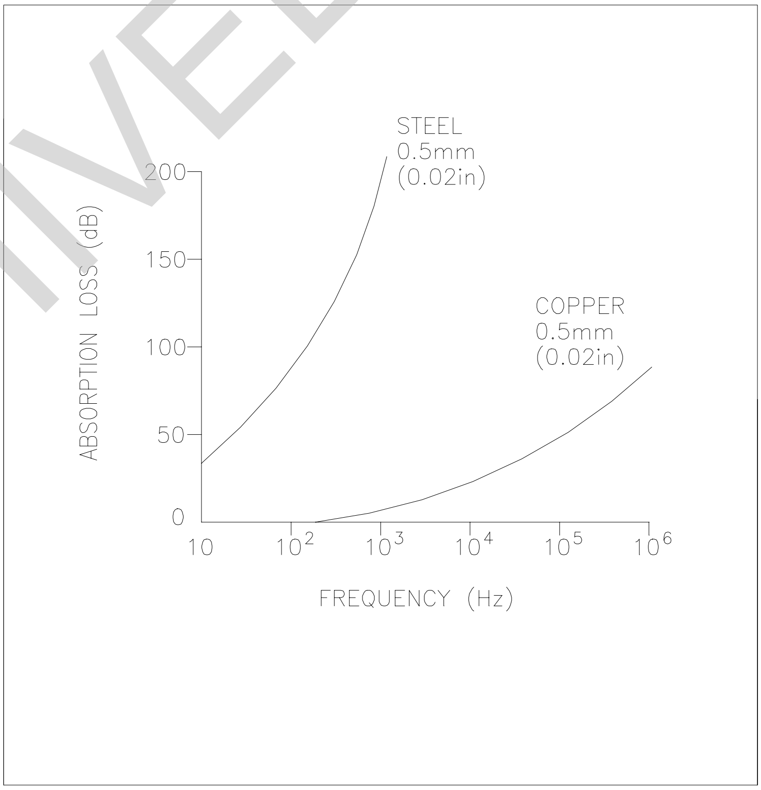
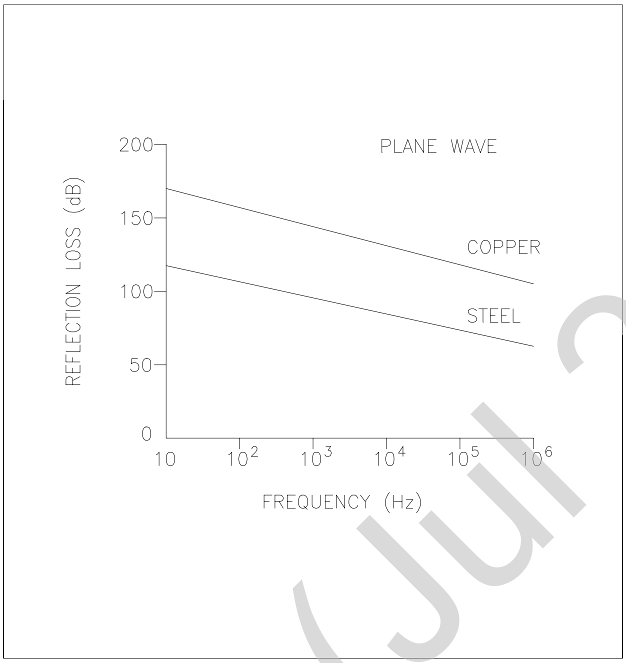


Figure 7: Reflection loss for steel and copper



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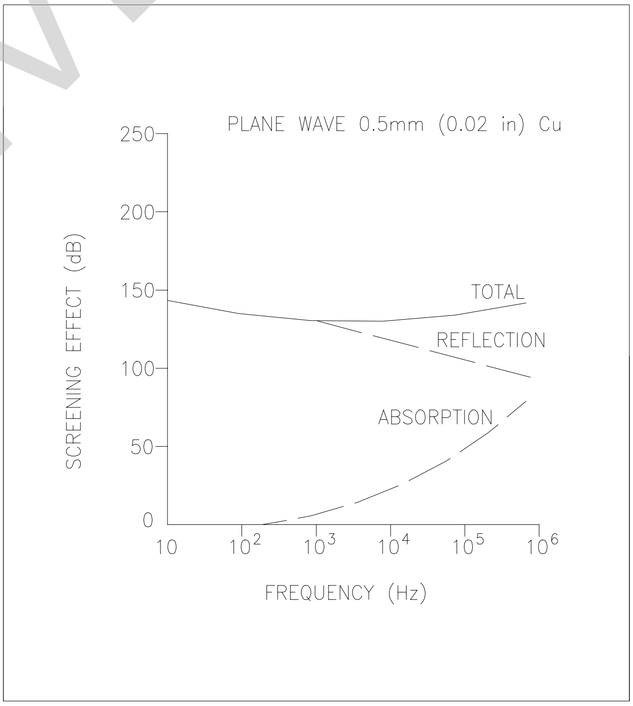

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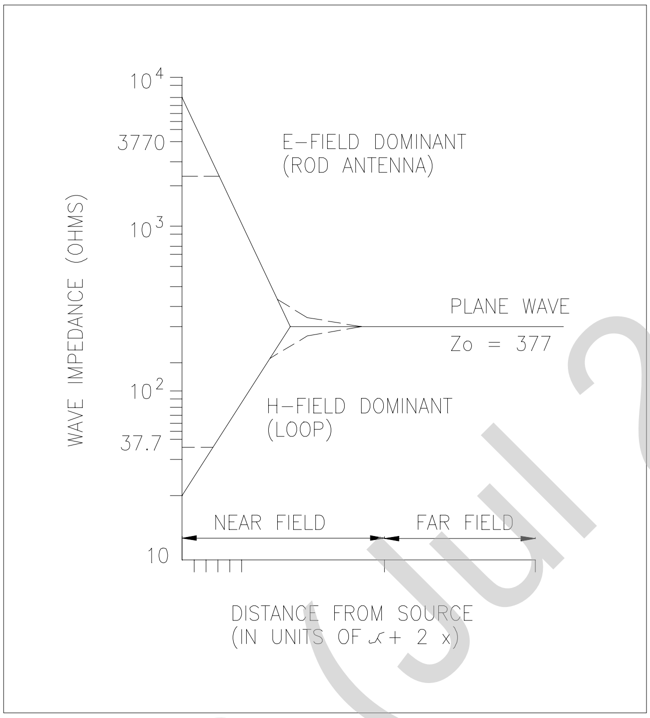

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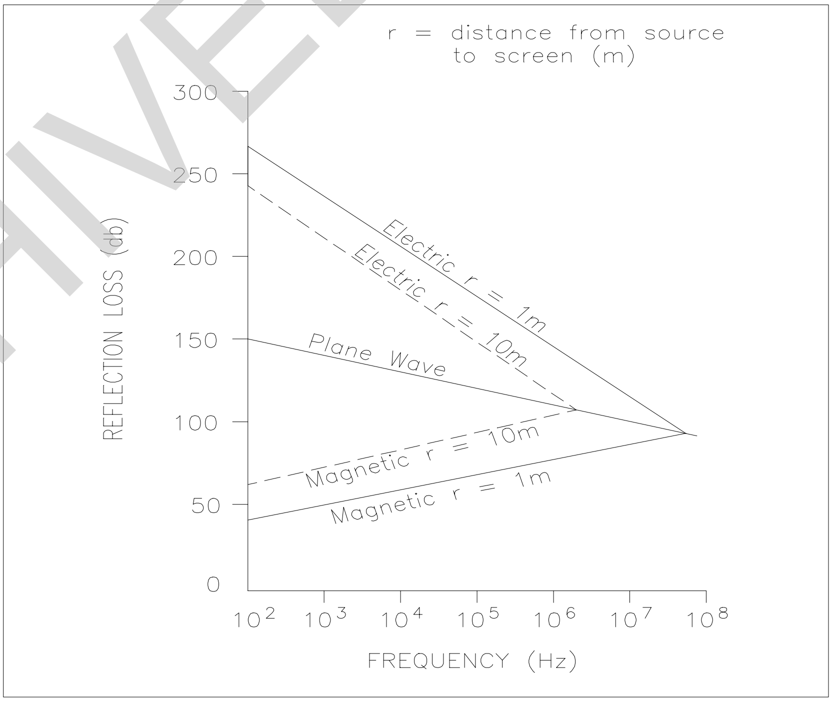
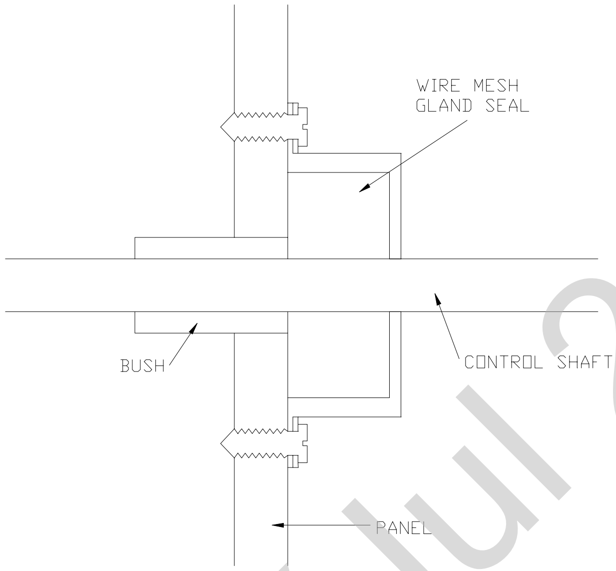


Figure 11: Example showing controlled flange separation with screw fastening



RFI Control shaft seal

Figure 12: Example showing controlled flange separation with screw fastening

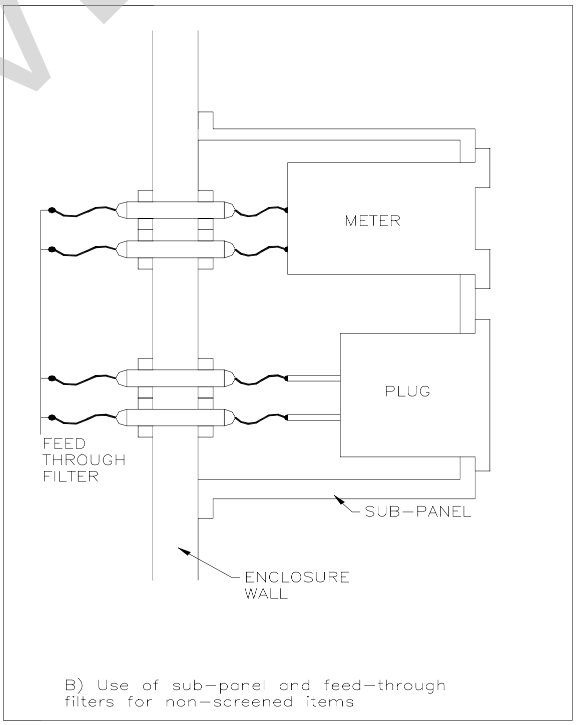


Figure 13: RFI and panel-mounting components

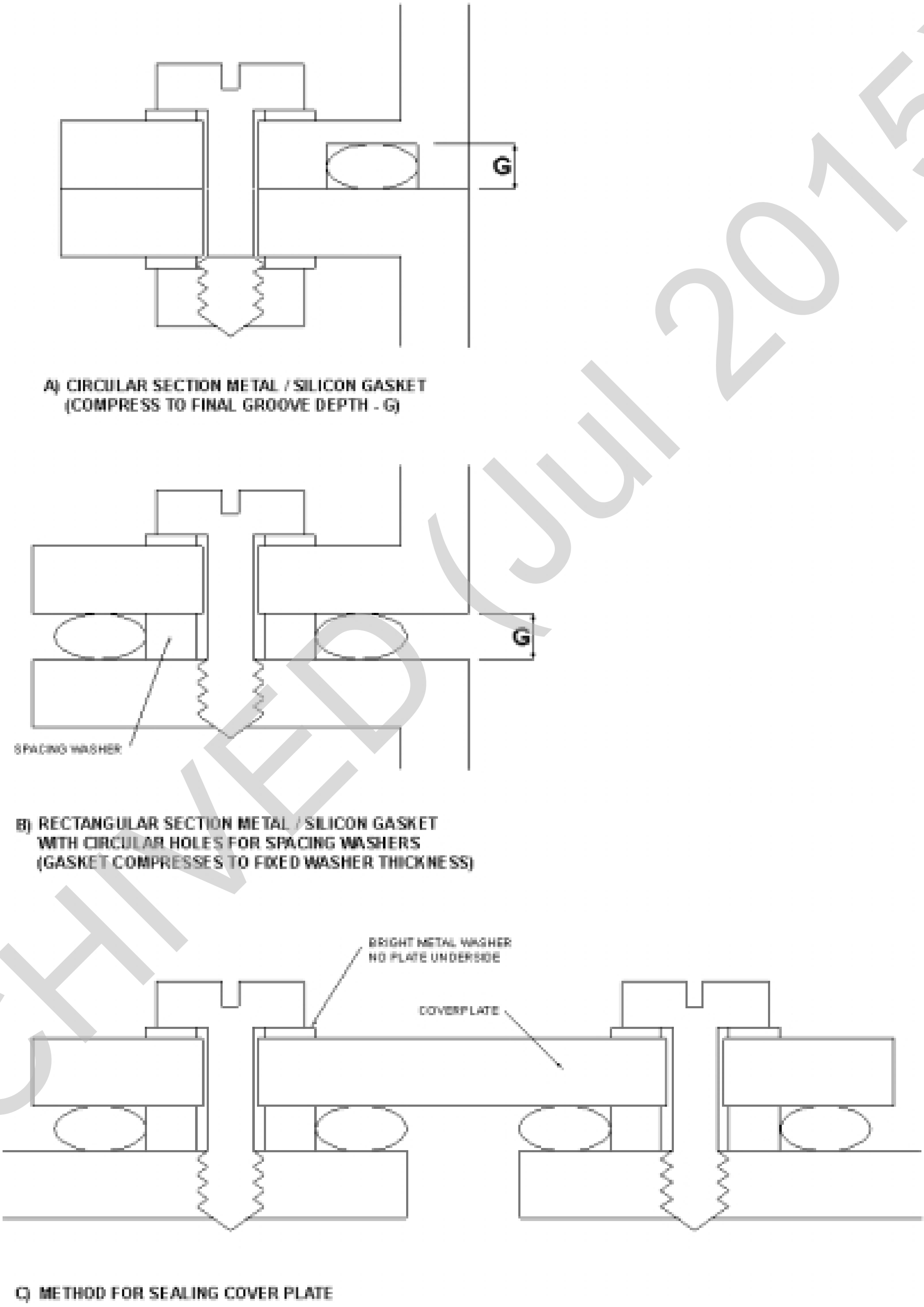


Figure 14: Low pass filter for transistor amplifier

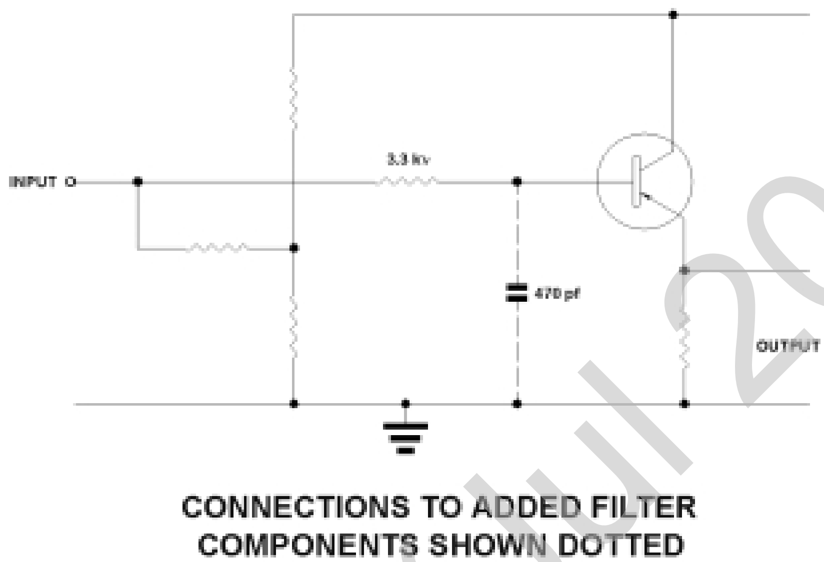


Figure 15: Frequency in MHz

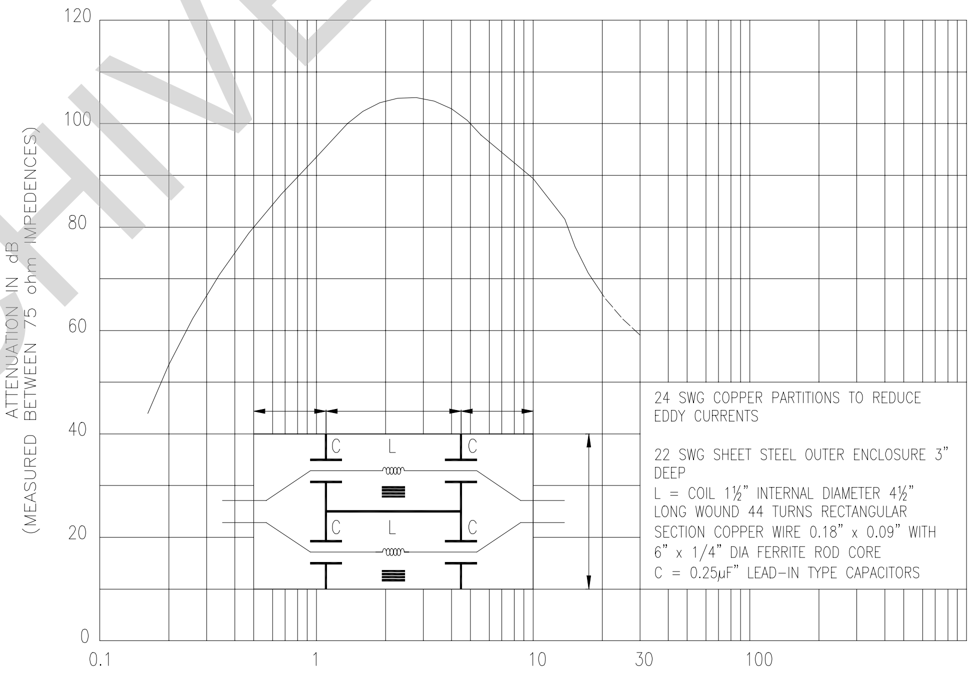


Figure 16: Frequency in MHz

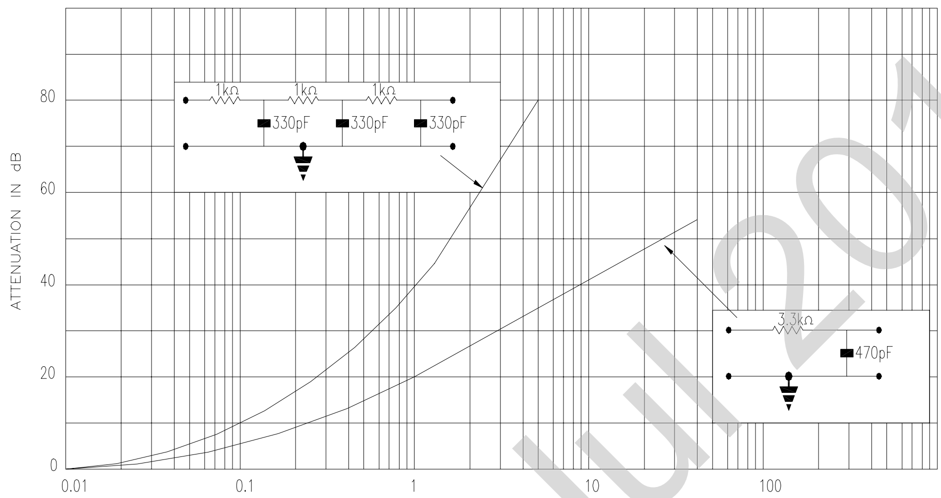


Figure 17: Circuit diagram and response curve of a twin "T" low frequency band stop filter

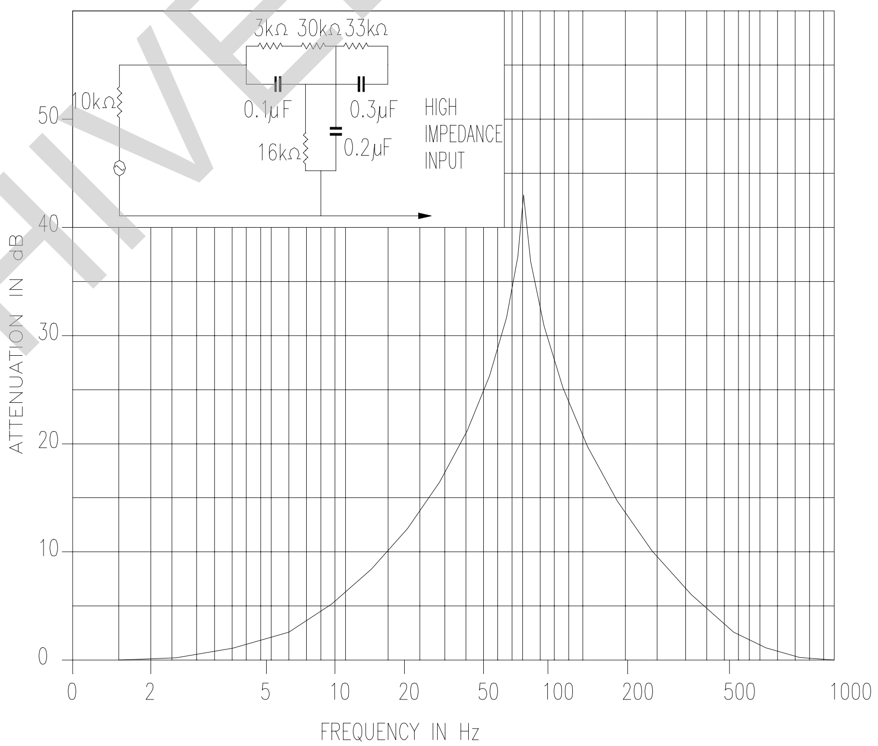
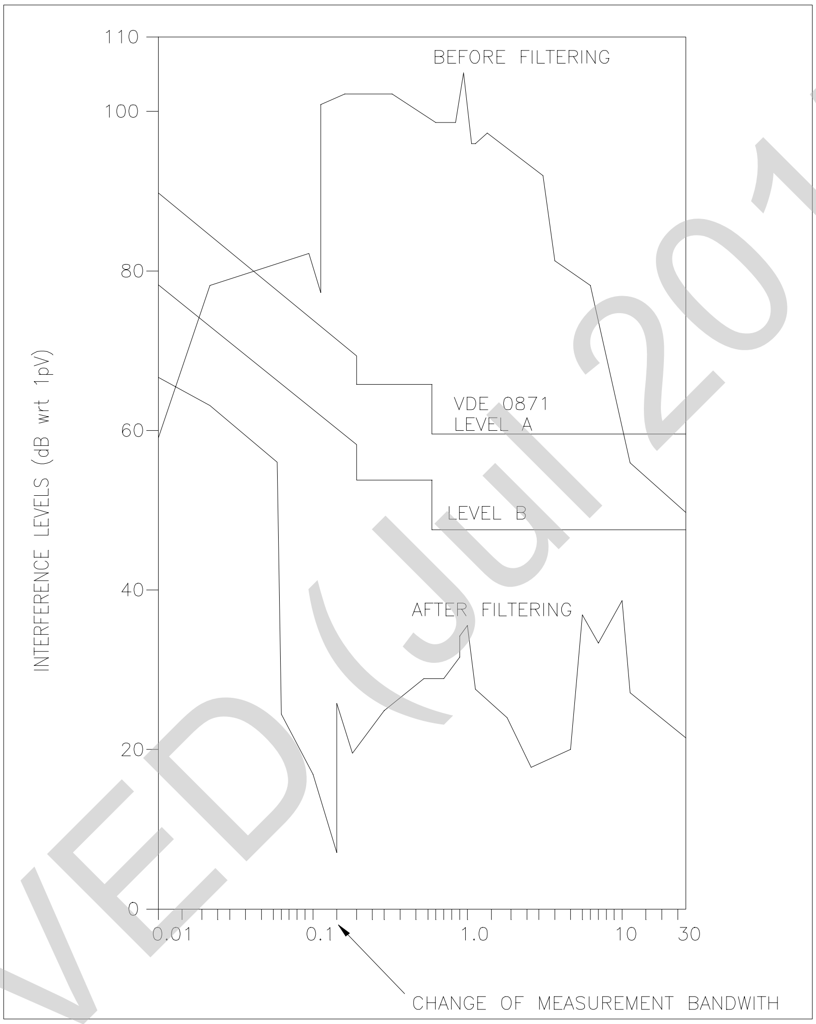


Figure 18: Frequency (MHz)



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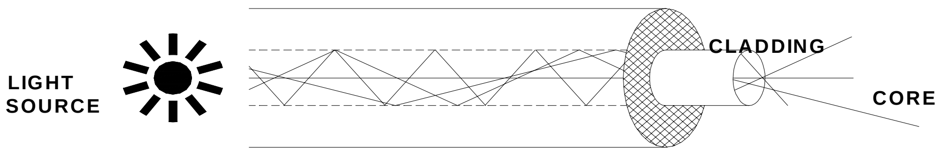


Figure 20: Expanded steel or aluminium suitable for screening

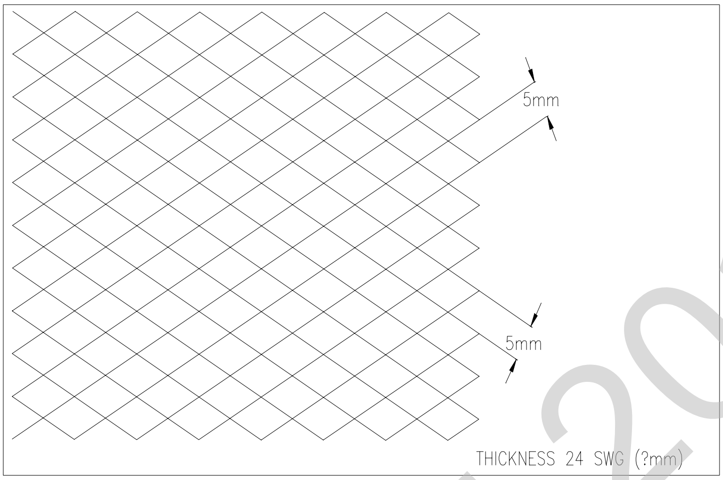


Figure 21: Screen for fluorescent light fitting

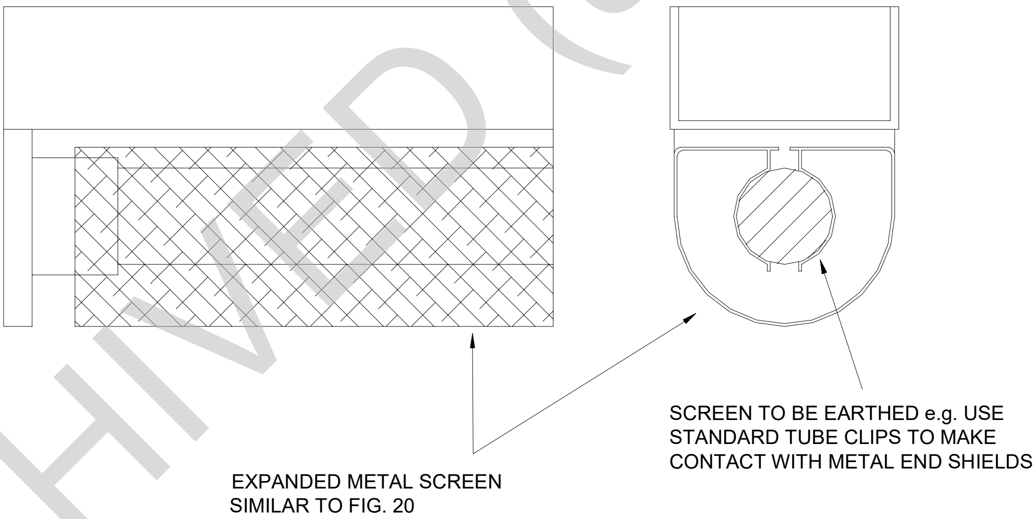


Figure 22: Window Screens

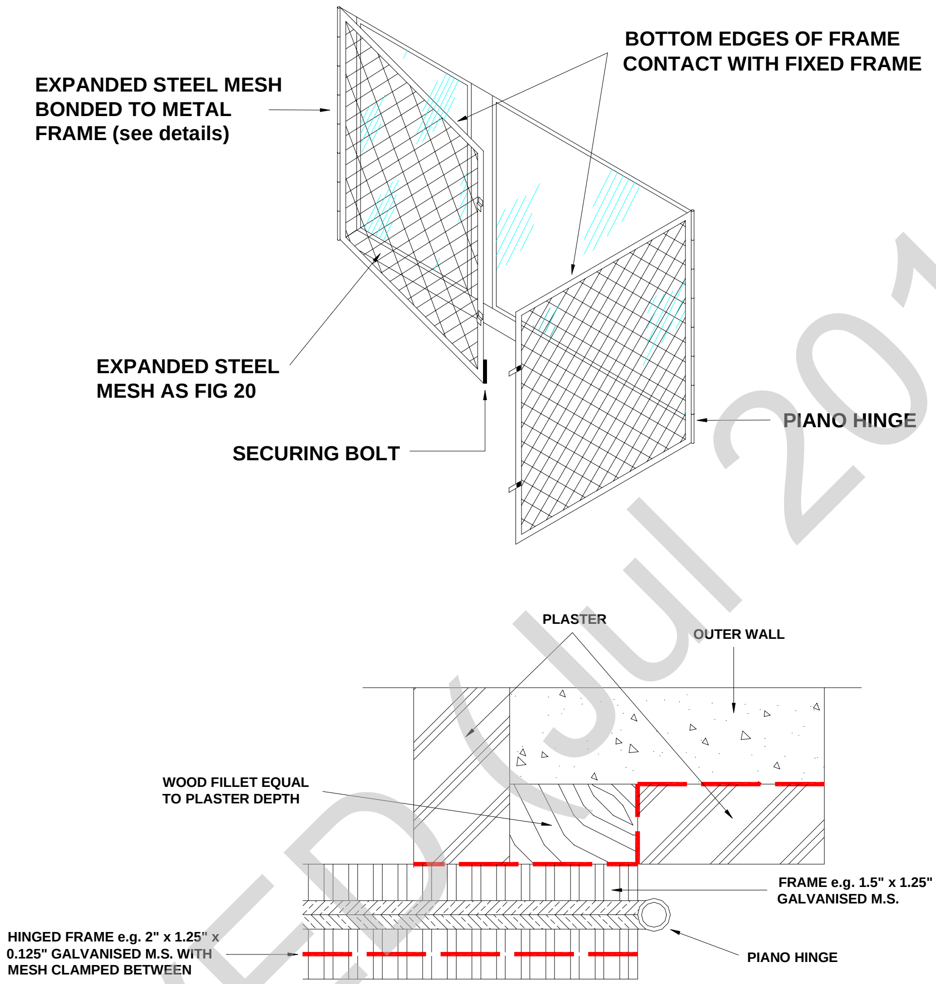


Figure 23: Screened window using wired glass

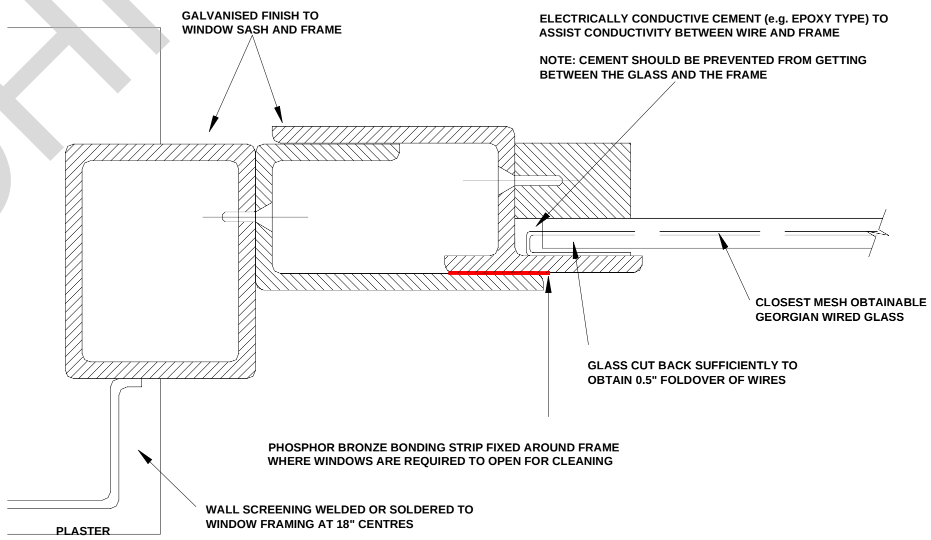


Figure 24: Bonding at bottom of door

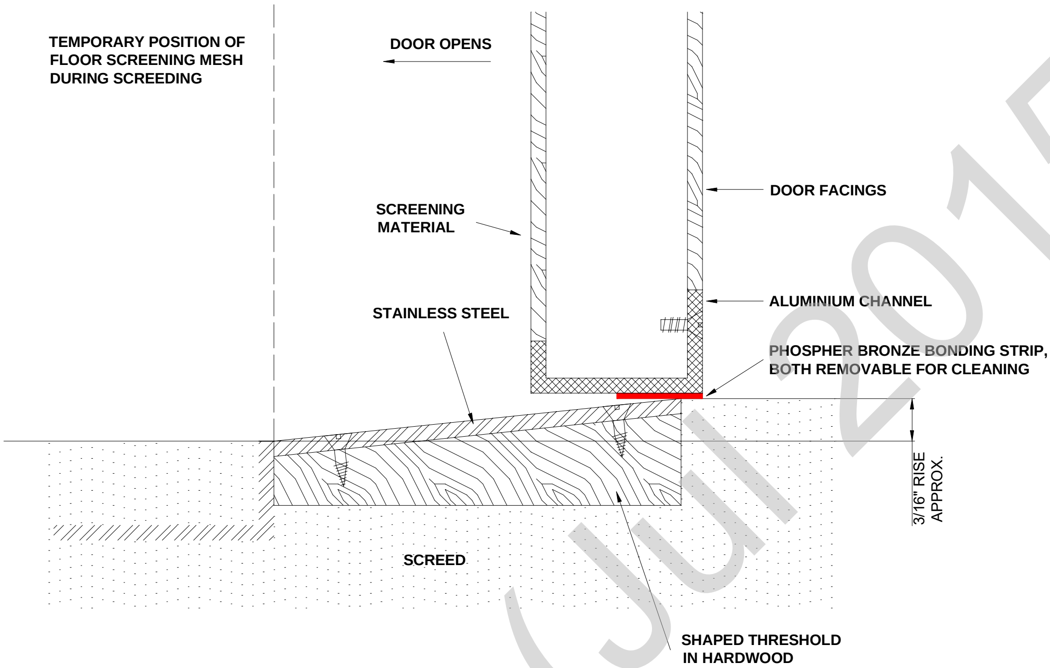
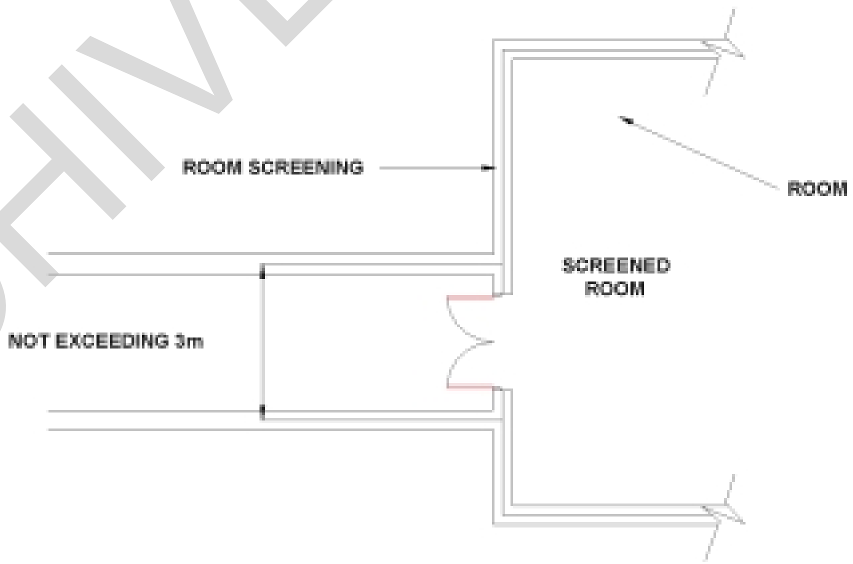


Figure 25: Waveguide entrance



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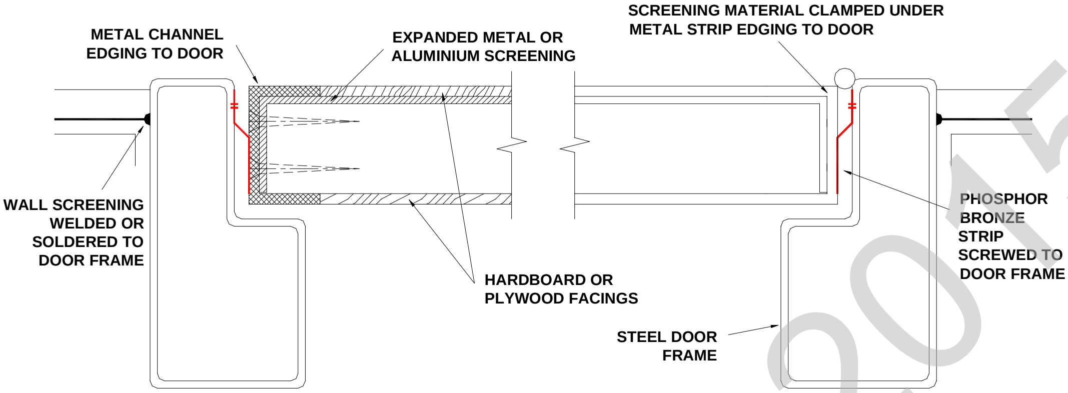

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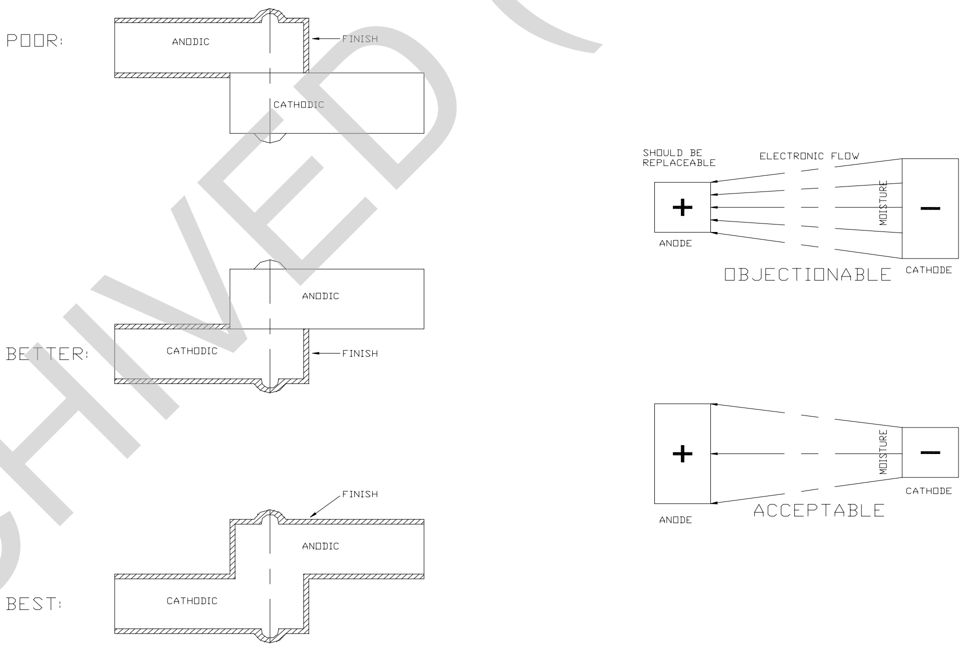

2. Sources of electromagnetic interference

2.1 Electromagnetic Interference (EMI) occurs when any unwanted signal adversely effects an undesired response from an electrical/electronic device. Potentially, every electronic device is susceptible to EMI and reciprocally, generates some degree of electromagnetic emissions. These emissions can be transmitted as electromagnetic radiation (non-ionising) or conducted through cables such as signal and power lines.

2.2 For an EMI situation to occur three elements must be present. These are:

a. a source of conducted or radiated electromagnetic waves;

b. a propagation medium by which electromagnetic energy is transmitted;

c. an element which suffers adverse effects from unwanted signals.

If any one of these elements is eliminated, interference will not occur. Thus, Electromagnetic Compatibility (EMC) can be achieved by reducing emission levels at the source, interrupting the propagation path, or hardening the victim device to make it immune to undesired signals.

2.3 Sources of electromagnetic noise are numerous and have both natural and man-made origins. Natural sources below 10 MHz are dominated by “atmospheric noise” generated by electrical storms. Above 10 MHz natural sources consist primarily of cosmic noise and solar radiation.

2.4 Man-made noise may be divided into intentional and unintentional sources. Intentional sources are those which must radiate to perform their task, and include amplitude and frequency modulated radio broadcast, television, police and other broadcast transmitters, radar and navigation transmitters, pagers, diathermy machines, mobile telephone and radios, etc. Unintentional sources include computing devices, relays, motor appliances, power lines, fluorescent lights, arc welders, etc. With the proliferation of both intentional and unintentional sources, EMI has reached levels, which have caused concern; the EMC Directive has laid down protection requirements to achieve EMC in electronic and electrical apparatus, systems and installations. Figure 1 illustrates a typical electromagnetic environment in an installation.

2.5 The main sources of electromagnetic interference in healthcare premises are described as follows.

Electrostatic discharge

2.6 Electrostatic charges are produced when different materials are brought into contact, then separated, the contact required being "make and break". Synthetic materials are most prone to electrostatic charge generation, resulting from the non-hydroscopic nature of the material; that is, electrostatic charge cannot so easily leak away or disperse as with natural hydroscopic materials. Electric fields that are generated by this simple method can reach levels of several thousand volts.

2.7 The average person has a body capacitance of about 150 picofarads (pf). At a voltage of 5.0 kV the release of discharge energy is small (2 mJ). However, the peak current may rise to 10 amperes in less than one nanosecond. This pulse contains high frequency radio components, which can couple into electronic circuits, break down or track into low voltage electronic components of electrical equipment.

2.8 As a precautionary measure, these low energy discharges must be diverted to earth, avoiding sensitive electronic circuitry. In mainframe computer areas, semiconductive floors should be provided. For work on solid state components, personnel may be earthed by metal wrist-straps to divert to earth possible electrostatic discharge from unscreened electronic components. To ensure personnel do not generate dangerous static discharges, the ambient air in mainframe or electronic work areas should be conditioned to above 50% relative humidity.

Mains supply

2.9 The quality of the public mains supply has been found, over many years, to be suitable for ordinary electrical equipment purposes, but there is also a requirement for a continuous, interference-free small power supply to sensitive electronic equipment. It is more convenient to provide the necessary interference protection at the equipment terminals, rather than attempt to improve the power supply source.

2.10 Equipment EMI protection may be enhanced by the use of mains filters, connected to the input terminals of static inverters; rectifiers to divert mains-borne harmonics; or suppressers for switching and lightning over voltages. As a word of caution, the guidance and assistance of the equipment manufacturer is advised in the provision of interference filters or suppression equipment, to ensure that the correct range of aggressive frequencies or over-voltages is removed. Refer to Figure 2.

Mains switching surges

2.11 When a switch is closed, the conductor is energised almost instantly. If the switch closes at or near the peak voltage of the mains 50 Hz waveform, a peak step voltage front will travel along the conductor with the current. The voltage step will be reflected by the load. The magnitude of the reflected wave is a function of the matching impedance.

2.12 The reflected voltage can reach a value up to twice the mains peak voltage and contain additional harmonics generated by the natural resonance of the circuit. The existence of spur connection circuits can also generate similar, additional parasitic harmonic effects.

2.13 The resulting harmonic effects now flowing in the emitter conductor can give rise to currents of the order of 100 mA over a frequency band 100 Hz to 100 MHz, which can be induced into the screens of adjacent potentially susceptible cables and subsequently carried into the victim device.

2.14 The phenomenon of "interference transfer" is also possible from high voltage cable switching operations, disturbance or transient effects.

Voltage deviation

2.15 This represents slow time changes in voltage. The requirement on a public distribution system in the UK is to maintain the voltage at the point of supply to a tolerance of ±6% of specified nominal voltage. The requirements of the EC Directives may stipulate the tolerance level in accordance with the generic specifications related to the equipment connected to the mains power supply. Voltage changes above 10% are classified as voltage dips and may extend from 60 milliseconds to 2 seconds duration.

2.16 The IEE regulations recommend a maximum voltage drop of 4% of normal voltage from the point of supply to the current-using equipment. The total culmination of voltage drops can prove to be a nuisance in cable design and may require rationalisation where large currents are involved.

Voltage fluctuation

2.17 Load demands upon a supply system are never steady, and with dynamic plant may change rapidly, causing a rapid rate of change in voltage. This condition is particularly noticeable when starting electric motors, which draw six times their full load current. The fluctuation may last up to 10 seconds and during that time, changes in the luminosity of tungsten lamps or the flickering of fluorescent luminaries is observed. Instability in indicating or electronic equipment may also be noticed.

2.18 The human eye is most sensitive to, and aware of, fluctuations that occur at 20 Hz. Electrical smoothing or thermal inertia may reduce this to 10 Hz.

System faults

2.19 System faults or sudden changes in conditions in an electric system do occur, and these in turn give rise to sudden dips or rises in voltages. These faults may arise from open circuits or a breakdown in circuit insulation.

2.20 Regional electricity companies carrying out operational switching, or the operation of automatic re-close circuit breakers, may generate reflected wave fronts within the system, giving rise to EMI.

Sine-wave distortion

2.21 The ac voltage generated in the supply is sine-wave in shape. Some magnetic distortion does occur from transformers. The main problem is from non-linear solid state power, motor speed converters and rectifiers, and also fluorescent lighting in large installations. These types of equipment generate harmonics, which reflect back into the system to cause undesirable effects on other potentially susceptible equipment controlled at mains reference normal voltage. The reflected harmonics result in non-sinusoidal voltage shapes containing 5th, 7th, 11th and higher order harmonics.

2.22 The perception of distortion is a matter of degree. In a normal mains supply these distortion effects are readily swamped by the system capacity. In locations where internally isolated electric generation is present, these harmonic distortion effects can be most undesirable on electrical equipment and result in a requirement for additional uprating of generators. The main remedy is to cause the non-linear load to limit harmonics to approximately 40% of generator rating, or to provide input load power filters to remove the distortion effects. The Electricity Association document G5/4 (2001): ‘Limits for harmonics in the UK electricity supply system’ advises.

High frequency effects

2.23 These can be produced by lightning, mains signalling, switching, fluorescent lighting, and radio frequencies induced from powerful transmitters. The high frequency transient interference can affect data and signalling cables in building management systems (BMS). The high voltage-low energy transients were not apparent in power systems until the use of the inherently susceptible semiconductor rectifiers in radios and similar equipment in the 1960s. Figure 3 outlines typical interference waveforms.

Switching and lightning pulses

2.24 An electrical wave pulse, originating from a disturbance, may flow along passive cables and metal structure, cladding or pipes, to induce high peak currents in cables connecting to instruments. This pulse may have amplitudes up to 10 amperes with rise times of 10 nanoseconds for 1 microsecond duration and be effective over bandwidths of 10 kHz to 100 MHz. A lightning strike may have a voltage drop of 100 kV per metre and currents in the order of 10^5 amperes with a rapid rise time of 10 nanoseconds. Side strikes to a metal building structure may distress instruments and printed circuitry in electronic equipment. For this reason, mainframe data equipment should be located centrally in a building, as far as possible from the outer metal structure, lightning conductors or main cable routes.

2.25 New or old buildings should be suitably protected against lightning strikes as advised in BS 6651: 1999: ‘Code of practice for protection of structures against lightning’.

High frequency lighting and dimmer switches

2.26 High frequency lighting and dimmer control switches, with thyristor type voltage control, inject very little interference into a lighting and power system and may for practical purposes be ignored. Where a large installation is in operation, an assessment should be made.

Transmitters

2.27 The operation of nearby radio frequency equipment may cause intolerable effects in the operation of electronic equipment and instrumentation. A radio transmitter can induce radio frequency (RF) voltages and currents into cables and conductors within equipment. These voltages or currents may affect the normal operation of this equipment or instrumentation.

2.28 The position of transmitters will dictate the nature of the EMI effects of an emitting dipole. At less than 0.16 times the wavelength distance between an emitting dipole and a receiver (susceptor), the wave impedance value of the magnetic (H) component is much less than that of the electric (E) component. These (H) and (E) impedance values may be shown graphically converging towards the common characteristic wave impedance value of 377 ohms, from approximately 0.16 times the wavelength. Refer to Figure 4.

2.29 This means that at close range (near the source) the magnetic component is more significant than the electric component of the wave. Conversely, away from the field the electric component is the dominant mechanism for interference.

2.30 The field strength from a RF transmitter, observed at a particular location, is a function of the Effective Radiated Power (ERP) and the distance between the transmitter and location.

2.31 Secondary effects, caused by structural metal work in the intervening distance and the contour of the ground, function as a partial screen, particularly where the impedance to earth is high. This can distort the theoretical value, as will the retransmission of the signal.

2.32 In free space conditions, the field strength at a distance ‘d’ metres from a transmitter of ‘P’ watts ERP, is given by the equation:

$$\text{Field strength (volts/metre)} = \frac{5.5(P)^{0.5}}{d}$$

2.33 At most locations the background or ambient field strengths do not exceed 1 Volt/metre.

Magnetic field effects

2.34 Magnetic fields are caused by external as well as internal sources. Typical external sources are nearby power lines, power distribution sub-stations and transformers. Water pipes carrying unbalanced neutral currents can create significant magnetic fields. The maximum magnetic flux close to a power line is in the order of 10-30 microTesla, decreasing to less than 1 microTesla at a distance of 50-200 metres. Internal aggressive sources can be a variety of electrical equipment, for example visual display units, and normal electrical cables or wiring.

2.35 Generally the background magnetic field is less than 0.1 microTesla.

3. Propagation of electromagnetic interference

3.1 There are three essential mechanisms for the transfer of electromagnetic energy:

a. conducted or induced;
b. radiated;
c. earth loops or common impedance.

3.2 Coupling paths are made up of resistive, inductive and capacitive transfer. The transfer of conducted interference requires a complete circuit path between the source and the victim. This path may consist of wiring, power supply, common impedance due to equipment chassis, supporting metallic structure, a ground plane, or mutual inductance or capacitance. Cables which have picked up interference may re-radiate energy into low level signal cables. Power lines could transfer any switching transients (from, say, switch mode power supplies).

3.3 Energy may be radiated with equal magnetic and electric field components (in the far field); or in the near field with the magnetic component larger than the electric field (low impedance induction) or the electric component more dominant than the magnetic field (high impedance induction). Each of these three gives rise to different interference mechanisms and consequently the abatement of the interference will need different approaches.

3.4 Earth loops are normally associated with currents flowing in a loop along the screen or earth lines of a signal cable, with the return path through the earth return of the power supply. Earth loops may incorporate equipment chassis and cause extended interference effects.

Coupling mechanisms

3.5 For the propagation of conducted interference, two modes of transfer can occur:

a. U_1 = asymmetrical noise value (differential mode coupling). Here, different voltages occur on a pair of signal or power lines resulting in an imbalance of, say, the power supply;
b. U_2 = symmetrical noise value (common mode coupling). Here, equal amounts of interference occur on a pair of signal or power lines such that the designed tolerance of a circuit is exceeded.

Coupling to signal cables

3.6 RF induced into signal input cables is the most likely, and the dominant, coupling interference signal. This is particularly evident with small input signals where no filter has been provided at the equipment input connection.

Mutual inductance/capacitive transfer

3.7 The further apart that parallel non-circuit conductors are placed, the smaller will be the mutual inductance present between those conductors. Reducing the loop area enclosed by the conductors of a circuit will contribute to a reduction in the mutual inductance of that circuit.

3.8 Capacitive transfer is encouraged by a high impedance circuit to earth, which allows a maximum voltage to persist longer for a given current. Stray capacitance is introduced by close spacing of conductors. This capacitance can be reduced by increased spacing, guarding or by placing intermediate non-floating conductors between the affected conductors.

3.9 Capacitive reactance decreases with increase of frequency. To be effective two paths must exist, the earth path often being a common conductor. Multiconductor cables may act as good capacitive couplers to RF.

3.10 Where distances and the circuits become more widespread, more attention must be given to mutual inductance effects. Earth plane inductance may present a problem but may be reduced by increasing the number of earth conductor connections in parallel. Cross coupling with circuits other than with printed circuit boards must be avoided.

Coupling via earth conductor

3.11 In the frequency range between 27 and 500 MHz, earth conductors may have comparable straight lengths of quarter wavelengths or multiples of quarter wavelengths to the points at which they are bonded to the earthed metalwork. Induced RF current can unexpectedly cause a standing wave voltage, which may affect instrumentation.

Coupling into instrumentation

3.12 The RF energy produced by a local transmitter may penetrate into instrument cases with very little attenuation, particularly where the cases are non-metallic, and where there are slits or openings exceeding 1/10 wavelength. The RF leaking into an instrument will induce currents in conductors connected to amplifier or sensitive semiconductor devices to give noise interference.

Coupling into equipment circuits

3.13 An electrostatic discharge producing electromagnetic radiation through a high voltage pulse current can be coupled into electrical circuits by various mechanisms:

a. by unearthed or poorly earthed components such as metallic switches, rotary spindle controls, panels, sockets and bezels surrounding instruments;
b. by near field induced interference, if protective earth conductor connections are not at zero impedance;
c. by metal panels with a non-zero impedance to earth, or capacitively coupled to circuit boards;
d. by electrostatic discharges acting as an impulse wave into instrument panels, inducing an interference pulse into data cables.

3.14 The above effects can produce the following secondary results:

a. damage to semiconductors in logic gates, microprocessors, field effect transistors, signal checks;
b. paralysis in data systems;
c. data errors in computers;
d. spurious alarms.

Decoupling mechanisms

3.15 The coupling effect between components of an EMI situation can be reduced by the provision of:

a. a low impedance path to earth and direct earth protective conductor for the equipment;
b. short conductor lengths to avoid standing wave resonant effects;
c. an increase in the width-to-thickness ratio of the conductors (but this may increase mutual inductance);
d. an increase in the spacing between conductors.

Decoupling has the added benefit of reducing the high frequency components in an aggressor current.

Prevention of electrostatic discharge

3.16 Good materials with excellent insulating or screening properties are essential as the starting point in equipment design. Sharp points or corners should be designed out and the following guidelines observed:

a. use insulating or resistive materials in panels to impede discharge current flow;
b. use metallic screen enclosures with a low impedance to the earth electrode;
c. use screened cables of low surface transfer impedance between interconnected panels;
d. arrange cable looms and circuit boards with terminal enclosures;
e. provide diode protection in printed circuits to prevent damage to components;
f. use opto-couplers/fibre optics to prevent electrostatic current flow;
g. correctly specify the equipment for its use, and ensure that the manufacturer's certificate clearly states the test results are within the specified frequency range, maximum and rise times.

Remedial action

3.17 If interference has become apparent, the improvements required to reduce this interference in the susceptible areas may include action to:

a. decouple offending circuits;
b. filter incoming wires into the equipment;
c. shorten and re-route earth conductors;
d. improve earth connections;
e. route sensitive circuits in good quality screened cables;
f. reconnect earth screens by passing the earth screen through the connector;
g. look for inadequately screened areas.

3.18 Areas for investigation should be explored with the assistance of the manufacturer and/or a NAMAS accredited EMC test laboratory, so that all areas are fully covered.

4. Electromagnetic interference in healthcare premises

4.1 The location of mobile purpose-built medical electrical equipment in healthcare premises, the method of installation, and the route of the interconnecting power, earth and signal cables, are critical for the equipment's effective and reliable clinical use. The reduction in its susceptibility to outside sources of interference or their ability to cause interference or data transfer to other electrical equipment, must conform to a minimum standard, by statutory requirements.

Electrostatic interference

4.2 The presence of electrostatic discharges between dissimilar materials is well known. Incidences of this are found on wards or in operating departments. Electrostatic discharges are associated with tactile shock effects on staff during the course of their duties. The use of artificial fibres in clothing and bed-making materials encourages the frequency of this incidence and can produce electric discharges of greater than 8 kV.

Equipment interference

4.3 Sources of electrical power supply and their load had previously been considered non-contributory sources or even victims of interference. The sensitivity of solid state electronic equipment has now shown that this is no longer the case, and that many items of everyday electrical equipment used in building premises, including healthcare premises, produce uncontrolled interference which is injected into the power supply or emitted as electromagnetic radiation, to cause all manner of control difficulties or annoyance to the operators of other equipment.

Use of metal ducts/conduits

4.4 Cable armour or metal conduit and ductwork, connected to a permanent multiple earth system (pme, TN-C-S), are paths for unequal potential circulating ground currents. It is for this reason that Scottish Health Technical Memorandum (SHTM) 2007 'Electrical services: supply and distribution' advises against the pme system. Metal ductwork, conduits and cable armour in healthcare premises must be equipotentially bonded to the main earth system.

Thermostats/relays

4.5 Switch operations, either at power capacity or for small loads such as thermostats or relay contacts, can inject or radiate interference. Suppression should be used for these devices where nuisance is apparent.

UPS/rectifier/speed control

4.6 Uninterruptible Power Supplies (UPS), motor speed control and battery rectifiers are a source of mains injected harmonic interference. For this reason, in essential circuits the proportion of this type of load should be restricted to no more than 40% of the emergency generator rating or be filtered at the load input.

Diathermy equipment

4.7 Diathermy equipment is permitted under existing legislation to emit unlimited interference in the 13.56 MHz and 27.12 MHz frequency ranges. This interference can cause considerable disturbances in digital communications and alarm systems used around healthcare premises. The first consideration is to ensure aggressive radiation sources are well separated from signal cable routes.

Intentional transmitters

4.8 Personal transmitters/receivers, main transmitters and local radar devices should be evaluated to ensure that they do not cause random operations or failure of electronically controlled equipment. Personal transmitter/receivers are particularly likely to cause this problem. Checks should be made with these devices on all new plant installed, at a convenient time, to ensure there is no susceptibility. Any operational faults may be corrected by more effective screening, filtering or earthing.

4.9 Unearthed intervening metalwork panels can increase or decrease the problem. The electric component of the electromagnetic wave is reduced, and the magnetic component increased, by re-radiation from the metalwork (depending on the type of material used).

Power transformers

4.10 Power transformers are a concentrated source of low frequency magnetic interference. Mineral oil or synthetic liquid cooled transformers give fewer problems, as the steel casing is hermetically sealed and earthed. As a fire hazard they must not be housed within the main healthcare premises building. Dry type, air cooled transformers can be housed within a building; as their windings are exposed and often only partially screened by a cubicle, they freely emit considerable 50 Hz leakage radiation. The location and cubicle screening of these transformers should be carefully considered in relation to sensitive equipment and the building structure at an early stage.

4.11 The influence of the transformer and the route of unscreened or single core main LV cables must not be ignored. There may be magnetic coupling with the steel and reinforcement bars of the building structure, thus inducing a network of currents flowing in the steel to earth, with associated localised secondary magnetic fields.

Equipment location

4.12 Mainframe computer equipment must be placed in purpose-designed rooms. The preferred location is for easy equipment access or removal, in the centre of the building, away from lift shafts, cable ducts or flumes and lightning roof/down conductors. This gives the best possible isolation from the influence of power cables or building lightning conductor currents. Lightning strike currents can also flow to earth in the outside steel of incorrectly protected buildings.

4.13 To reduce EMI entering or confidential data and information leaking, from mainframe computer rooms, the processing of secure data and information may require the protection of screened rooms and doors, with anti-static flooring and screened incoming power and lighting cables.

4.14 Telephone system wires and cables should also be screened overall, and the screens earthed to a low impedance earthed rod facility at the point of room exit, to prevent the telephone wires behaving as data radiating antennae to the outside.

4.15 Power and lighting supplies may be required to pass through an isolation and screening transformer and/or filtering to prevent the injection of data into the public supply.

4.16 Metal conduits, ducts and pipes should have inserted transition insulation pieces and metalwork earthed at point of exit from the screened space.

Earth plane

4.17 The supply lines and protective conductor-earth return path form part of the common impedance of any two sub-circuits.

4.18 The common impedance can be reduced by de-coupling the protective conductor to a nearby earth plane. Copper backed printed circuit boards greatly reduce the common impedance and response times since:

a. resistance and inductance are reduced due to the larger copper backed area;
b. return paths of any two circuits are less likely to coincide;
c. sub-circuit area is smaller, reducing mutual induction;
d. capacitance is reduced between sub-circuits due to the guard effect of the earth plane.

General interference prevention methods

4.19 These are:

a. whole room screening to protect data processing equipment from RF;
b. screened equipment cabinets;
c. short screened signal input and power cables;
d. low pass filters on all equipment input and output cables;
e. filters installed on printed circuits or on critical, active devices;
f. circuits designed to be less susceptible;
g. sufficient signal magnitude;
h. use of local area network (LAN) fibre optics;
i. low impedance protective conductor and earth.

4.20 In cases where tracing the source of interference becomes more difficult, expert opinion should be sought from establishments which are accredited by the National Measurement Accreditation Scheme (NAMAS), under the executive management of the National Physical Laboratory (NPL). These establishments possess the experience and test equipment to locate the source and type of interference and to recommend solutions.

5. Control of electromagnetic interference

5.1 Source, propagating medium and victim must all be present for an interference situation to exist. Each of these entities must be designed such that any associated electromagnetic interference can be contained to a tolerable level.

5.2 Noise control design must consider the sources, modes of operation, and factors such as the types of signal pulse, and the occurrence of transients. Interference sources must be operated on the most linear part of their design curves so as to minimise the harmonic content in their outputs. Oscillatory circuits, clocks and switching devices must not be operated at a speed that is faster than that necessary to perform the desired function. Pulsed signals will produce the least EMI when they have slow rates and are of long duration. The magnitudes of high frequency components increase as the pulse width decreases and as pulse rise and fall times are shortened. The transition times of a control or other pulse should only be fast enough to ensure reliable operation within specified time constraints.

5.3 Wherever possible, use the minimum bandwidth value. Filters are important in channelling the correct energy into the correct devices, as well as in noise prevention. For example, powerline filters should be installed near the dc motors. The use of a pi-filter in a motor application diverts high RF currents to earth at the motor.

5.4 Low inductance wiring minimises induced voltages. However, as frequency increases into the HF and VHF ranges, wire-wound resistors exhibit series inductance: even composite resistors exhibit lead inductance. Stray capacitance may then result in an anti-resonant circuit. Capacitors exhibit series resistance due to losses and also inductance. Care in wiring design is needed to minimise these effects.

5.5 “Noisy” components should be located as close as possible to their associated loads, to minimise the lengths of the coupling paths.

5.6 Devices fed from the same power bus should be decoupled from one another through the use of bypass capacitors or, at extremely low frequencies, through the use of zener diodes or separate power supplies for isolation. Decoupling of possible interference sources (for example flip-flop) as well as sensitive devices (FET amplifiers) may be needed. Minimise the use of low-level technology devices-for example CMOS, use only the level of sensitivity needed to perform the task.

5.7 Remove power from devices when their use is not required for systems operation.

5.8 Screening is an effective means of curing the problem of radiating sources. Both physical and electronic isolation should be provided between radiating antennae, if their RF links are operated simultaneously.

Interference within circuits

5.9 Interference within circuits is most prevalent in situations where long wires are run in close proximity to one another for appreciable distances. To minimise interference coupling in these situations, the following actions should be taken:

a. isolate noise-carrying components and wiring from wiring attached to sensitive components;

b. minimise wiring length to reduce EMI coupling path lengths;

c. segregate return lines of noisy components from the return lines of sensitive components. In general, signal and return leads, as well as control or supply and return leads, should be run in close proximity to one another and if possible, twisted as twisted pairs;

d. reduce capacitive coupling between wires by the use of thick wire insulation or insulating sleeves.

5.10 The "antenna" characteristics of wiring and structural members should be recognised: any conductor that carries current will, unless shielded, radiate an electromagnetic field (Biot-Savart law). Correspondingly, any conductor present in an electromagnetic field will develop a voltage proportional to the electric field component parallel to the conductor, or if a loop, current proportional to the magnetic field strength traversing the loop. This means that every wire in a circuit, as well as every metallic line on a printed circuit board, acts to a greater or lesser degree as a transmitting antenna and a receiving antenna. Such action becomes more prevalent as frequency increases. For wires it becomes more dominant at the higher impedance levels, and for loops it becomes more noticeable at the lower impedance levels. The amount of interference coupled may be reduced by decreasing the circuit impedance. Correspondingly, coupling that occurs primarily via the magnetic field (current loops) can be reduced by increasing the circuit impedance.

Earthing design guidelines

5.11 Earthing is the establishment of an electrically conductive path between two points to connect electrical and electronic elements of a system to one another or to some reference point which may be designated the "earth".

5.12 The following design guidelines represent good practice, but are not to be applied rigidly. It is the equipment design objectives which should govern the final design:

a. use single point earthing for circuit dimensions which are less than 0.03 wavelength and multipoint earthing for circuit dimensions greater than 0.15 wavelength. The type of earthing for circuits between those two dimensions depends upon the physical arrangement of the earth leads as well as the conducted emission and susceptibility limits of the circuits being earthed. Hybrid earths may be needed for circuits which must handle a broad portion of the frequency spectrum;

b. apply floating earth isolation techniques (for example the use of isolation transformers) if earth loop problems occur;

c. keep all earth leads as short and wide as possible;

d. design earth reference planes so they have high electrical conductivity and can be maintained easily to retain good conductivity;

e. for safety considerations, make certain that earth connections can handle fault currents that might flow unexpectedly or lightning current surges;

f. provide separate circuit earth systems for signal returns, signal screen returns, power returns and chassis or case protective earths. These returns can then be tied together at a single earth reference point;

g. for circuits that produce large abrupt current variations, provide a separate earthing system, or provide a separate return lead to the earths to reduce transient coupling to other circuits;

h. isolate the earths of solid state circuits from all other earths;

i. where signal and power leads must cross, make the crossings so that the wires are at right angles to each other;

j. use balanced differential circuitry to minimise the effects of earth circuit interference;

k. for those circuits whose maximum dimensions are significantly less than $\lambda/4$, use tightly twisted wires (either screened or unscreened) that are single-point earthed to minimise equipment susceptibility.

Bonding design practices

5.13 Bonding is the establishment of a low impedance path between two metal surfaces. The following list represents good bonding practices:

a. ensure intimate contact between metallic surfaces. These surfaces should be smooth and clean with no non-conductive finishes in the contact area. The fastening method should exert enough pressure to maintain surface contact in the presence of mechanical deformations, shock and vibration;

b. join similar metals (in the electrochemical series) or interpose replaceable washers between dissimilar metals and use protective finishes after the bond has been made. Refer to Tables 3 and 4;

c. do not rely on solder for mechanical strength;

d. protect the bond from moisture and other corrosion causes;

e. jumper braids are only a substitute for direct bonds. Keep them short for low resistance and small L/C ratios;

f. keep length to width ratios for jumper leads to five or less;

g. avoid jumpers that are lower in the electrochemical series than the bonded members. Bond directly to the basic structure rather than through an adjacent part. Do not use self-tapping screws;

h. make certain that the bond or jumper can carry the expected current.

Screening design practices

5.14 The purpose of screening is to confine radiated energy within the bounds of a specific region, or to prevent radiated energy from entering a specific region.

5.15 Screens may be in the form of partitions and boxes, as well as in the form of cable and connector screens. A screen is characterised by its attenuating effectiveness: the ratio of the electromagnetic field without the screen in place to the electromagnetic field with the screen in place. The two principal mechanisms that reduce field strength due to screening are absorptive loss and reflective loss. An electromagnetic field propagating through a conductor is subjected to absorptive losses due to the conductor's extremely poor dielectric characteristics.

5.16 The amount of absorptive loss is determined by the conductor's skin depth: the field intensity is decreased exponentially inside the conductor. Reflective loss occurs due to the impedance discontinuity at every boundary between air and the metal.

5.17 Screening effectiveness of a material depends not only on the material and its thickness, but also on the distance from the source, the frequency of the source and any discontinuities in the shield:

a. good conductors such as copper and aluminium should be used for electric field screens to obtain high reflection loss. A screening material thick enough to support itself usually provides good electric field screening at all frequencies;

b. magnetic materials such as iron and mumetal should be used as magnetic field screens to obtain high penetration loss (absorptive effect);

c. multiple screens for enclosures and cables can provide high screening effectiveness over wide frequency ranges;

d. thin film screens have a screening effectiveness that is fairly constant with frequency, for material thickness of less than wavelength/4. Screening effectiveness increases markedly as thickness increases beyond wavelength/4;

e. all openings and slots or discontinuities, such as seams, should be designed so as to cause the minimum disturbance in the current flow in the metal set up by an impinging electromagnetic field;

f. discontinuities such as seams must provide good metal-to-metal contact;

g. corrosion effects between dissimilar metals in the electrochemical series must be avoided;

h. equipment casing should have good screening properties (plastic casings may be coated in conductive paint finishes);

i. seams and panels should be welded or overlapped or sealed with gasketing materials;

j. panels and covers should be attached using conductive gasketing material with closely placed screws;

k. the waveguide attenuator principle is useful for maintaining screening effectiveness for slots and apertures;

l. internal interference generating circuits must be isolated both electrically and physically. Electrical isolation is achieved by circuit design and physical isolation may be achieved by proper screening;

m. cabling that penetrates a case should be screened and the screen terminated in a peripheral bond at the point of entry. This peripheral bond should be made to the connector or adaptor shell;

n. connector screens that make the earth connection before the signal pins mate are preferable. Similarly, pins should disconnect before the plug screen separates;

o. avoid wire braid tails when terminating cable screens;

p. when coaxial cables are used for signal transmission use the screen as the return path and ground it at the generator (source) and for low frequency circuits. Use multipoint grounding (peripheral) of the screen for high frequency circuits;

q. provide multiple shields for low level transmission lines. Single point earthing of each screen is recommended.

Filtering design practices

5.18 An electrical filter provides the means whereby levels of conducted interference are substantially reduced if the spectral content of the interference is different from that of the desired signal. As such, filters perform a function that cannot be fulfilled by any other interference reduction means. Filters are often used as stop-gap measures to resolve problems resulting from previous poor design. Careful design in the early stages will often eliminate the need for makeshift filtering.

5.19 The insertion loss of a filter is defined as the ratio in decibels of the output voltage of a circuit with the filter in place, to the output voltage of the same circuit without the filter in place:

a. when fitting a filter it is essential that the metal case of a power mains filter is adequately earthed. Failure to do this can result in the filter being ineffective and even becoming an interference source;

b. the filter compartment must be carefully designed, otherwise the filter effectiveness will be compromised by interwiring crosstalk. The wires into the filter (carrying unfiltered signals) must be kept well away from the wires out of the filter;

c. mismatched filters can cause resonant voltage peaks in the region of the designed cut-off frequency, leading to increased noise voltages: check the performance of the filter in the circuit - most manufacturers claim a filter performance, as measured in a 50 ohm system;

d. filters normally shunt the unwanted noise signals directly to the structure/casing. Any RF earth signal return (0 V) then becomes a significant factor in the effectiveness of the filter;

e. the choice of best filter for a particular application entails detailed analysis of the source, load and signal (0 V) return impedance of every circuit associated with the cable loom to be filtered.

6. Electromagnetic compatibility aids

Screening

6.1 The enclosure surrounding an item of electrical equipment can offer the best possible interference protection from radiated interference. This must be fully realised in the design stage. Once committed it becomes virtually impossible to modify. A screen for an item of electrical equipment must be conductive metal, or be comprised partially of conductive metal filler in a non-conductive matrix.

6.2 It is required to confine electromagnetic energy within a specific space, or prevent the ingress of wave energy into a specific space and/or to reduce the wavefield strength to a tolerable level.

6.3 The level of attenuation by which an electromagnetic field strength is reduced to a tolerable level will be determined by the following characteristics:

a. type of material;

b. thickness of material;

c. distance between the aggressor source and the victim electrical equipment;

d. frequency of the radiated wave;

e. quantity and shape of any intervening obstacles to the radiated wave path.

6.4 The reduction or attenuation of the field energy (S) of an electromagnetic wave after passing through a screen is expressed in decibels (dB). This loss is represented by the equation:

$$S = 20 \log_{10} \frac{\text{incident wave strength volts/m}}{\text{exit wave strength volts/m}}$$

6.5 The loss "S" in decibels is derived from the sum of the following quantities:

a. part absorption (A) of the wave energy passing through the material, determined by the generic quality of the material;

b. reflection loss (R) at the incident surface due to the mismatch in the wave impedance and the material surface impedance. R is generally the largest quantity in S at the higher frequencies;

and to a lesser extent,

c. the number of internal reflections between the internal faces of the material that a wave is subjected to, before exit from the material (B). Refer to Figures 5 to 10.

6.6 Absorptive loss (A) is expressed as

$$A = 3.34d(f\mu_r\sigma_r)^{0.5}\ \text{dB}$$

Where: d = material thickness

f = frequency of wave

σ_r = conductivity of material relative to copper

μ_r = relative magnetic permeability

If "d" is very small, so that A ≤ 15 dB, then the type of material must be carefully chosen in terms of re-reflective properties for magnetic field containment, that is, for low frequency and low impedance sources.

6.7 Reflective loss (R) is expressed for varying conditions of wave source:

a. low impedance - magnetic field;

b. high impedance - electric field;

c. plane wave - transverse electromagnetic field.

In general, $R = 20\text{Log}_{10} \dfrac{[4\eta_s\eta_w]}{[(\eta_s + \eta_w)^2]}$ dB

Where: η_s = surface impedance

η_w = wave impedance

Metal screened apertures

6.8 The dimensions of any open aperture, and the thickness of the metal can significantly influence the effect of the total electromagnetic wave energy penetrating the enclosed electrical equipment (waveguide techniques). The "cut-off" point of a wavelength is equal to 2 x the maximum dimension of the aperture. For a round hole, the factor is 1.703 x the diameter.

6.9 For a wavelength of less than this cut-off value, there is very little attenuation. By decreasing the dimensions of a rectangle or hole the aperture attenuation increases for a fixed bandwidth of frequencies, up to a maximum, to finally equal that of a solid sheet of metal of uniform thickness.

6.10 Where effective screening is required to function with an adequate component of ventilation, the total cooling area of the apertures must be rationalised to obtain the maximum attenuation, and the number of apertures, the area of maximum dimension of the apertures and the metal thickness have to be considered. The dimension/thickness ratio of the metal must be large in relation to the aperture's largest dimension to maximise the attenuation for a wide bandwidth of interference.

Honeycomb

6.11 Where a ventilation duct must penetrate into a screened enclosure, or more supporting strength is required than offered by a wire mesh, or where weight is critical, a honeycomb structured aperture should be provided across the duct cross-sectional area, using the same wavelength "cut-off" criteria of thickness/dimension as used in the previous item.

Panel apertures

6.12 Any structured panel should limit the size of control/operation spindles, push buttons and analogue/digital visual display units. The apertures may require a minimal thickness/dimension ratio and therefore offer very little wave attenuation over a large part of the incident frequencies bandwidth. The attenuation properties can be increased by incorporating in the original design the following factors:

a. screened enclosure, placed behind the display instrument, etc, with feed through filters for outgoing wires or through panel spindles;

b. viewing panel where the protective glass is covered with transparent conductive surface film or metal gauze screens. Refer to paragraphs 6.10 and 6.11.

Magnetic screening material

6.13 The relative magnetic permeability (μ_r) of magnetic materials can vary with the strength of the magnetic field, and also be changed during the manufacturing process as the result of forging, machining or major temperature changes.

6.14 In addition to the usual iron magnetic materials available, sophisticated alloys may be used possessing a high proportion of nickel, potassium and boron. These alloys have values of relative permeability, which increase with magnetic flux density (Tesla).

Thin film screening material

6.15 This is defined as material, which is less than one-quarter wavelength in thickness at the propagation velocity dictated by the screen material. The material is very thin, is not self-supporting and must adhere to a supporting material, for example a plastic sheet, by spraying or vacuum depositing.

6.16 In thin film material the greatest component of screening is derived from the reflective term (R). The effectiveness can be reduced by the internal reflective term (B).

Frequency dependence

6.17 Where the thickness (t) of the screening material is less than a quarter wavelength of the incident wave the attenuation loss is almost independent of the wave frequency. For a thickness in excess of a quarter wavelength the loss is frequency dependent, as the skin depth absorptive loss comes into play.

6.18 The incident electromagnetic radiation will usually cover more than one frequency. Attenuation calculations apply to a specific frequency. The incident spectrum may require analysis to find the worst offending band of frequencies.

6.19 Surface resistance: The surface resistance (R_s) of a film of material applied to a sheet of material for screening, earthing or electrostatic dissipation is expressed as R_s:

$$R_s = \frac{\rho}{d}$$

Where: ρ = resistivity in ohm/centimetres

d = thickness of the film in centimetres

The thinner the coating the less effective will be the surface attenuation (A).

Skin effect resistance

6.20 As the currents induced by the incident wave into a screened material increase in frequency, then the induced current will flow closer to the surface of the material. For a material capable of absorbing energy from a wave, the depth of effective current flow below the material surface is the skin depth (d). This depth is represented in a conductor by the equation:

$$d = \frac{1}{(f\pi\mu\sigma)^{0.5}}$$

Where: f = frequency

μ = permeability

σ = conductivity

The metal with the best attenuation is indicated by the metal with greatest skin depth. Such materials are, in order of preference, mumetal, hypernick, nickel-iron, cold rolled steel, nickel, stainless steel, copper, aluminium, brass, zinc.

Conductive surface films

6.21 Metal conductive films should be used on plastic enclosures, which offer no screening to electromagnetic waves, and those which encourage the build-up of electrostatic charge. Conductive films can be applied as:

a. surface finish;
b. tape or thin sheet;
c. compound filler for holes or caulking seams.

6.22 The conductive film may comprise:

a. metal filled acrylic paint containing nickel or silver, which must be compatible with the parent surface. The paint may be sprayed:
   (i) nickel fillers are suitable for foam and moulded grade plastic;
   (ii) silver fillers provide better conductivity, temperature operating range and environmental stability;
b. vacuum depositing requires molten metal spraying (usually zinc) onto a plastic parent surface and can be undertaken by specialist laboratories;
c. adhesive backed tapes: can be used for bridging small gaps in surface areas, or as a temporary repair.

6.23 The materials mostly used are silver, copper and graphite:

a. silver will require a surface bonding agent to give reliable adhesion to the parent surface, and will require surface protection to prevent damage or removal;
b. copper has a disadvantage in that it tends to oxidise with age. This can be prevented by using a filling agent mixed with copper particles to reduce environmental effects. The filler may be a thermosetting epoxy resin, with a good balance of physical strength and electrical properties. Films may be 50-70 micrometres thick giving a surface resistance of 0.5 ohms square and effective screening of 40 dB;
c. graphite is mainly used as a filler in a mixture for the dispersal of electrostatic charge, and may be found principally in floor materials where the release of electric high voltage charge causes stress failure in electrical equipment or irritation to attendant personnel. The graphite is a derived petroleum product and is mixed with a filler plastic. Typical surface resistance value is 150 ohms square.

Conductive plastic

6.24 This is best used as a volume production requirement or where difficult shapes or complex contours are involved. It is applied by injection transfer in compression moulding methods. The plastic resin has a filler of aluminium metal flakes which when thoroughly mixed produces a fine, homogeneous composite material.

The plastic polymer used with conductive fillers can be:

a. polyolefino;
b. styremics;
c. thermoplastic;
d. thermosetting resin.

Conductive glass

6.25 Where visual apertures are required for monitoring and control, the glass surface may be coated with a fine film of material which is highly absorbent to a wide frequency rate of radiation outside the visible spectrum.

6.26 Visual efficiency of conductive glass: the objective is to provide a conductive coating to the glass surface which will not excessively reduce the transmission of visual light.

6.27 The thicker the conductive coating applied, the lower will be the surface resistance, R_S, and the poorer the light transmission.

6.28 Conductive glass surface coatings are available which offer high transmission/low reflection percentage to visible light, but above and below this band of visual frequencies, a low transmission/high reflection percentage.

Wire screened displays

6.29 As an alternative to conductive coated glass, a wire gauze covering may be placed across standard glass. The gauze mesh can give very effective screening but is more obtrusive and intrudes into the observer's line of sight.

6.30 Permanent apertures: these are essential openings that cannot be screened effectively or conveniently by a metal cover or conductive glass. They may comprise:

a. exposed connector or plug-socket pins;
b. indication or control lights;
c. push-buttons;
d. cracks, holes, breaks or seams in a screened construction.

6.31 In some cases wavelength cut-off technique may be possible: for instance control spindle outer cylinders can be used as tubular waveguides.

6.32 When instruments are fully enclosed in a metal box, and entries are required for instrument wires, then a filter type gland should be used. If an opening is required for temporary operational access, a metal spring-loaded flap onto a conductive seal should be used. Push buttons may be covered by flexible conductive rubber diaphragms.

Cable screen

6.33 The effectiveness of the screen surrounding the conductor can vary considerably. This is defined as the surface transfer impedance. Cable conductors may be screened by the following techniques:

a. metal wire braid - in single, double or triple woven layers;
b. flexible metal conduit;
c. rigid metal conduit;
d. helical wound, overlapping strips of highly permeable alloys of iron and aluminium or copper strip.

Braid and conduit

6.34 The effectiveness of braid depends ultimately at high frequencies upon the tightness of the weave and the overlap of any other woven layers to seal weave openings. As the half wavelength becomes less than the openings in the weave, so the wave energy will become less attenuated.

6.35 Flexible conduit suffers the same weakness as braided cable. The openings in the helical lay can act as slotted antennae.

6.36 Solid walled metal conduit gives the same effective screen as would a solid sheet of the same material and thickness. Solid metal conduit is the preferred screen material for use in screened rooms for power and lighting conductors. The surface transfer impedance of this conduit decreases with increase of frequency.

Determining factors for cable screening

6.37 Screened conductors or cables will require an overlay of conductive bedding and an outer sheath of material impervious to environmental penetration or deterioration. Other factors are:

a. screen material and thickness of the material;

b. method of securing a uniform contact between the screen and parent metal of the gland;

c. the orientation of the gland to the wave plane;

d. distance and direction of source;

e. standing wave ratios on straight sections of the cable;.

f. cable flexibility required;

g. surface transfer impedance (Z_T);

h. ground plane loop impedance (Z_{loop}).

Below 1 MHz, braided and metal conduit of the same material have screens of almost the same surface transfer impedance Z_T.

Above 1 MHz the Z_T of braid cable increases while that of metal conduit decreases.

Transformer screening

6.38 The connecting path of a protective conductor between earth and the interwinding screen of an equipment transformer, must be as short as practical.

6.39 A long, high impedance protective conductor path may be ineffective in preventing high frequency current transients flowing into the load through the capacitances existing between the primary winding and the screen, and the secondary winding and the screen. These reactances generated by the transient current high frequencies may prevent the transient current filtering to earth, but instead will divert through the parallel, relatively lower reactances, offered in the load circuit.

6.40 Where the screen connects to a short, relatively lower impedance protective conductor which in turn is effectively connected to a locally buried, auxiliary earth electrode, then a transient current would filter to earth in preference to flowing in the load circuit. The ground-resistivity to the main earth electrode should be of low impedance to allow the return of the transient current to the point of its occurrence, through the 3 phase main distribution transformer winding.

Terminations of cable screens

6.41 Cable screens must always be insulated along the route length to prevent undesirable earth contacts inducing circuit noise.

6.42 Cable screens must not be used as a signal return path, except in the case of co-axial cable. Tightly twisted wire pairs may be used for a flow and return path. The screens of wires conducting wide bandwidth signals should be earthed at both ends and at intermediate points where feasible.

6.43 For audio frequency circuits, the screen should be earthed at the equipment or receiving end only.

Crimped terminations

6.44 A crimped termination is preferred. The size of the crimping tool and anvil must be preferably of a size recommended by the termination manufacturer. An undercrimped termination will give poor contact and allow the wire to become easily detached.

An overcrimped termination will be "pinched" and will harden the wire strands, which then become susceptible to breakaway separation when handled.

Magnetic terminations

6.45 A magnetic termination is compressed onto the stranded wire by a concentrated magnetic field, using special equipment. This technique requires a correctly dimensioned wire size and a magnetically permeable terminal screen.

Soldered terminations

6.46 Soldered terminations are not suitable where the heat applied may damage the insulation, sleeving or screen. A cold silver epoxy resin solder provides a good adhesion bond when applied correctly. A termination must be fully enclosed by the screen to be effectively protected from interference. The screen must make all round contact with the equipment metal within the connector or plug, to the equipment's low impedance earth. Pigtail screen-earth connection should not be used.

Gasket screens

6.47 Conductive gaskets should always be used where contact is required between two irregular surfaces to limit or prevent the ingress of stray electromagnetic waves. The gasket must have a low value electrical conductivity, and be corrosion resistant, physically resilient and tough. Refer to Figure 13: RFI and panel-mounting components.

6.48 The gasket materials may comprise:

a. monel;

b. silver-plated brass;

c. copper or aluminium with sponge silicon or neoprene;

d. combinations of materials which are compatible for use with fluids, gas and air requirement.

6.49 The gasket may be of the following construction:

a. spongy rubber, through which fine wires are run in matrix to provide conductivity;

b. electrically conductive, silicon elastomer which is resistive to environmental corrosion. The active filler will normally be silver;

c. knitted wire mesh, which comprises looped springs, interlocked as hinges for resilient movement, and is flexible and cohesive.

6.50 Gaskets may be used as permanent seals in equipment on cladding or as temporary seals for lids or inspection covers. The compression required to form a tight seal between the opposing surfaces must not overstress the seal material and cause permanent deformation. Up to one-third of the elastic stress limit is advised for removable gaskets and one-sixth for permanent gasket seals.

6.51 Torque limiting tools should be used wherever special care is required. The bare metal facing surfaces must be smooth finished machined or milled to give all round contact. Where studs, screws or clips reduce the contact area, then these areas must be locally increased, or considered as the nett gasket width.

Spring clips and fingers

6.52 These can be used as an alternative to a sealing gasket where regular access may be required without tool assistance. The closing edges of the aperture must have labyrinth overhangs to deflect ingressing radiation waves, and spring clips to maintain close contact with the fingers at a conductivity equal to the parent material.

7. Electromagnetic compatibility aids - suppression devices

Filters

7.1 An electrical circuit filter may be defined as a network of lumped or distributed, fixed resistors, inductors and capacitors, their equivalents or any combination of them, that will offer comparatively little impedance to the passage of current at certain frequencies or dc, while blocking the flow of other frequencies.

7.2 A substantial reduction in conducted interference current can be obtained by filters, based upon the spectral content of that current being different from that of the desired current. Filters should not be used as a first attempt solution to a conducted interference problem. The first attempt should be to remove any transfer interference, by the provision of adequate screening and a low impedance earth connection.

7.3 Filtering is less reliable than screening or earthing. Costs, design and procurement time dictate that filters should be used only where required.

Filter characteristics

7.4 The effectiveness of a filter is represented by its ability to remove or reduce undesirable harmonic frequency voltages from the input to the load.

This is represented overall as:

$$\text{Insertion Loss (IL)} = 20\text{Log}_{10} \frac{[E_1]}{[E_2]} \ \textbf{dB}$$

Where: E_1 = voltage at load, with filter in circuit;

E_2 = voltage at source without use of filter.

7.5 The reduction of undesirable harmonics is also represented as a power loss, that is, absorbed in the filter components.

$$\text{(IL)} = 10\text{Log}_{10} \frac{[p_1]}{[p_2]} \ \textbf{dB}$$

Where: P_1 = power transfer between source/load;

P_2 = power transfer between source/load with filter.

This overall insertion loss can be shown for various frequencies for fixed values for L and C, as a characteristic graph of insertion loss against frequency.

7.6 Due to the interaction of the various frequencies on the R, C and L components of the filter, the step change from zero to maximum insertion loss, or vice-versa, is never attainable. In practice a positive or a negative ramp function is more realisable. For a simple low pass filter of the capacitive shunt, inductive series configuration, the insertion loss in decibels is:

$IL = 10 \, Log_{10} (1 + F^2) \, dB$

Where $F = \pi f R C$

or for an inductive low pass filter, $F = \pi f \dfrac{L}{R}$

and R = the source (R_S) and load (R_L) resistances in ohms

C = capacitance in Farads

L = inductance in Henrys

Reflective filter configurations

7.7 Filter designs are based upon three circuit arrangements:

a. "T" type;

b. "Pi" type;

c. "L" type.

The configuration of the active filter inductive (L) and capacitive (C) components is indicative of the type.

7.8 The reflective filter is designed to present a low series impedance and high shunt impedance in the accept or pass band frequencies, and a high series impedance and low shunt impedance in the reject or stop band frequencies. The basic source/load matches are:

a. "T" type, for use with equal source and load impedances, of less than 50 ohms;

b. "Pi" type, for use with equal source and load impedances, of greater than 50 ohms;

c. "L" type, for asymmetric source and load impedance requirements.

7.9 Mismatches associated with the use of reflective filters can result in an increase in interference rather than the desired decrease. One method is to convert unwanted frequencies to heat by the use of Lossy filters; others are:

a. the voltage must be sufficient to provide protection against unexpected voltage and transient changes in supply;
b. resistors and capacitors must be adequately rated for rapid changes in the normal voltage from spikes and fluctuation, resulting from heavy current switching or lightning induced surges;
c. the peak voltage of any surge in voltage must be limited to a specified maximum, to protect vulnerable electrical equipment;
d. the current rating must be based upon the maximum expected load current to prevent overheating of the resistors, inductors and capacitors in the operating ambient;
e. the electrical protection and cableworks should be rated to the supply switching device and associated protection;
f. any overrating is undesirable, as this results in excess weight, cost and space required;
g. insufficient rating will lead to unreliability and unsafe operation;
h. the components used should be of the highest quality and comparable, at least, to that of the electrical equipment of the load;
i. allowance in the design should be made for a decrease in filter insulation resistance for proper and long-term operation;
j. guidance of the electrical equipment manufacturer should be sought for design or supply.

Band pass filters

7.10 This type of filter is a combination of the low pass filter and the high pass filter. The cut-off point of a low pass filter is defined as frequency f_1. Up to f_1, the filter offers a low series impedance and a high shunt impedance to frequencies zero to f_1. Beyond f_1, the series impedance is high and the shunt impedance is low. Refer to Figures 14, 15 and 16.

7.11 The switch-on point of a high pass filter is defined as frequency f_2. Beyond f_2, the filter offers a low series impedance and a high shunt impedance to frequencies f_2 to infinity. Up to f_2, the series impedance is high and the shunt impedance is low.

7.12 By arranging a low pass filter in series with a high pass filter, where $f_2 < f_1$, a selected range or band of frequencies between f_2 and f_1 would flow in the circuit. This is called a band pass filter.

7.13 By arranging a low pass filter in parallel with a high pass filter, where $f_1 < f_2$, a selected range of frequencies, zero to f_1 would flow through the low pass filter and a selected range of frequencies f_2 to infinity would flow through the high pass filter. The mixing at the down stream junction would indicate the omission or rejection of a band of frequencies, f_1 to f_2. This is called a band stop filter (Figure 17).

7.14 It is important that the overall source impedance should match the load impedance in reflective filters, as a mismatch can result in increased interference instead of a reduction. Where a mismatch is apparent a Lossy filter can be easily attached to a circuit, which in turn will absorb the energy in a range of frequencies which have not been fully absorbed in the high series impedance frequency range represented in the filter characteristic.

Lossy filters

7.15 The Lossy filter can be comprised of a material known as "ferrite" - a mixture of 6:1, iron and epoxy resin, in a homogeneous magnetic matrix. Ferrite can be provided in tubes with inner and outer conductive coatings, as for power line filters, or as clip-on beads for high frequency requirements. In the electronic range, plug and socket arrangements for equipment can have sockets with ferrite inserts, to increase the insertion loss at undesirable, reject frequencies. The addition of a Lossy filter to the main filter in cascade can steepen the "cut off" or "switch-on" point of a filter, and remove undesirable frequencies that have been conducted due to the presence of resistance, and stray inductance and capacitance. These components will be evident, by degree, due to the material and manner of manufacture of the individual components, and response to the harmonics frequencies within the supply.

Component behaviour

7.16 Spurious behaviour of components due to frequency and temperature of the component may alter the filter designed characteristics.

7.17 Capacitors exhibit the following behaviour:

a. resistance resulting from:
   - (i) dielectric losses;
   - (ii) foil resistance;
   - (iii) wire lead to foil surface contact resistance.

b. inductance resulting from:
   - (i) foil inductance of capacitor plates;
   - (ii) wire lead inductance.

7.18 Types of capacitor for VHF:

a. mica;

b. ceramic - disc type with round flat plates remains effective to highest frequencies;

c. metallised mylar - low dissipation factor for good RF performance in the shunt capacitive filter applications. Compact design and good reliability;

d. tantalum - large capacitance in a small volume, electrolytic and sensitive to reverse polarity, poor ratio frequency characteristics, series resonance may occur at 2-5 MHz.

7.19 Metallised paper capacitors:

a. self-healing dielectric causes radio noise as the metal film burns away;

b. equivalent circuits of R, L, and C, of individual parts of the capacitor.

Aluminium foil capacitors:

a. not self-healing;

b. unusable as an RF bypass up to 20 MHz.

7.20 Inductors exhibit the following behaviour:

a. interwinding capacitance causes resonance (more than one coil may be required in series to offset) - inductors are best wound toroidally.

b. loss resistance:

(i) hysteresis;

(ii) core absorption;

(iii) ohmic.

c. core materials:

(i) powdered iron;

(ii) molybdenum alloy;

(iii) ferrite for currents less than 100 mA.

RC transient suppression

7.21 Opening of relay contacts causes the collapse of the magnetic field, which induces a reverse voltage. The reverse voltage increases between contacts until an arc is struck. The arc is extinguished when energy in the inductance is dissipated and voltage drops to a low level.

7.22 To prevent or reduce arcing, the transient energy may be dissipated in the inductor coil as follows:

a. resistance (R) damping by high value parallel resistance or arc chute. Applicable to ac or dc circuits. The lowest value R is most desirable but this must be offset by need to limit the possible input current, power consumption and 'R' rating;

b. capacitive (C) suppression by capacitance and resistance (R) in parallel, generally used for dc circuits. The value of R should be 25%-50% the value of the inductor resistance (R_L) for the load to appear resistive.

$$C = \frac{L}{R} R_L$$

7.23 Resistive/capacitive damping, with resistance in parallel with capacitor (C), combines resistance damping with capacitive suppression and is used for dc voltages.

Diode suppression

7.24 This may be used in parallel with an inductor:

a. for dc voltages;

b. diode must be connected with the correct polarity, that is, across the inductor in the non-conducting direction with a series ballast resistor of several ohms;

c. diode must be able to withstand the inductor induced voltage.

7.25 Back-to-back diode suppression: this may be used in parallel with an inductor, as follows:

a. dc or ac inputs;

b. diodes must be connected with correct polarity;

c. diode avalanche voltage must exceed input voltage;

d. diode must be of sufficient rating to handle transient current; a ballast resistor may be required.

Power line filters

7.26 This type of filter reduces the electromagnetic interference that may be present in a source induced power supply circuit. The line impedance is lowered thus reducing load induced EMI. Refer to Figure 18. Below frequencies of 15 kHz this impedance decreases to below 1.0 ohm.

Active filters

7.27 These types of filters are designed to react to the level of EMI that is injected or enters into a main circuit. The use of solid state device controls has enabled the provision of large values of L and C, without excessive size or weight.

7.28 Active filter devices are required in the presence of:

a. low impedance levels (well below 1.0 ohm);

b. power line characteristics at a near power frequency.

These filters consist of capacitors as storage elements, modified shunt regulation with high gain feedback for interference cancellation, limited to a narrow power frequency band. Noise attenuation of 30 dB per filter can be achieved and can be further improved by cascading filters.

Noise reduction circuits

7.29 These can be applied to function as noise blankers, that is, render circuit inoperative during interference.

Noise cancellers

7.30 These devices take a sample of the noise, without the signal, and by a 180° phase shift and amplitude adjustment, cancel the signal interference, to leave the signal unattenuated by noise.

Noise limiters

7.31 These devices restrict the level of the noise spike from rising above a present amplitude, by clipping (class ‘C’ amplifier). This is not effective against thermally generated noise or steady interference.

The passband must be wide enough to prevent resonance from noise pulses.

Gated noise limiters

7.32 This device is designed with a faster time constant at the input, than that at the output. The output must be able to follow the charge-discharge time of the input. If the shape of the pulse does not allow this functional relationship then the controlling diode will cut off until the noise passes, to conduct again after the interfering noise has passed, that is, most pulses are gated out and the sinusoidal waves are allowed to pass.

7.33 Special filters:

a. three terminals - one foil wound capacitor plate is connected to an earth terminal, and the other plate connected internally between the input and output line terminals of the capacitor;

b. feed-through capacitors - a case construction allows a high resonant frequency of 1 GHz. Input and output terminals are isolated by screen partition and rating determined by the diameter of the feed-through bus to be filtered. Refer to Figure 12.

Ferrite beads

7.33 These comprise mainly ferrite toroids and when threaded onto a wire, attenuate high frequency noise or sinusoidal components. Each bead behaves as a single turn (N) in an RF choke inductor, functioning mainly as a resistive impedance to the wire currents. The intensity of attenuation can be increased, or reduced, by increasing or reducing the number of beads as a function of N^2.

7.34 Ferrite mainly comprises iron granule compounds free of organic substances and is not degraded by most environments. The Curie temperature is the temperature above which the ferrite will lose its magnetic property.

7.35 Contact connectors: these are comprised of ferrite tubes surrounding the conductor. The ferrite tube is surrounded by a ceramic sleeve, which has two separate plated, inner sections, arranging the shunt capacitors into a “pi” section. The outer surface of the ceramic sleeve is metal coated and connected to the earth terminal. The ferrite tube constitutes a single turn. This can be increased by multi-layer capacitance. The inductance of the ferrite increases progressively for lowering frequencies and the resistance increases progressively for increasing frequencies (1-100 MHz).

Leakage current

7.36 During normal operation, leakage current flows through the capacitors or other circuit insulation between live parts and earth.

7.39 As a safety precaution, in the event of a faulty protective earth conductor, leakage current is limited to the following maximum values:

a. portable (class I) - 0.5 mA;

b. equipment (class II) - 0.25 mA;

c. fixed equipment - 5.0 mA.

8. Electromagnetic compatibility aids - fibre optic cables

8.1 An optical fibre is an ultra pure, solid rod of glass, finer than a human hair. The core carries pulses of light which make up the signal. The outer cladding, which has a lower refractive index than the core, ensures that the light is kept within the fibre via a process known as Total Internal Reflection (TIR). Refer to Figure 19.

8.2 There are four main parameters which should be considered when selecting an optical fibre for use in a communication system:

a. bandwidth: the bandwidth (which is specified at a certain wavelength) represents the highest sinusoidal light modulation frequency which can be transmitted through a length of optical fibre with an optical signal power loss equal to 50% (-3 dB) of the zero modulation frequency component. The bandwidth is expressed in megaHertz per kilometre (MHz/km);

b. attenuation: the attenuation denotes the loss of power in an optical signal, at a specified wavelength, due to scattering and absorption in an optical fibre. It is expressed as an attenuation rate in decibels of optical power per kilometre (dB/km);

c. numerical aperture: the numerical aperture is a measure of angular light acceptance of the optical fibre. It is the cosine of the largest angle of incidence of a ray that can be accepted by the fibre, and therefore is a dimensionless number;

d. core diameter: the fibre core is the central region of an optical fibre whose refractive index is greater than the surrounding cladding. Two core diameters (50 microns and 62.5 microns) are a normal standard product range. These sizes permit efficient coupling to commercially available light sources such as LED's or laser diodes.

Optical fibre cable structure

8.3 Currently two general cable constructions are employed to contain the optical fibres:

a. Loose buffer: one or more fibres are contained in plastic tubes that have an inner diameter considerably larger than the optical fibre. This provides a high level of isolation for the optical fibre from exterior mechanical forces that may be present on the cable. For multi-fibre cables, a number of these tubes are combined with the necessary longitudinal strength members;

b. Tight buffer: in this cable a thicker buffer coating is placed directly onto the optical fibre which is concentrically surrounded by a layer of yarn for added strength and protection. An outer jacket of polyethylene or PVC then completes the structure.

Optical fibre connectors

8.4 The two popular optical fibre connectors for use in local area network (LAN) and data communication systems are:

a. 9mm SMA style connector (screw type);

b. ST **II** style connector (bayonet type).

Both have precision ceramic ferrules, and both can be terminated in the field.

Optical fibre termination

8.5 Termination of the optical fibre is a very straightforward series of simple operations:

a. the outer sheath of the optical fibre cable is stripped back a few centimetres, exposing the optical fibre;

b. a measured amount of epoxy resin adhesive is placed into the connector body, which is then threaded onto the exposed optical fibre, where it is crimped on to the sheath of the cable;

c. the epoxy glue is cured, using a simple heater;

d. the optical fibre, which is protruding from the connector is then ‘sliced off’ (cleaved);

e. the remaining stub is polished flat using a simple polishing tool and fine polishing paper.

8.6 Advantages of optical fibre

a. Freedom from EMI: transmitted data cannot be corrupted by external means such as mutual coupling, interference from electrical machinery or lighting.

b. Complete electrical isolation: there is no direct electrical connection between equipment at either end of the link, thus eliminating ground loops. A non-metallic cable is immune to lightning strikes.

c. High bandwidth/low transmission loss: signals can be transmitted at high speed over great distances without regeneration.

d. Secure transmission: information cannot be intercepted by electronic surveillance devices. The cable cannot easily be tapped.

e. Intrinsically safe: if the cable is cut or damaged there is no spark risk, so safety is ensured in hazardous environments.

f. Easy installation: the light weight and high strength of optical fibre cable means that installation is easy. Optical fibres can be used both inside and outside buildings.

9. Electromagnetic compatibility in healthcare premises

9.1 Most interference problems can be dealt with satisfactorily by suppressing "noisy" sources by:

a. reducing the coupling mechanism;

b. "hardening" sensitive apparatus;

c. a combination of these.

9.2 Whole room screening methods of protection will only be necessary where very sensitive apparatus, for example electromyography (EMG), will be used in close proximity to equipment which is likely to generate interference signals (diathermy equipment). With less sensitive apparatus such as electro-cardiograph (ECG) and electro-encephalograph (EEG) satisfactory working should be possible where appropriate steps have been taken to minimise or suppress interference.

9.3 Physical separation of sensitive equipment from RF generating equipment may significantly degrade the coupling mechanism. The distances in Table 1 are intended as a guide to be used in deciding whether equipment modification or installation modification will be necessary.

Screening

9.4 Where room screening is necessary, the room must be completely sealed against electromagnetic fields to be effective. Tests have shown that partial screening, excluding doors and windows, is not effective against this type of interference, but reduces local electrostatic and magnetic interference.

9.5 Partial screening against electrostatic transmitted radiation interference from adjacent rooms, etc can be obtained by coating walls with an electrically conducting paint, for example a graphite or metal filled epoxy resin paint having a surface resistance not exceeding 50 ohms square. A low impedance earth must be provided.

9.6 The above treatment is particularly desirable where EMG, EEG and ECG rooms are formed from lightly constructed partitions, that is, construction other than brick or slab. Normal wall finishes can be applied over the conducting coat when dry.

9.7 Room screening and filtering of operating theatres may be necessary where two or more theatres adjoin or are closely located and sensitive physiological monitoring apparatus is likely to be used in the theatres. Where a separate apparatus room is provided in the suite, this may require screening and filtering.

9.8 It should be noted that room screening will not be effective against interference radiations generated within a room which contains operating medical electrical equipment, but will reduce externally radiated interference, for example where diathermy is used in an adjoining theatre.

9.9 Since diathermy is the primary source of interference in operating suites, then only equipment certified by the manufacturer not to cause interference, over a band of agreed frequencies, should be purchased. A contractual certificate is desirable where freedom from interference is important. In these circumstances room screening may not be necessary.

Screened rooms

9.10 A screened room may be required where the separation guidelines, Tables 1 and 2, cannot be achieved between noise sources and sensitive equipment, for example in a physical medicine department where diathermy apparatus will be used in the vicinity of electromyography equipment.

Basic requirements for room screening

9.11 To screen a room against external sources of interference the walls, floor, ceiling, windows and doors forming the room must incorporate or be faced with a low impedance, earthed, conducting surface, which is electrically continuous throughout. Ideally screening should be electrically insulated from all external conducting metal, except for the effective low impedance protective earth conductor, connected at one point only.

9.12 Where practicable, all metal service pipes and conduits should be electrically bonded, at the point of room entry, to the protective earth conductor. It should be arranged that other service pipes or conduits do not pass through the room. Where this cannot conveniently be arranged, pipes should be bonded to the protective conductor or screen material at both the entry and exit points. Insulation inserts must be used to isolate those sections of in-shield metal service pipes and conduits from external interference.

9.13 Electrical power circuits entering the screened room should incorporate filters and/or screening transformers. These should be located outside the room but as close as is practicable to the entry point.

9.14 All conductors including equipment flexible cords, telephone wires and electrical components within the room should be screened and the screen connected to earth at the protective conductor.

9.15 Sources of possible wave interference and resonance generated within the room should be absorbed by a flame retardant radio absorbent material, such as ferrite loaded panelwork or carbon filled material in the shape of cones, pyramids or wedges.

9.16 A well-screened room should provide interference attenuation above 100 dB.

Size of enclosures

9.17 With large screened rooms there is increased risk of cavity resonance at high frequencies. To minimise this possibility, enclosures having any dimension exceeding 7 m are not recommended. The resonant signature of the room must be finally determined by test, with and without the intended installed equipment. Enclosure resonance occurs at any frequency at which one dimension of the enclosure is an integral number of half wavelengths. The most serious are between floor and ceiling (vertically polarised electric fields).

9.18 Where a room is larger than the screened space required, then a sheet metal portable container should be considered for partitioning. This container may be fabricated from works manufactured parts, and site erected. Services may be modified and added as required from the existing building services.

Materials

9.19 For radio frequency and electrostatic screening, any earthed material that is a good electrical conductor is effective. For magnetic screening, for example against low frequency interference signals, a material with high permeability, such as a ferrous sheet, is superior.

9.20 In general the greater the electrical conductivity of the screening material the greater the reflective attenuation. In practice, however, the many joints which will be necessary in forming the conducting surface may be the limiting factor.

9.21 The resistivity of the joints tend to be more important than that of the screening material itself in terms of discontinuity. The aim should be to ensure a good electrical conductivity across a joint and to eliminate unnecessary jointing.

9.22 Joints in the conducting surface should be reduced to a minimum by the use of the largest width/length of material obtainable. Joints should butt closely or overlap and be electrically bonded by a covering conductive strip along the joint or by welding. The conductive surface should be bonded to the steel door and window frames. It is preferable that joints in ferrous materials, for example expanded steel, are welded. Joints to non-ferrous metals should be soldered or brazed.

9.23 Metals which are close in the electrochemical scale should be chosen to prevent the possibility of significant potentials across joints, and thereby reduce the risk of electrolytic action, particularly in situations where dampness may be expected.

9.24 Metals differing by more than about 0.5 volt in the scale should not be used in direct contact with each other, but may be separated via a third metal, provided this potential difference is not exceeded. For example, copper and steel (or zinc) should be connected via a brass or gunmetal alloy washer or lug.

9.25 It is desirable to avoid joints between dissimilar metals where they are buried in plaster or other moisture absorbing materials. See Tables 3 and 4.

9.26 Metals used should be protected from or have resistance to corrosion, for example steel should have a galvanised finish. The use of aluminium in walls containing lime or cement is not recommended due to the corrosive compounds in the building material.

9.27 Expanded mesh steel having an electro-galvanised finish has been found to be effective, and to be an economical material to use in buried situations. Details of a suitable mesh are given in Figure 20. In operating theatres and data rooms, there is no objection to galvanised zinc mesh being used as an anti-static sub-floor conductor. The concrete mix must not contain corrosive compounds.

9.28 For electromagnetic radiation screening, the floor mesh should be electrically continuous with any screen material incorporated in the walls, etc. Reference should be made to Figures 20 to 22.

9.29 For surface applications, a metallic, powder filled paint coating aluminium foil or galvanised steel sheet, can be used. Expanded sheet or copper or aluminium is also suitable for non-buried situations, for example for screening windows. Materials must be chosen carefully with regard to permeance.

9.30 Aluminium foil may corrode with time, tear, lose surface adhesion, or the foil surface may become damaged, reducing the low impedance paths for the safe flow of electromagnetic energy to ground.

Metallic paint

9.31 Usually the treatment is applied in two coats, the first being a bonding coat of zinc followed by a copper coating. The sprayed coating will make good electrical contact with steel door and window frames particularly where these have a galvanised finish.

9.32 The finished thickness of the sprayed metal paint coating is usually about 0.005 mm, and when sprayed on to flat surfaces, a flat matt finish is obtained which can be treated with normal decorative finishes such as gloss or emulsion paints. The sprayed metal paint coating on floors should be protected with one of the usual forms of floor covering. Highly electrostatic materials should not be used for flooring in order to reduce the effects of electrostatic discharges.

Metal foil

9.33 Copper or aluminium foil can be applied to the surface of walls, ceilings or floors using a suitable adhesive, for example an epoxy resin type.

9.34 Joints between copper sheets and between the sheets and metal door or window frames can be soft soldered. Joints of aluminium foil should overlap and be secured by a suitable electrically conductive adhesive. Alternatively, two layers of conductive adhesive metal foil as gaskets can be used with the metallic surfaces face-to-face to ensure good electrical contact between the layers.

9.35 Metal surfaced board can be used as a lining to walls, ceilings and floors or with suitable supporting structure can be used to construct a screened room or enclosure which is faced with 24 or 26 swg galvanised steel. Capping or angle strips or other means of jointing between sheets should preferably be of galvanised steel with overlapping steel strip/copper gasket so arranged that there is a hard, unbroken contact throughout the length of the joints. Similar joints should be arranged between the sheets and door and window frames. Where screw fixings are used the spacing between screws should not exceed 300 mm.

Walls

9.36 The screening material can be buried in the walls, ceiling and floor or can be attached to the surface after construction. Alternatively a sheet of steel or metal surfaced board can be attached to a steel frame construction.

9.37 The method of construction will have an important influence on the choice of material for the surface metal. Expanded steel having a galvanised finish has been found to be a durable and economical material for buried situations for short periods. Joints between sheets should be close butted and overlapped with screwed strip metal and copper gasket. Joints between the expanded steel and door and window frames should be similarly constructed.

9.38 The alternative to a buried form of construction is to apply a metal film to the walls etc, after construction but prior to any decorative finish. The alternative treatments available are a metallic powered paint finish or a metal foil lining. The spraying technique will usually give the best finish, since it is difficult to avoid kinking when applying foils to walls etc. With either method it is recommended that corners are rounded, to avoid discontinuities and re-reflections.

Doors

9.39 Doors should be completely screened and there should be good electrical continuity between the door and the doorframe. Refer to Figures 24 to 26.

9.40 A conductive metal sheet similar to that recommended for walls can be incorporated within the door and bonded to a metal edging around the door. Alternatively copper or aluminium foil not less than 0.003 mm thick can be used.

9.41 It will be necessary to provide some means of ensuring good electrical contact between the door and the doorframe. This can be achieved by attaching a continuous phosphor-bronze spring contact around the doorframe so that continuous contact with the metal fixed contacts in the edging of the door is maintained in the closed position. It must be possible for the spring contacts around the doorframe to be cleaned and lubricated. The spring contact strips should be attached to an earthed metal back plate along the threshold.

9.42 In operating suites and other areas where aseptic conditions are important, the spring contacts should be attached to the metal strips at intervals by screws, so that they can be easily removed for cleaning purposes.

9.43 When a screened door or window is open, the room screening will be incomplete and wave interference may enter. This condition will be acceptable in most instances and where necessary the door can be fastened closed whilst sensitive apparatus is in use.

9.44 When it will be necessary to open a screened door frequently, whilst sensitive apparatus is in use, a waveguide entrance must be formed to screen the doorway opening, for example by screening the walls, ceiling and floor of the approach corridor.

9.45 Waveguide entrances are effective only for a range of frequencies, dependent on the dimensions of the openings, and the length of the waveguide entrance. The width and height of the entrance, therefore, should be kept as small as is practicable.

Windows

9.46 Window frames should preferably be constructed of steel and have a hot dipped galvanised coating complying with BS EN ISO 1461: 1999. The window glass surface may be coated with a fine film of screening material, or be fitted with wire mesh.

9.47 Windows introduce problems in ensuring satisfactory continuity of the screening and are best avoided. A close steel mesh glass, for example 6 mm mesh, may have a limited use in conjunction with the galvanised steel window frame finish. Refer to Figures 22 and 23.

9.48 Figure 22 shows a typical arrangement. It will be noted that at each edge the glass is cut back so that the wire extends approximately 12 mm. The wires are then bent round to make contact with the inside surface of the metal frame and set in a conductive paste.

9.49 An alternative arrangement is to fit fine mesh metallic shutters, which can be readily removed to clean the inside of the windows. The shutters must be so arranged that they make good electrical contact with the room metal conductive surface at intervals not exceeding 300 mm.

Ventilation ducts

9.50 Ventilation inlet and outlet ducts should be protected across their openings by a honeycombed deep metal matrix, to attenuate the widest range of aggressor frequencies entering the screened room.

Lighting

9.51 As screened rooms may have limited natural light, provision must be made to provide adequate artificial illumination. The quality of light emitted by any luminaire is unlikely to match the uniform quality of natural light. By careful selection, fluorescent lamps can be obtained which have a good colour rendering to suit the task requirement.

9.52 Fluorescent luminaires emit RF radiation. This can be reduced by an all-metal luminaire, with the light louvre clad by a mesh screen, as shown in Figure 5. To remove all RF radiation, incandescent luminaires should be fitted in sufficient numbers to maintain an adequate level of illumination. Lighting supply wires must be enclosed in solid metal conduit. Refer to Figure 21.

9.53 Emergency dc illumination should be provided at a level sufficient for personnel to shut down the equipment and evacuate the screened room in safety, on loss of the normal electrical supply.

10. Earthing

10.1 The primary purpose of an earthed protective conductor in equipment is to give personal safety, against the chance of a circuit insulation fault, by a phase conductor to the equipment chassis. This ensures that the circuit protective device operates and the chassis does not remain electrically charged and personally hazardous for a longer time than for the device to operate and isolate the equipment.

10.2 A connection to earth is also necessary in electronic equipment, to establish a signal and control reference of zero volts to earth (0 V).

10.3 With a multi-cabinet system, if the protective earth is connected to the signal reference in each cabinet, the interference existing in the mains earth is likely to be injected into the signal circuit.

10.4 All sensitive electronic equipment requires a dedicated earth connection. It is preferable not to connect the signal references to the equipment protective earth conductor, but instead, to connect by a separate, screened low impedance cable, directly to the main earth terminal, interconnected only to other cabinets with isolated 0 V leads.

10.5 In difficult locations or with mainframe computers, a separate earth rod may prove essential.

10.6 A bonding resistance of two milliohms indicates a junction of high quality. See part 4 of the 'Operational management' volume of this SHTM for details of earthing arrangements.

10.7 A good protective earth system is met by providing a low impedance path for power frequency current, thus preventing hazardous voltages appearing elsewhere in the system.

10.8 Designers of new installations should consider the safety of all persons, the prevention of fire or explosion, as well as the correct function of electronics systems. This may include the use of residual circuit breakers, as supplementary personal protection and as a circuit insulation monitoring device.

10.9 Special care must be taken to achieve and maintain a low impedance earth system. The common protective earth (pe) conductor, in all applications, shall be identified by a green/yellow outer sheath. None of the above pe conductors provide the required low impedance earth path for the control of RF EMI.

10.10 One way to minimise this problem is to provide a “clean” or dedicated earth for the building management system (BMS), earthed at the same point as the supply transformer neutral earth point.

10.11 The use of earth conductors with a low inductance per unit length is practical, when considering items of equipment in close proximity, but a typical BMS installation may be spread over a wide area and would share the power network with all kinds of other loads.

Bonding

10.12 Electrical bonding refers to the processes by which parts of an assembly, equipment, or subsystem are electrically inter-connected at their joints or by any low impedance medium. The purpose is to make the structures homogeneous with respect to the flow of EMI currents.

10.13 Poor bonds lead to a variety of hazardous and interference producing situations.

10.14 Loose connections in ac power lines may cause heat to be generated in the joint, and damage the insulation of the wires or loosen the contact pressure.

10.15 Loose or high impedance joints in signal lines are particularly annoying. They cause intermittent signal behaviour, changes in signal amplitude, and increase in noise level.

10.16 A primary requirement for effective bonding is that a low impedance path be established between two jointed objects. A dc bonding resistance, in milliohms, indicates a high quality junction. Note that the dc resistance of a joint is not indicative of its impedance at a higher frequency.

10.17 In many applications permanent bonds are not practical due to flexibility and access requirements. The most common semi-permanent bond is the bolted connection. Throughout the lifetime of the equipment, system or facility, the bonds must be inspected, tested and maintained. Refer to Figure 27.

Earth loops

10.18 An insidious problem to be aware of, is that of earth loops. These are formed when two or more interconnected items of equipment are located near an earthed place or protective earth conductor wire, regardless of whether they are directly connected or not. The term “earth loops” has been used to describe most EMI situations when an installation fails, so it is worth clarifying the mechanism by which an earth loop may cause problems.

10.19 A common impedance coupling, implies the connection of the protective earth conductor between two items of equipment in an installation. This may give rise to a common mode current circulating around the equipment, interconnecting cable and protective earth conductor.

10.20 A magnetic field-to-cable common mode coupling, where an ambient electromagnetic field couples onto the loop area formed by the protective conductor earth wire and the interconnecting cable, may also produce a common mode circulating current.

10.21 Either of the above mechanisms, operating separately or both together, may give rise to a differential mode noise voltage across the terminals of sensitive electronics. The effect of the first may be reduced by lowering the ground impedance, or the noise current by more effective screening around the cable.

10.22 If the noise current cannot be reduced, some extensive installation work, for example metal grids, screened rooms etc may be required. The level of re-construction may not be cost effective.

10.23 An alternative solution would be to make the sensitive equipment less susceptible to ground noise by reduction of the combined loop area, by keeping the interconnecting cable as close to a ground plane as possible. Equipment ground loops should be examined, to ensure inter-system compatibility.

Segregation

10.24 The coupling of interference can be reduced by suitable segregation of any equipment and/or cables, which emit high levels of interference, from sensitive systems. In particular the following measures should be considered:

a. power cables and signal cables should be separated by a distance of at least 0.37 m and preferably enclosed in a different steel trunking or conduit;

b. attention to the location of sensitive equipment relative to certain known sources of high level interference, for example X-ray equipment, ISM equipment transmitters, etc;

c. layout of power cables beneath computers, visual display units, monitors, etc;

d. prevent the use of portable radio transmitters close to certain analogue equipment, for example strain gauge amplifiers, computers, etc.

11. Power supply arrangements

11.1 It is common practice to connect sensitive electronic equipment to the normal power distribution system in the building. However, the other loads are likely to produce interference which can be readily coupled into the sensitive equipment via the distribution system. There may be some advantages in segregating the supplies to sensitive equipment from other loads. The amount of segregation that can be achieved depends on the arrangement adopted and is likely to vary over the frequency range.

11.2 The simplest measure is to have separate cables from the same distribution transformer to the two classes of load. More complex systems may be necessary to achieve greater isolation, for example separate distribution transformers with separate cables, ac generators driven by an electric motor or a diesel engine, a secondary battery charged from the mains to feed a static inverter with various levels of ac voltage output.

11.3 Where very high reliability supplies are required, such as no-break or uninterruptible power systems, complex arrangements using combinations of the above techniques may be used. Reference should be made to SHTM 2007 'Electrical services: supply and distribution' and SHTM 2011 'Emergency electrical services' for additional information.

11.4 With any of the special power arrangements, care must be taken that interference is not coupled into the supposedly "clean" supply from the other power systems. Segregation and screening of the power cables may be necessary.

11.5 Some of the special power system arrangements are likely to have a higher value of source impedance than the normal supply (as regards ripple, surges, dips and possibly spikes) so that interaction between the loads on the supply system may be more likely. It is also possible that the levels of repetitive interference produced by certain types of generation system may be unacceptable to some equipment, thus requiring the fitting of power filters.

Separate cables from the distribution transformer

11.6 This arrangement is comparatively inexpensive since no special equipment is required and the installation can be carried out in the normal manner, except in so far as switching devices to achieve isolation from the general purpose distribution system are necessary. The simplest measure is to run the "screened" cables in separate steel trunking or steel conduit, but it may also be necessary to install power filters. This technique is only likely to achieve a significant improvement in the reduction of spikes and other high frequency interference effects, since other forms of interference will usually enter at the busbars of the distribution transformer and will not be much attenuated in the local distribution cables.

Dedicated transformer

11.7 Where the isolation obtained in a separate circuit connected to the same transformer is inadequate, a much-improved performance can be achieved by using a dedicated isolation transformer for the supply of power to sensitive electronic equipment. Since the coupling between the HV network and low voltage is now via two transformers, considerable attenuation of various types of interference is possible. In particular, the spikes, surges and dips (which largely result from switching and faults associated with the local loads) will be significantly reduced in amplitude and frequency of occurrence. The levels of ripple injected from local loads will also be reduced, but ripple coupled from the high voltage system will not be totally eliminated.

Motor/ac generator

11.8 An ac generator may produce a 415 V, 3 phase 50 Hz supply. Whilst the effects of extraneous interference can be reduced by using an ac generator, there may be interaction between loads which share the supply, for example spikes, dips, harmonics, due to the increased effective source impedance compared with that of the mains. The flywheel action of the rotating masses of the generator and driver, together with the voltage regulator fitted, assist in maintaining a stable output despite input and load fluctuations. The use of a separate ac generator enables isolation from the main system earth to be achieved where necessary. The generator should be isolated from the main system earth so that a separate earth can be provided for the generator output circuit.

11.9 The generator can be driven by:

a. mains powered, speed regulated ac motor;

b. diesel or petrol engine - independent of mains supply for primary energy;

c. dc motor - supplied from a battery which may be charged from the mains supply. This arrangement can provide a reliable supply during power failures, depending on the battery capacity.

Static inverter

11.10 This provides the advantage of isolation from the mains supply (as with a motor/alternator) without the need of a heavy rotating machine. However, the load waveform of a typical inverter is likely to be inferior to that of the mains or an ac generator output.

11.11 Harmonics, repeated spikes, radio interference etc and load changes may produce undesired transient effects. With the non-dual configuration there is also the likelihood of interference being coupled into the input dc supply. Reference should be made to SHTM 2011 -'Emergency electrical services'.

11.12 For special purposes, static inverters can have comprehensive filtering at the input and output in order to give a sinusoidal output waveform with negligible emission of interference.

No-break/uninterruptible power supply (UPS) system

11.13 For certain critical instrumentation or computing systems the normal reliability of the public supply mains may not be considered adequate and a special no-break or UPS system may be installed. Whilst the quality of the output waveform from some of these systems may be no better, or even inferior to that of the normal supply mains, the long term reliability can be considerably better.

11.14 There is a wide variety of possible designs of these systems using ac generators, or static inverters powered from the mains or diesel engines or batteries, with duplication of some critical components and possibly static switching to transfer loads between alternative supplies. Reference should be made to SHTM 2011 - 'Emergency electrical services'.

Battery

11.15 A battery may be used for the direct current supply of power to drive electronic equipment in order to overcome various types of interference or temporary loss of supply. This technique may also be used to provide power to limited sections of a system, for example clocks and/or memory:

a. a primary or secondary type battery enclosed within an item of equipment, enables complete isolation from mains supply and main system earth to be obtained. The equipment will only be subject to induced interference effects, for example radiated fields;

b. a secondary battery within an item of equipment maintained by a mains powered charger, provides considerable storage to overcome dips, power failures etc. Suitable filtering to overcome audio frequency and radio frequency interference can also be incorporated;

c. an external secondary battery with a mains powered charger and a distribution system to equipment has the same advantages as (b) in regard to extraneous interference, but there is a possibility of interaction between items of equipment sharing the same battery supply, for example switching and relay spikes, inverter ripple etc;

d. automotive starting batteries must not be used for dc supply or stand-by emergencies. Refer to SHTM 2011 - 'Emergency electrical services'.

Table 1: Approximate minimum spacing for interference-free working with unfiltered equipment

	Distance in metres		
Source of Interference	EMG etc Sensitivity 20 µV/cm	EMG etc Sensitivity 100 µV/cm	ECG etc Sensitivity 1000 µV/cm
Medical diathermy * (27 MHz 100% modulation)	60	60	30
Medical diathermy (27 MHz 30% modulation)	30	30	18
Medical diathermy (27 MHz 10% modulation)	18	18	9
Surgical diathermy (valve type)	21	15	9
Surgical diathermy (HF impulse type)	15	9	6
Surgical diathermy (HF impulse type)	9	5	3
Linear accelerator † (impulse generator)	30	21	15
LF inductive loop (paging) distance outside loop$^{\nabla}$	6	0	0
Lift motor rooms (controls unsuppressed)	9	6	3
Lift wells (controls unsuppressed)	9	6	3
Power transformers (100-750 kVA)	9	9	9
Small transformers up to 1 kVA	2	2	2
Commutator motors (unsuppressed)	6	5	3
Thermostats, relays and other switching devices (unsuppressed)	6	5	3
Electric clocks (mains and impulse types)	3	2	2
Fluorescent lamps	5	3	3
Tungsten lamps	3	2	2

* For interference-free working with old medical diathermy sets operating on 40-50 MHz, it will be necessary to increase the distance given.

† Applicable only where the generator is installed outside the radiation screening. When installed within the radiation screening no interference should be experienced.

$^{\nabla}$There is a possibility of interference being experienced within an LF inductive loop with ECG and EEG equipment. Interference within this type of loop is much more likely with EMG equipment.

Table 2: Approximate minimum spacing for interference-free working with filtered equipment

	Distance in metres		
Source of Interference	EMG etc Sensitivity 20 µV/cm	EMG etc Sensitivity 100 µV/cm	ECG etc Sensitivity 1000 µV/cm
Medical diathermy * (27 MHz 100% modulation)	18	12	12
Medical diathermy (27 MHz 30% modulation)	15	9	9
Medical diathermy (27 MHz 10% modulation)	9	6	6
Surgical diathermy (valve type)	6	3	3
Surgical diathermy (HF impulse type)	6	3	3
Surgical diathermy (HF impulse type)	5	3	3
Linear accelerator † (impulse generator)	15	9	9
LF inductive loop (paging) distance outside loop Δ	6	0	0
Lift motor rooms (controls unsuppressed)	3	3	3
Lift wells (controls unsuppressed)	3	2	2
Power transformers (100-750 kVA)	9	9	9
Small transformers up to 1 kVA	2	2	2
Commutator motors (unsuppressed)	6	2	2
Thermostats, relays and other switching devices (unsuppressed)	6	2	2
Electric clocks (mains and impulse types)	3	2	2
Fluorescent lamps	9	3	3
Tungsten lamps	3	2	2

* For interference-free working with old medical diathermy sets operating on 40-50 MHz, it will be necessary to increase the distance given.

† Applicable only where the generator is installed outside the radiation screening. When installed within the radiation screening no interference should be experienced.

Δ There is a possibility of interference being experienced within an LF inductive loop with ECG and EEG equipment. Interference within this type of loop is much more likely with EMG equipment.

Table 3: Electrochemical series ordered by decreasing sensitivity to corrosion

	Anodic end (most easily corroded)
Group **I**	Magnesium
Group **II**	Aluminium, aluminium alloys, zinc, cadmium, galvanised iron
Group **III**	Carbon steel, iron, lead, tin, tin-lead solder
Group **IV**	Nickel, chromium, stainless steel, brass
Group **V**	Copper, silver, gold, platinum, titanium, bronze
	Cathodic end (least corroded)

Table 4: Groups of materials recommended for providing protective bond between two dissimilar metals used as anode and cathode

Condition of Exposure	Anode				Cathode
	I	**II**	**III**	**IV**	
Exposed	A	A			
Sheltered	A	A			**II**
Housed	A	A			
Exposed	C	A	B		
Sheltered	A	B	B		**III**
Housed	A	B	B		
Exposed	C	A	B	B	
Sheltered	A	A	B	B	**IV**
Housed	A	B	B	B	
Exposed	C	C	C	A	
Sheltered	A	A	A	B	**V**
Housed	A	A	B	B	

Notes: Bond protection code:

A. The couple must have a protective finish after metal-to-metal contact has been established so that no liquid film can bridge the two elements of the couple.

B. The two metals may be joined with bare metal exposed at junction surfaces. The remainder must be given an appropriate protective finish.

C. This combination cannot be used except where short life expectancy can be tolerated or when the equipment is normally stored and exposed for only short intervals. Protective coatings are mandatory.

References

NOTE:
Where there is a requirement to address a listed reference, care should be taken to ensure that all amendments following the date of issue are included.

Publication ID	*Title*	*Publisher*	*Date*	*Notes*
Acts and Regulations				
	Building (Scotland) Act	HMSO	1959	
	Clean Air Act	HMSO	1993	
	Electricity Act	HMSO	1989	
	Health and Safety at Work etc. Act	HMSO	1974	
	Registered Establishments (Scotland) Act	HMSO	1998	
	Water (Scotland) Act	HMSO	1980	
SI 1671	Active Implantable Medical Devices Regulations	HMSO	1995	
SI 1315	In Vitro Diagnostic Medical Devices Regulations	HMSO	2000	
SI 3017	Medical Devices Regulations	HMSO	1994	
SI 2179	Building Standards (Scotland) Regulations	HMSO	1990	
	Building Standards (Scotland) Regulations: Technical Standards Guidance	HMSO	1998	
SI 3140	Construction (Design and Management) Regulations	HMSO	1994	
SI 437	Control of Substances Hazardous to Health Regulations (COSHH)	HMSO	1999	
SI 635	Electricity at Work Regulations	HMSO	1989	
SI 1057	Electricity Supply Regulations	HMSO	1998	
SI 2372	Electromagnetic Compatibility Regulations	HMSO	1992	
SI 2451	Gas Safety (Installation and Use) Regulations	HMSO	1998	
SI 917	Health & Safety (First Aid) Regulations	HMSO	1981	

Publication ID	***Title***	***Publisher***	***Date***	***Notes***
SI 682	Health & Safety (Information for Employees) Regulations	HMSO	1989	
SI 2792	Health and Safety (Display Screen Equipment) Regulations	HMSO	1992	
SI 341	Health and Safety (Safety Signs and Signals) Regulations	HMSO	1996	
SI 1380	Health and Safety (Training for Employment) Regulations	HMSO	1990	
SI 2307	Lifting Operations and Lifting Equipment Regulations (LOLER)	HMSO	1998	
SI 3242	Management of Health and Safety at Work Regulations	HMSO	1999	
SI 2793	Manual Handling Operations Regulations	HMSO	1992	
SI 1790	Noise at Work Regulations	HMSO	1989	
SI 3139	Personal Protective Equipment (EC Directive) Regulations	HMSO	1992	
SI 2966	Personal Protective Equipment at Work (PPE) Regulations	HMSO	1992	
SI 128	Pressure Systems Safety Regulations (PSSR)	HMSO	2000	
SI 2306	Provision and Use of Work Equipment Regulations (PUWER)	HMSO	1998	
SI 3163	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)	HMSO	1995	
SI 3004	Workplace (Health, Safety and Welfare) Regulations	HMSO	1992	
SI 1895	Wireless Telegraphy (Control of Interference from Electro-medical Apparatus) Regulations 1963	HMSO	1963	
SI 1675	Wireless Telegraphy (Control of Interference from Radio Frequency Heating Apparatus) Regulations 1971	HMSO	1971	
SI 1217	Wireless Telegraphy (Control of Interference from Ignition Apparatus) Regulations 1973	HMSO	1973	
SI 1267	Wireless Telegraphy (Control of Interference from Household Appliances, Portable Tools, etc.) Regulations 1978 (as amended)	HMSO	1978	

Publication ID	**Title**	**Publisher**	**Date**	**Notes**
SI 1268	Wireless Telegraphy (Control of Interference from Fluorescent Lighting Apparatus) Regulations 1978 (as amended)	HMSO	1978	
89/336/EEC	Electromagnetic Compatibility (EMC) Directive	HMSO	1992	
90/385/EEC	Active Implantable Medical Devices Directive	HMSO	1990	
91/236/EEC	Telecommunications Terminal Equipment Directive	HMSO	1991	
93/42/EEC	Medical Devices Directive	HMSO	1993	
98/79/EC	In Vitro Diagnostic Medical Devices Directive	HMSO	1998	
British Standards				
BS 5049-1	Radio interference characteristics of overhead power lines and high-voltage equipment. Description of phenomena	BSI Standards	1994	
BS 5049-2	Radio interference characteristics of overhead power lines and high-voltage equipment. Methods of measurement and procedure for determining limits	BSI Standards	1994	
BS 5049-3	Radio interference characteristics of overhead power lines and high-voltage equipment. Code of practice for minimising the generation of radio noise	BSI Standards	1994	
BS 5260	Code of Practice for Radio Interference Suppression on Marine Installations	BSI Standards	1975	
BS 6299	Methods of measurement of the suppression characteristics of passive radio interference filters and suppression components	BSI Standards	1982	
BS 6345	Method for Measurement of Radio Interference Terminal Voltage of Lighting Equipment (based on BS CISPR 15)	BSI Standards	1983	
BS 6626	Code of practice for the maintenance of electrical switchgear and control gear voltages above 1 kV and up to and including 36 kV	BSI Standards	1985	
BS 6667: Part 1	Electromagnetic compatibility for industrial-process measurement and control equipment: General introduction	BSI Standards	1985	
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Publication ID	***Title***	***Publisher***	***Date***	***Notes***
BS 6902-1	Cardiac Pacemakers: Specification for implantable cardiac pacemakers	BSI Standards	1990	
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BS 727	Specification for Radio-Interference Measuring Apparatus (based on BS CISPR 16)	BSI Standards	1983	
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BS CISPR 12	Vehicles, motorboats and spark-ignited engine-driven devices. Radio disturbance characteristics. Limits and methods of measurement	BSI Standards	1997	
BS CISPR 16-1	Specification for radio disturbance and immunity measuring apparatus and methods. Radio disturbance and immunity measuring apparatus	BSI Standards	1999	
BS CISPR 16-2	Specification for radio disturbance and immunity measuring apparatus and methods. Methods of measurement of disturbances and immunity	BSI Standards	1996	
BS CISPR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods. Reports and recommendations of CISPR	BSI Standards	2000	
BS EN 50065-1	Specification for signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz. General requirements, frequency bands and elecromagnetic disturbances	BSI Standards	1992	
BS EN 50081-1	Electromagnetic compatibility. Generic emission standard: Residential, commercial and light industry	BSI Standards	1992	
BS EN 50082-1	Electromagnetic compatibility. Generic immunity standard: Residential, commercial and light industry	BSI Standards	1992	
BS EN 50083-2	Cabled distribution systems for television and sound signals. Part 2: Electromagnetic compatibility for equipment	BSI Standards	1995	

Publication ID	***Title***	***Publisher***	***Date***	***Notes***
BS EN 50098-1	Customer premises cabling for information technology. ISDN basic access	BSI Standards	1999	
BS EN 50098-2	Customer premises cabling for information technology. 2048 k/bit/s ISDN primary access and leased line network interface	BSI Standards	1996	
BS EN 55011	Specification for limits and methods of measurement of radio disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment	BSI Standards	1998	
BS EN 55013	Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment.	BSI Standards	1997	
BS EN 55014 -1	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Emission. Product family standard	BSI Standards	2001	
BS EN 55014 -2	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Immunity. Product family standard	BSI Standards	2001	
BS EN 55015	Limits and methods of measurement of radio interference characteristics of electrical lighting and similar equipment	BSI Standards	2001	
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BS EN 55022	Information technology equipment. Radio disturbance characteristics. Limits and methods of measurement	BSI Standards	1998	
BS EN 55024	Information technology equipment. Immunity characteristics: Limits and methods of measurement	BSI Standards	1998	
BS EN 60601-1	Medical electrical equipment. General requirements for safety	BSI Standards	1990	
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BS EN 61000-4-1	Electromagnetic compatibility (EMC). Testing and measurement techniques. Overview of immunity tests. Basic EMC publication	BSI Standards	1995	
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SHTM 2007	Electrical services supply and distribution	PEF	2001	CD-ROM
SHTM 2011	Emergency electrical services	PEF	2001	CD-ROM
SHTM 2020	Electrical safety code for LV systems (Escode – LV)	PEF	2001	CD-ROM
SHTM 2021	Electrical safety code for high voltage systems (Escode – HV)	PEF	2001	CD-ROM
SHPN 1	Health service building in Scotland	HMSO	1991	
SHPN 2	Hospital briefing and operational policy	HMSO	1993	
SHTN 1	Post commissioning documentation for health buildings in Scotland	HMSO	1993	
SHTN 4	General Purposes States and Functions Model Safety Permit-to-Work Systems	PEF	1997	
	NHS in Scotland – Procode	PEF	2001	
NHS in Scotland Fire Safety Management				
SHTM 81	Fire precautions in new hospitals	PEF	1999	CD-ROM
SHTM 82	Alarm and detection systems	PEF	1999	CD-ROM
SHTM 83	Fire safety in healthcare premises: general fire precautions	PEF	1999	CD-ROM
SHTM 84	Fire safety in NHS residential care properties	PEF	1999	CD-ROM
SHTM 85	Fire precautions in existing hospitals	PEF	1999	CD-ROM
SHTM 86	Fire risk assessment in hospitals	PEF	1999	CD-ROM
SHTM 87	Textiles and furniture	PEF	1999	CD-ROM
SFPN 3	Escape bed lifts	PEF	1999	CD-ROM
SFPN 4	Hospital main kitchens	PEF	1999	CD-ROM
SFPN 5	Commercial enterprises on hospital premises	PEF	1999	CD-ROM
SFPN 6	Arson prevention and control in NHS healthcare premises	PEF	1999	CD-ROM
SFPN 7	Fire precautions in patient hotels	PEF	1999	CD-ROM
SFPN 10	Laboratories on hospital premises	PEF	1999	CD-ROM
	Scottish Executive Health Department 'Fire Safety Policy'	PEF	1999	
	Fire Safety Documentation Reference Guide	PEF	1999	
	A Model Management Structure for Fire Safety	PEF	1999	

Publication ID	*Title*	*Publisher*	*Date*	*Notes*
UK Health Technical Guidance				
EH 40	HSE Occupational Exposure limits	HSE	Annual	
MES	Model Engineering Specifications	NHS Estates	1997	As required
HTM 2020	Electrical safety code for low voltage systems (Escode – LV): Volume 2	HMSO		
Department of Health Publications				
	Management of medical equipment and devices (Health Equipment Information 98). Medical Devices Agency	Dept. of Health	1991	
	First aid at work. Health and safety (First Aid) regulations 1981. Approved code of practice and guidance (L 74)	HSE	1997	