Ministry of Defence
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Issue 1

Public Comment Draft

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The Electric, Magnetic and Electromagnetic Environment

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Not to be used as an Agreed Defence Standard

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DRAFT DEFENCE STANDARD - INVITATION TO COMMENT

Defence Standard Number: DEF STAN 59-411 Part 2 Issue 1
Title: Electromagnetic Compatibility – The Electric, Magnetic and Electromagnetic Environment

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The purpose of this form is to solicit any beneficial and constructive comment that will assist the author and/or working group to finalise the above standard for full publication.

Comments are to be entered below and any additional pertinent data which may also be of use in improving the standard should be attached to this form and returned to writer at the above address, to be received not later than **27th October 2006**.
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AMENDMENT RECORD

Amd No	Date	Text Affected	Signature and Date

REVISION NOTE

This standard is raised to Issue 1 to update its content.

HISTORICAL RECORD

This standard supersedes the following:

Defence Standard 08-46 Issue 2 Published 9 August 2002

Defence Standard 08-46 Issue 1 Published December 1999

a) This standard provides requirements for Ministry of Defence (MOD) Project Officers and defence contractors to assist them to identify and quantify the Electromagnetic Environment present for a variety of Defence Scenarios. Detailed descriptions of the environment for some particular scenarios are also given.

b) This standard has been produced on behalf of the Defence Material Standardization Committee (DMSC) by DCSA DE3A.

c) This standard has been agreed by the authorities concerned with its use and is intended to be used whenever relevant in all future designs, contracts, orders etc. and whenever practicable by amendment to those already in existence. If any difficulty arises which prevents application of the Defence Standard, UK Defence Standardization (DStan) shall be informed so that a remedy may be sought.

d) Any enquiries regarding this standard in relation to an invitation to tender or a contract in which it is incorporated are to be addressed to the responsible technical or supervising authority named in the invitation to tender or contract.

e) Compliance with this Defence Standard shall not in itself relieve any person from any legal obligations imposed upon them.

f) This standard has been devised solely for the use of the Ministry of Defence (MOD) and its contractors in the execution of contracts for the MOD. To the extent permitted by law, the MOD hereby excludes all liability whatsoever and howsoever arising (including, but without limitation, liability resulting from negligence) for any loss or damage however caused when the standard is used for any other purpose.

Introduction

Military systems must be designed to ensure Electromagnetic Compatibility (EMC) with the natural and man-made Electric, Magnetic and Electromagnetic (EM) environments in which they are to be deployed. This Part of the Standard describes how to identify and quantify the environments so that their EM impact on a system can be assessed. It may then be used to determine the parameters of any incident field upon any boundary drawn around a victim platform or its systems. Equipment designers can then assess the effects of this field on internal systems by considering the EM coupling mechanisms across the chosen boundary.

The aim of this Part of the Standard is to provide a comprehensive description of the principal intentional and unintentional EM threats, within the scope described in clause 1, to which military systems will be subjected. This will assist the process of defining a specific EM environment for a system based on the operational scenario.

Typical Air, Sea and Land design environments for a number of different military scenarios are included, which may be appropriate to certain generic equipment. Also, some guidance on possible routes to demonstrate compliance with Military EMC requirements is provided.

The means of defining the climatic and mechanical environments that are experienced by military materiel is described in Defence Standard 00-35 [Ref 1].

This part of the Defence Standard is to be read in conjunction with the following parts in the Def Stan 59-411 series.

Def Stan 59-411 Part 1: Management and Planning

Def Stan 59-411 Part 3: Electromagnetic Compatibility, Technical Requirements, Test Methods and Limits for Sub-Systems

Def Stan 59-411 Part 4: Electromagnetic Compatibility, Platform and System Test and Trials.

Def Stan 59-411 Part 5: Electromagnetic Compatibility, Code of Practice for Tri-Service Design and Installation.

Electromagnetic Compatibility - Part 2 - The Electric, Magnetic and Electromagnetic Environment

1 Scope

1.1 This Part of the Standard provides guidance on the typical electromagnetic environment in which military equipment is deployed.

1.2 It covers stationary and mobile military equipment including ordnance, deployed and operated by Land, Sea and Air Services on land, under and on the sea, and in the air. The environments considered include those with sources arising from natural phenomena as well as those generated by man-made activities, both civil and military. The Part of the Standard does not discuss the environment of materiel deployed outside the Earth's atmosphere.

1.3 The electromagnetic environments due to Radio Frequency Weapons (RFW) such as High Power Microwave (HPM) and Ultra-Wideband (UWB) Weapons are not currently included in this part of the Defence Standard. Where immunity to such threats is a requirement, specialist advice on such environments should be sought from the relevant authorities.

1.4 This Part of the Standard only considers field magnitudes that are likely to cause malfunctions to materiel by unintentional coupling mechanisms (sometimes called "back-door" mechanisms). For this reason, many sources of EM radiation are ignored because they are evidently so low that it is inconceivable that they could cause an indirect threat to materiel. The environments described may also be used to assess the protection requirements for the "front-end" of a receiver to prevent damage. In addition, fields that may impinge on a weapon system as it approaches a hostile target and those caused by deliberate enemy jamming are not considered in this Part of the Standard. User and system requirement documents should specify if these threats need to be taken into account and the relevant scenarios should be defined by the Equipment Capability customer.

1.5 This Part of the Standard contains descriptions of the EM environment in both the time domain and the frequency domain. When the description is in the frequency domain, the maximum frequency considered will be 40 GHz. (NOTE: above this frequency there are few deployed systems and currently no recorded problems. A system using a transmitter above 40 GHz should however include it in the environment definition for that system). Both the radiated and conducted environment (due to sources external to an equipment) are considered. For the conducted EM environment, levels will be platform specific and only the generic test limits as used in Part 3 of this Standard are discussed. Phenomena described in the frequency domain include static and quasi-static electric and magnetic fields, communications, radar and conducted emissions. Phenomena described in the time domain include Electro-Static Discharge (ESD), switching transients, Nuclear Electro-Magnetic Pulse (EMP) and lightning.

1.6 The depth of treatment for any given environment or related matter has been determined by the availability of information on the subject, in conjunction with its importance in the light of contemporary EMC problems. For this reason the following sources of EM radiation are not treated in this Part of this Standard:

a) Low power (<10 W) radio communications from a distant transmitter (>100 m).

b) Cosmic / solar radiation.

c) Terrestrial magnetic field.

1.7 Environments are given in some detail, but the methods of minimizing degradation of performance and maximizing reliability are not covered here. Such descriptions can be found in Part 5 of this Standard and many textbooks.

1.8 This Part of the Standard recognizes that applying a worst case description of an environment to be used in all cases can lead to wasteful and unrealistic levels of hardening. There are two ways of overcoming this. The first is to give a statistical description of the field. This would be very difficult and time consuming to calculate and would be dependent on the operational scenario. The second is to give a maximum possible field for a variety of operational scenarios along with a rationale for each scenario. For systems with a different scenario it will then be necessary for revised figures to be produced using the rationale that has been given. This second approach has been adopted and is expected to offer a realistic solution to the problem of unnecessarily high field descriptions. Each new system to be deployed should therefore have one or more operational scenarios defined in terms of likely distances from various types of transmitter. These can then be transformed into EM environments using the information provided in this Part of the Standard and/or seeking guidance from relevant specialists.

1.9 This Defence Standard includes a large number of EM susceptibility tests with a variety of limits which may be used for different classes of equipment. These Limits have been established recognising the information contained in this part of the standard which may be relevant to common scenarios/conditions that exist in each service environment. Part 1 of this Standard calls for the limits to be tailored for each project to avoid under- or over-testing. The information provided in this part of the standard should be used to assist this tailoring process.

2 Warning

The Ministry of Defence (MOD), like its contractors, is subject to both United Kingdom and European laws regarding Health and Safety at Work. All Defence Standards either directly or indirectly invoke the use of processes and procedures that could be injurious to health if adequate precautions are not taken. Defence Standards or their use in no way absolves users from complying with statutory and legal requirements relating to Health and Safety at Work.

3 Related Documents

Reference to this Standard in any related document means in any invitation to tender or contract, the edition and all amendments current at the date of such tender or contract unless a specific edition is indicated.

In consideration of the above, users shall be fully aware of the issue and amendment status of all related documents, particularly when forming part of an invitation to tender or contract. Responsibility for the correct application of standards rests with users.

DStan can advise regarding where related documents are obtained from. Requests for such information can be made to the DStan Helpdesk. How to contact the helpdesk is shown on the outside cover of Def Stans

4 Abbreviations and Definitions

4.1 Abbreviations

AM	Amplitude Modulation
CNR	Combat Net Radio
COTS	Commercial Off The Shelf
CW	Continuous Wave
ECAC	Electromagnetic Compatibility Analysis Centre
EED	Electro-Explosive Device
EM	Electromagnetic

EMC	Electromagnetic Compatibility
EMP	Electromagnetic Pulse
ESD	Electrostatic Discharge
FM	Frequency Modulation
HF	High Frequency (frequencies in the range 3 MHz–30 MHz)
HIRF	High Intensity Radiated Field
HIRTA	High Intensity Radiated Transmission Area
HPM	High Power Microwave
IPT	Integrated Project Team (a Defence Procurement Agency / Defence Logistics Organization term)
LEMP	Lightning Electromagnetic Pulse
NATO	North Atlantic Treaty Organization
NEMP	Nuclear Electromagnetic Pulse
RADHAZ	Radiation Hazards (this term is usually applied to the biological effects of non-ionizing (i.e. RF) radiation on humans but is also applied to ordnance and fuel)
RAS	Replenishment At Sea
RF	Radio Frequency
RFA	Royal Fleet Auxiliary
RFW	Radio Frequency Weapons
RN	Royal Navy
SATCOM	Satellite Communications
SOLAS	Safety of Life at Sea
STANAG	NATO Standardization Agreement
VHF	Very High Frequency
UEME	Unified Electromagnetic Environment
UHF	Ultra High Frequency
UWB	Ultra Wideband
VERTREP	Vertical Replenishment

4.2 Definition of the Environment of a System

For the purposes of this Part of the Standard, a system is defined as one or more devices that both perform a worthwhile integrated function, and that are subjected to the same external EM environment. This allows a wide range of materiel to be defined as systems. Having defined a system in this way, one can apply the same method for deriving the EM environment for any system. It is also possible and frequently necessary to define a large item of materiel as a system (for example an aircraft), and to use the EM field at the boundary of this system (i.e. the aircraft skin) as a source for calculating the EM environment of a subsystem. It may be necessary to define different system boundaries when considering the different EM threats, in order to allow a suitable test environment / method to be devised. It is also recognised that for some sub-systems, which are distributed throughout a higher level system, that the environment may be different for each element of the sub-system. In such cases, the manner in which each external EM threat will be modified by the platform at each sub-system may then need to be considered separately. Techniques for deriving these sub-system threat levels, which may be expressed in terms of cable currents, are discussed in Part 5 of this Standard.

Having defined an arbitrary boundary of a system, it is then necessary to identify the EM sources external to that system. The following sections and clauses provide the necessary information for the calculation of the EM field characteristics at the system boundary due to each source.

In general the victim system may be subjected to simultaneous interference from more than one source and the resulting disturbance can theoretically be calculated from the vector sum of the individual disturbances. However, in practice one source is usually dominant at any one time so that such a process is not necessary and each aspect of the environment can be applied separately during susceptibility tests.

Having derived a description of all the EM fields at the boundary of the system, this gives a guide as to how the system may be designed and tested for EMC. The design should be approached in an integrated manner such that protection is optimised against all threats. However, in the simplest case, if the boundary field strength is applied to the system in a test environment, then the relevant performance criteria should be achieved to demonstrate compatibility with the environment.

It is intended that the boundary EM field data will set limits of susceptibility for the system under test. It is important that the assumptions made when deriving the EM field data form, where possible, an integral part of the description of the EM environment. It is also important at the lower part of the frequency band in particular to recognize the nature of the field that exists in service and to ensure the test method reflects this as far as practicable.

While assessing the fields that penetrate a system boundary due to external sources, an assessment should be made of any sources of electromagnetic fields which are created within the system to ensure that these do not compromise the EMC of the system. In this way, both inter-system and intra-system EMC should be addressed together.

5 Categorization

Materiel will in general be intended for use in a number of operational scenarios. The EM environment across the scenarios may vary but there are likely to be only a limited number of scenarios that are significantly different. Thus it is convenient to categorize materiel so that its EM environment can be determined. It is also necessary to further subdivide the EM environmental descriptions to provide a description of each threat in each scenario.

Table 1 shows the scenarios for which the EM environments will be significantly different. Although there are different environments for different situations, it may be necessary to look at only the worst case threats when testing a system (for example, one would not manufacture an aircraft that was compatible with the EM environment in flight but not compatible with the airport EM environment).

Operational Restrictions, Failure Modes and Frequency of Occurrence: When determining the applicable EM environment, recognition needs to be given to any possible operational restrictions that may be acceptable and to potential failure modes. Thus it may be decided that a minimum separation between a system and a potential interference source can be accepted since the separation does not significantly restrict deployment; or certain failure modes are not mission or safety critical and a lesser degree of hardening is acceptable. However, the use of a minimum separation to prevent a safety hazard would only be acceptable where a well-controlled and documented clearance and control regime is in place (e.g. High Intensity Radiated Transmission Areas (HIRTA) for aircraft). Any operational restrictions / minimum separations should be formally agreed between the Equipment Capability Manager and the Integrated Project Team (IPT) in the process of agreeing the details of the scenarios to be used.

Similarly, the frequency of occurrence of a particular environment may be sufficiently rare to allow it to be ignored or be considered only relevant to safety critical failure modes. (E.g. for a direct lightning strike, some systems may only be required to remain safe but not necessarily suitable for service). Again the detail of the requirement needs to be agreed between the Capability Manager and the IPT.

Table 1 Categorization

Threat	**Air**	**Sea**	**Land**	**Ordnance**
Lightning	a) Indirect strike b) Direct strike c) Radiated EMP	a) Ground nearby strike b) Ground Direct/ Indirect strike c) Radiated EMP	a) Ground nearby strike b) Ground Direct/ Indirect strike c) Radiated EMP	a) Ground nearby strike b) Direct/Indirect strike c) Radiated EMP
Electrostatic discharge (ESD)	a) Rotary wing aircraft ESD b) P-Static c) Human ESD d) Discharge from other materials	a) Human ESD b) Discharge from other materials	a) Human ESD b) Discharge from other materials	a) Human ESD b) Discharge from other materials c) Rotary wing ESD d) P Static
Conducted EM energy	a) In flight, power generated internally b) On ground, as for land service c) On ship flight-deck as for sea service	a) At sea, power generated internally b) In port, as for land service	a) Power generated by field / vehicle generators b) Power from civilian mains distribution c) LAN, military and National d) Telephone, and other data input / output lines	a) Own internal generated power b) External power as relevant land / sea / air platform
Static and Low Frequency Fields	a) Power System Magnetic Field b) Terrestrial Electric Field	a) Power System, Degaussing and Deperming Magnetic Fields b) Terrestrial Electric Field	a) Power System Magnetic Field b) Terrestrial Electric Field	a) As for relevant platform environment
Radiated Communications / Radar	a) Rotary at airfield b) Rotary in flight c) Rotary near / on ship d) Fixed Wing at	(a) Above decks (b) Below decks (metal ships) (c) Below Decks (non-metal ships) (d) Submarine	a) Different classes based on proximity of transmitting antennas.	a) Full life cycle (derived from one or many platform systems) b) Operational as for land / sea / air as appropriate.

Threat	Air	Sea	Land	Ordnance
	airfield e) Fixed wing in flight f) Fixed wing near / on ship	(e) Rotary Wing near / on ship (f) Fixed Wing near / on ship		
Nuclear Electromagnetic Pulse (NEMP)1	a) Endo-atmospheric NEMP b) Exo-atmospheric NEMP	a) Endo-atmospheric NEMP b) Exo-atmospheric NEMP	a) Endo-atmospheric NEMP b) Exo-atmospheric NEMP	a) Endo-atmospheric NEMP b) Exo-atmospheric NEMP

NOTE This standard does not address other effects produced by a nuclear explosion such as Transient Radiation Effects on Electronics (TREE) or Initial Nuclear Radiation (INR). The Equipment Capability Customer should be consulted as to whether hardening to these effects is required. In the relatively few cases where it is called up Def Stan 08-4 [Ref 2] should be consulted.

6 Terrestrial Electrostatics

The terrestrial electrostatic field is described in Ref [1] Chapter 12-01. The fair weather electrostatic field exists in the absence of highly charged clouds and has a magnitude of between 10 Vm^{-1} and 100 Vm^{-1}. The source of this field is a charge imbalance between the earth and the atmosphere. The charge imbalance is created when current flows to/from the ground in lightning strikes.

In the vicinity of a large cumulo-nimbus cloud, electrostatic field strengths of up to ±6 kVm^{-1} are observed at ground level. Even greater field strengths exist at higher altitudes within the cloud.

In particular, Ref [1], Chapter 12-01, states that the terrestrial electrostatic field can have a significant effect on systems such as wire guided missiles. It also contributes significantly to the helicopter electrostatic discharge level discussed in clause 8.6.

7 Lightning

7.1 Ref [1] Chapter 7-01 contains information about the occurrence of lightning in different parts of the world. The number of days in a year on which thunder is heard varies from less than 1 day in the arctic, through 10 days in the UK up to 180 days in the Middle East and South America. British Standard BS 6651 [Ref 3] provides a map of the UK giving contours related to lightning strike frequency averaged over a number of years.

7.2 A thorough description of the fields and currents due to lightning can be found in Def Stan 59-113 [Ref 4]. Although this is an aircraft related standard the discussion on lightning parameters can largely be read across to other platforms. The electrical effects of a lightning strike on metal structures are primarily determined by the lightning discharge current, its rise time and its duration. This current may rise to a peak value as high as 200 kA in little over a microsecond and take two or three hundred microseconds to decay. Lower levels of current of up to 500 A may then flow for up to 0.5 s. As well as possibly causing mechanical damage and melting / hot-spots a direct lightning strike will induce currents in nearby cables. A lightning strike also produces a radiated EM field that can induce currents in circuits and structures. The fields from a nearby strike can reach values of up to 3 MVm^{-1} at 10 m.

7.3 It is acknowledged that the important lightning parameters with respect to design and testing are:

d) Peak current

e) Rate of change of current

f) Action Integral

g) Charge content

h) Duration

i) Rate of change of E field.

7.4 The numerical values of the parameters of lightning strikes have been determined in measurement surveys over many years. Each lightning strike will have unique characteristics so a statistical description of the parameters is necessary. Moreover the statistics vary according to geographic location and whether the strikes are positive or negative. Data on these parameters is sparse but evidence from recent strikes has shown that levels higher than some certification standards are possible. Full international agreement on some parameter values has not therefore been reached. The data for positive and negative flashes from Ref [4] are shown in Table 2 and Table 3. The percentages at the top of each table describe the statistical nature of the flashes. For example, in the case of peak current in negative flashes, 50 % of flashes have a current greater than 20 kA, 2 % have a current greater than 140 kA, and so on. The 2 % values should be used for safety critical applications (i.e. aircraft or ordnance).

7.5 The tables do not give data for dE/dt, which can be an important parameter. Although data concerning dE/dt is somewhat limited, the value usually used, as far as it affects aircraft in flight and ground installations, is 10^{13} $Vm^{-1}s^{-1}$.

Table 2 Parameters for Negative Lightning Flashes Measured at Ground Level

Parameters	Unit	Lightning Parameters		
		95%	50% (typical)	2%
Number of Strokes		1-2	3	11
Time Intervals between strokes	ms	8	60	320
Peak current (1st stroke)	kA	14	20	140
Peak rate of rise (1st stroke)	As^{-1}	5.5x10^{9}	1.2 x 10^{10}	4 x 10^{10}
Time to peak (all strokes)	μs		1.8	1.2
Pulse width at half peak current (all strokes in flash)	μs	30	45	170
		95%	50% (typical)	2%
Peak current (subsequent strokes)	kA	4.6	10	100
Peak rate of rise (subsequent strokes)	As^{-1}	1.2x10^{10}	2.2 x 10_{10}	1 x 10^{11}
Amplitude of continuing current	A	33	140	500
Duration of continuing current	s	0.058	0.16	0.4
Charge in continuing current	C	7	26	110

Parameters	Unit	Lightning Parameters		
Action integral	A^2s		2×10^4	0.8×10^6
Charge per stroke	C		5	20
Total charge in flash	C	1.3	15	200
Flash duration	s	0.04	0.2	1

Table 3 Parameters for Positive Lightning Flashes Measured at Ground Level

Parameters	Unit	Lightning Parameters	
		50% (typical)	10%
Peak current	kA	25	170
Peak rate of rise	As^{-1}	2.5×10^9	1.2×10^{10}
Estimated time to peak	μs	20	120
Pulse width at half peak current	ms	15	60
Total charge in flash	C	70	310
Action integral	A^2s	5×10^5	8×10^6
Flash duration	s	0.1	0.4

7.6 Combined Lightning Environment

It is generally accepted that worldwide approximately 90% of all cloud-ground lightning strikes are negative and 10% positive. However, depending on the geographic region, season, type of cloud and phase of the thunderstorm, very different percentages can occur. For example in the UK the percentage of positives is about 40% in summer and 60% in winter. There is also debate on how a combined set of parameter levels should be derived even once a ratio of positive to negative strikes has been set. Ref [4] assumes a 10% positive content and for 98% of all strikes gives the threat levels noted in Table 4 – using a statistical method referenced in the standard.

Table 4 Parameters for Design and Test (combined Positive and Negative Flashes)

Parameters	Unit	Lightning Parameters
Peak rate of change of current (aircraft)	As^{-1}	1.4×10^{11}
Peak rate of change of current (ground and sea platforms)	As^{-1}	1.0×10^{11}
Peak current	kA	200
Action integral	A^2s	3.75×10^6
Charge content (of continuing current)	C	300
NOTE The action integral and charge content values are higher than those currently defined for international civil		

aircraft. However recent air accidents in the UK have shown that these higher levels do occur and should be specified for critical systems

The radiated environment from a nearby lightning strike is given in Table 5.

Table 5 Radiated Parameters of Lightning Strike

Rate of change of Magnetic Field (dH/dt)	$\frac{1.6\times 10^{10}}{R}$ Am^{-1}s^{-1}
Rate of change of Electric Field (dE/dt)	$\frac{6\times 10^{12}}{\sqrt{1+\frac{R^2}{50^2}}}$ Vm^{-1}s^{-1}
Maximum Electric Field	$\frac{3\times 10^{6}}{\sqrt{1+\frac{R^2}{50^2}}}$ Vm^{-1}
NOTE R is distance in m from strike and must be > 10m.	

The current flowing in a structure or a vehicle struck by lightning (or subjected to a nearby strike) will cause induction of currents in cables on / in the structure by a number of mechanisms. The magnitude and frequency of these currents will depend on the dimensions of the structure, the material used in its construction, the presence of apertures and on the position and type of cable. A description of the environmental levels and the waveforms that have been determined for aircraft is given in Ref [4]. Where necessary and since no other data is available the same levels may be used for land vehicles. It is rarely necessary for such induced currents to be taken into account on ship systems due to the spread of current to the sea over a wide area. Specialist modelling will be required if this effect is thought to be an issue on say a composite mast structure.

8 Electrostatic Charging and Discharging

8.1 There are three types of electrostatic charging process that may be experienced by military systems. These are described as follows.

8.2 Firstly, triboelectric charging occurs due to charge transfer that takes place when two different materials are rubbed together or repeatedly brought into contact and then separated. This can lead to the charging of a human body, or of a vehicle / aircraft. The two other types of electrostatic charging process apply only to air platforms and missiles/shells in flight. Precipitation charging occurs when only part of a polarized raindrop stays on the surface of an aircraft or missile thus causing a net charge transfer. Exhaust gas charging is due to charge that is lost with the exhaust gas leaving an aircraft or rocket motor.

8.3 The main problem with electrostatic charging is that the discharge of the object is usually via a series of pulses of electric current that can directly or indirectly upset sensitive circuits particularly radio receivers or initiate electro-explosive devices. It is also possible for the discharge from an insulating or poorly bonded surface of a missile or shell to couple into a firing circuit or proximity detector.

8.4 On both fixed wing and rotary wing aircraft, two types of ESD are common. Firstly, a large charge can build up on a dielectric surface such as a window. When a discharge finally occurs, there is a large current that induces voltages on nearby cables. Secondly, when the overall charge on an aircraft gets very high, the charge starts to leak off the sharp parts of the aircraft. This transfer of charge is known as corona discharge. The remaining charge is redistributed through the metallic structure and the resulting currents, which are spiky in nature, cause broadband noise to be radiated. This noise is known as precipitation static or p-static. P-static generally affects only reception of radio signals and a fuller description is given in AEP 29 [Ref 5].

8.5 The phenomenon of ESD is described in STANAG 4235 [Ref 6]. This document gives guidance as to the maximum charge that can exist on a human body (voltages up to approximately 25 kV are possible). Also, equivalent circuit representations of the human body are given which enables characterisation of the discharge current (up to 30 A peak with a rise time of 1ns). Such a high voltage level is rare and requires dry (favourable for static) conditions to exist. These levels are therefore generally only used where safety critical applications are being considered. Lower levels of 8 kV are commonly used in the civil community for ESD testing and these are generally sufficient for non safety-critical equipment. The characteristics are as shown in IEC 61000-4-2 [Ref 7].

8.6 A particular cause for concern is the charge that can be built up on a helicopter in flight that will then be discharged if the helicopter is grounded via, for example an under-slung load. The capacitance of a helicopter in flight is typically 500–1000 pF. The equilibrium voltage has been measured in various helicopter types and may range from 20/30 kV to perhaps 1 MV (in a high electrostatic field close to storm clouds). A value of 300 kV in 1000 pF is generally accepted as a realistic maximum for a helicopter at VERTREP height in a reasonably high terrestrial electrostatic field. The energy available for discharge may therefore be up to 45 J and nearly all may be deposited in the load since the helicopter represents a low impedance source. Such a discharge would be extremely hazardous to both humans and equipment.

8.7 ESD environments and test levels currently used are summarized in Table 6.

Table 6 Design Environments / Test Levels for ESD¹

Application	Potential difference (kV)	Capacitance (pF)	Resistance (Ω)	Inductance (μH)
Human ESD Safety critical	±25	500	500 & 5000^2	<5
Human ESD Non-safety critical	±8 (contact discharge) ± 15 (air discharge)	150	330	<5
Helicopter ESD	±300	1000	≤1	<20

NOTE 1 Tolerances are ±5 % except where shown as <

NOTE 2 The 5000 Ω resistance will generally be more benign than the 500 Ω but since it will modify the pulse shape produced it will be necessary to use both values when testing Electrically initiated devices in the pin to case mode.

A very comprehensive description of the problem of ESD for Aircraft can be found in Ref [5].

9 Conducted DC and LF Electromagnetics

9.1 Power Supply – Civilian Environment

The conducted environment of a power supply network can be degraded by several phenomena. The civil environment is described thoroughly in IEC 1000-2-1 [Ref 8] and IEC 1000-2-2 [Ref 9].

The problems that occur can be either due to changes in the quality of the supply from the generator, or alternatively can be due to the loads that are connected to the supply in close proximity to the point of interest.

Problems due to the supply are described in terms of dips or interruption of the supply when compared with the nominal supply voltage and frequency.

Problems due to nearby loads include harmonics, bursts and flicker.

9.2 Power Supply – Military Environment

The parameters that military power supply systems must satisfy are documented in Defence Standard 61-5 [Ref 10]. Aircraft currently satisfy the requirements of British Standard BS 3G100 [Ref 11].

The low frequency "noise" that exists in a military supply is due to generators and loads. These levels may best be described by reference to the limits in the conducted emission and susceptibility tests listed in Part 3 of this Standard.

10 Low Frequency Fields

The low frequency fields generated by power distribution cables should be easily calculable from the equations in clauses 16.1 and 16.2. The electric field does not generally cause any EMC problems to materiel but the magnetic field is known to cause problems to cathode ray tube monitors (distorting picture and colour), sensitive audio frequency circuits and could cause problems to sensitive magnetic data storage media. As integrated circuit gates become smaller it is also possible that they may be affected by these fields. Except for the special cases described below, the magnetic field radiated susceptibility test levels of Part 3 of this Standard should be used to define this environment.

10.1 Degaussing / Deperming of Navy Vessels

There are known problems with degaussing systems on navy vessels. Firstly, the DC currents cause high static magnetic fields to be generated which may affect devices previously mentioned. Secondly, the electric potential generated in a circuit will be proportional to the rate of change of magnetic field. The rate of change that occurs when degaussing systems have their currents changed can be as high as 1,600 $Am^{-1}s^{-1}$. This large rate of change of magnetic field could therefore be hazardous to the safety of a sensitive device that may have a fortuitous loop “antenna” connected to it or to a magnetically sensitive component. In addition it has been shown that when degaussing currents are suddenly interrupted due to emergency shut down or a fault then the subsequent collapse of the current will give rise a high rate of change of field which may be a short damped oscillation or just a fast decay. The frequency content and duration of this will depend on the degaussing coil arrangement and work to try to characterise this more accurately is ongoing. Estimates of a damped sinewave with frequency between 100 and 3000 Hz collapsing to zero in approximately of 100 msecs have been made but these remain to be validated. These values would only be relevant to equipments sited within 0.5m of a degaussing coil and only safety critical equipments possibly need to consider their effect. For equipments sited further away from degaussing cables the low frequency magnetic field susceptibility test levels quoted in Part 3 of this Standard are adequate. If this threat is considered significant for say a weapon system then this test level should be increased to match the predictions for the actual installation.

Deperming operations are carried out on submarines in order to reduce the permanent magnetic field remaining in the steel hull. These operations require the generation of high magnetic fields. Sensitive equipments will generally be removed for this operation where practicable but many equipment will be required to remain on board and some may need to be operational.

The DC magnetic field environment that is present on Navy vessels is summarized in Table 7, which gives the design requirements for equipment fitted to navy surface ships and submarines. The data is taken from "Magnetic Field Effects" Def Stan 08-123 data sheet 38 [Ref 12]. The levels quoted for degaussing systems will only exist relatively close to the degaussing cables. If a system is known to be sited some distance from the cables (say >3m), advice should be sought on the levels to be used. Equally, however, if a system is known to be sited very close to a degaussing cable (say within 0.3m) considerably greater field strengths may exist and further advice should be sought.

Table 7 Design Requirements for Degaussing and Deperming Magnetic Field Environments

Process	Surface Ships	Submarine
Degaussing - Equipment within 2m of a DG cable.		
Static field	800 Am^{-1}	800 Am^{-1}
Rate of change of field	1600 $Am^{-1}s^{-1}$ Note: In some situations within 0.2m of degaussing cables, levels up to 10 times the rate of change have been measured.	1600 $Am^{-1}s^{-1}$ Note: In some situations within 0.2m of degaussing cables, levels up to 10 times the rate of change value have been measured.
Deperming - Equipment must be able to survive these fields without any impairment	(Current policy is not to deperm surface ships)	
Static field		3200 Am^{-1}
Rate of change of field		1600 $Am^{-1}s^{-1}$
Deperming - Safety Critical Systems - should be able to operate within these fields without any impairment.	(Current policy is not to deperm surface ships)	
Static field		4800 Am^{-1}
Rate of change of field		1600 $Am^{-1}s^{-1}$

11 Intentional Emitters – Air Environment

The US Federal Aviation Administration and the European Joint Aviation Authority first expressed concern, in 1986, over the integrity and safety of new technology civil transport aircraft with full electronic flight critical systems.

The Electromagnetic Compatibility Analysis Centre (ECAC) was commissioned to produce a study document to predict the maximum electromagnetic radiated fields in the United States for specific scenarios. The resultant study document Ref [13] was issued in September 1987 and forms the basis for most of the EM environmental assessments that are currently performed by regulatory authorities.

The threat field in the frequency range 10 kHz–40 GHz is due to a variety of communication and radar sources.

The fields that result from various sources are derived using the antenna theory from clause 19. Direct measurements are rarely needed since the theory is considered to be acceptably accurate.

The techniques and assumptions for deriving the aircraft environment are mostly taken from Ref [13]. To derive an EM environment for an aircraft, the characteristics of all transmitters that will be encountered in use must be evaluated.

In the UK, the High Intensity Radiated Transmission Area (HIRTA) scheme is used to protect military aircraft from hazardous EM environments. The keystone of the HIRTA is a database of high power transmitters, the EM fields from which can be calculated.

Currently, the HIRTA database is used to calculate the areas in which an aircraft can safely fly based on information about the aircraft's hardness to EM fields. The HIRTA information can be used conversely to provide a description of the EM environment in the region of space in which an aircraft will fly. The region of space will mainly be governed by the capability of an aircraft to approach a transmitter (i.e. minimum height above ground / minimum distance of approach to airport radars etc.). The assumptions of how an aircraft will operate are therefore an important part of the calculations of the EM environment of the aircraft.

The air environments described in this Part of the Standard are derived using the HIRTA database as described above and additional transmitter data from similar sources.

A known EMC problem is that often a system is susceptible to an AM modulated signal when it is not susceptible to the same amplitude of CW signal. Hence the modulation type of the threat fields should be determined. For communications signals, the modulation is likely to be AM or FM. For radar signals, the modulation type is typically pulsed CW with between 100 to 10000 pulses per second and a typical duty cycle of between 0.0005 % and 5 %1) However, due to the complex nature of radars, further information should be sought for any specific scenario.

11.1 Air-service Environmental Assumptions

The assumptions that were used when calculating the air-service environment for this Part of the Standard are described as follows.

a) The electromagnetic environment exists due to the transmission of electromagnetic energy into free space. This energy is radiated from radar, radio, television, and other sources.

b) These transmitters are ground-based, shipborne, or airborne.

c) The electromagnetic environment has been modelled using the databases that contain parameters pertaining to all known transmitters in the United States and Western Europe. The resulting HIRF envelope is a representation of electromagnetic field strength over a frequency range of 10 kHz to 40 GHz. This HIRF envelope has been verified by examining the databases for accuracy, and, in the past, by taking measurements of field strength through flight tests at selected sites.

d) In calculating the environment, both specific and general assumptions were made. The specific assumptions deal with aircraft to transmitter distance criteria and are discussed later for each scenario.

11.1.1 General Assumptions

a) The envelope was divided into frequency bands with the maximum level in each band being determined.

b) Main beam illumination by a transmitting antenna was used.

c) Maximum main beam gain of a transmitter antenna was used.

d) Modulation of a transmitted signal was not considered. However, the duty cycle was used to calculate the average power for pulsed transmitters.

e) Constructive ground reflections of High Frequency (HF) signals, i.e. direct and reflected waves were assumed to be in phase.

f) Non-cumulative field strength was calculated. Simultaneous illumination by more than one antenna was not considered.

g) Near field corrections for aperture and phased-array antennas were used.

h) Field strengths were calculated at minimum distances that were dependent upon the location of the transmitter and aircraft.

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1) [1]Duty cycle is the product of pulse width and pulse repetition frequency

i) Peak field strength was based on the maximum authorised peak power of the transmitter, maximum antenna gain, and system losses (where known).

j) Average field strength was based on the maximum authorised peak power of the transmitter, maximum operational duty cycle[1], maximum antenna gain, and system losses. This applies to pulse systems only

k) The field strength values are in volts per metre and were calculated from the power density. It is very important to note that although only values of E field are stated, an H field of magnitude E/377 Am^{-1} is implied.

l) The terms "direct range" and "slant range" are defined as follows: Direct range is the "line-of-sight" distance between a transmitter and an aircraft. Slant range is the distance between a transmitter and an aircraft taking into account the aircraft altitude and the maximum antenna elevation angle of the transmitter. If the maximum elevation angle is not available, 90 degrees is assumed (unless otherwise stated in the text).

m) Transmitters with experimental licences were excluded.

n) Transmitters located in Prohibited, Restricted or Danger areas were not included in the environment.

o) Non-airport mobile tactical military transmitters were excluded.

p) The assumptions about particular peacetime aircraft environments are summarized in Table 8.

11.1.2 Aircraft Scenarios

In considering what aircraft scenarios to use the following issues were taken into account:

a) For a new aircraft project/design specific assumptions on scenarios and operational use should be made and a comprehensive study made of the EM environment that should be specified.

b) For existing aircraft with a known clearance level new equipment will generally be specified to match that level or exceed it by a suitable margin.

c) The EM environment for aircraft which have to undergo a mid-life update should be assessed in a similar manner as for new aircraft or be based on existing clearance levels.

For these reasons the number of environments given in this Part of the Standard has been limited.

The environments cover possible wartime scenarios and where possible the assumptions made are described for each scenario. Full details of distances used cannot be included for classification reasons. As noted in clause 1.3 the threat which could arise from future RF weapons has been excluded. The scenarios covered which may be used for information on the generic levels to be expected for military aircraft are:

a) Transport Aircraft

b) Fixed and Rotary Wing Aircraft capable of operating from a ship

c) Strike Aircraft not capable of landing on a ship

Table 8 gives the assumptions used for all aircraft types for peacetime operations. The distance figures have been modified to allow for wartime scenarios but are not included here for classification reasons.

Table 8 Summary of Assumptions for Air Environment in Peacetime

Location	Type of transmitter	Strike aircraft assumptions	Transport aircraft assumptions	Rotorcraft assumptions
Airport Transmitters (within 5 nautical miles of an Airport runway)	Airport surveillance and Air route surveillance	500ft, slant range	500ft, slant range	300ft, slant range
	All other fixed transmitter	250ft, slant range	250ft, slant range	100ft, direct range
	Aircraft weather radar	150ft, direct range	150ft, direct range	100ft, direct range
	All other mobile transmitters, including other aircraft	50ft, direct range	50ft, direct range	50ft, direct range
Non-airport transmitters		500ft, slant range[a]	1000ft, slant range[b]	100ft, direct range
Offshore platforms		N/A	N/A	100ft, direct range
Shipborne Transmitters[c]		500ft, slant range	1000ft, slant range	500ft, direct range
Air - air transmitters	Non-interceptor with all transmitters operational	500ft, direct range	500ft, direct range	N/A
	Interceptor aircraft with all non-hostile transmitters operational	100ft, direct range	100ft, direct range	N/A

[a] Assumes a minimum flight altitude of 500ft, and avoiding all obstructions (including transmitter antennas) by 500 ft

[b] Assumes a minimum flight altitude of 1000ft, and avoiding all obstructions (including transmitter antennas) by 1000ft. Where maximum elevation angle of antenna was not known, 45 degrees was assumed

[c] Except for aircraft/rotorcraft capable of landing on a ship

11.2 Military Fixed Wing Transport Aircraft

The environment is given in Table 9. The civilian aircraft severe environment has been used as being typical for the environment expected to be seen by this type of aircraft.

Table 9 Field Strength for Military Fixed Wing Transport Aircraft

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—100 kHz	50	50
100 kHz—500 kHz	60	60
500 kHz—2 MHz	70	70
2 MHz—30 MHz	200	200
30 MHz—70 MHz	30	30
70 MHz—100 MHz	30	30
100 MHz—200 MHz	90	30
200 MHz—400 MHz	70	70
400 MHz—700 MHz	730	80
700 MHz—1 GHz	1400	240
1 GHz—2 GHz	3300	160
2 GHz—4 GHz	4500	490
4 GHz—6 GHz	7200	300
6 GHz—8 GHz	1100	170
8 GHz—12 GHz	2600	330
12 GHz—18 GHz	2000	330
18 GHz—40 GHz	1000	420

11.3 Military Strike Aircraft - Capable of Ship Operations

For the purpose of this Part of the Standard a single separation distance between any ship capable aircraft/rotorcraft and all ship transmitters has been assumed. It is recognised that this is a worst case assumption but for specific approaches to any or all ships further information will need to be sought. The environment is given in Table 10.

Table 10 Field Strength for Military Strike Aircraft Capable of Ship Operations

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—100 kHz	50	50
100 kHz—200 kHz	60	60
200 kHz—600 kHz	300	300
0.6 MHz—30 MHz	300	300
30 MHz—150 MHz	60	60
150 MHz—200 MHz	200	200
200 MHz—225 MHz	200	200
225 MHz—400 MHz	137	140
400 MHz—700 MHz	950	140
700 MHz—790 MHz	2400	140
790 MHz—1 GHz	2400	600
1 GHz—2 GHz	3300	600
2 GHz—4 GHz	10000	1345
4 GHz—6 GHz	7200	750
6 GHz—8 GHz	2500	600
8 GHz—12 GHz	9800	600
12 GHz—18 GHz	4000	600
18 GHz—40 GHz	10550	600

11.4 Military Rotorcraft Capable of Ship Operations

The environment is given in Table 11.

Table 11 Field Strengths for Military Rotorcraft Capable of Ship Operations

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—200 kHz	200	200
200 kHz—600 kHz	300	300
0.6 MHz—30 MHz	300	300
30 MHz—150 MHz	200	200
150 MHz—400 MHz	200	200
400 MHz—700 MHz	950	200
700 MHz—790 MHz	2400	140
790 MHz—1 GHz	2400	600
1 GHz—2 GHz	5000	600
2 GHz—4 GHz	10000	1345
4 GHz—6 GHz	7200	750
6 GHz—8 GHz	2500	600
8 GHz—12 GHz	9800	600
12 GHz—18 GHz	4000	600
18 GHz—40 GHz	10550	600

11.5 Military Strike Aircraft not Capable of Ship Operations

The environment is given in Table 12.

Table 12 Field Strength for Military Strike Aircraft not Capable of Ship Operations

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—100 kHz	50	50
100 kHz—500 kHz	60	60
500 kHz—2 MHz	70	70
2 MHz—30 MHz	200	200
30 MHz—70 MHz	30	30
70 MHz—100 MHz	30	30
100 MHz—200 MHz	90	30
200 MHz—400 MHz	70	70
400 MHz—700 MHz	730	80
700 MHz—1 GHz	1400	240
1 GHz—2 GHz	3300	160
2 GHz—4 GHz	4500	490
4 GHz—6 GHz	7200	300
6 GHz—8 GHz	2500	170
8 GHz—12 GHz	3450	330
12 GHz—18 GHz	2000	330
18 GHz—40 GHz	3000	420

11.6 Military Rotorcraft not Capable of Ship Operations

The environment is given in Table 13.

Table 13 Field Strengths for Military Rotorcraft not Capable of Ship Operations

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—100 kHz	150	150
100 kHz—500 kHz	200	200
500 kHz—2 MHz	200	200
2 MHz—30 MHz	200	200
30 MHz—70 MHz	200	200
70 MHz—100 MHz	200	200
100 MHz—200 MHz	200	200
200 MHz—400 MHz	200	200
400 MHz—700 MHz	730	200
700 MHz—1 GHz	1400	240
1 GHz—2 GHz	5000	250
2 GHz—4 GHz	6000	490
4 GHz—6 GHz	7200	400
6 GHz—8 GHz	1100	170
8 GHz—12 GHz	5000	330
12 GHz—18 GHz	2000	330
18 GHz—40 GHz	1000	420

12 Intentional Emitters – Sea Environment

For any new ship project, the external EM environment at relevant upper deck positions from own ship transmitters can be defined and determined using theoretical calculations, numerical modelling techniques and historical data. When a equipment is to be fitted externally to an existing ship, the EM environment at the intended location should be determined with advice sought from the ship IPT and the sponsor of this standard. If a number of different platforms or locations are involved the generic information provided below should be used. For the below decks environment, account should be taken of the potential shielding provided by the hull/superstructure in the area of interest.

In addition, the generic EM environment caused by other ships in company can be determined using the information provided below. Where the EM environment for a specific scenario is required, additional advice should be sought.

The remaining content of this clause is generic information about the EM environments of current RN ships and ships in build.

12.1 Sea Environment - Above Decks

The Above Decks environment on a naval platform can be stated as the area containing the exposed upper decks of the platform and a number of internal areas. These areas include the hangar, the bridge, any compartment with direct opening onto the exposed upper-deck, any compartment constructed of unscreened material (i.e. glass fibre) on a metallic ship and any compartment on a non-metallic ship that is not enclosed by an electromagnetic screen.

The radiated EM environment above decks on a ship is largely self-generated. The main sources are the ship’s own communications, radar and satcom systems. The strength and coverage of the emissions from some radar and satcom sources can be controlled to some extent by: sector control of transmissions / waveforms, use of blind arcs, physical blockage by RF screens or platform superstructure and synchronization of transmitter pulses or antenna rotation. Additionally, for certain systems, it is possible to control the output power, prevent transmissions or control directivity by operational procedures or where phased arrays are being used by system design. However, owing to the unsynchronised use of most equipment a complete description of the environment becomes complex and unpredictable.

Due to the radio-frequency hazards (RADHAZ) to personnel posed by very high HF fields, the RN has conducted a measurement programme over many years. The magnitude of the electric and magnetic HF fields has been measured at points on grid over large areas of the deck of many Royal Navy and some Royal Fleet Auxiliary (RFA) ships, at a height of 1.5m above the deck. The data has been used to derive a restricted frequency and power operating regime which minimises the affected area. More extensive hazard areas are implemented when the restrictions cannot be applied for operational reasons. The hazard areas are clearly marked and access to them is controlled. However, since these controls are for personnel safety and the areas are extensive many types of equipment will be sited within such areas.

In addition to the high fields present near HF transmitting antennas, metal structures (e.g. stanchions, ladders or davits) on the ship which are some distance away from the transmitting antennas can receive and re-radiate the transmitted power. This can produce a localized high field in the vicinity of the re-radiating structure. This effect is monitored during the surveys discussed above.

In order to classify the above decks ship environment it is convenient to consider different parts of the frequency range separately

12.1.1 Below HF (10 kHz – 2 MHz)

Following changes in the requirements for safety of life at sea (SOLAS), the RN no longer has any requirements for any major communications transmitters operating below 2 MHz on its ships or submarines. The EM environment for this part of the spectrum can therefore be considered equal to the normal background/civil environment.

12.1.2 HF (2 MHz – 30 MHz)

The HF transmissions can be high power typically 1 kW per source and are a major source of EM energy. Wherever possible, the transmit antennas are located away from regular personnel routes and sited on top of superstructure blocks/decks or strung high between the masts. Despite this their impact upon the EM environment is one of the largest and most likely to be felt by other equipment particularly on non-metallic ships.

For HF fields the above deck areas can be considered as three zones: very close to a high power HF antenna (say<4m); outside this area but inside the RADHAZ area (defined as restricted area when there is no operational limit on power or frequency) and outside these areas.

a) Very close to the antenna field strengths will be extremely high (exceeding 1 kVm^{-1}) but will not be uniform or have the impedance of free space so a description in terms of an E-field is not meaningful. Normally equipment should be excluded from positions very close to HF antennas but where it is essential to mount equipment in theses areas special precautions will be required and EMC proving will have to take place in-situ.

b) Inside a RADHAZ zone (but at a distance > 4m from an HF antenna) care must be taken if equipment is to be installed as electric field strengths in the HF band will be high. These fields will have high wave impedance and therefore care should be taken in designing relevant test methods. The boundary for the RADHAZ area is defined by the personnel hazard limits. The maximum field strength at these boundaries is defined in Table 14. Table 14 defines a curve that changes between 307 Vm^{-1} and 61 Vm^{-1} between 2 MHz and 10 MHz and is then constant at 61 Vm^{-1}. (Note that RADHAZ zones are considered to extend vertically above the deck with no height limit). The RADHAZ zones are also defined to protect personnel from high HF magnetic fields. The levels of magnetic field for defining the RADHAZ areas are shown in Table 15. The RADHAZ zones are determined such that neither the electric nor magnetic field strength levels are exceeded at their boundary. Clearly the closer an equipment is to the antenna the higher the field that is likely to be experienced.

c) Outside the RADHAZ zone the fields will fall rapidly with distance. Except very close to re-radiating structures/wires, an equipment well away from the HF antenna (say >15m) will experience field strengths considerably less than the personnel limits and a general E field value of 60 Vm^{-1} across the band may be used.

Each ship will have drawings showing the HF RADHAZ boundaries and where equipment siting is known these drawings should be consulted to determine the zone applicable.

Table 14 HF Electric Field Strength Levels for RN Above Decks Personnel Boundary

Frequency	Maximum (rms) Field Strength (Vm^{-1})
1 MHz – 10 MHz	610 / Frequency in MHz
10 MHz – 30 MHz	61

Table 15 HF Magnetic Field Strength Levels for RN Above-Decks Personnel Boundary

Frequency	Maximum (rms) Field Strength (Vm^{-1})
1 MHz – 10 MHz	1.6 / Frequency in MHz
10 MHz – 30 MHz	0.61

It should be noted that the commercial maritime standard IEC 60945 [Ref 14] uses an above decks immunity testing level of 30 Vm^{-1} for the frequency range 1.5–30 MHz although commercial transmitters generally have much lower power outputs than RN systems

Portable or vehicle mounted radios used by embarked forces may dominate the levels in the HF, VHF and UHF ranges at a number of positions around a ship. Field strengths from such systems are discussed in clause 13.

12.1.3 VHF/UHF (30 MHz—400 MHz)

The RN operates a large number of transmitters in the VHF/UHF region. Most of these are relatively low power transmitters and have the fixed antennas sited on yardarms or the bridge roof. The personnel

RADHAZ boundary limits are set very close to these antennas. However, the fields from these antennas can have a detrimental effect on other equipment, as typical intermediate frequencies are in this range. Should equipment have to be sited in close proximity to these antennas, then the fields can be predicted using numerical modelling. At distances away from these antennas (approximately > m), a generic field strength of 10Vm^{-1} may be assumed

Other sources of radiated EM energy in this frequency range include mobile transportable and portable radios used by land / sea service personnel. These may include types of the Bowman Radio described below in clause 13.1. The electric field strengths at 1m distance from a man-pack radio in this frequency range generally do not exceed 50 Vm^{-1}.

On amphibious ships that carry land service vehicles, the vehicle mounted transmitters will contribute significantly to the EM environment in the HF, VHF and UHF frequency ranges.

12.1.4 UHF (400 MHz – 915 MHz)

There are currently no significant fixed RN ship transmitters in this part of the RF spectrum. However, BOWMAN and small personal transmitters (mobile phones, mobile radios etc) may be present and hence may dominate the EM environment in this frequency range. The electric field strength at 1 m distance from a man-pack radio or hand-set in the frequency range 400 MHz–450 MHz. does not exceed 30 Vm^{-1}. The discussion on fields from mobile cellular telephones in clause 13.2.3 is also applicable to the sea service environment in this frequency range.

12.1.5 Microwave Transmitters

The principal microwave transmitters on a naval platform are radars, missile trackers and satcom terminals. These systems generally produce very high power directional microwave beams, and present a significant RADHAZ to personnel, fuels and ordnance. Due to the RADHAZ problems, some microwave antennas are prevented from illuminating parts of the platform superstructure or deck through the use of sector transmission arcs, ships operating procedures and antenna blind arcs / safety cams. The average field strengths generated by in-service naval microwave transmitters for a range of distances can be found by consulting the technical data in BR2924 [Ref 15]. For new to service equipment, theoretical predictions and/or measurements need to be made. In case of technical queries and specific problems, advice should be sought from the relevant MOD Equipment or Platform Project.

It is possible for the high power microwave transmitters on one platform to affect another platform in consort. In general, when RN platforms are in a task force, some microwave transmitters are restricted from illuminating other platforms, principally to reduce RADHAZ risks to fuels and ordnance. Information on RADHAZ restrictions on transmitters in a task force is contained in Ref [15].

12.1.6 Typical Sea Service Electromagnetic Environments

The EM environments given in this clause are derived from technical data on in-service RN transmitters. Four different sets of assumptions have been used to generate the environments shown in Tables 16 to 18.

The EM environment has been expressed as an electric field strength. Note The H field cannot necessarily be calculated from E/377Ω since for some RN radars the far field distance will be greater than 100m from the transmitter. Where the calculated environment was below 10 Vm^{-1}, average and 200 Vm^{-1} peak above 1 GHz, a baseline at these levels has been assumed as a realistic minimum cut-off.

Table 16: This environment is based on all current naval ship and aircraft transmitters. The fields have been estimated at a distance which may be taken as typical for close approach by UK consorts when no RADHAZ controls are observed.

Table 16 Environment from Consort Ship Transmitters

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
400 MHz—700 MHz	10	10
700 MHz—1 GHz	10	10
1 GHz—2 GHz	750	200
2 GHz—4 GHz	2800	450
4 GHz—6 GHz	200	10
6 GHz—8 GHz	200	200
8 GHz—12 GHz	6000	400
12 GHz—18 GHz	250	50
18 GHz—40 GHz	200	10

Table 17: This environment is based on all current naval ship radar transmitters. The fields have been estimated for a distance from the antenna that represents the potential effect of equipment being illuminated by the antenna main beam. It should be noted that most radars, etc are mounted on the top of masts and/or mast sponsons and yardarms, which means that most of the superstructure/deck areas are not illuminated by these fields. It should also be noted that this includes all ship mounted systems but they are not in practice all on a single ship.

Table 17 EM Environment from all Ship Radar Transmitters in Main Beam

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
400 MHz—700 MHz	10	10
700 MHz—1 GHz	10	10
1 GHz—2 GHz	3000	400
2 GHz—4 GHz	10000	1500
4 GHz—6 GHz	200	10
6 GHz—8 GHz	200	10
8 GHz—12 GHz	10000	700
12 GHz—18 GHz	6000	700
18 GHz—40 GHz	3500	200

Table 18: This environment is based on all naval ship search and surveillance radars. The fields were calculated for a scenario which might occur during a Replenishment At Sea (RAS) operation where deliberate illumination by tracker radars is avoided.

Table 18 EM Environment for Replenishment at Sea

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
400 MHz—700 MHz	200	10
700 MHz—1 GHz	200	10
1 GHz—2 GHz	1750	280
2 GHz—4 GHz	6350	250
4 GHz—6 GHz	200	10
6 GHz—8 GHz	650	650
8 GHz—12 GHz	9800	650
12 GHz—18 GHz	4000	600
18 GHz—40 GHz	8900	400

On the majority of the upper decks of ships, where areas will not be illuminated by the main beam of the ship's own microwave transmitters, the fields will be caused by reflections, refractions and sidelobes. Typical levels on most deck areas across the whole microwave band can be taken as 50 V/m (average) but hotspots may exist on some ships/decks especially where radars are not sited high on masts.

12.2 Sea Environment – Below Deck

The naval below decks environment is difficult to characterize and no significant work has been performed to date in truly defining the EM environment. For equipment areas inside a metal hull, it has largely been assumed that the metal will provide good attenuation to the external Above Decks EM Environment, and figures of up to 60 dB have been quoted. In most cases, the internal below decks environment is self-generated by emissions from the enclosed equipment. This had led to a radiated susceptibility test level of 1 Vm^{-1} in previous versions of Part 3 of this Standard. However, there are a number of equipments that can raise this level, including arc welders, mobile phones, mobile radios and electrical generators. These items can generate local field strengths of up to 10 Vm^{-1} at 1 metre distance and much greater levels closer to the antenna of a mobile transmitter.

A short study was conducted in trying to define the internal field strength for a metal-hulled naval platform, using all available naval references. This study concluded that the average field strength based on these measurements was less than 1 Vm^{-1} and the level that covered 90 % of all the measurements was 1 Vm^{-1}. However, the study did not include mobile transmitters. In summary, the maximum below decks fields can be assumed to be 10 Vm^{-1} except where mobile radios are to be used in close proximity (<1m).

For naval platforms using composite materials (e.g. Fibre Reinforced Plastic) for their hull structure or areas of the superstructure or alternatively areas containing large amounts of glass (e.g. Bridge), the Above Decks EM environment will have a direct impact on the below decks environment. This is due to the lack of screening provided by composite material, which would give at best only 1 or 2 dB attenuation. It is possible to provide some screening to the composite material through the inclusion of metallic or carbon materials into the composite. Alternatively, the inside can be screened by using metallic / conducting sprays or cloths. However, in all cases, the typical amount of screening protection offered is less than that of metallic materials required to provide the same structure. For such ships therefore the below decks environment is considered to be the same as the above decks.

13 Intentional Emitters – Land Environment

13.1 Transmitting Radios

The main radiated EM threats to materiel in the land environment are the radio transmitters used by BOWMAN.

BOWMAN operates in the HF band (1.6 MHz—30 MHz), VHF band (30 MHz - 88 MHz) and UHF (225 MHz – 450 MHz). The transmitter powers vary between different types of radio which can be either man packs (that can also be installed on board vehicles), or vehicle only units that can also be fitted to helicopters and ships. Temporary tented and permanent fixed installations are also used. The Personal Role Radio (PRR) operates at only very low power at a frequency of 2.4GHz.

The antennas used on BOWMAN are usually monopole antennas except on ships where some loop antennas are used. For HF systems the signal from the radio set passes through a matching unit to allow reasonable power transfer into the antenna.

The field strengths generated by earlier radio systems were historically calculated using far field assumptions since there was little detailed experience of how to predict the near field of such antennas. However during the fit of BOWMAN systems considerable measurements have been made of the field strength produced at various distances. The likely maximum field strengths from these radios taken from a range of vehicles have therefore been characterised.

Above approximately 30 MHz, for distances of a few metres from the transmitting antenna, the wave structure has 377 Ω radiated wave impedance. Hence an electric field environment implies a magnetic field environment as well. Below 30 MHz, for distances of a few metres from the transmitting antenna, the wave structure close to the antenna does not have 377 Ω wave impedance. The transmitting antennas used in the land service are electric field antenna and hence the near field wave impedance will be higher than 377 Ω. The effect of these fields on electronic apparatus is not well known and there are no established test methods. Hence these field strengths should not be directly used with standard EMC test methods without appropriate validation and it is probable that at frequencies below 10 MHz a vehicle installed test will be necessary.

13.2 Typical Land Service Electromagnetic Environments

For new equipment projects an EMC scenario, which takes account of all transmitters expected to be in the area, should be generated. Equally, the new equipment may fall into one of the generic scenarios in this standard. For equipments that do not clearly fall into these scenarios, a new specifically generated scenario must be produced.

The scenario will be especially important for systems that will be deployed close to non-standard systems.

Equipment suppliers should demonstrate compliance with the parameters identified in the relevant scenario. Advice on this matter may be sought from DCSA DE3A at Blandford.

Some typical land service EMC environments, including the assumptions used, are given in the following clauses.

13.2.1 General Assumptions

The environments below were calculated from a list of Army transmitters and RAF radios.

Above 30 MHz, the environment has been calculated using far field assumptions. Measured data has been used for lower frequencies.

Below 1 GHz where the calculated environment is below 10 Vm^{-1}, a baseline environment of 10 Vm^{-1} has been assumed. Above 1 GHz a baseline average field of 50 Vm^{-1} has been used. For frequencies below 1 GHz some of the automotive industry uses 30 Vm^{-1} as a baseline (and up to 50 Vm^{-1} for safety critical systems). Different baselines can easily be applied to the data.

13.2.2 Front Line and Operational Support Equipment

This environment is intended to cover equipment that would be taken into the battlefield and used with minimum restrictions as far as co-location of equipments is concerned. Examples of equipments that would fall into this scenario are those mounted externally on an armoured/engineering vehicle, or those carried in unshielded trucks / utility /logistic vehicles.

Main beam illumination from Satcom systems has not been included since the probability of encounter is very low - their narrow beam and the requirement to lock onto a satellite means they should not be illuminating the ground.

Mobile telephones are excluded from these calculations, but the fields that they create are discussed in clause 13.2.3.

The calculated EM environment for these assumptions is shown in Table 19.

Table 19 Front Line and Operational Support Equipment Field Strength

Frequency	**Peak Field Strength (Vm^{-1})**	**Average Field Strength (Vm^{-1})**
10 kHz—100 kHz	10	10
100 kHz—500 kHz	10	10
500 kHz—1.5 MHz	10	10
1.5 MHz—5 MHz	560[1]	560[1]
5 MHz—30 MHz	380[1]	380[1]
30 MHz—100 MHz	100	100
100 MHz—200 MHz	35	35
200 MHz—700 MHz	50	50
700 MHz—1 GHz	25	25
1 GHz—2 GHz	200	50
2 GHz—4 GHz	200	50
4 GHz—6 GHz	200	70
6 GHz—8 GHz	390	390
8 GHz—12 GHz	470	390
12 GHz—18 GHz	200	50
18 GHz—40 GHz	440	50
NOTE For fields between 1.5 MHz and 30 MHz, refer to last paragraph of clause 13.1		

13.2.3 Man Portable / Man Carried Equipment

This environment is typical of small items with no restrictions on use. Examples of equipment that would fall into this scenario are man carried radios, navigation equipment and training equipment.

Mobile cellular telephones are significant sources of EM energy, and are often used very close to equipment without any precautions. However, they have not been included when calculating the EM environments in this section. The fields close to a mobile phone are likely to be highly dependent on the phone type and its interaction with the user so detailed investigation of this threat is needed to ensure that it is fully characterised. It is possible to estimate typical field strengths near to a mobile phone using the following assumptions and the theory from clause 16.3.1. The frequencies of operation of mobile phones in the majority of the world2) is 800 MHz – 1 GHz and 1.7 GHz – 1.9 GHz. Assuming that the maximum transmitted power of the handset is 2W, the antenna gain is 1.5 (dipole) then the electric field strength at 1m would be 9.5 Vm^{-1} and the field strength at 0.5 m would be 19 Vm^{-1}.

For the reasons given above for front line equipment main beam illumination from satcom antennas has not been taken into consideration.

The calculated EM environment is shown in Table 20. The high field strength in the HF to UHF bands are due to an assumption that the equipment may be used very close to a vehicle mounted communications antenna when it is required to operate. If this is not the case fields in these bands will be reduced to those shown in Table 18 or perhaps lower. If necessary the scenario should be defined and advice should be sought.

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2) Japan also has systems that operate in the range 1.429 – 1.453 GHz

Table 20 Man Portable / Man Carried Equipment Electric Field Strength

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—100 kHz	10	10
100 kHz—500 kHz	10	10
500 kHz—1.5 MHz	10	10
1.5 MHz—5 MHz	1120[1]	1120[1]
5 MHz—30 MHz	760[1]	760[1]
30 MHz—100 MHz	215	215
100 MHz—200 MHz	35	35
200 MHz—700 MHz	100	100
700 MHz—1 GHz	25	25
1 GHz—2 GHz	50	50
2 GHz—4 GHz	50	50
4 GHz—6 GHz	1780	570
6 GHz—8 GHz	1550	1550
8 GHz—12 GHz	1860	1550
12 GHz—18 GHz	740	50
18 GHz—40 GHz	1740	35
NOTE For fields between 1.5 MHz and 30 MHz, refer to last paragraph of clause 13.1		

13.2.4 Training, Test and Office Equipment

There are a number of equipments purchased for military use and installed in office type environments. These may or may not be on a site that contains military transmitters. In general a survey of such sites should be carried out to determine what the environment will be, this will require measurements in some cases. If the survey shows that no military or high power transmitters are in the vicinity then it will normally be sufficient to use an appropriate EN standard for the equipment. However if there are military transmitters on the site or if the equipment is mobile and will be used alongside military systems, then the RF environment will need to be quantified (possibly using one of the earlier scenarios). A scenario which may be typical for some training equipments (excluding any used on front line platforms) is given in below and in Table 21. (Note that both the frequency range and level of this environment are more severe than is required for COTS office equipment).

Mobile telephones are excluded from these calculations, but the fields that they create are discussed in clause 13.2.3. A baseline level of 10 V/m average and 50 V/m peak (above 1GHz) has been applied to this environment.

Table 21 Training Test and Office Equipment Electric Field Strength

Frequency	Peak Field Strength (Vm^{-1})	Average Field Strength (Vm^{-1})
10 kHz—100 kHz	10	10
100 kHz—500 kHz	10	10
500 kHz—1.5 MHz	10	10
1.5 MHz—5 MHz	40	40
5 MHz—30 MHz	25	25
30 MHz—100 MHz	20	20
100 MHz—200 MHz	10	10
200 MHz—700 MHz	10	10
700 MHz—1 GHz	10	10
1 GHz—2 GHz	50	10
2 GHz—4 GHz	50	10
4 GHz—6 GHz	50	20
6 GHz—8 GHz	50	35
8 GHz—12 GHz	50	35
12 GHz—18 GHz	50	10
18 GHz—40 GHz	50	10
12 GHz—18 GHz	50	10
18 GHz—40 GHz	50	10

14 Intentional Emitters – Ordnance Environment

EM fields pose a hazard to ordnance systems. The main design problem is to ensure that EM radiation does not cause Electrically Initiated Devices (EIDs) to malfunction.

STANAG 4234 [Ref 16], STANAG 1307 [Ref 17] and Defence Standard 08-123 [Ref 18] have been used for a number of years to define a design EM environment due to RF emitting sources to be used for Ordnance world-wide, covering the complete lifecycle up to the point of launch/initiation. These environments were determined as a result of equipment surveys, but the assumptions used and the sources considered are not documented in the standards. For this reason and due to the increased use of high power transmitters in many applications and the use of additional parts of the spectrum the design environment for ordnance has been re-examined. The resulting figures are to be published in Defence Standard 59-114 Part 3 [Ref 19]. This will give a single table for all 3 services since it is considered likely that any ordnance system will be carried by ship or air at some time in its life. The table is repeated below as Table 22 and it is applicable to ordnance, munitions and explosives which contain EIDs in their storage and transport configuration. It is to be used as a design environment against which items containing EIDs must be shown to be immune when unpowered.

Table 22 Minimum Service RF Environment for OME

Frequency	Average Power Density (W/m^2)	Peak Power Density (W/m^2)
0.01 - 2	300 V/m	300 V/m
2 – 30	200 V/m	200 V/m
30 – 150	10	10
150 – 225	100	100
225 – 400	100	100
400 – 700	100	Numbers below to be confirmed
700 – 790	100	
790 – 1000	500	
1000 – 2000	1000	
2000 – 4000	3000	
4000 – 6000	2000	
6000 -7900	1000	
7900 – 8400	1000	
8400 – 10000	1000	
10000 – 14000	1000	
14000 – 18000	1000	
18000 – 40000	1000	

Ordnance systems are also required to operate satisfactorily and safely in the EM environment in which they will be powered. These environments will generally be the same as for the service platform on which they operate. However, where, for example, a vertical launch missile is used its flight profile may mean it has to survive a considerably higher EM environment immediately after launch. Also some systems will be required to survive a harsh environment while in flight – particularly as a target is approached. These aspects will need to be considered on a case by case basis and more discussion is provided in Ref [19].

For the related design requirements for weapons see Defence Standard 07-85 Part 1 Chapters 3-04, 6-14 and 6-15 [Ref 20]

15 Nuclear EMP (NEMP)

One of the effects of a nuclear explosion is a pulse of EM energy. The NEMP environment for military materiel is described in AEP 4 [Ref 21]. Due to its classification, it is not repeated here. Ref [2] discusses the NEMP environment and test methods / facilities.

An unclassified description of the NEMP environment and its causes can be found in Ref [22].

16 Theory of Free Field Environments

16.1 Electrostatic Field

The electrostatic field at an observation point due to a point charge is described by Coulomb's Law (see Figure 1):

$$E = \frac{Q}{4\pi\varepsilon_0 r^2} \qquad (\mathrm{Vm^{-1}})$$

Where:

E Electric field strength ($\mathrm{Vm^{-1}}$)

Q Magnitude of point source (C)

ε_0 Permittivity of free space (= 8.85×10-12 $\mathrm{Fm^{-1}}$)

r Radial distance from charge to observation point (m)

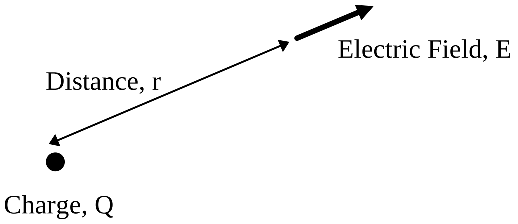

Figure 1 Electric Field due to a point of change

The field due to a large flat conducting charged surface does not vary with distance. The electric field for this situation obeys (see Figure 2):

$$E = \frac{\rho}{2\varepsilon_0} \qquad (\mathrm{Vm^{-1}})$$

Where:

E Electric field strength ($\mathrm{Vm^{-1}}$)

ρ Surface charge density ($\mathrm{Cm^{-2}}$)

ε_0 Permittivity of free space (= 8.85×10-12 $\mathrm{Fm^{-1}}$)

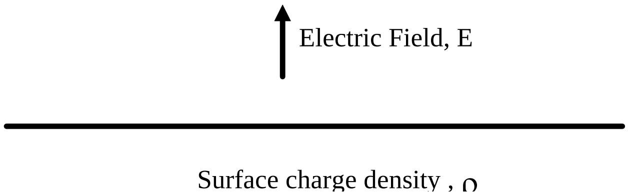

Figure 2 **Electric Field due to a large flat conducting surface**

16.1.1 Electrostatic Charging and Electrostatic Discharge

Both materiel and the human body may experience an accumulation of electrostatic charge through a variety of mechanisms that are described in clause 6. Where there is a high resistance leakage path to earth, an object can accumulate enough charge for a potential of many kV to exist between the object and earth. The resulting discharge, known as electrostatic discharge (ESD), often involves ionization of the air and an associated short burst of current. The spark can ignite volatile liquids (e.g. fuel). The short burst of current can cause spurious voltages to be induced in adjacent wires, and hence can cause malfunctions in electronic systems attached to these wires.

In the case of electrostatic discharge from a human, it is possible to disrupt the operation of sensitive electronic equipment. ESD between materiel is a known hazard to electronic equipment, ordnance (because of spurious voltages picked-up in electronic fuzes) and volatile liquids (e.g. fuel).

The susceptibility of an item to an electrostatic discharge is assessed using an ESD generator that is essentially a capacitor and series resistor with values corresponding to the source which is being simulated (Figure 3).

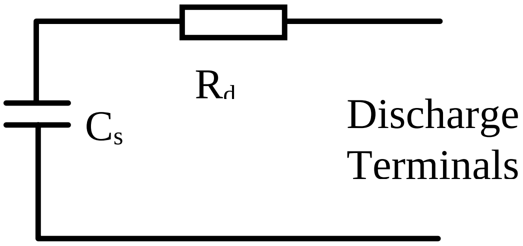

Figure 3 **Equivalent Circuit Diagram of a Simple ESD Source**

16.2 Magnetostatic Field

Magnetic Field due to a current carrying conductor: is directed in a circle around the conductor (see Figure 4). The direction of the field is given by the “right-hand screw” rule. The magnitude is given by:

$$H = \frac{I}{2\pi r} \quad (\mathrm{Am}^{-1})$$

Where:

I Current in conductor (A)

r Perpendicular distance from conductor (m)

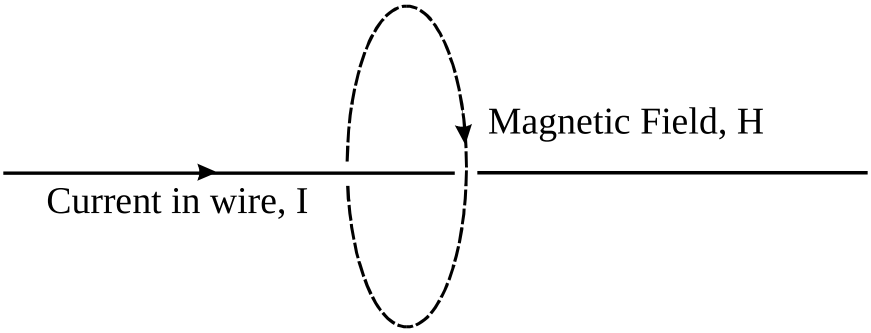

Figure 4 Magnetic Field due to a Straight Wire

Magnetic Field Due to a current-carrying loop: is directed along the axis of the loop (see Figure 5). It is usual for a loop to consist of many turns of wire. The number of turns of wire is denoted by N in the following expression. The field strength on the axis of the loop is stronger than at other places near the loop. The field strength on the axis is given by:

$$H = \frac{NI}{2} \frac{a^2}{(z^2 + a^2)^{3/2}} \quad (\mathrm{Am}^{-1})$$

Where:

I Current in conductor (A)

N Number of turns in loop (dimensionless)

a Radius of loop (m)

z Distance of observation point from plane of loop (m)

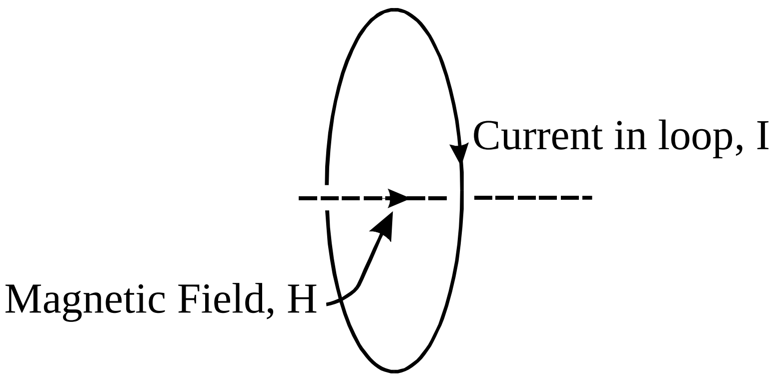

Figure 5 Magnetic Filed due to a Loop

16.3 Electromagnetic Waves – Antenna Propagation Theory

Most sources of high intensity electromagnetic waves are either communications or radar antennas. For this reason, elements of antenna theory are reviewed as follows.

For the antenna theory in this document, antennas are classified into two types:

“Thin-wire antennas” include dipole antennas, monopole antennas, biconical antennas, log-periodic dipole arrays and Yagi antennas. The operating frequency of these antennas is usually less than 1 GHz.

“Aperture antennas” consist of reflecting-dish antennas, other reflector antennas, horn antennas, open-ended waveguides or large array antennas composed of small dipoles, horns or other radiating elements. The operating frequency of these antennas is usually greater than 1 GHz

16.3.1 Antenna Gain, Power Density, Electric Field Strength

All antennas radiate more power in some directions than others. Antenna gain is a measure of the extent to which the radiated power is concentrated into a given direction.

The antenna gain is the ratio of the power density emitted in a direction (θ,ϕ to the average power density. It is common for only the maximum gain of an antenna to be quoted in performance specifications.

As the distance of a measurement point from an antenna increases, the power density in the main beam of an antenna becomes:

$$S_D = \frac{P_T G}{4\pi r^2}$$

Where:

S_D Power density (Wm^{-2})

P_T Total transmitted power (W)

G Maximum gain of antenna (Dimensionless – ratio to isotropic

r Distance from antenna (m)

Since the power density can be written as:

$$S_D = E \times H$$

Where:

E Electric field strength ($\mathrm{Vm^{-1}}$)

H Magnetic field strength ($\mathrm{Am^{-1}}$)

It is possible[4)] to show that the electric field strength is given by:

$$E = \sqrt{120\pi \cdot S_D} = \sqrt{\frac{120\pi \cdot P_T G}{4\pi r^2}} = \frac{\sqrt{30 \cdot P_T G}}{r}$$

For a short dipole, the radiation pattern is proportional to sin(θ). The gain is 1.5 (1.76 $\mathrm{dB_i}$[5)]). Since the short dipole is the simplest type of radiator, it is reasonable to assume that the gain of an antenna will always be greater than or equal to this value. The gain of a half-wave dipole is 1.64 (2.15 $\mathrm{dB_i}$)

Gains of thin wire antennas vary from 1.76 $\mathrm{dB_i}$ to approximately 20 dBi. Aperture antennas can have gains of 50 $\mathrm{dB_i}$.

16.3.2 Fields from Antennas

As the measurement point becomes close to the antenna, the fields from antennas have properties different from those described in clause 19.3.1. For thin wire antennas, the distance at which the properties change is approximately three times the free space wavelength see Ref 23,(page 214).

For aperture antennas, the properties change at a distance of: $2D^2 / \lambda$

Where: λ is the free space wavelength

D is the maximum dimension of the antenna

The following clauses provide descriptions of the properties of the near fields of both types of antennas

16.3.2.1 Thin Wire Antenna

Thin wire antennas have near field properties that are similar to electrically small dipole antennas. A dipole is considered to be electrically small when it is smaller than approximately one twentieth of the free space wavelength.

As the size of small dipole antennas approaches zero, they are described as being infinitesimally small[6)]. The fields due to infinitesimally small dipole antennas can be derived analytically with relative ease see Ref 23, (page 177).

The dipole equations concern two types of dipole; electric and magnetic. These dipole types are shown schematically in Figure 6 and Figure 7. A small electric dipole is a straight segment of wire of length *dl* in which a uniform current I_e flows. Similarly, a magnetic dipole is a small current loop of area *dA* in which a uniform current I_m flows.

[4)] using the fact that a long way from an antenna in free space E/H ≈ 377Ω

[5)] Gain relative to an isotropic radiating source is denoted $\mathrm{dB_i}$

[6)] Infinitesimally small electric dipoles are sometimes known as Herzian dipoles

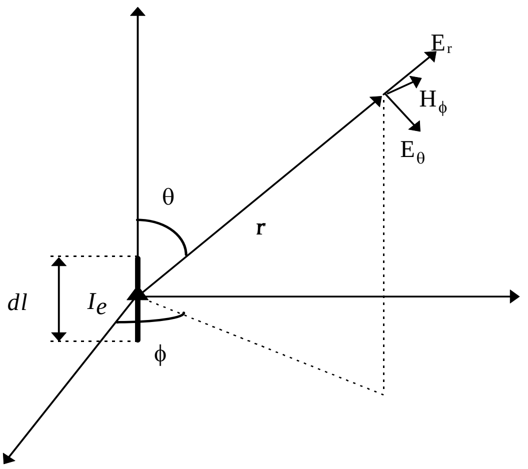

Figure 6 Schematic Diagram of small Electric Dipole Antenna

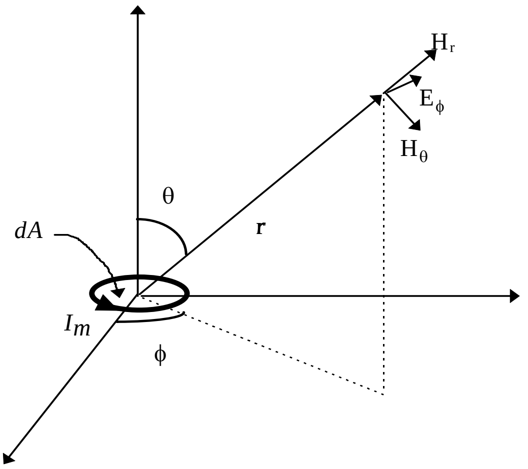

Figure 7 Schematic Diagram of small Magnetic Dipole Antenna

The following clauses describe some important features of the fields due to electrically small antennas.

16.3.2.1.1 Far Field

The far field is the region of space around the antenna for which the distance from the antenna is large compared to the wavelength. The characteristics of the fields in this region are classed as “far field” characteristics. A good engineering approximation is that the far field is the region outside a distance 2λ (λ is the wavelength) from the antenna.

In the far field, the Eθ and Eφ fields, and the Hθ and Hφ fields, are much larger than the E_r and H_r fields. For this reason the fields are described as “transverse electromagnetic (TEM) waves”. It can be shown that this wave represents a power flow away from the antenna.

For the case of the electric dipole, only Eθ and Hφ fields exist. The ratio Eθ/Hφ (the wave impedance) is 377 Ω. This value is known as the impedance of free space.

For the case of the magnetic dipole, only Hθ and Eφ fields exist. The ratio Eθ/Hφ is also 377 Ω.

The information in the previous two paragraphs shows that in the far field, the fields from both the electric dipole and the magnetic dipole are very similar. For this reason, the source type is not normally identified at high frequencies (approximately 100 MHz or above).

If the distance from the antenna is denoted by r, both the E field and the H field reduce with distance as 1/r in the far field. It can be shown that the power associated with a wave is the vector product E x H. This means that in the far field, the power flow can be written as:

$$E^2/377 \text{ or } H^2 \cdot 377$$

Since both E and H fall off as 1/r, then the fall off of power with distance is $1/r^2$, an inverse square law as might be expected.

To summarise, the characteristics of the far field are:

a) It occurs in the region more than 2 wavelengths away from the source (e.g. 600 m at 1 MHz, 6 m at 100 MHz)

b) Field falls off as 1/r, power density as $1/r^2$

c) The wave impedance (E/H) is a constant, the impedance of free space (=377 Ω)

16.3.2.1.2 Near Field

The near field is the region of space around the antenna for which the distance from the antenna is small compared to the wavelength. The characteristics of the fields in this region are classed as “near field” characteristics. A good engineering approximation is that the near field is the region inside a distance λ/2π from the antenna. This region is sometimes referred to as “the radian-sphere”.

In the near field for the case of the electric dipole, the E_r field becomes a similar magnitude to the Eθ field, and the Hφ field is small in comparison. For the case of the magnetic dipole, the H_r field becomes similar to the Hθ field, with the Eφ being small in comparison. Whereas the fields in the far field region represent a power flow away from the antenna, the near fields represent mainly stored energy which leaves and returns to the antenna every cycle.

In the near field, the fall off of the main field components with distance is very steep and falls as $1/r^3$. To put it another way, when the antenna is approached, the field grows rapidly as the antenna becomes closer. This leads to extremely large fields very close to the antenna.

One implication of the facts described above is that close to an electric dipole, the electric fields dominate. The wave impedance becomes very large and this type of source is sometimes referred to as a high impedance source.

The magnetic fields near a magnetic dipole are dominant. The wave impedance becomes very low and it is sometimes referred to as a low impedance source.

The characteristics of the near field are:

a) Is the region less than 1/2π (=0.16) wavelengths away from the source (e.g. 48 m at 1 MHz, 0.48 m at 100 MHz)

b) Field falls off $1/r^3$.

c) The wave impedance (E/H) is not a constant. Electric field sources (straight wires) are high impedance sources (electric field dominant), magnetic field sources (loops) are low impedance sources (magnetic field dominant).

16.3.2.1.3 Intermediate Region

The region of space which is between λ/2π and 2λ from a small dipole is known as the intermediate region. In this region, the characteristics of the fields gradually change from near field characteristics to far field characteristics.

In the intermediate region, the magnitudes of the transverse fields differ by only 1.3dB from the value that would be predicted using far field assumptions.

16.3.2.1.4 Far Field to Near Field Conversion Factor

If the fields from electrically small antennas are predicted using far field assumptions (1/r fall off in field), then the magnitude of the dominant transverse field (Eθ for electric dipoles and Hθ for magnetic dipoles) can be predicted using the following equation:

$$F_{\text{Near}} = F_{\text{Far}} \cdot \frac{1}{(\beta r)^2}$$

Where:

F Field (i.e. E or H)

β Propagation constant (=2π/λ m^{-1})

r Distance from antenna (m)

16.3.2.1.5 Numerical Modelling

Obviously, the dipole equations only give an approximate solution to the field behaviour near to a real antenna, because real antennas will not in general be small compared to the observation distance. More accurate analysis is possible with numerical modelling codes (e.g. NEC 4 Ref [24]) that are extremely good at predicting the behaviour of thin wire structures.

It is important to note that it is very hard to match a driving unit to an electrically small antenna. For this reason, only a small fraction of the power being supplied to a driving unit will be transmitted.

16.3.2.2 Near Fields of Aperture Antennas

The distance at which the behaviour of aperture antennas differs from far field behaviour can be derived by considering Figure 6. At observation points, O, a long way from the antenna, fields radiated from point A are in phase with those from point B. As O becomes close to the antenna, a phase difference occurs because path OA becomes proportionally longer than path OB.

The phase difference for r>>D can be shown to be:

$$\Delta = \frac{2\pi}{\lambda}\left[\frac{D^2}{8r}\right]$$

For the case where the phase difference is equivalent to λ/16 (considered to be in phase see Ref [23](page 214), the following is true:

$$\frac{2\pi}{16\lambda} = \frac{2\pi}{\lambda}\left[\frac{D^2}{8r}\right]$$

i.e. $r = \dfrac{2D^2}{\lambda}$

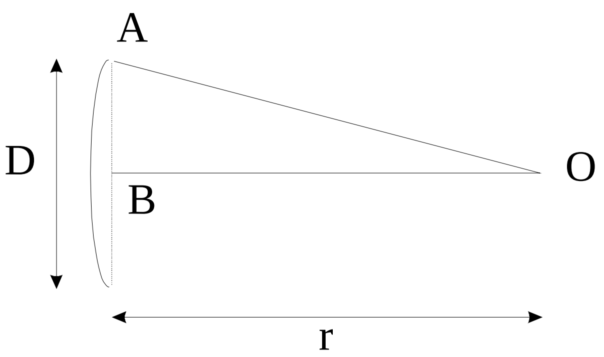

Figure 8 Geometry for Calculating Near Field of Aperture Antenna

The behaviour in the near field of an electrically large antenna is effectively a reduction in the gain of the antenna. A "gain reduction factor" is used to account for this behaviour and the equation for the near field is:

$$S_D = \frac{P_T G \chi}{4\pi r^2}$$

χ Is the gain reduction factor and can be obtained from look-up tables.

16.3.3 Maximum possible Field Strength of Aperture Antennas

This clause is a description on the fundamental limitations on the maximum possible field strengths that can be generated by a dish-type electrically large antenna.

The first limitation that is applicable to electrically large antennas is that the field strength across the surface of the antenna cannot exceed the breakdown field strength of air. The maximum power that can be radiated by an antenna which is limited by air breakdown is given by:

$$P_{\text{max}} = \frac{\pi d^2}{4}\left(\frac{E_{\text{peak}}^2}{2Z_0}\right) \text{ Watts}$$

Where:

d Diameter of antenna (m)

Z_0 Impedance of free space (377Ω)

E_{peak} Peak (*not* rms peak) field strength (Vm^{-1})

Using the value E_{peak} = 3 MVm^{-1} [7] gives:

$$P_{\text{max}} \approx 9.4\times10^9 d^2 \text{Watts} \qquad \text{equation (1)}$$

The maximum field strength in the far field of the antenna is limited by the antenna diameter[8] the gain is limited to be:

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7) This value is valid at sea level, for CW fields only; for other situations, the derivation should be followed using a different value

8) The mechanism is effectively single slit diffraction

$$G_{\max} = \frac{\pi^2 d^2}{\lambda^2} \approx 109 d^2 f_{\mathrm{GHz}}^2$$

Where:

$G_{\max}$ Maximum linear gain of antenna (dimensionless)

f_{GHz} Frequency (GHz)

If both of these considerations are taken into account, the maximum power density observed is given by :

$$P_{D\max} = \frac{P_{\max} G_{\max}}{4\pi r^2} \approx \frac{109 d^4 f_{\mathrm{GHz}}^2 E_{\mathrm{peak}}^2}{32 r^2 Z_0} \approx \frac{82 d^4 f_{\mathrm{GHz}}^2}{r_{\mathrm{km}}^2} kWm^{-2}$$

In practice, this theoretical maximum is not achieved because the necessary transmitter power of 10^{10} Watts (see equation 1) is difficult to realize and because it is hard to build an antenna with the maximum possible gain.

16.3.4 Attenuation of Waves in Dielectric

Attenuation of waves in materials (both dielectrics and conductors) can be found with reference to the propagation constant, γ (see Ref 23):

$$\gamma = j\omega\sqrt{\mu\varepsilon}\sqrt{1 + \frac{\sigma}{j\omega\varepsilon}}$$

Where:

ω Angular frequency (s^{-1})

μ Permeability of medium (Hm^{-1})

ε Permittivity of medium (Fm^{-1})

σ Conductivity of medium (Sm^{-1})

The attenuation of waves in Nepers per meter is equal to the real part of the propagation constant. Figure 9 shows the attenuation of EM radiation in dB /m for a series of typical materials.

These are desert (σ=0.01 Sm^{-1}, ε=3ε0 Fm^{-1}), agricultural land (σ=0.1 Sm-1, ε=15ε0 Fm^{-1}), fresh water (σ=0.005 Sm^{-1}, ε=80ε0 Fm^{-1}) and sea water (σ=4 Sm^{-1}, ε=80ε0 Fm^{-1}). It is apparent from these calculations that only sea water offers significant shielding to materiel which is within a few metres of the surface.

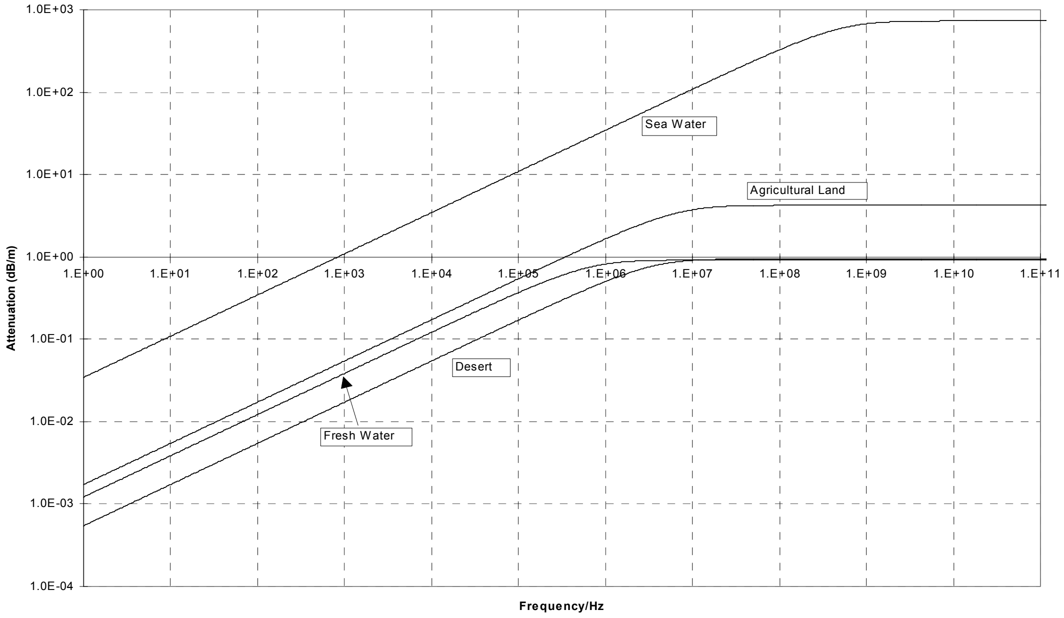

Figure 9 Attenuation of EM Waves in Dielectrics

17 Materiel Internal Environments Description

17.1 Introduction to Materiel Internal Environment

The internal EM environment of a platform will in general be less harsh than the external environment. The magnitude of the EM field strengths inside a platform relative to the external environment will depend on the physical structure, material and geometry of the platform. To derive the characteristics of the internal environment, one can calculate the shielding effectiveness using formulae. Alternatively, depending on the cost of a platform, it may be more economical to measure the internal environment. The internal environment is needed for the derivation of the test levels needed for equipment to be installed in that environment. The process of calculating the Shielding Effectiveness (SE) for a typical platform is not straightforward because of resonances, local discontinuities, joints, gaskets etc. that make simple calculations either difficult to achieve or makes them incorrect.

17.2 Shielding

Losses due to reflection and absorption of a dielectric—see Ref [23](page 111) for the formulae (documented in clause 16.3.4). This includes water and hence provides a description for materiel used under water.

Shielding for metallic materials is described by Ref [23](page 638):

$$S = R + A + B \quad \text{(all in terms of dB)}$$

Where:

R Reflection loss from surface

A Attenuation in material

B Correction term to account for multiple reflections that can be ignored if A is greater than approximately 6 dB

In the following formulae, it is important to note that the conductivity is relative to that of copper

$$\sigma_{\mathrm{Cu}} = 5.8 \times 10^{7} S/m$$

i.e. $\sigma = \sigma_{\mathrm{Cu}} \sigma_r$

Far-field plane-wave reflection loss is given in Ref [23](page 649):

$$R = 168 + 10\log_{10} \frac{\sigma_r}{\mu_r f}$$

Where:

σ_r Relative conductivity of material (dimensionless)

μ_r Relative permeability of material (dimensionless

f Frequency (Hz)

Electric field (high impedance) reflection loss is given in Ref [23](page 656):

$$R = 322 + 10\log_{10} \frac{\sigma_r}{\mu_r f^3 r^2}$$

Magnetic field (low impedance) reflection loss is given in Ref [23](page 656):

$$R = 14.57 + 10\log_{10} \frac{f r^2 \sigma_r}{\mu_r}$$

Absorption loss is given in Ref [23](page 649):

$$A = 131.5t\sqrt{\mu_r f \sigma_r}$$

Where: t Thickness of material (m)

17.3 Internal EM Environment

The internal EM environment induces currents and voltages onto internally mounted cabling by a variety of coupling mechanisms. Details about the way that the external environment couples into internally mounted equipments can be found in many text books and for example in Ref [19] and Part 5 of this Standard.

Generic curves to describe the typical levels of current induced on cables in aircraft and fighting vehicles are given in Part 5 of this Standard.

Further discussion of these environments is excluded from this issue of this Defence Standard.

18 Test Environment Description

18.1 Test Environments

In order to test the EMC of a system, the ideal situation would be to replicate the most severe transmitters and subject the system to the resulting EM environment. This is, in practice, very costly, and the test environment used differs in some respects from the threat environment. The principle that should be used if possible is to make the test EM environment resemble the threat EM environment as closely as possible.

18.2 Combined or Integrated Test Environments

The aim of “Integrated Hardening” for EMC is to devise a testing strategy where systems can be tested for EMC susceptibility by the application of as few tests as possible.

It is widely acknowledged that at least two types of test are needed for susceptibility – one frequency domain test and one time domain test.

The work done to research Integrated Hardening looked at the feasibility of combining all the time domain tests into a single pulse test. A drawback of Integrated Hardening is that the derived wave-form must over-test a system for all of the individual wave-form characteristics to be combined. Depending on the level of over-testing, a system may be made uneconomically hard. Also the production of a generator for this purpose is very costly and is still in a prototyping stage. The problems mean that currently individual tests for each time domain threat remain the normal way of qualifying equipments and systems. If a project wishes to undertake combined testing then further advice should be sought.

For frequency domain threats it is clearly much simpler to derive a maximum threat level for each relevant frequency band and use this to determine the test level to be applied. Considerable care is still needed though when deciding the parameters relevant to a peak pulsed field.

Annex A
References

[1] Defence Standard 00-35 Part 4 Issue 3, 1999 (Amendment 1 April 2000)

[2] Defence Standard 08-4 Nuclear weapons and explosions effects and hardening

[3] BS 6651 Code of Practice for Protection of Structures against Lightning – Latest Issue

[4] Defence Standard 59-113 Lightning Strike Protection for Service Aircraft – Latest Issues

[5] AEP 29. Protection of Aircraft Crew and Sub-Systems in flight against Electrostatic Discharge”.

[6] STANAG 4235 Electrostatic Discharge Environment – Edition 2

[7] IEC 61000-4-2. EMC Part 4-2, Electromagnetic compatibility (EMC) Testing and measurement techniques, Electrostatic discharge immunity test

[8] IEC 1000-2-1. Electromagnetic compatibility (EMC) Part 2: Environment – Section 1: Guide to Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems.

[9] IEC 1000-2-2. Electromagnetic compatibility (EMC) Part 2: Environment – Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems.

[10] Defence Standard 61-5 Electrical Power Supply Systems Below 650 Volts – Latest Issue

[11] BS 3G 100 Specification for general requirements for equipment for use in aircraft. All Equipment. Environmental conditions

[12] “Defence Standard 08-123 Magnetic Field Effects” data sheet 38 Amendment 1.

[13] Guidelines for Developing Maximum Peak and Average Field Strengths Envelope Graphs for Aircraft. Alexander Gross, DOD Electromagnetic Compatibility Analysis Center. 1987.

[14] IEC 60945 Maritime Navigation and Radio Communications Equipment and Systems – General Requirements Methods of Test and Required Test Results.

[15] BR2924 Vols I and II RF Hazards in the Naval Service. Issue 3 2003

[16] STANAG 4234 Electromagnetic radiation (radio frequency) – 200 kHz to 40 GHz environment – affecting the design of materiel for use by NATO Forces.

[17] STANAG 1307 Maximum NATO naval operational electromagnetic environment produced by radio and radar.

[18] Defence Standard 08-123 Requirements for the Design and Testing of Equipment to Meet Environmental Conditions – Category 2

[19] Defence Standard 59-114 Principles for the Design and Assessment of Electrical Circuits Incorporating Explosive Components

[20] Defence Standard 07-85 Design Requirements for Weapons and Associated Systems

[21] AEP 4 – Allied Environmental Publication 4 The Nuclear environment

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