NATO INTERNATIONAL STAFF - DEFENCE INVESTMENT DIVISION

ALLIED
ENVIRONMENTAL
CONDITIONS
AND TEST
PUBLICATION

AECTP-250
(EDITION 1)

ELECTRICAL AND ELECTROMAGNETIC ENVIRONMENTAL CONDITIONS

AECTP-250
EDITION 1

February 2009

NATO HQ - QG OTAN
DMS 1704301
DOCUMENT

0090-09

AECTP 250

ELECTRICAL AND ELECTROMAGNETIC ENVIRONMENTAL CONDITIONS

February 2009

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NORTH ATLANTIC TREATY ORGANIZATION

NATO STANDARDIZATION AGENCY

NATO LETTER OF PROMULGATION

11 February 2009

1. AECTP-250 (Edition 1) – ELECTRICAL AND ELECTROMAGNETIC ENVIRONMENTAL CONDITIONS is a non-classified NATO publication. The Agreement of Nations to use this publication is recorded in STANAG 4370.

2. AECTP-250(Edition 1) is effective upon receipt. It supersedes leaflet 250 of AECTP 200 Edition 3 which shall be destroyed in accordance with local procedures for the destruction of documents.

for Juan A. MORENO
Vice Admiral, ESP(N)
Director, NATO Standardization Agency

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AECTP 250

INTRODUCTION

AECTP 250 is a series of leaflets to present the characteristics and sources for electrical and electromagnetic environmental conditions that influence the design and operation of defence materiel. Leaflet 251 provides a summary description of the environments described in each of the other leaflets.

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GENERAL

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LEAFLET 251

GENERAL

1. GENERAL

The purpose of the AECTP 250 series of leaflets is to present characteristics and sources for electrical and electromagnetic conditions that influence the design and operation of defence materiel.

This series of leaflets provides sufficient data on electrical and electromagnetic conditions for an item of defence materiel which, when used in conjunction with AECTP 500, should facilitate the development of a comprehensive and cost effective set of electrical/electromagnetic environmental definitions and tests in response to project requirements.

2. APPLICATION

The characteristics and data contained in the AECTP 250 series of leaflets are intended for use in the following manner:

a. to permit procurers or potential procurers to identify key electrical/electromagnetic environments for inclusion in requirements documents and/or procurement specifications;

b. to enable procurers and suppliers to ask intelligent questions concerning the “standard” environments defined in the leaflets and their applicability to the project concerned and its operational scenarios;

c. to assist project engineers in compiling electrical environmental design criteria specifications through the identification of all major environments, and through the illustration and quantification of the key characteristics and parameters that influence their magnitude.

3. ENVIRONMENTS

The environments defined in the AECTP 250 leaflets are generic and are therefore widely applicable to service materiel. There will be some systems, however, where the place or type of use means that the assumptions behind the generic environments are not valid and a specific definition for that system will be required. This may be either more or less severe than the generic environment. Where insufficient data are provided in a leaflet to enable a specific environment to be developed, the relevant National E3 Authority should be consulted.

The environments covered by the AECTP 250 leaflets are:

a. **Leaflet 252 – Radio Frequency (RF) Ambient Environments**. This leaflet defines the electromagnetic background noise environment likely to exist at radio communication receive sites in typical rural and urban environments.

b. **Leaflet 253** – **Electrostatic Charging, Discharge and Precipitation Static (P-Static)**. This leaflet describes the electrostatic charging phenomenon and the worst case electrostatic charges/discharges that can occur on personnel and helicopters in flight. The P-static levels likely to be experienced by aircraft in flight are also defined.

c. **Leaflet 254** – **Atmospheric Electricity and Lightning**. This leaflet describes the statistical nature of lightning strikes and the level of key parameters that exist in natural lightning. Derived environments for use in lightning testing are then defined along with typical induced current levels in cables in systems struck by lightning. Electric and magnetic field levels are also defined for Nearby and Distant lightning strikes.

d. **Leaflet 255** – **Direct Current (DC) Magnetic and Low Frequency (LF) Fields**. This leaflet defines the DC magnetic fields encountered in the shipboard operational environment, and LF fields encountered in all three services.

e. **Leaflet 256** – **Nuclear Electromagnetic Pulse (NEMP/EMP)**. This leaflet describes in simple terms the origin of a NEMP, its basic characteristics and the methods by which it couples onto platforms and systems. The complex nature of a NEMP due to its origin, burst altitude and location and the effect the equipment-to-detonation distance has on signal strength and wave shape, the high-altitude EMP (HEMP), source-region EMP (SREMP) and system-generated EMP (SGEMP) are also characterised.

f. **Leaflet 257** – **High Power Microwave (HPM)**. This leaflet describes the type of HPM sources and the general Intentional Electromagnetic Interference (IEMI) and/or damage they can induce in electronic systems.

g. **Leaflet 258** – **RF Electromagnetic Environments (EME)**. This leaflet describes the EMEs likely to be produced by communication and radar transmitter systems during North Atlantic Treaty Organisation (NATO) operations. NATO EME Tables are provided for ship (above deck), ground, air and space environments; and for the worst case NATO EME.

h. **Leaflet 259** – **Electrical Power Quality and Intra-System Electromagnetic Environments**. This leaflet describes the RF conducted environments that may be encountered by materiel due to AC/DC power system disturbances when installed in weapon system platforms or land based communication-electronic facilities and shelters.

4. ACRONYMS

The following acronyms are used in the 250 series of leaflets:

A/m	Amps per Metre
AC	Alternating Current
AM	Amplitude Modulation
CRT	Cathode Ray Tube
CW	Carrier Wave
DC	Direct Current

EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EMV	Electromagnetic Vulnerability
ESD	Electrostatic Discharge
FM	Frequency Modulation
HEMP	High Altitude Electromagnetic Pulse
HF	High Frequency
HIRF	High Intensity Radiated Fields
HPEM	High Power Electromagnetic Environment
HPM	High Power Microwave
IEMI	Intentional Electromagnetic Interference
LEMP	Lightning Electromagnetic Pulse
LF	Low Frequency
NATO	North Atlantic Treaty Organisation
NB	Narrow Band
NCF	Near-Field Correction Factor
NRF	Near-Field Gain Reduction Factor
NEMP	Nuclear Electromagnetic Pulse
PCM	Pulse Code Modulation
PEL	Permissible Exposure Limits
QRSL	Quiet Rural Site Line
RADHAZ	Radio and Radar Radiation Hazard
RF	Radio Frequency
SGEMP	System Generated Electromagnetic Pulse
SM	Static Magnetic
SREMP	Source Region Electromagnetic Pulse
UE^3	Unified Electromagnetic Environmental Effects
UWB	Ultra Wide Band
VSWR	Voltage Standing Wave Ratio

5. DEFINITIONS

The following definitions are used in the 250 series of leaflets:

Antenna Correction Factor

The factor which when applied to the voltage appearing on the measuring instrument, gives the field strength at the antenna

Antenna Efficiency

The ratio of the total radiated power to the total input power.

Note: The total radiated power is the total power less antenna dissipative losses.

Antenna Illumination

The field distribution in amplitude and phase over the physical aperture.

Beam Width

Bean Width is the angle between the half power (3 dB) points on the main lobe, when referenced to the peak efficiency radiated power of the main lobe.

Note: Beam Width is normally expressed in degrees.

Degaussing Coil System

A degaussing coil system consisting of control equipment of one or more coils of electrical cable installed at specific locations on board ship for the purpose of reducing the ship's DC magnetic signature. In operation, these coils are energized with DC so that the magnetic field produced is in opposition to, and reduces, the magnetic field of the ship. Provision is made to vary the current through the coils in both magnitude and polarity.

Direct Strike

A direct strike is a lightning discharge which attaches directly to the materiel (system) considered, causing actual lightning current to flow in parts or the whole of that system.

Duty Cycle

The proportion of time during which a component, device or system is operated

Free Space Loss

The loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space with no obstacles near by to cause reflection or diffraction.

Flux Aperture Coupling

The process of inducing voltages or currents in avionic wiring or systems by electric or magnetic fields passing through apertures.

HEMP

The electric wave produced by an exo-atmospheric nuclear detonation.

HPM

Narrow Band Signal normally with a peak power in a pulse in excess of 100 MW at the source.

Indirect Effects

The effects due to coupling of the lightning's magnetic or electric field. Such effects can arise as a result of either a direct strike or a nearby flash. An example is a transient voltage induced in materiel wiring.

LEMP

The electromagnetic radiation associated with a lightning discharge.

Note: The resulting electric and magnetic fields may couple with electrical or electronic systems to produce damaging current and voltage surges.

Lightning Attachment Zones

Because of the sweeping action of the lightning channel, the proportion of the flash experienced by any particular point depends on its location on the vehicle surface and this has led to the concept of dividing the surface into three Zones depending on the probability of initial attachment, sweeping and hang-on, as follows:

a. **Zone 1** – Surfaces for which there is a high probability of initial lightning flash attachment (leader or return stroke current, entry and exit).

b. **Zone 2** – Surfaces of the vehicle for which there is a low probability of initial attachment but a high probability of a lightning flash (return current) being swept by airflow from a Zone 1 point of initial flash attachment.

c. **Zone 3** – All other surfaces not in Zones 1 and 2. Such areas have a low probability of flash attachment but may carry substantial lightning current between attachment points situated in Zone 1 or Zone 2. In some Zone 3 areas, that may be due to the whole of the lightning discharge.

Zones 1 and 2 may be further divided into A and B regions depending on the probability that the flash will hang on for a protracted period of time, this probability being low for the A region and high for the B region. These zones are defined as follows:

a. **Zone 1A** – Initial attachment point with low probability of flash hang on for a time exceeding 50 ms, such as a leading edge.

b. **Zone 1B** – Initial attachment point with high probability of flash hang on for a time exceeding 50 ms, such as a trailing edge.

c. **Zone 1C** – A limited area of an aerospace vehicle surface behind Zone 1A into which a leader attachment may be swept, and which may therefore experience a first return stroke attachment.

d. **Zone 2A** – A swept stroke with low probability of flash hang on for a time exceeding 50 ms, such as a forward or mid position of a Zone 2.

e. **Zone 2B** – A swept stroke with high probability of flash hang on for a time exceeding 50 ms, such as a trailing edge in Zone 2.

Magnetic Treatment

Magnetic treatment is a method of altering, reducing or removing the permanent magnetic field of a ship. This is accomplished by temporarily rigging coils of electrical cable externally around the ship and about the ship, including the superstructure, where necessary, and energizing the coils with a sequence of DC pulses of predetermined polarities and magnitudes.

Nearby Flash/Strike

A nearby flash is a lightning discharge which does not attach to the materiel (system) but, due to its proximity, may induce significant current in the system either by electric field coupling, magnetic field coupling, ground currents or by a combination of all three.

Near Field

A region generally in close proximity to an antenna or other radiating structure in which the electric and magnetic fields do not exhibit a plane wave relationship and the field strength does not decrease proportionally with the distance from the source but varies considerably from point to point.

NEMP

The electromagnetic radiation caused by Crompton-recoil electrons and photoelectrons from photons scattered in the materials of the nuclear device or in a surrounding medium as a result of a nuclear explosion.

Phase Array Antenna

A phase array is a group of antenna in which the relative phases of the respected signals feeding the antenna are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions

Power Density

Radiating power per unit cross sectional area normal to the direction of propagation, expressed in units of watts per square metre (W/m^2) or milliwatts or microwatts per square centimetre (mW/cm^2 or $\mu W/cm^2$).

Ship Degaussing

The technology dealing with the methods and techniques of reducing a ship's static magnetic (SM) field with onboard coils.

Ship Deperming

The process whereby a ship's permanent longitudinal and athwartship magnetism is ideally removed and its vertical permanent magnetism is stabilized at a known level by exposing the platform to large magnetic fields of alternating polarities and decreasing magnitude.

Ship Flashing

Flashing is a type of magnetic treatment for reducing the permanent magnetism from ships and submarines to camouflage against magnetic detection vessels and enemy marine mines. Flashing energizes coils placed horizontally around the ship.

UWB

A signal that has a percent bandwidth greater than 25%.

Voltage Standing Wave Ratio

The ratio of the maximum to minimum voltage on the antenna feeder line. Standing wave pattern is created when the impedance match is not perfect and a fraction of the power put into the antenna is reflected back and not radiated. For perfect impedance match the VSWR is 1:1.

LEAFLET 252

RADIO FREQUENCY AMBIENT ENVIRONMENTS

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LEAFLET 252

RADIO FREQUENCY AMBIENT ENVIRONMENTS

1. GENERAL

This leaflet addresses the ambient electromagnetic noise environments encountered external to fixed communication-electronic facilities that serve as radio communication receive-only sites. The external Radio Frequency (RF) ambient establishes the minimum usable signal strength for satisfactory service.

The objective of this leaflet is to provide a general description of the RF ambient encountered locally in typical rural and urban settings. This description of the environment can then be taken into account during the design, engineering and site planning and site evaluation of fixed radio communication system architectures to ensure that acceptable radio communication performance levels are maintained.

Detailed descriptions of the RF ambient typically encountered at specific geographical locations worldwide, their characterization, measurement and use in radiocommunication system design can be found in the references cited.

2. IMPACT TO NATO INTEROPERABILITY

Addressing the local RF ambient environment is a necessary condition to support interoperability within the North Atlantic Treaty Organisation (NATO). NATO strategic and tactical operations require that nations communicate and share information, and may involve monitoring regional or global radio communication traffic. Received radio communication signals must compete against the local RF ambient for proper reception. If local levels of radio noise are too great, then adequate reception of Signals of Interest can suffer.

3. CHARACTERISTICS OF THE ENVIRONMENT

3.1. Sources

Sources of the RF ambient may be generated locally or may be due to sources and disturbances located a great distance away. They may be naturally occurring or due to manmade sources. Their amplitudes are therefore heavily influenced by the RF propagation conditions experienced over each season and the time of day at a particular geographical location. Naturally occurring sources of RF energy include lightning, atmospheric disturbances, galactic sources and solar flares. Each is a highly random process. Manmade sources include broadcast, communication, radar and navigation transmitters, electrical motors and generators, fluorescent and neon lighting, arc welders, RF induction heaters and many others. The largest contribution to manmade noise over the critical High Frequency (HF) band is typically due to electrical power lines.

3.2. Describing the RF Ambient Environment

The electromagnetic ambient in the vicinity of a radio receive-only location centres on two internationally accepted parameters F_a and V_d. F_a is the external System Noise Factor expressed in decibels and represents the power available at the output terminals of an antenna. The median value of F_a, expressed as F_{am}, serves as a useful statistical estimate of the expected RF noise level to be encountered at a receive site. V_d, or Voltage Deviation, is the ratio of the Root Mean Square (RMS) voltage at the receive antenna terminals to the Average voltage level also expressed in decibels.

3.3. Models

In order to evaluate a site, there must be a reference or a standard for a good site. Within the 0.15 to 32 MHz frequency range, there is such a reference. It is referred to as the expected values of manmade noise at an electrically quiet receiving location and is known as the Quiet Rural Site Line (QRSL). Those values are typical of the lowest values chosen to ensure a minimum amount of manmade noise, and lower levels will seldom be found at sites that are not several kilometres from power lines and electrical equipment. The equation of this line as a function of frequency is:

$F_a = -28.6 \log f + 53.6$ [dB above kT_o] (equation 3.1)

where (f) is the frequency in megahertz.

An RMS difference of 3 to 4 dB between measured F_{am}'s (the median values of F_a) and the QRSL defines a "good" site (ie: one that has no manmade noise radio noise degradation and is thus natural noise limited). For a site degraded by manmade noise, this RMS difference will be much larger (see Radio Noise Survey for a Communication Site [A1]). It has been determined experimentally that the level of manmade noise decreases with increasing frequency due to the characteristics of the radiated spectrum and the propagation factors involved (See Characteristics and Applications of Atmospheric Noise Data [A2]). Since manmade radio noise is usually most prominent in the morning hours, the QRSL has more usefulness as a reference standard during the 0800 to 1200 hour time frame.

Use of the QRSL as a reference, though desirable, has limited applicability in typical rural and urban settings. Prediction models useful over the 250 kHz to 250 MHz frequency range have been developed that describe the expected radio noise ambient levels for various environments [A3], [A4]. They serve as useful benchmarks as well:

Business: $F_{am} = -27.7 \log f + 76.8$ [dB above kT_o] (equation 3.2)

Residential: $F_{am} = -27.7 \log f + 72.5$ [dB above kT_o] (equation 3.3)

Parks & Universities: $F_{am} = -27.7 \log f + 69.3$ [dB above kT_o] (equation 3.4)

Rural: $F_{am} = -27.7 \log f + 67.2$ [dB above kT_o] (equation 3.5)

Predictions about Freeways are largely identical to the Residential model.

To assess evening radio noise contributions, another reference standard is employed. These are referred to as the expected atmospheric radio noise levels likely to exist at any site. They vary with frequency, geographic location, season of the year and time of day. This information is provided from [A2]. Unfortunately, this reference can only serve as being informative as opposed to representing absolute values. [A2] also provides comparable statistical analyses of the atmospheric F_{am}'s and V_{am}'s. Thus, it is also possible to extract atmospheric expected values (ie: medians) together with standard deviation information and/or Upper Decile (D_u) and Lower Decile (D_l) values. Figure 252-1 presents these prediction models versus frequency.

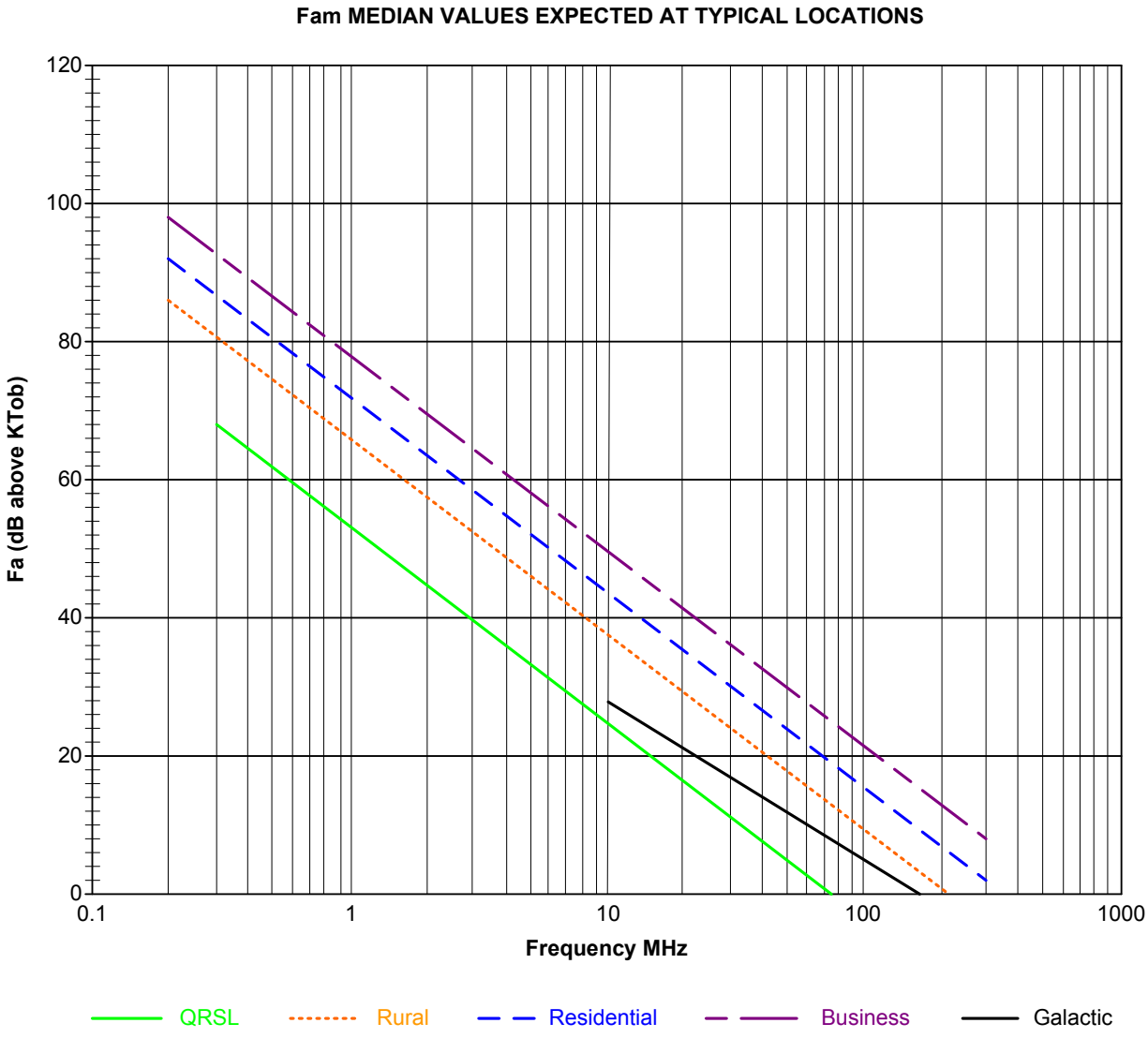

Figure 252-1 Models of Expected RF Ambient Levels

Finally, predictions of galactic noise contributions can be modeled as:

F_{am} = -23 log f + 52 [dB above kT_o] [A5] (equation 3.6)

The Voltage Deviation, or V_d parameter, is defined as the decibel difference between the RMS and Average noise envelope voltages. It can be described as the expected amount of deviation from the Average radio noise voltage. It is therefore an indication of the degree of spikiness of a noise signal and therefore of the noise type. A V_d of 0 dB indicates a continuous wave (CW) signal. Test receiver set noise at a truly quiet frequency would indicate 1.05 dB. Low V_d values of between 4 to 10 dB could indicate atmospheric or natural noise, whereas high values between 15 to 20 dB would indicate the presence of manmade noise. This V_d parameter, along with aural discrimination of the radio noise signal, aids test personnel in identifying and localizing the noise sources that pollute the radio noise spectrum. ([A4] lists demodulated audible sounds of interfering sources commonly encountered at many radio communication sites.)

4. SITE SURVEY TECHNIQUE

A description of the local RF ambient is statistical in nature, constantly fluctuating in frequency and amplitude at any instant of time. The site survey must collect enough frequency and amplitude data points over time in which to develop an Amplitude Distribution Function for the selected site. Site surveys are typically repeated for each of the four seasons. Measurements are made in the morning hours between 0800 and 1200 hours when levels of atmospheric noise are lowest. Thus, any locally generated manmade radio noise easily will be made apparent. Measurements are also made during the 2000 to 2400 hour time frame when atmospheric radio noise is at its strongest. A frequency sweep is made over the frequency range of interest, typically over the HF band, to identify several "quiet" frequencies that could be monitored daily. For example, a detailed study can be made of 12 selected frequencies with ambient level readings taken every 15 seconds for 3 minutes. Over a continuous period of 10 to 14 days, this method provides a statistically large number of measurements from which median noise levels can be determined. (It is actually preferable to continuously monitor the radio noise environment about a radiocommunication receiver-only site, 24 hours a day, every day of the year). The measured daily median RMS voltages are converted to a noise figure parameter (F_a) in units of [dB above kT_o] or [dB above kT_oB]. The site assessment is based on the daily median F_{am} and V_{dm} data sets for both the morning and evening time frames. These are then plotted versus frequency for visual data examination.

It is possible to apply statistical analyses to the accumulated sets of daily medians to determine an expected range of values for F_a or V_d. Calculating the median ± one standard deviation estimates the range of amplitudes to be encountered at the site roughly 67% of the time. The median ± two standard deviations provides an expected range of values over 95% of the time. Plus/minus three standard deviations yields a range of values encountered 97% of the time, and so on. Data can also be plotted as the median between D_u and D_l. Thus, 10% of all expected values of F_a or V_d will be below D_l, while 10% will be above D_u. In other words, plotting a median with D_u and D_l provides an expected range of values to be encountered 80% of the time.

An example of the finalized data obtained using the above survey technique is presented as **Figures 252-2** through to **252-5**.

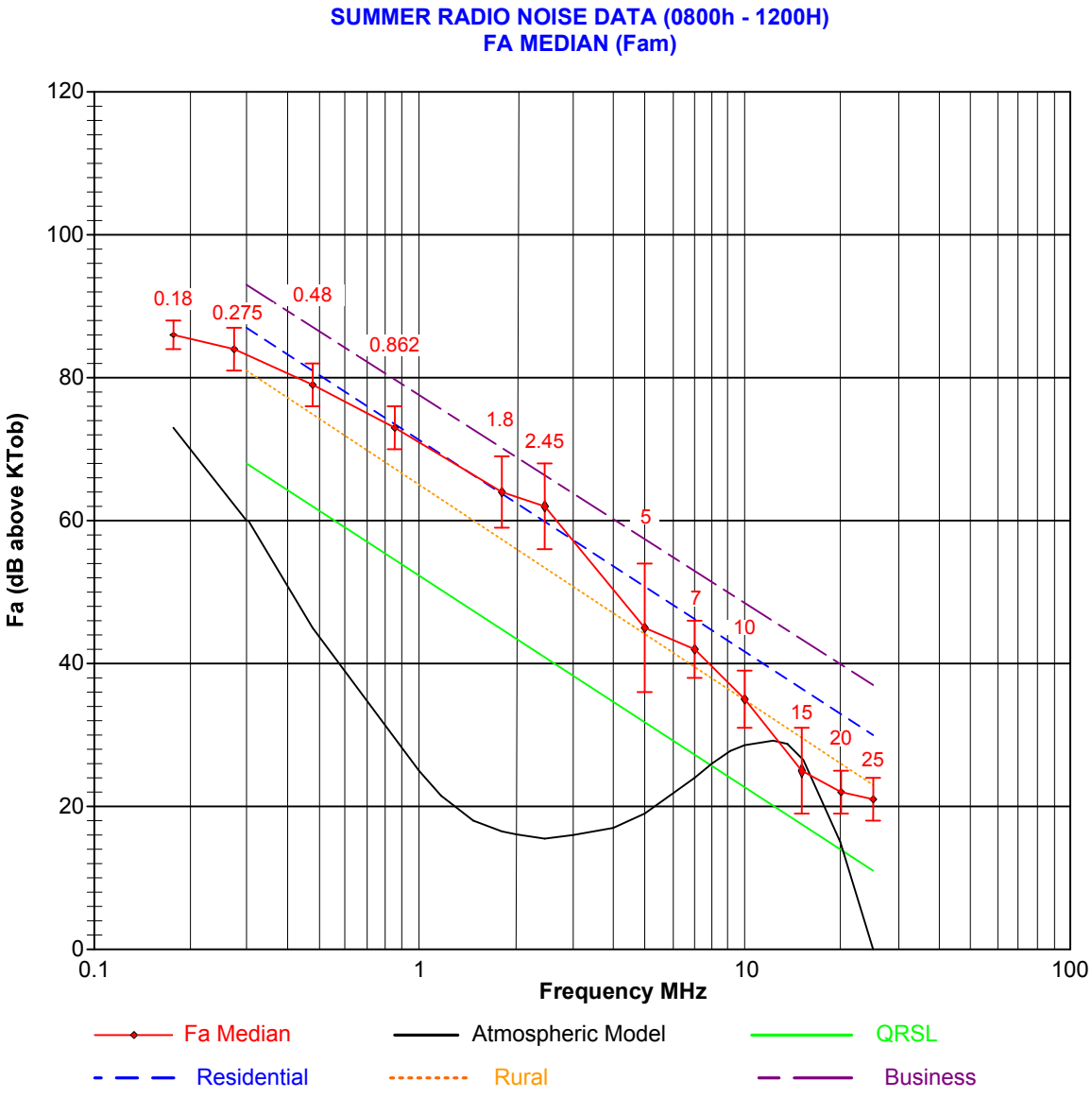

Figure 252-2 Example of RF Ambient Data, Summer Morning

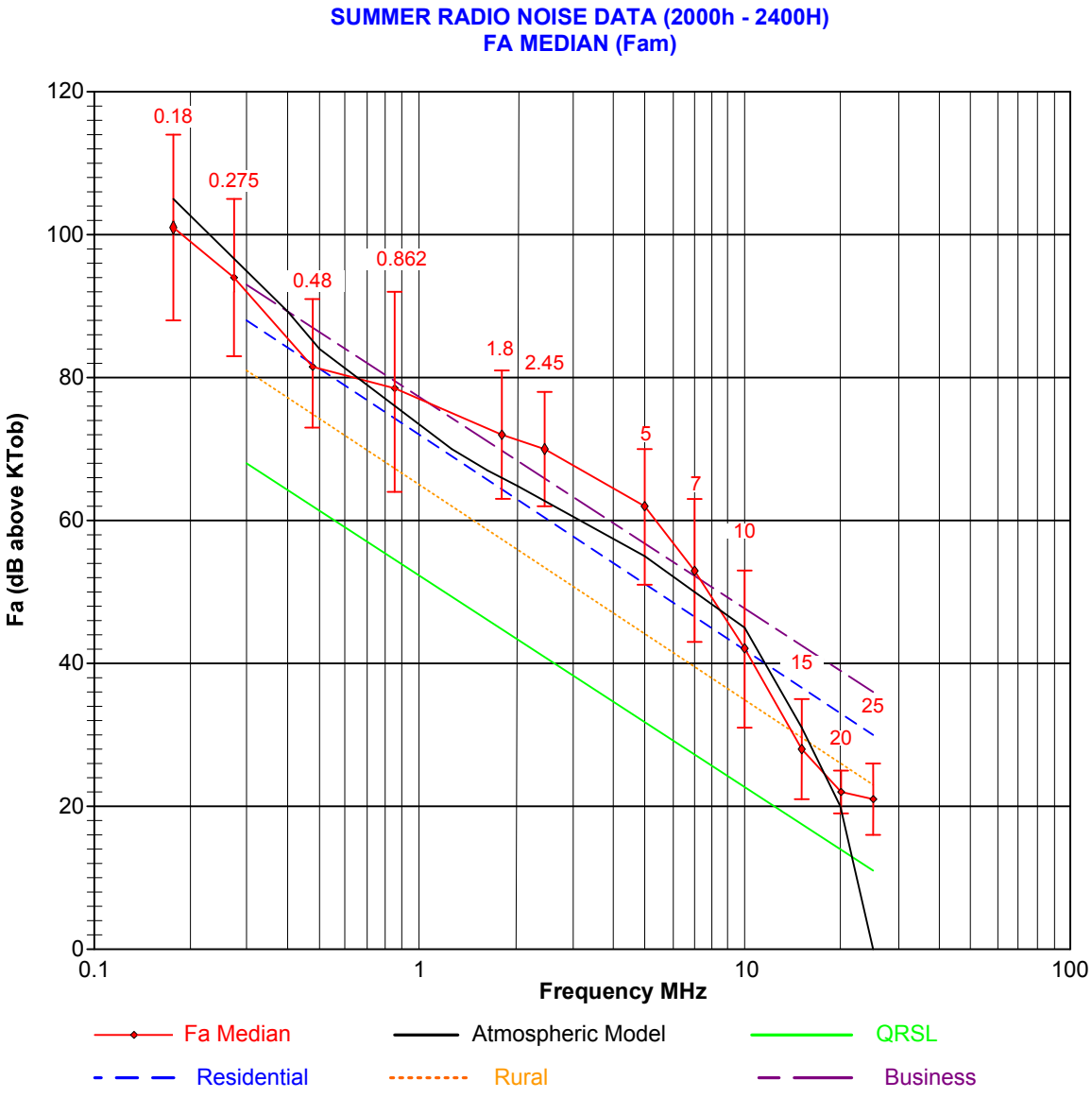

Figure 252-3 Example of RF Ambient Data, Summer Evening

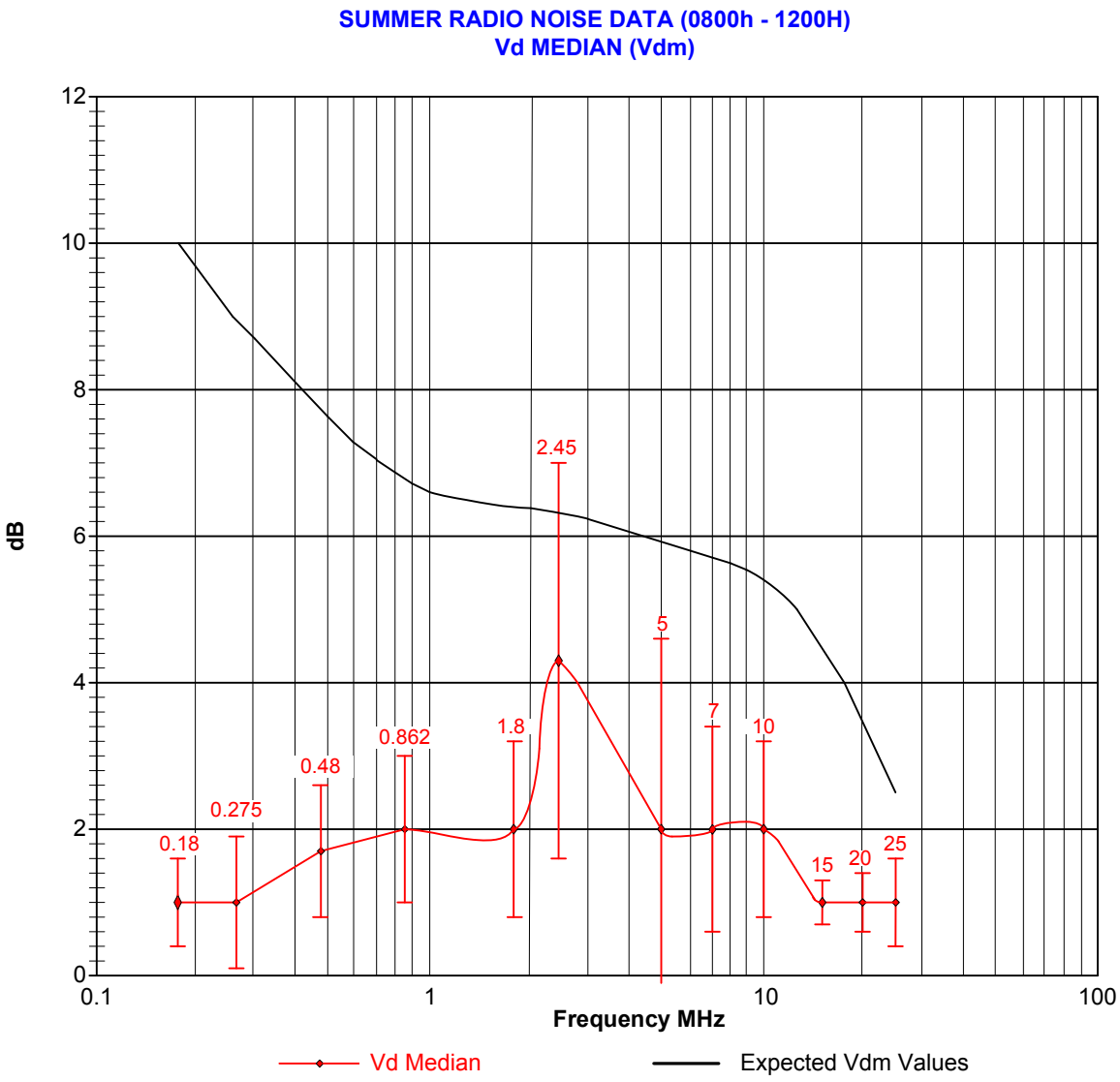

Figure 252-4 Example of Voltage Deviation Data, Summer Morning

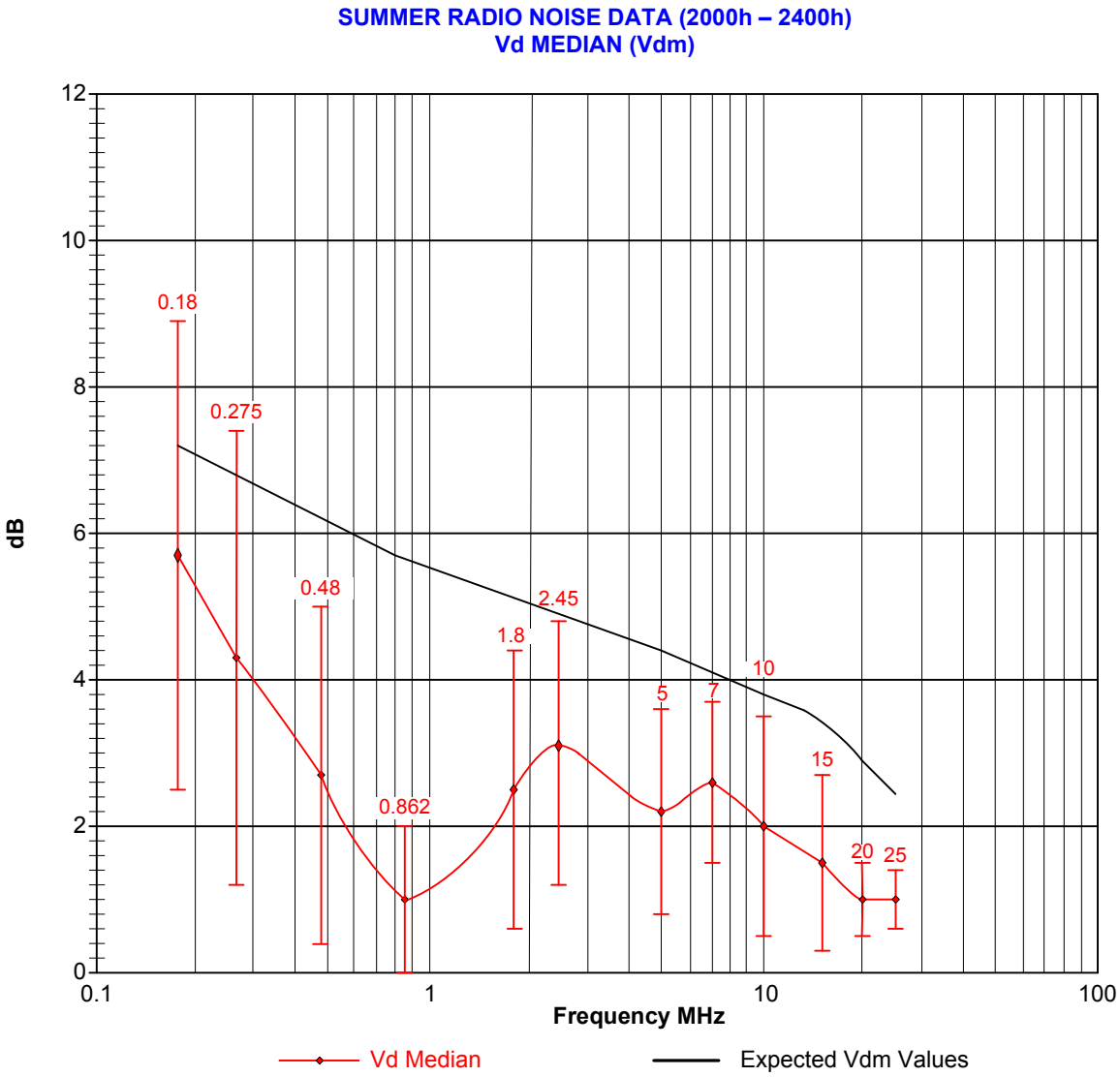

Figure 252-5 Example of Voltage Deviation Data, Summer Evening

5. ESTIMATING SITE PERFORMANCE

Armed with the estimated F_a and V_d median values, data comparison against the [A2] atmospheric noise predictions, and several rules of thumb listed below will aid in the site evaluation. Changing seasons will affect atmospheric noise contributions. However, propagation of manmade noise is (usually) over power lines and is thus relatively unaffected by diurnal (daily) or seasonal changes in the ionosphere [A2].

a. A *good site* has F_{am}'s no more than 3 to 4 dB higher than the QRSL.

b. Evening (2000 to 2400 hours) atmospheric noise predictions from ITU-R P-372-8 [A2] should be considered as indicative of the highest radio noise levels a site should experience; thus, manmade radio noise (morning) levels should not exceed these levels.

c. At a *good site*, there exists at least a 20 dB difference between the morning and evening F_{am}'s at 2.5 MHz. This applies to the spring, summer and autumn seasons. During winter, a difference of 10 dB or more should be noted.

d. At a *good site*, the daytime V_{dm}'s are no more than three.

ANNEX A

REFERENCES

A1 Lauber, W. and Pike, C.: “Radio Noise Survey Procedures for a Communication Site 0.15 - 30 MHz”.

A2 ITU-R P-372-8: Characteristics and Application of Atmospheric Radio Noise Data; International Radio Consultative Committee; Geneva, Switzerland.

A3 Skomal, E. and Smith, A.: Measuring the Radio Frequency Environment.

A4 IEEE Std 473-1985: "IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz)".

A5 Hagn, G. and Shephard, R.: Selected Radio Noise Topics; Appendix A; SRI International; Project # 5002.

LEAFLET 253

ELECTROSTATIC CHARGING, DISCHARGE AND PRECIPITATION STATIC

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LEAFLET 253

ELECTROSTATIC CHARGING, DISCHARGE AND PRECIPITATION STATIC

1. INTRODUCTION

The phenomenon of electrostatic charging and resulting discharges can result in interference to the operation of electronic equipment or damage to electronic circuitry. The energy released during discharges is potentially hazardous to personnel, fuel vapors and ordnance.

Electrical charges are transferred whenever two objects make contact and separate. A net charge can remain on the objects, especially if they are non-conductors. Multiple contacts, such as rubbing or particle impact, can greatly increase the accumulation of charge. These are all due to frictional (triboelectric) charging. A system can accumulate electrostatic charge by this mechanism through activities such as: an aircraft passing through rain, dust, snow or ice; a plastic cover removed suddenly from a weapon or component. The specific charging due to collisions with rain or snow is known as precipitation static (p-static) charging. Personnel can also accumulate charge by friction when walking across non-conductive surfaces especially when wearing polyester clothing.

As well as triboelectric charging, there are two other mechanisms that can cause aircraft to become charged:

a. Engine and rocket exhausts tend to carry net charge, so the engine or rocket will become charged up by this process.

b. Objects can become charged by induction in the presence of electric fields such as proximity to a highly charged cloud or another charged object. For example, a charged object can cause the charge on a second object to redistribute by merely approaching (not contacting) the second object. This is especially true if the second object is a conductor. If a momentary ground connection is then provided to the second object, charge is removed or added to the second object, resulting in a residual electrostatic charge on it.

Electrical charges are transferred in a sudden surge whenever two objects of differing electrostatic potentials make contact and separate. This sudden surge will generate electromagnetic fields over a broad frequency range from modest frequencies to the low gigahertz region. As well as the fast discharge current generating electromagnetic fields (for more information see IEC 60749-26 [A1]), there will be electromagnetic fields and possible corona effects due to the high voltages and associated electric field strengths that have been built up before and during a discharge.

2. ENVIRONMENTS

2.1 Personnel Borne Electrostatic Parameters

During maintenance, contact of personnel with the structure can create an electrostatic charge build-up on both personnel and structures (particularly on non-conductive surfaces). This build-up and subsequent discharge can constitute a safety hazard to personnel or may damage electronics. Potentially susceptible electronic parts are microcircuits, discrete semiconductors, thick and thin film resistors, integrated circuits, hybrid devices and piezoelectric crystals. Susceptibility depends upon the magnitude and shape of the Electrostatic Discharge (ESD) pulse.

ESD from personnel is considered to pose the greatest hazard to munitions. A means of avoiding the threat altogether is to make the munitions immune to electrical discharges that exceed the largest possible on humans. There are a number of characteristics that affect the personnel electrostatic hazard and these vary over a wide range. The degree of the hazard depends on the type of clothing, footwear, flooring and the relative humidity and temperature of the ambient air. See Ref [A2].

There has been some debate over the levels and waveform of the human body model for ESD because of the varying human body chemistry. The parameters that have been chosen to simulate the human body ESD represent the worst case munitions and non-munitions environment. Thus, similar environments are also used in AOP 43 [A3], MIL-STD-331 [A4], and MIL-STD-464 [A5]. The electrostatic environment (charge/discharge levels) to be used for assessment and testing of materiel against personnel handling procedures within the North Atlantic Treaty Organisation (NATO) is given in Table 253-1 and described in Clauses 2.1.1 and 2.1.2. AECTP 508/2 discusses ESD testing [A6].

TABLE 253-1 Worst Case Personnel Borne Electrostatic Parameters

EQUIPMENT	PARAMETERS			
	ELECTROSTATIC VOLTAGE (kV)	CAPACITANCE (pF)	RESISTANCE (Ω)	CIRCUIT INDUCTANCE (μH)
MUNITIONS	25 ± 5%	500 ± 5%	500 ± 5%	5 max.
MUNITIONS	25 ± 5%	500 ± 5%	5000 ± 5%	5 max.
NON-MUNITIONS	8 ± 5% or 15 ± 5%	150 ± 5%	330 ± 5%	5 max.

Note: The voltage will be charged to positive and negative voltage.

2.1.1. Munitions: In the case of munitions and safety critical electrical/electronic equipment, there is a need to reduce risk due to the possible consequences of a failure. The hazard may be represented by charging a 500 picofarad (pF) capacitor to 25 kilovolts (kV) and discharging it through a 500 or 5000 ohm (Ω) resistor with less than 5 micro henries (μH) of total circuit inductance. These represent the potential a human can be charged up to and his capacitance and resistance that will affect the discharge waveform. System level ESD testing through a 500 Ω resistor is considered worst case human body discharge. System

level ESD testing through a 5000 Ω resistor creates less damaging current. However, the 5000 Ω resistor hazard comes from the different shape of the pulse that could possibly cause current to travel an alternate path.

2.1.2. Non-munitions: In cases where safety is not a concern, the hazard may be represented by charging a 150 pF capacitor to 15 kV for an air discharge or 8 kV for contact discharge, then discharging it through a 330 Ω resistor with not more than 5 μH of total circuit inductance. [A5].

2.2. Helicopter Borne Electrostatic Parameters

Helicopter charging characteristics, particularly vertical lift and in-flight refuelling, vary over a wide range; however, charging a 1000 pF (a representative capacitance of the helicopter; the capacitance will be a function of helicopter size) capacitor to 300 kV and discharging it through a 1 Ω (maximum) resistor with no more than 20 μH of total circuit inductance may represent a typical value. See Table 253-2.

During in-flight refueling, pilots have reported seeing arcing between the refueling probe and the fueling basket during mating. These discharges were several inches long. Based on these observations, the 300 kV number was derived. Aircraft that have experienced discharges from in-flight refueling have had upsets to the navigation system resulting in control problems. The 1000 pF capacitance used for testing represents a reasonable value for a large size aircraft. [A5]

TABLE 253-2 Helicopter Borne Electrostatic Parameters

CONFIGURATION	PARAMETERS			
	ELECTROSTATIC VOLTAGE (kV)	CAPACITANCE (pF)	RESISTANCE (Ω)	CIRCUIT INDUCTANCE (μH)
HELICOPTER	300 ± 5%	1000 ± 5%	≤1	20 max.

Note: The voltage of 300 kV will be charged to positive and negative voltage.

2.3. Precipitation Static (P-Static)

Static electricity accumulates on aircraft in flight (p-static charging) because there is no direct electrical path to allow the charges to flow off the aircraft. Special control mechanisms become necessary to dissipate the charge. The accumulated charge develops a voltage on an aircraft with respect to the surrounding air. When the voltage becomes high enough, the air periodically breaks down in an impulse fashion at sharp contour points where the charge is the highest. The sharp impulses produce broadband radiated interference, which can degrade antenna connected receivers, particularly lower frequency receivers. Impulses can occur so rapidly that the receivers produce only a hissing sound and become useless. P-static dischargers are usually used to control this effect. These devices are designed to bleed the accumulated charge from the aircraft at levels low enough not to cause receiver interference.

The total charging current is dependent on weather conditions, the frontal surface area of the aircraft and the speed of the aircraft (V). The total charging current can be estimated by the following equation:

$$I_t = Q \times C \times S_a \times V \qquad \text{(equation 2.1)}$$

where

I_t is total charging current (µA)

Q is the charge transfer per particle impacting the frontal surface (□C/particle)

C is the density of particles (particles/m^3)

S_a is the frontal surface area (m^2)

V is aircraft velocity (m/s)

Note though that the linear relationship with velocity does not hold true at higher speeds. This is reflected by use of an effective surface area term in the simplified equation:-

$$I_t = I_c \times S_{eff} \qquad \text{(equation 2.2)}$$

where:

S_{eff} is the effective frontal area (m^2)

I_c is the current charge density (µA/m^2)

S_{eff} is a function of velocity. It tends to increase with speed. However, at supersonic velocities the charge rate decreases as the ice crystals melt on impact.

The following peak current densities have been determined for various types of clouds:

Cirrus	50 to 100 µA/m^2
Strato-cumulus	100 to 200 µA/m^2
Frontal Snow	300 µA/m^2

On rare occasions, levels as high as 400 µA/m^2 have been observed. Control of static charge accumulation is accomplished by ensuring that all structural surfaces are at least mildly conductive (mega-ohms). Radomes and fairings on antennas cannot have too high conductivity as the dielectric transmittivity would be impaired. Conductive coatings should be applied to all external electrically non-conductive sections of the system structure. Any component of the structure can accumulate an electrostatic charge. Adequate means must be provided to dissipate the charge at low levels to prevent any significant voltage from developing.

2.4. Spacecraft Charging

Spacecraft charging is the process by which orbiting spacecraft accumulate electric charge from the surrounding natural space plasma. In effect, charged plasma particles hit the spacecraft and cause charge accumulation on exposed surfaces. Above approximately 90 kilometres (km), a portion of the molecules comprising the Earth's atmosphere are ionized by solar radiation, and positively charged ions and free electrons are produced. This collection of electrically charged particles, known as the natural space plasma, exists in all spacecraft orbits around the Earth. The properties of natural space plasma are strongly dependent on altitude and latitude. Low inclination, low-Earth orbit plasma is relatively dense

and has low energy, whereas geosynchronous-Earth orbit spacecraft typically encounter high energy, low density plasma associated with geomagnetic substorms.

Two main classes of spacecraft charging are defined. These are classified as surface charging (external) and dielectric charging (internal or bulk).

a. Surface charging is produced by interactions between satellite surfaces and space plasma, geomagnetic fields and solar radiation. Due to different geometries and surface materiel properties, these interactions cause unequal negative and positive currents to spacecraft surfaces, producing differential charging that can lead to surface arcing or ESD between satellite surfaces of different potentials.

b. Deep dielectric or bulk charging, also referred to as internal charging, is the build-up of charge on and within dielectric materiels or on insulated floating conductors inside the spacecraft. Energetic electrons, tens of KeV to several MeV, can penetrate the surface of the spacecraft and deposit charges inside. When the rate of electron deposition becomes greater than the rate of charge leakage, the electric field begins to increase until the breakdown threshold is reached and arc discharge occurs.

Both types of charging can lead to ESDs that impact space missions. (Note that the rise time of space ESD is faster than that on Earth.) Usually, deep dielectric discharges are more damaging because they occur within dielectric materiels or in well-insulated conductors inside a spacecraft. Some of the effects that have been attributed to spacecraft charging include the following:

a. Operational anomalies (i.e. telemetry glitches, logic upsets, component failures, spurious commands) caused by the coupling of ESD transients into spacecraft electronics, and

b. Physical spacecraft surface damage (i.e. mirrored thermal control surfaces) as a result of arc discharging.

ANNEX A

REFERENCES

A1 IEC 60749-26: Semiconductor devices — Mechanical and Climatic Test Methods — Part 26: Electrostatic Discharge (ESD) Sensitivity Testing — Human Body Model (HBM)

A2 Air and Space Interoperability Council (ASIC) - Air Standards - Advisory Publication 20/36 - Hazards of Electrostatic Discharge to Aircraft Stores

A3 AOP-43 - Electro-Explosive Devices: Test Methods for Characterization: Guidelines for STANAG 4560.

A4 MIL-STD-331 - Fuze and Fuze Components, Environmental and Performance Tests

A5 MIL-STD-464 - Electromagnetic Environmental Effects Requirements for Systems

A6 AECTP 508 Leaflet 2: Electrical /Electromagnetic Environmental Effects Test and Verification – Electrostatic Discharge Munitions Test Procedures

Other Relevant National/International Standards

IEC-61000-4-2: Electromagnetic Compatibility (EMC) – Part 4: Testing and Measurement Techniques – Section 2: Electrostatic discharge immunity test. Basic EMC publication

LEAFLET 254

ATMOSPHERIC ELECTRICITY AND LIGHTNING

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LEAFLET 254

ATMOSPHERIC ELECTRICITY AND LIGHTNING

1. GENERAL

1.1. Background

This leaflet describes the phenomenon of atmospheric electrostatic charging and the resulting discharge as lightning. It gives the values of lightning parameters for naturally occurring cloud to ground and Inter/Intra cloud discharges and the more normal levels of electrostatic charge that exist without lightning events. The derivation of standardised definitions of lightning parameters for induced effects and for testing is also explained.

1.2. Application

The environments described here are applicable to land, sea and air systems. Parameters are defined for both the natural, derived and test environments from lightning attachments. Equipment procurers and designers will need to decide whether particular systems and equipments need to be hardened against the direct or indirect effects of lightning striking the platform/sub-system or nearby lightning strikes. These decisions will be based on the criticality of the system/equipment. Systems may be required to survive and continue functioning or merely to remain safe but are permitted to be non-functional following a strike.

2. ATMOSPHERIC ELECTROSTATICS

Atmospheric electricity is considered as an environment as it gives rise to induced electro-magnetic effects and the possibility of direct damage due to lightning strikes. Factors involved in the electrical properties of the atmosphere include electric fields, currents and conductivity, and positive and negative ions of a wide range of size. Precipitation charging constitutes an induced environment and is dealt with in AECTP Leaflet 253 [A1].

In fair weather, the horizontal layering of the atmosphere produces a predominately vertical electric field gradient varying from less than 10 V/m at 10 km to about 100 V/m at the Earth's surface, as shown in **Figure 254-1**.

The fair weather field can have significant effect in special cases such as a missile controlled by wire from a helicopter, where circulating currents may be produced by the missile moving in a region where the electrostatic potential is different from that in the vicinity of the helicopter.

In the troposphere, the region up to about 8 km above the poles and about 16 km above the equator, factors which have an important influence on the electrical properties include air mass motions, pressure systems, temperature gradients and water vapour distribution, which together control the distribution of charged and uncharged aerosols and radioactive particles of terrestrial origin.

These influences are greatest in the Exchange Layer, which varies in height up to about 3 km above the Earth's surface. Within this layer are small scale convection currents which carry the surface air, together with ions and nuclei which it contains, to the top of the region, ensuring thorough mixing. The upper boundary is often visible as the level of fine weather cumulus clouds or haze, and is markedly indicated by electrical measurements.

Temperature inversion, that is temperature increasing with height, has a profound effect on the exchange mechanisms.

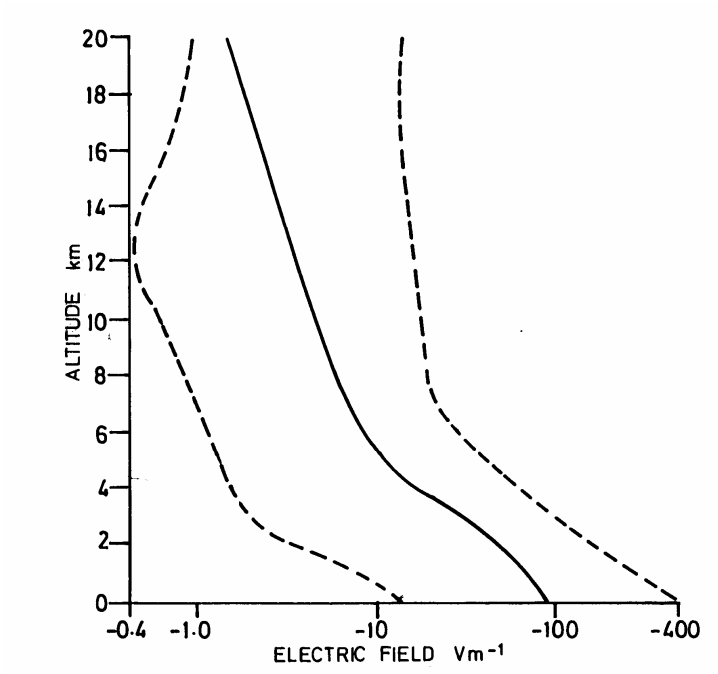


Figure 254-1 Average Values and Limits of Variation of Observed Fair Weather Vertical Electrical Field as a Function of Altitude

According to the laws of electrostatics, over 90% of the Earth's negative charge should leak off in about 10 minutes due to the conductivity of the air, but the net charge remains practically constant. Thunderstorms and shower clouds appear to act as generators that drive current upward in the reverse direction to the current flow in fair weather areas.

The potential gradient in undisturbed fair weather areas has the same diurnal variation over all the Earth, when referred to universal time. This is in phase with the diurnal variation of world-wide thunderstorm activity. The potential difference between the Earth and the ionosphere, that is the region beyond the stratosphere, is about 275 kV.

When clouds are present, their surfaces become electrically charged, the distribution of charge depending largely on temperature gradient. When the accumulation of charge is sufficient, discharge occurs and thunderstorm conditions prevail, the effects of which completely mask the fair weather field distribution. In the vicinity of thunderclouds, electrostatic field strengths of up to 6 kV/m are observed at ground level. Even greater field strengths exist at greater altitudes within the cloud.

Thunderclouds are of the cumulo-nimbus type and the distributions of electric charges within the clouds are very complex. Theoretical models of the charge structure within thunderclouds are described in many papers and text books but when the distribution and charge levels are sufficiently severe, then lightning strikes occur. The distribution of lightning strikes around the world varies greatly as illustrated by **Figures 254-2** and **254-3**. At any given time, the total number of storms in progress over the Earth's surface is about 2000; the daily occurrence is about 50,000. A description of the processes and mechanisms leading to

a lightning strike or stroke can be found in many widely available publications/text books (e.g. [A2]). Only the important issues related to a description of the environment as it affects defence materiel are described in this leaflet.

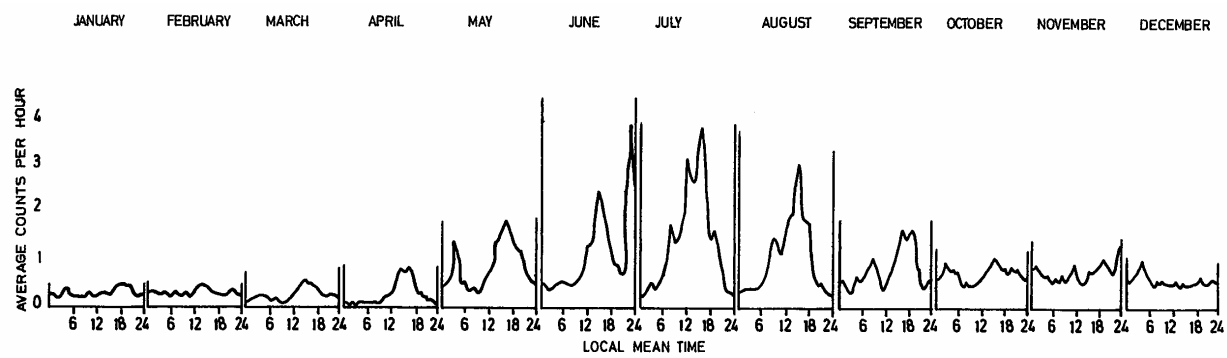


Figure 254-2
Average Count of Lightning Flashes per Hour in Southern UK over a 7 year Period

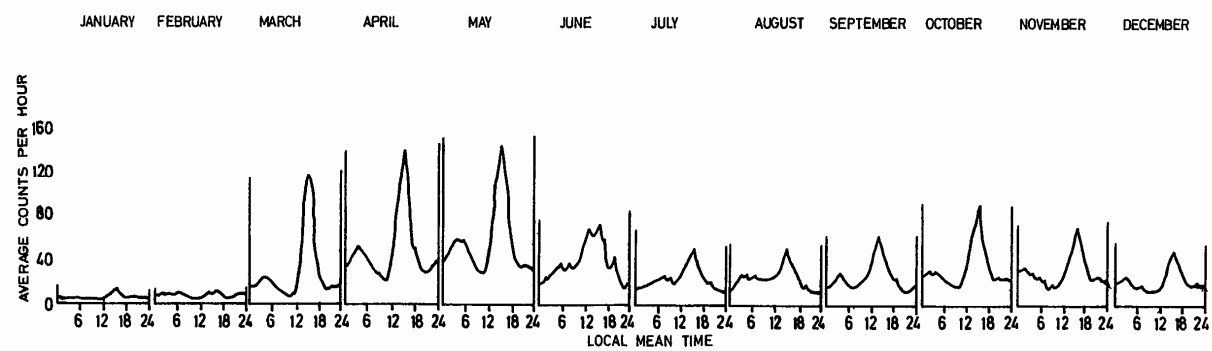


Figure 254-3
Average Count of Lightning Flashes per Hour in Singapore over a 4 year Period

3. NATURAL LIGHTNING ENVIRONMENT

3.1. Cloud to Ground Parameters

Tables 254-1 and **254-2** give data derived from various sources, stating parameter values measured at or near ground level for certain probabilities of occurrence of cloud to ground discharges.

The numerical values of the parameters vary widely from flash to flash and are therefore best stated in statistical terms. For any given parameter, this may take the form of a curve which indicates the percentage of flashes in which that parameter exceeds any chosen level. In **Tables 254-1** and **254-2**, levels are given for negative and positive strikes at various probabilities of occurrence. The values are those published in Eurocae document ED-84 ([A3]) except for the addition of a 2% column for negative strikes which is an estimation taken

from published data and considered to be a best fit to the graphs. The parameters at the levels and probabilities stated do not all occur in one flash; for example, there is no such thing as a 2- or 5-percentile flash. Considerable work has been done however to establish a threat that can be used as a design criterion. This “derived threat”, given in **Clause 5**, takes into account the relative frequency of occurrence of positive and negative strokes to ground. The tables illustrate the diverse nature of natural lightning and provide an appreciation of the probability and severity of the derived threat.

3.2. Inter and Intra Cloud Lightning

Inter and intra cloud discharges are similar to the ground flash but have different parameter values. For intra cloud discharges, recoil streamers occur with peak currents up to 60 kA and a typical rate of rise of less than 0.4 μs. These levels have been recorded but are more typically 20-30 kA with a, duration in the order of 200 ms. A typical intra cloud lightning flash is shown in **Figure 254-4**. The pulses occurring during the initial attachment might also occur in a negative flash to ground.

3.3. Electric Field

Lightning discharges arise from the breakdown of air/clouds in the presence of a high electric field caused by the atmospheric conditions. The static field level at which breakdown occurs will vary according to the presence of water and/or ice and may be anything from 500 kV/m to 2 or 3 MV/m. It is the rate of change of this field when the lightning channel forms that is the principal concern.

This rate of change of the E field, dE/dt, must sometimes be simulated when making Indirect Effects tests. The value usually considered, as far as it affects aircraft in flight and ground installations, is between 10^{12} and 10^{13} V/m/s.

Although the electromagnetic radiation from a Distant or “Far Field” flash is unlikely to be hazardous to materiel a typical far field environment is given in **Figure 254-5**. The amplitude of this environment is inversely proportional to the distance from the flash. No derived threats are given and, if required, derived environments suitable for testing shall be according to National procedures.

Table 254-1 Parameters for Negative Lightning Flash Measured at Ground Level

PARAMETERS	UNIT	LIGHTNING PARAMETERS			
		95%	50 % typical	5%	2%
Number of strokes		1-2	3 - 4	12	>12
Time intervals between strokes	ms	8	35	140	320
Peak current (1st stroke)	kA	14	30	80	140
Peak rate of rise (1st stroke)	A/s	5.5×10^{9}	1.2×10^{10}	3.2×10^{10}	4×10^{10}
Time to peak (all strokes) (see Note 1)	µs	18	5.5	1.8	1.2
Pulse width at half peak current (all strokes in flash)	µs	30	75	200	170
Peak current (subsequent strokes)	kA	4.6	12	30	100
Peak rate of rise (subsequent strokes)	A/s	1.2×10^{10}	4×10^{10}	1.2×10^{11}	Note 2
Amplitude of continuing current	A	33	140	520	520
Duration of continuing current	s	0.058	0.16	0.4	0.4
Charge in continuing current	C	7	26	110	110
Action integral	A^2s	6×10^{3}	5.5×10^{4}	5.5×10^{5}	0.8×10^{6}
Charge per subsequent stroke	C	0.2	1.4	11	20
Total charge in flash (ex continuing current)	C	1.3	7.5	40	90
Flash duration	s	0.03 – 0.04	0.2	1	1

Note 1: Value for this parameter is for percentage of strikes where value is lower than figure given.

Note 2: Value of 1.4×10^{11} used since this has been measured in intra cloud discharges.

Table 254-2 Parameters for Positive Lightning Flash at Ground Level

PARAMETERS	UNIT	LIGHTNING PARAMETERS		
		50% typical		**5%**
Peak current	kA	35		250
Peak rate of rise	A/s	2.4×10^{9}		3.2×10^{10}
Estimated time to peak	µs	22		200
Pulse width at half peak current	ms	230		2000
Total charge in flash	C	80		350
Action integral	A^2s	6.5×10^{5}		15×10^{6}
Flash duration	S	0.085		0.5

Note:% figures are the percentage of all strikes in which the given parameter values are equalled or exceeded.

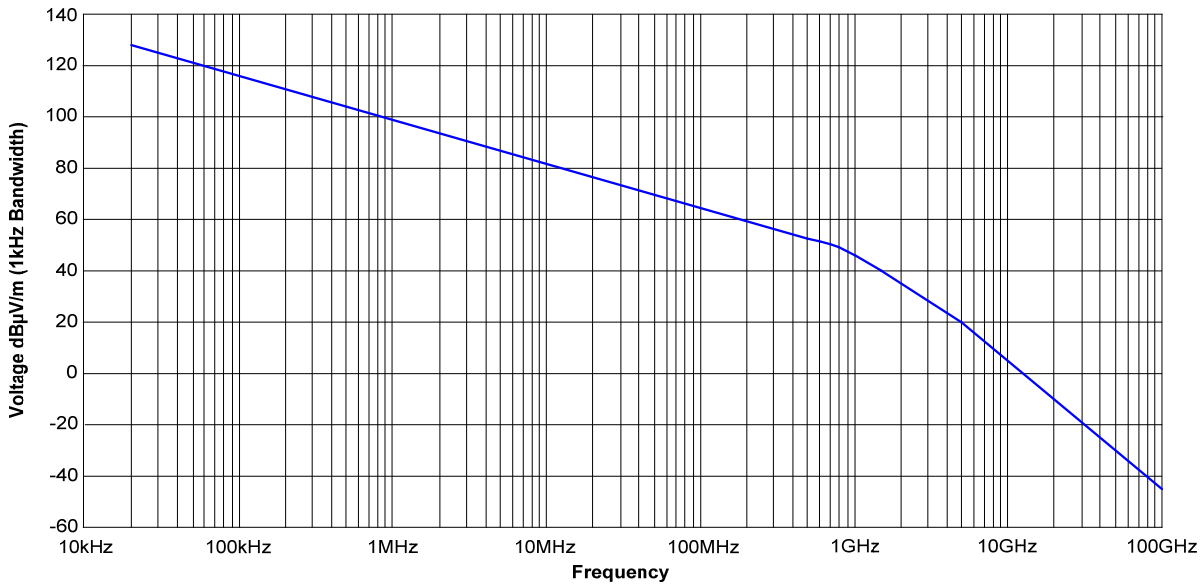


Figure 254-4 Typical Intra Cloud Lightning Flash to an Aircraft

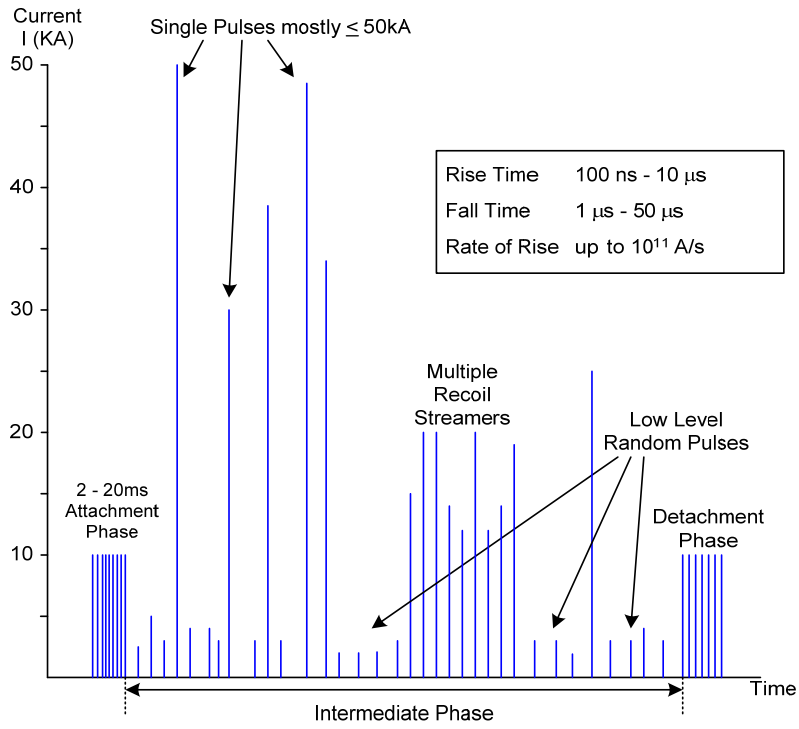


Figure 254-5
Envelope of Peak Field Intensity v Frequency at Ground Level at 3 km from Discharge

4. DERIVED EXTERNAL LIGHTNING ENVIRONMENT

This Clause specifies the lightning threat environment to be considered for land, sea and air based materiel. The levels are derived from the Natural Lightning Parameters defined above and the air platform derived environment is used as a basis for the other systems. These derived environments are not used directly for tests and assessments but they are discussed here to provide the basis and justification for the internal environments which are addressed later. This process is necessary due to the statistical nature of lightning parameters and as it is not possible to reproduce a true lightning strike in a test. It is therefore necessary to ensure the important lightning parameters are defined.

Inter and Intra Cloud Parameters only have relevance to the air platform threat and especially to the so called ”Multiple Burst Environment”. The parameters of the single pulses and bursts of pulses, due to the intra (and sometimes inter) cloud discharges which can interact with an aircraft, will have typical values as shown in **Figures 254-6** and **254-7**.

4.1. The Lightning Discharge Parameters and Environments for all Materiel

The idealised waveforms derived here represent the environment to be applied for the purposes of analysis and test. They do not replicate actual lightning events but contain the parameters most likely to affect materiel.

The most relevant parameters in a lightning discharge are given in **Table 254-3**. These are used since they are responsible for the most likely damage/upset mechanisms.

Since negative and positive strikes have very different characteristics and probabilities of occurrence in different parts of the world, there is a problem in combining their parameters to give a realistic worst case. A 9:1 ratio of negative to positive flashes for all environments has been used here. There is also debate on the percentage level that should be used to define a worst case environment and how the positive and negative statistics should be combined. Eurocae [A4] and the Society of Automotive Engineers (SAE) [A5} in their aircraft lightning standards use the levels shown in column 3 of **Table 254-3**. However, due to the higher ratio of positive to negative strikes in some parts of the world (particularly Northern Europe and the UK) and to account for the overall 2% level of all such strikes, the higher values shown in column 4 have been adopted by some Military authorities (eg: [A6]). (Note: Hereafter in this document the civil aircraft levels are termed the "standard" levels whilst the higher levels are referred to as the "alternative" levels). Whilst either set of levels can be used for the ground and sea environments, the standard levels are based on a higher di/dt than has been measured at ground level. The alternative levels allow for this but are based on the higher action integral specified for that waveform.

Table 254-3 Combined Positive and Negative Discharge Parameters for Cloud to Ground Strikes

PARAMETERS		UNITS	Standard Levels	Alternative Levels
Maximum rate of change of current	di/dt max	A/s	1.4×10^{11}	1.4×10^{11} *
Peak current	i pk	kA	200	200
Action integral	$\int i^2 dt$	A^2s	2.25×10^{6} **	3.75×10^{6}
Charge content	$\int i\, dt$	C	200	300
Rate of Change of E field	dE/dt	V/m/s	10^{12}	10^{13}
*1.4×10^{11} is used for the air platform environment as this has been measured in inter/intra cloud discharges to aircraft. For ground and sea use 1×10^{11}.				
**Includes contribution from components A and D. For the ground environment, a definition of a nearby strike is also required.				

4.2. Air Platform Environment

Discharges that affect aerospace vehicles can be either cloud to ground, inter cloud, or intra cloud events. They can also be triggered by the presence of the vehicle, when they are more likely to be intra cloud discharges. It has always been assumed that inter and intra cloud discharges are probably less severe (apart from the value of di/dt) than cloud to ground discharges. A combination of cloud to ground and cloud to cloud parameters has therefore been used to define the lightning threat levels for aircraft.

Materiel shall be designed to survive the parameters relevant to lightning attachment zones as given in **Table 254-4**. It should be clearly understood that the parameters listed are the worst case parameters that are expected to apply. They are approximations to a real lightning waveform and cannot be described (for a particular attachment zone) by a double exponential waveform.

Table 254-4 Air Platform Design Parameters for Lightning Attachment Zones

Attachment Zone	**i pk kA**	**di/dt max A/s x 10^{11}**		**Action Integral A^2s x 10^6**		**Charge Transfer**		**Remarks**
		Standard	Alternative	Standard	Alternative	Standard	Alternative	
1A	200	1.4	2	2	3.5	20C in 50 ms	30 C in 50 ms	For Standard and Alternative - 0.4 x 10^{11} applies when flux aperture coupling is not relevant.
1B	200	1.4	2	2.25	3.75	200 C	300 C	For Alternative - 1.4 x 10^{11} applies when flux aperture coupling is not relevant.
1C	150	1.4	2		0.8	10C	30C in 50 ms	For Alternative - 1.4 x 10^{11} applies when flux aperture coupling is not relevant.
2A	100	1.4	2	0.25	0.25	10C	30 C in 50 ms	For Alternative - 1.4 x 10^{11} applies when the flux aperture coupling is not relevant.
2B	100	1.4	2	0.25	0.25	200 C	300 C	For Alternative - 1.4 x 10^{11} applies when the flux aperture coupling is not relevant.
3	200	1.4	2	2.25	3.75	200 C	300 C	It may be necessary to reduce the parameter levels according to local geometry except for the attachment / exit point.
*Flux aperture coupling is defined in **Clause 6**.								

Note: A rate of change of E field (dE/dt) of 10^{13} V/m/s shall be applied to the air platform environment.

For a definition of zones see **Clause 6**.

In addition, all air platform materiel shall be designed to survive the Multiple Burst

environment, based on a repetitive component H waveform as defined in **Table 254-5** and **Figure 254-6**.

All air materiel shall also be designed to survive the multi-stroke environment as defined in **Figure 254-7**.

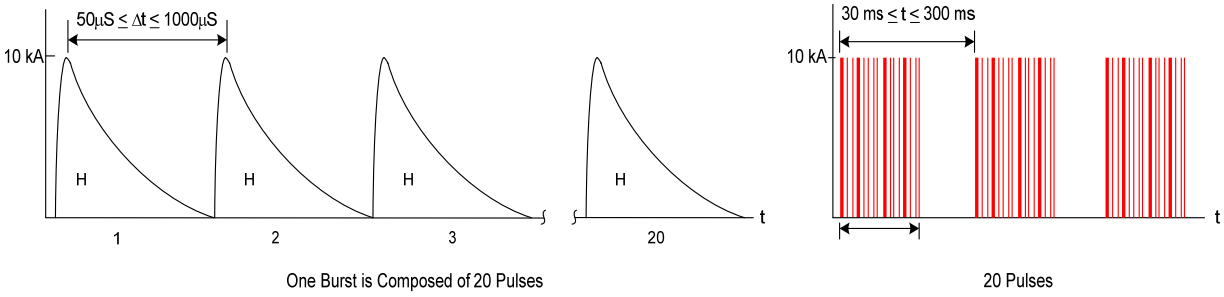


Figure 254-6 Multiple Burst Waveforms

Table 254-5 Component H Waveform

PARAMETERS	CHARACTERISTIC
Peak current (of each pulse)	10 kA
Peak rate of rise at t_o	2×10^{11} A/s
Mathematical representation (of each pulse)	$i = I_o (e^{-\alpha t} - e^{-\beta t})$ where I_o = 10572 (A) α = 187191s^{-1}, β = 19105,100 s^{-1}
Repetitive component H	3 bursts of 20 pulses
Minimum time between pulses within a burst	50 µs
Maximum time between pulses within a burst	1000 µs
The 3 bursts shall be distributed with a minimum period between start of bursts	30 ms
The 3 bursts shall be distributed with a maximum period between start of bursts	300 ms

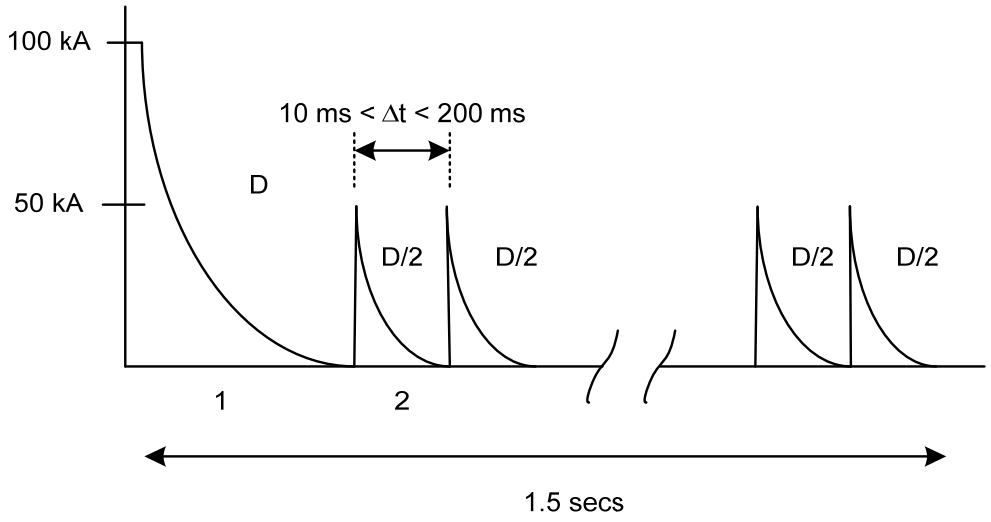


Figure 254-7 Multiple Stroke Waveform

4.3. Ground and Sea Environments

The zoning concepts that apply to air vehicles cannot apply to ground and sea applications in the same way. Such materiel will however have attachment points (Zone 1) and conduction paths (Zone 3) between those attachment points or Earth and in that respect, the principles of zoning can be applied. All attachment points to ground and sea materiel are therefore designated Zone 1B. The parameters applicable to Zone 1B and Zone 3 for ground and sea vehicles and installations are therefore as given for those zones in **Table 254-4**.

In certain geographical areas (e.g. North Sea), where the ratio of negative to positive flashes is known to be less than 9:1, it may be necessary to recalculate the values using the method given in [A7].

Ground and sea equipments shall also survive the multiple stroke environment defined in **Figure 254-7**.

4.4. Particular Ground Environment for Nearby Strikes

The minimum distance that a nearby flash can be from materiel before it forms a direct attachment to the materiel will depend on the topography of the location and the materiel. A worst case can be obtained if the location is assumed to be flat. The minimum distance (R) before direct attachment occurs can then be predicted by strike location methods such as the "Rolling Sphere". The environment due to a strike to ground R metres away is then given by the expressions in **Table 254-6**, where R is > 10 m, di/dt = 10^{11} A/s and I_{pk} = 200 kA.

Table 254-6 Nearby Strike Environment, R Metres from a Strike to Flat Ground

PARAMETERS		VALUE	UNIT
Maximum (horizontal) magnetic field	H	$3.2 \times 10^4/R$	A/m
Rate of change of magnetic field	dH/dt	$1.6 \times 10^{10}/R$	A/m/s
Maximum (vertical) electric field	E	$3 \times 10^6/(1+R^2/50^2)^{½}$	V/m
Rate of change of electric field	dE/dt	$6 \times 10^{12}/(1+R^2/50^2)^{½}$	V/m/s

5. DERIVED PARAMETERS AND EXTERNAL LIGHTNING TEST WAVEFORMS

Owing to the complex nature of the various types of lightning discharges and the limitations of laboratory facilities, it is necessary to define an outline waveform for test purposes that contains the most important features of both negative and positive discharges to ground. The environments given above are therefore represented diagrammatically in the internationally agreed waveform given in **Figures 254-8a** (civil aircraft waveform) and **254-8b** (alternative waveform). Waveforms derived for the internal environments are discussed in **Annexes B** and **C**.

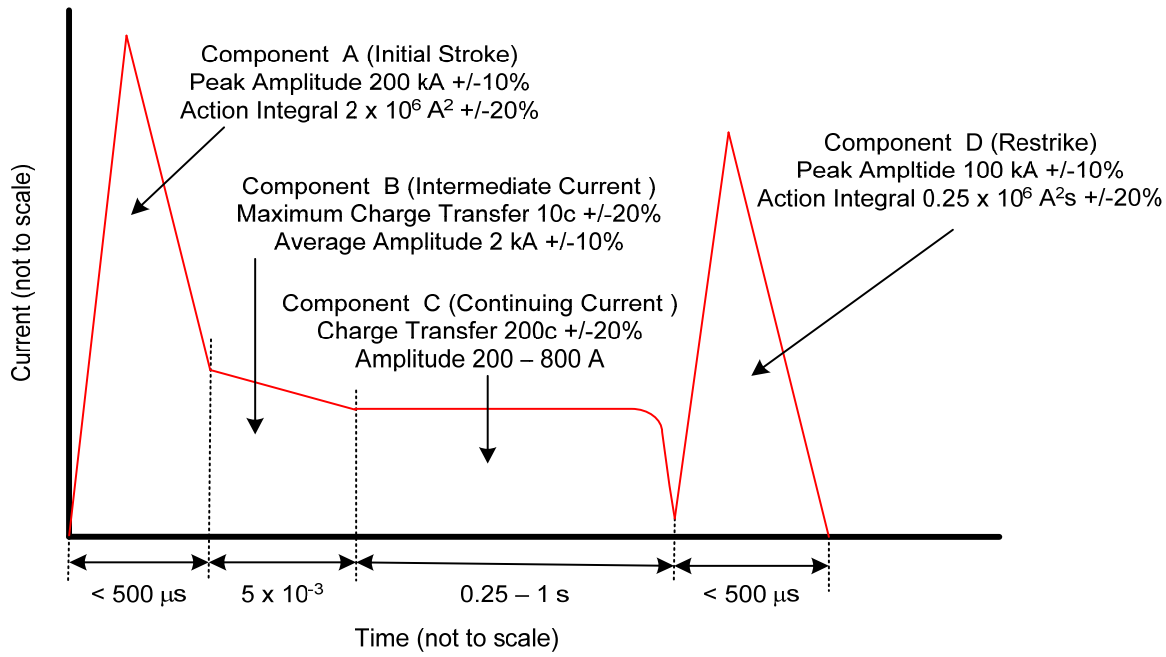


Figure 254-8a
Schematic Representation of Test Current Components – Standard Waveforms

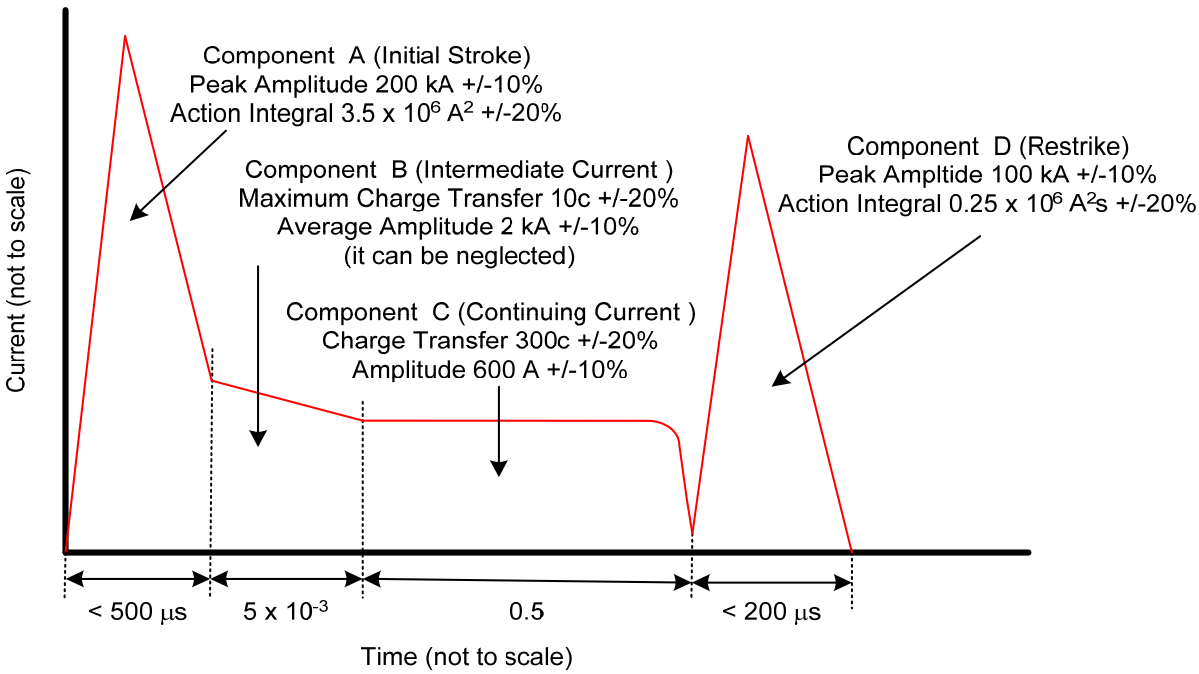


Figure 254-8b
Schematic Representation of Test Current Components – Alternative Waveforms

5.1. Waveforms for Test and Analysis Derived from the External Threat

5.1.1. Test Waveforms for Direct Effects Testing

Test waveform components designated as Component A, Component B, Component C and Component D are as given in **Figure 254-8a** or **Figure 254-8b** together with additional parameters/comments shown in **Table 254-7**. It should be noted that when Component C is combined with Component D, the continuing current must fall to near zero before the restrike component commences.

The current test components applicable to the part of the materiel under investigation according to the Lightning Zone ascribed to it are shown in **Table 254-8**.

Table 254-7 Test Current Component Parameters

Component	Parameter	Value	Tolerance	Remarks
Component A High Current	Time to peak current	<10 µs		For Zone 1C use 150 kA and 0.8×10^6 A^2s.
		A longer time to peak may be used for non rise-time dependent damage.		
		A quasi double exponential waveform should be used for Component A when testing CFC or similar materiels, although a sinusoidal waveform may be used for metallic components.		
Component B Intermediate Current				Component B has little importance and often can be neglected.
Component C Continuing Current	Amplitude	600 A	+10%	
Component D Restrike (Direct Effect)	Time to peak current	<3.5 µs* * A longer time to peak current is not required for direct effects tests. This rate of rise is, however, significant for indirect effects tests and also for combined direct and indirect tests.		In natural lightning, Component D may have a di/dt of 10^{11} A/s (1.4×10^{11} for the air platform)

Table 254-8 Current Components Applicable to Test Zones

USE	ATTACHMENT ZONE	CURRENT COMPONENT			
		A	B	C	D
Air	1A	X	X	X (**Note 1**)	
Air, Ground & Sea	1B (**Note 3**)	X	X	X	X
Air	1C	X (**Note 2**)		X (**Note 1**)	
Air	2A		X	X (**Note 1**)	X
Air	2B		X	X	X
Air, Ground & Sea	3 (**Note 3**)	X	X	X	X

Note 1: Experiments have been conducted to establish some basic rules on the action of swept strokes. So far no method has given confidence in the ability to predict the probable hang-on time under any given set of circumstances. It is generally agreed that a restrike will generate a new attachment point, and that the mean interval between strikes is of the order of 50 ms. This figure has therefore been accepted as an International test level for dwell time duration.

Note 2: Reduced Component A with I_{pk} = 150 kA, Act Int = 0.8 x 10^6 A^2s.

Note 3: Also applies to Ground & Sea use.

5.2. Waveforms for Lightning Induced Transient Assessment and Pulse Tests

When an assessment is made of the lightning induced transients in a whole system, for example, a whole aircraft by means of analysis or test or a combination of both, it is necessary to define the threat level in the form of a current pulse having appropriate values of those parameters which are relevant to indirect effects in extensive systems. These are peak current, maximum rate of current rise and action integral. These parameters are important for the production of persistent circulating currents between low resistivity and high resistivity parts of the materiel, particularly when composite materials are extensively employed. In some cases, such circulating currents persist well after the original disturbance has died away. The waveforms for this application are dependent on whether the “standard” or “alternative” levels defined above are to be used. Since the description of the waveforms for both direct and indirect effects testing is complex, the waveforms for each level are described separately in **Annexes B** and **C**.

5.3. Waveform for the Nearby Flash Environment

Waveforms for the nearby flash environment should be according to National procedures.

5.4. Waveforms for Equipment Testing

Internal environment waveforms are given in **Annexes B** and **C** for the standard and alternative levels respectively.

ANNEX A

REFERENCES

A1 AECTP 253 Electrostatic Charging, Discharging and Precipitation Static

A2 Lightning Vol 1, Edited by RH Golde. Academic Press

A3 EUROCAE ED 84 Aircraft Lightning Environments and Related Test Waveforms

A4 EUROCAE ED105 Aircraft Lightning Test Methods

A5 SAE ARP 5416 Aircraft Lightning Test Methods

A6 UK Def Stan 59-113 Lightning Strike Protection Requirements for Service Aircraft

A7 The selection of parameter values of negative and positive lightning for combination in the composite test waveform. RH Evans & GAM Odam. International Aerospace & Ground Conference on Lightning and Static Electricity, Williamsburg, 1995

A8 AECTP 508/4 Electrical/Electromagnetic Environmental Test and Verification Leaflet 4 Lightning Munition Assessment and Test Procedures

ANNEX B

WAVEFORMS FOR USE WITH STANDARD ENVIRONMENT LEVELS

B.1. External and Internal Direct and Indirect Test Waveforms

A full description of the direct and indirect lightning strike waveforms based on the “standard” parameters defined in this document is contained in [A4] and [A5]. Since these are complex descriptions and may be subject to change they are not repeated here. Those Nations wishing to use these standards (civil aircraft certification levels) should therefore refer to the latest edition of either publication.

ANNEX C

WAVEFORMS FOR USE WITH ALTERNATIVE ENVIRONMENT LEVELS

Since the alternative lightning waveform description has higher values of action integral and charge content than the civil aircraft levels the derived direct and indirect test waveforms have different values. These are fully described below.

C.1. External Direct Test Waveforms

The external direct threat testing waveforms to meet the parameters of the alternative lightning description of **Figure 254-8b** (of main section of this leaflet) are shown in **Table 254-C1**.

Table 254-C1 Threat Level and Waveforms

Environment	Parameter	Theoretical Full Value	Practical Values Quarter Amplitude	Mathematical Full Value Representation
Ground & Sea Use **Figure 254-8b** and **Table 254-7** A_{2s}	Peak current	200 kA	50 kA	$I_o (e^{-\alpha t} - e^{-\beta t})$
	Maximum rate of rise	10^{11} A/s	0.25×10^{11} A/s	$I_o = 214980$ A
	Action integral	3.5×10^6 A^2s	0.22×10^6 A^2s	$\alpha=6341\ s^{-1}$ $\beta=471500\ s^{-1}$
	Shape of waveform A_{2s}	9.3/125 µs with duration 484 µs to 5% of peak		
Air Side Use **Figure 254-8b** and **Table 254-7** A_{2a}	Peak current	200 kA	50 kA	$I_o (e^{-\alpha t} - e^{-\beta t})$
	Maximum rate of rise	1.4×10^{11} A/s	0.35×10^{11} A/s	$I_o = 210859$ A
	Action integral	3.5×10^6 A^2s	0.22×10^6 A^2s	$\alpha=6179\ s^{-1}$ $\beta=671141\ s^{-1}$
	Shape of waveform A_{2a}	7.1/121 µs with duration 494 µs to 5% of peak		

Notes:

A tolerance of ±10% shall be used for all rise time and peak current figures and ±20% for action integral.

If it is necessary to test for both ground and air environments together the air side waveform shall be used (since this waveform has a faster rate of rise).

Testing with a D/2 pulse will satisfy the rise time aspect of the A_2 tests.

For air side equipments, since waveform H has a higher frequency content, it is also necessary to conduct tests with this waveform (as defined in **Clause 4 Table 254-5**).

The quarter amplitude values with same shape rise and fall times shall be used in tests where practical considerations dictate that the full values are not possible.

C.2. Waveform for Dielectric Puncture (Leader Phase Effects) Testing

The waveform for dielectric puncture tests is a 200/2000 µs waveform superimposed on a dc level as described in the following paragraphs.

The open circuit voltage (voltage across the test electrode gap, when breakdown does not occur in that gap) of the high voltage generator shall rise to peak from t_0 in 200 µs (+10%) and decay to half of peak amplitude in 2000 µs (+10%), superimposed, after at least 500 ms, on a dc level equal to the HV generator peak voltage +20%.

The use of the dc level on which the pulse waveform is superimposed is to simulate the ambient E field that is likely to be encountered before the system is struck. However, it is recognised that present test equipments are generally not able to include the standing dc level and the effect on damage mechanisms is not clear. The dc level may therefore be omitted.

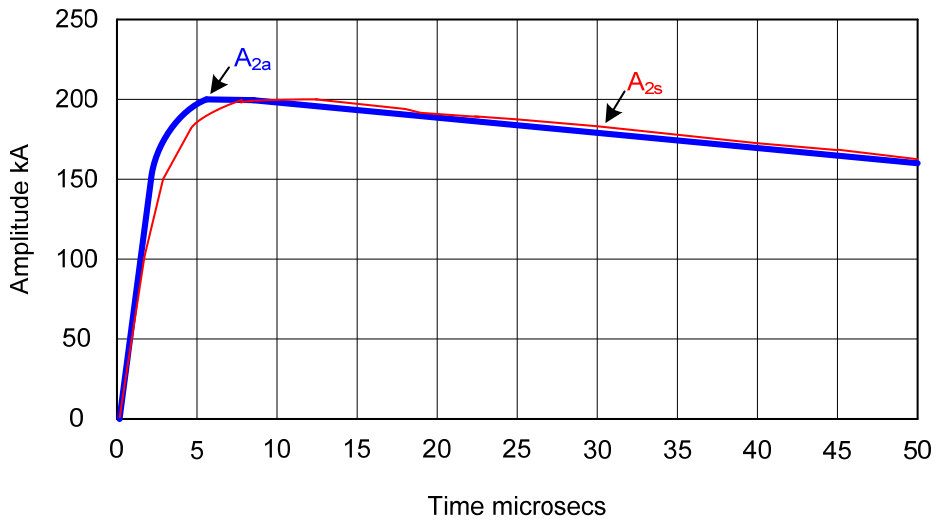


Figure 254-C1
Waveforms A_{2s} and A_{2a} – Pulse Tests and Analysis (plotted to 50 µs only)

C.3. Internal Environment Tests and Waveforms for Equipment Susceptibility Tests

The external environment described in the previous section gives rise to internal environments, which induce transients on the internal equipment wiring. These internal environments are “vehicle dependent” making it difficult to define generic environments for all classes of materiel, although an environment has been developed for aircraft which is described below. Coupling mechanisms between the external and internal environments are common to all materiel and give rise to characteristic transient waveforms as is noted below for the aircraft environment.

C.3.1. Origin and Shape of Induced Waveforms

Materiel struck by lightning, or affected by nearby lightning, will have transient voltages and currents induced in its electrical wiring, which may cause equipment malfunctioning or possibly permanent damage if the equipment is not adequately hardened. Transient testing of equipment needs to include a variety of voltage and current waveforms selected to cover the principal coupling modes. The purpose of such tests is to determine whether the equipment can experience a given level of transient testing (of representative waveform) without damage or malfunction. The values discussed in **Table 254-C2** are for cable bundle tests on equipments/sub-systems.

Table 254-C2 Four Standard Waveforms for Equipment Testing

WAVEFORM	CHARACTERISTIC	MATHEMATICAL REPRESENTATION	
Intermediate Pulse (IP) **Figure 254-C2**	6.4/70 µs	$i = 1.09405\ I_p\ (e^{-\alpha t} - e^{-\beta t})$ To be used for a well protected metallic structure $\alpha = 11354\ s^{-1}$, $\beta = 647265\ s^{-1}$	
Short Pulse (SP) **Figure 254-C3**	100 ns rise 6.4 µs to zero crossover	It is the derivative of i for IP $= 1.09405\ I_p\ (-\alpha e^{-\alpha t} + \beta e^{-\beta t})$ this gives an instantaneous rise at time zero, so for practical purposes a rise time of 100 ns is assumed instead; see **Figure 254-C3**.	
Long Pulse (LP) **Figure 254-C4**	50/500 and 40/120 µs	$i = K\ I_p\ (e^{-\alpha t} - e^{-\beta t})$	
		The 50/500 waveform is for poorly protected composite structure $\alpha = 1585\ s^{-1}$, $\beta = 80022\ s^{-1}$, K = 1.104	The 40/120 waveform is for an aluminium structure $\alpha = 12400\ s^{-1}$, $\beta = 45000\ s^{-1}$, K = 2.25
Damped Sinusoidal (DS) **Figure 254-C5**	See **Figure 254-C5** for details.	$I_o\ e^{-\pi ft/Q} \sin(2\pi ft)$ I_o is the initial (t=0) amplitude of envelope of oscillations. Q is the Q factor = π/r where r is the logarithmic decrement between 0.462 and 0.0959. Note: the ratio of successive peaks of the same sign is $e^{-\pi/Q}$	

Equipment Installation Categories and test levels for the IP, SP and LP waveforms are given in **Clause C.3.2**.

C.3.2. Application of Waveforms

When assessment of an individual equipment is deemed to be necessary, as is always the case on the Air Side, the relevant test plans will define the waveforms and appropriate test levels to be used. For the Air Side, waveforms DS and SP and either IP or LP will be used. (The relevant LP waveform is to be used where equipments or cables are sited under a composite structure or close to an aluminium structure with significant inductance/resistance. It should also be used if unshielded harnesses are run through or in metallic trays or conduits or have overbraids installed. The IP waveform is to be used where cables are run close to a well protected metallic structure that may be carrying lightning currents.) Test levels appropriate to these waveforms for the Air Side use are given in **Clauses C.3.4** through to **C.3.8**. Waveforms and levels for other materiel shall be agreed with the National Authority.

C.3.3. Ground Based and Seaborne Equipment

Test levels for ground based and seaborne equipment are not addressed by this leaflet and must be decided in consultation with the National Authority. Where it can be shown that the waveforms relevant to aircraft apply, there may be read across from the aircraft levels.

C.3.4. Airside Equipment

Equipment test levels for IP, SP and LP waveforms are obtained from pulse tests made on materiel to calculate the Computed Transient Level (CTL) as explained in AECTP 508 Leaflet 4 [A8]. If those tests have not been made and modelling has not been done, levels for airborne equipment are given below.

C.3.5. Equipment Installation Categories for IP, SP and LP Waveforms

When CTLs are not known, maximum amplitudes for the test waveforms are chosen according to equipment installation categories A - D (electromagnetic environments of the equipment) and E (criticality of equipment).

a. **CAT A** Equipment and cabling installed in a protected electromagnetic environment such as a completely enclosed compartment in metallic materiel.

b. **CAT B** Equipment and cabling installed in a partially exposed electromagnetic environment such as a dielectric cover in a largely metallic structure.

c. **CAT C** Equipment and cabling bonded to the same part of the materiel structure and installed in an exposed electromagnetic environment where large portions of the structure are constructed from poorly conducting or CFC materiels.

d. **CAT D** Equipment and cabling bonded to different parts of the materiel structure and installed in an exposed electromagnetic environment where large portions of the structure are constructed from poorly conducting materiels or CFC.

e. **CAT E** Equipments where lightning ground transients are judged not to have any impact or where upset or damage would not compromise materiel safety or mission success.

Where equipment and cables can be defined in more than one of the above categories, the test levels associated with the more severe environment shall apply.

Test levels appropriate to the test categories with a tolerance of ±10% are defined in **Table 254-C3**.

Table 254-C3 Test Levels for Equipment Installation Categories

CATEGORY	WAVEFORM (VOLTAGE/CURRENT V/A ±10%)			
	SP (Short) V/I	IP (Intermediate) as current V/I	IP (Intermediate) as voltage V/I	LP (Long) V/I
A	125/250	125/250	N/A	N/A
B	300/600	300/600	2000/1000	2000/1000
C	750/1500	750/1500	2000/3000	2000/3000
D	1600/3200	1600/3200	2000/10000	2000/10000
E	N/A	N/A	N/A	N/A

C.3.6. Levels and Frequencies for DS Waveform for Air Side Use

C.3.6.1. Selection of Transient Test Frequencies

During injection tests, transients shall be injected at frequencies according to the following:

a. The most susceptible frequencies in the range 2 to 50 MHz found from any previous CW bulk current injection EMC testing.

b. The frequencies at which maxima and minima cable impedance occur.

c. Over the frequency range 2 to 50 MHz inclusive not less than 50 frequencies such that any resonance in the equipment under test (EUT) internal circuitry are excited, so subjecting any active or passive devices to maximum voltage or current threat. These frequencies shall be spaced evenly with a logarithmic increment. The approximate frequency of each injection is obtained by the use of the following equation:

$$\text{Test Frequency (MHz)} = 10(0.3 + 0.028k) \qquad \text{(equation C.1)}$$

where k = 0, 1, 2, 3 to 50 for 50 frequencies.

C.3.6.2. Test Limits

When CTLs are not known, the limits shown in **Figure 254-C6** and explicitly mentioned below shall be used.

a. a current limit of 30 A from 2 to 30 MHz decreasing to 15A at 50 MHz.

b. a voltage limit of 3 kV between 2 and 30 MHz decreasing to 1.5 kV at 50 MHz.

c. a kVA limit of 30 kVA between 2 and 30 MHz decreasing to 7.5 kVA at 50 MHz.

Note: The current, voltage and KVA limits do not apply together. The maximum test level is set when any one of these limits is reached.

C.3.7. Multiple Burst and Multiple Stroke Test Waveform and Levels

If it is necessary to undertake multiple burst or multiple stroke testing at equipment level the pulse sets as defined in **Figures 254-6** and **254-7** (of main section of leaflet) shall be applied as a current injection into the cable looms. The value of the current injection shall be calculated/assessed based on relative position of the cable to the structure, which may carry the current.

C.3.8. Test Waveforms for Indirect Induced Voltage and Insulation Breakdown Tests

It is often desirable to evaluate the voltages likely to be induced by lightning in individual sub-systems or components, such as aerials and external sensors when these are thought to be particularly vulnerable to insulation breakdown or voltage flashover. Such tests may be done separately or combined with the pulse tests described above. In tests for aperture flux or fast flux coupling, the important waveform parameter is di/dt; therefore such tests should be conducted using Waveform D_2, which is defined in **Table 254-C4**.

Table 254-C4 Threat Level and Waveform D_2

ENVIRONMENT	WAVEFORM	MATHEMATICAL REPRESENTATION
Ground Use D_{2s}	**Figure 254-C7**	$I_o (e^{-\alpha t} - e^{-\beta t})$ $I_o = 113235$ A $\alpha=27702\ s^{-1}$ $\beta=906820\ s^{-1}$
Air Side Use D_{2a}	**Figure 254-C7**	$I_o (e^{-\alpha t} - e^{-\beta t})$ $I_o = 109405$ A $\alpha=22708\ s^{-1}$ $\beta=1294530\ s^{-1}$

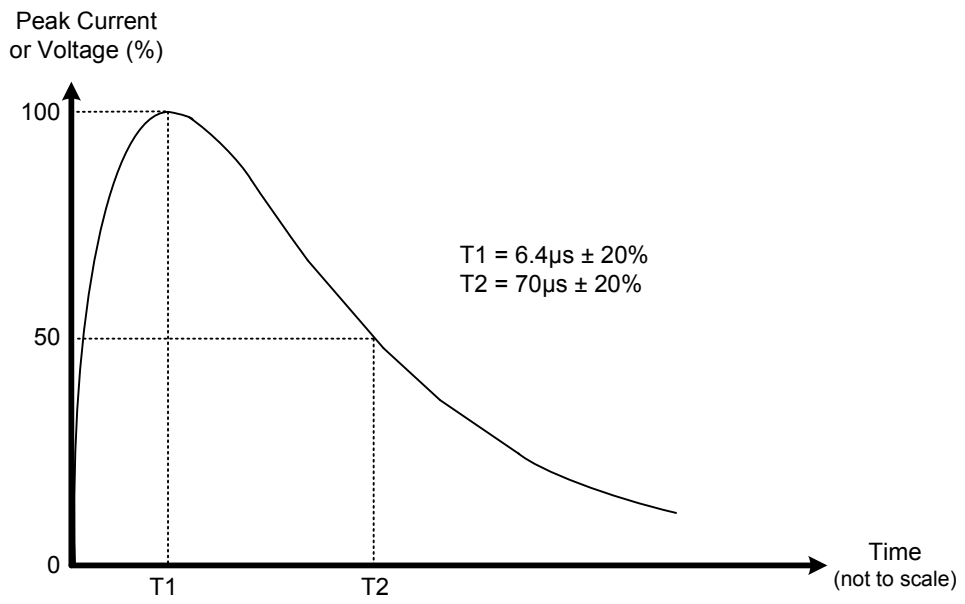


Figure 254-C2 Intermediate Pulse (IP) Waveform Simulating Resistive Coupling

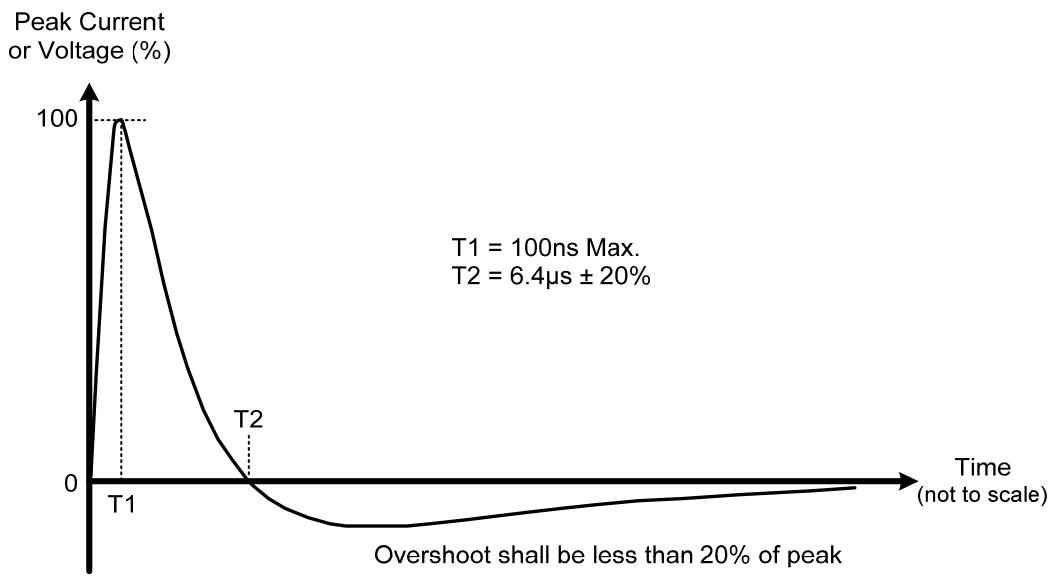


Figure 254-C3 Short Pulse (SP) Waveform Simulating Aperture Flux Coupling

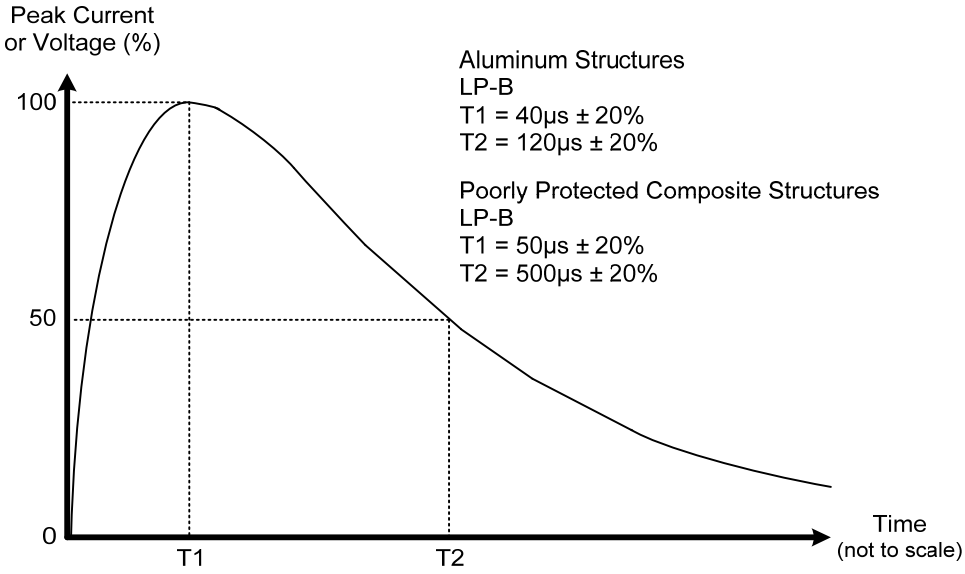


Figure 254-C4
Long pulse (LP) Waveform Simulating Diffusion/Redistribution Coupling

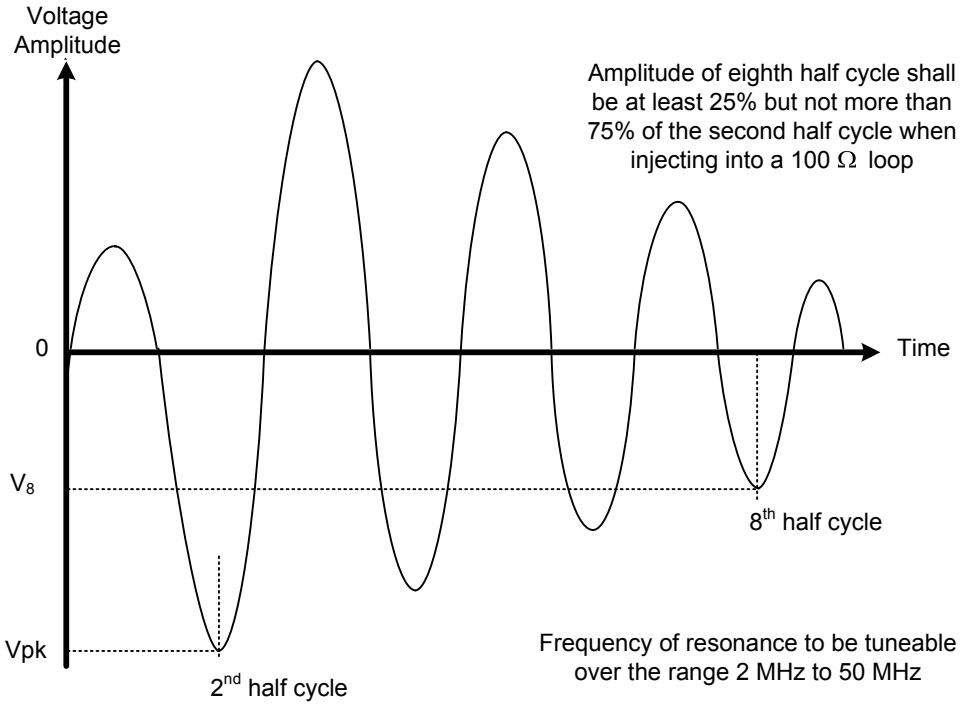
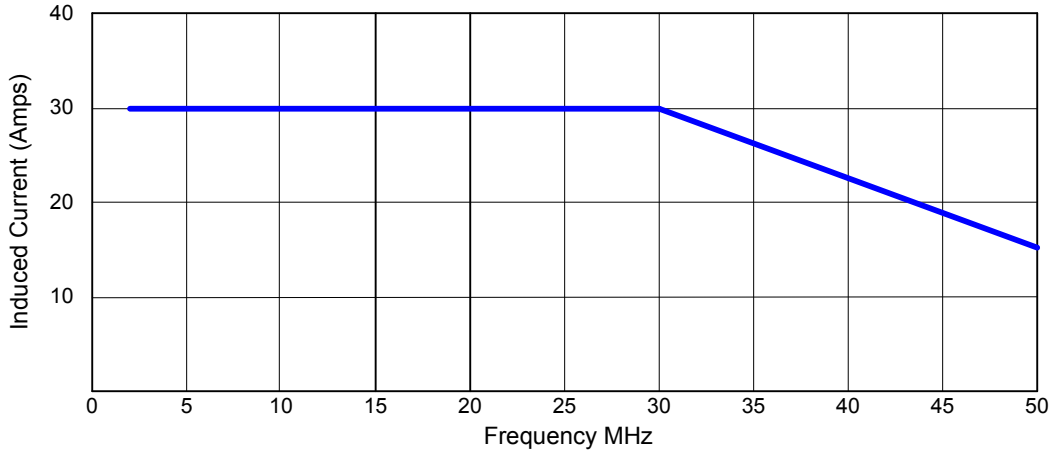


Figure 254-C5 Damped Sinewave (DS) Test Waveform



Voltage Limit: 3kV - 2 to 30 MHz reducing to 1.5 kV for 50 MHz

kVA Limit: 30kVA - 2 to 30 MHz reducing to 7.5 kVA for 50 MHz

Figure 254-C6 Current, Voltage and kVA Test Limits

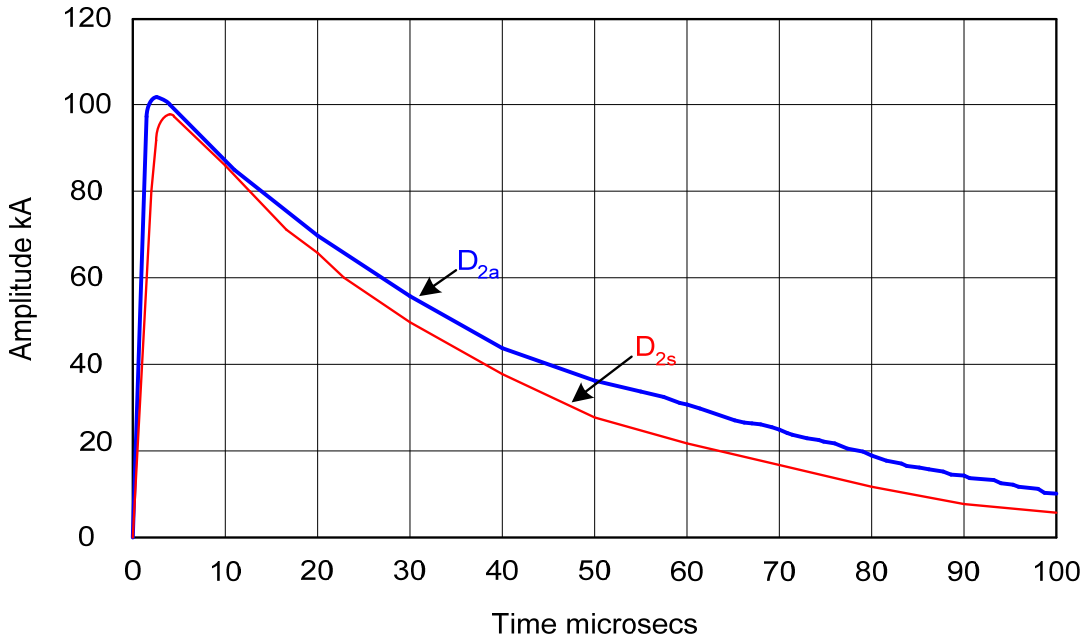


Figure 254-C7 Waveforms D_{2s} and D_{2a} – Indirect Effects Tests

LEAFLET 255

DC AND LOW FREQUENCY MAGNETIC FIELDS

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LEAFLET 255

DC AND LOW FREQUENCY MAGNETIC FIELDS

1. AIM

The aim of this leaflet is to define the direct current (DC) magnetic and low frequency (LF) fields encountered in the shipboard operational electromagnetic environment. These environments can be used to define design and test requirements for shipboard systems and equipment. LF fields to be used as design and test requirements for aircraft and land based systems and equipment are also defined.

2. APPLICABILITY

This leaflet applies primarily to the development of environmental design and test requirements for shipboard equipment and systems. This is due to the presence of ship degaussing systems and use of ship deperming and flashing, which means that there are particular issues for DC magnetic fields on ships and submarines. The DC fields on land vehicles and aircraft are not defined since they are not believed to be significant and there is no history of problems. LF magnetic fields are defined for all platforms.

Note: Unless specifically stated, the terms ship and shipboard in this leaflet encompass both surface ships and submarines.

3. DC AND LF MAGNETIC FIELDS

3.1. Introduction

This leaflet describes the phenomenon of shipboard DC magnetic fields and all LF fields resulting from electrical current flowing in power leads or other electrical current carrying leads. This phenomenon can cause interference to electronic equipment that uses magnetic fields in its operation such as Cathode Ray Tubes (CRT) and gyros.

3.2. Shipboard DC Magnetic Fields

3.2.1. Shipboard DC magnetic fields are caused primarily by ship degaussing systems and are the summation of magnetic lines of force existing in or about a ship. These fields are not uniform and vary in both location and time. If a field is of sufficient magnitude in any given instance, it may have a degrading influence on the performance of equipment installed in or on the ship. Detailed knowledge of the exact installation location, as well as a forecast of future changes, would be needed if a determination of equipment suitability was made on other than general environmental expectations. Equipment should be designed and built so that it will not be adversely affected even in the “worst case” situation, which can normally be expected. DC fields are also created when the ship undergoes magnetic treatment, including both deperming and flashing.

3.2.2. Degaussing cables:

The magnetic field is not uniform throughout the ship, but in normal use depends on the proximity to degaussing cables. These are installed in approximately 75 % of compartments located between the keel and main deck. During ship deperming, these fields can be expected over the entire ship.

3.2.3. Structural Discontinuities:

Bulkheads or other steel structural members (including equipment) may act as a return path for magnetic flux lines and result in a localized concentration of the magnetic field. Discontinuities (gaps, openings, etc.) in the return path may significantly increase nearby magnetic field values. For equipment installed near such a discontinuity, the possible degrading effect of the enhanced magnetic field environment shall be taken into account.

3.2.4. Location Considerations:

The magnetic field is not uniform throughout a ship. Consideration shall be given to varying field strengths when determining shipboard equipment location. Field strengths in excess of the figures defined below may be expected in areas closer than 0.3 metres from degaussing cables. Conversely, if it is known that equipment will be sited at least 3 metres from degaussing cables, levels lower than those specified in **Clause 3.4** are expected. Regardless of location, however, equipment must meet Detailed Test Methods Requirements of AECTP 500 –501 Test Method NRS04.

3.2.5. Structural Shielding

Steel decks and bulkheads between degaussing cables or other sources of magnetic fields and equipment may provide some degree of shielding and reduce the magnetic field that would otherwise exist. However, taking advantage of this shielding effect requires precise knowledge of degaussing cable location or other field sources in relation to equipment location, and requires rigid control over location changes. This shielding effect shall not exempt any equipment from requirements of this section. However, in cases where it has been established that it is not technically feasible for equipment to meet the requirements of this section, a deviation utilizing structural shielding may be justified.

3.3. LF Magnetic Fields

3.3.1. Magnetic Field Frequency:

Magnetic fields in any platform are generally caused by stray fields from high current carrying conductors. Fields are therefore only significant at the power system fundamental frequency, its harmonics and at low frequencies up to approximately 100 kHz.

3.3.2. Local Magnetic Fields:

Local magnetic fields can be generated by various individual sources such as:

a. Electrical power cables
b. Generators
c. Motors

d. Welding circuits

e. Electrical power switchboards and control equipment

f. Transformers

Location of equipment very close to those sources shall be judiciously considered.

3.3.3. All-Electric Ship Power Leads:

All-electric ships typically do not employ steam or other mechanical power methods for ship movement or aircraft launch. These ships exhibit very high levels of electrical current on major electrical power leads and potentially have high levels of harmonics/switching frequencies. These may produce a substantial magnetic field near power cables and associated equipments, but these will depend on generation and load system design and type of cables used. The fields given in **Figure 255-1** are expected to cover most situations, but where power cables are routed near sensitive equipment, higher levels may be relevant.

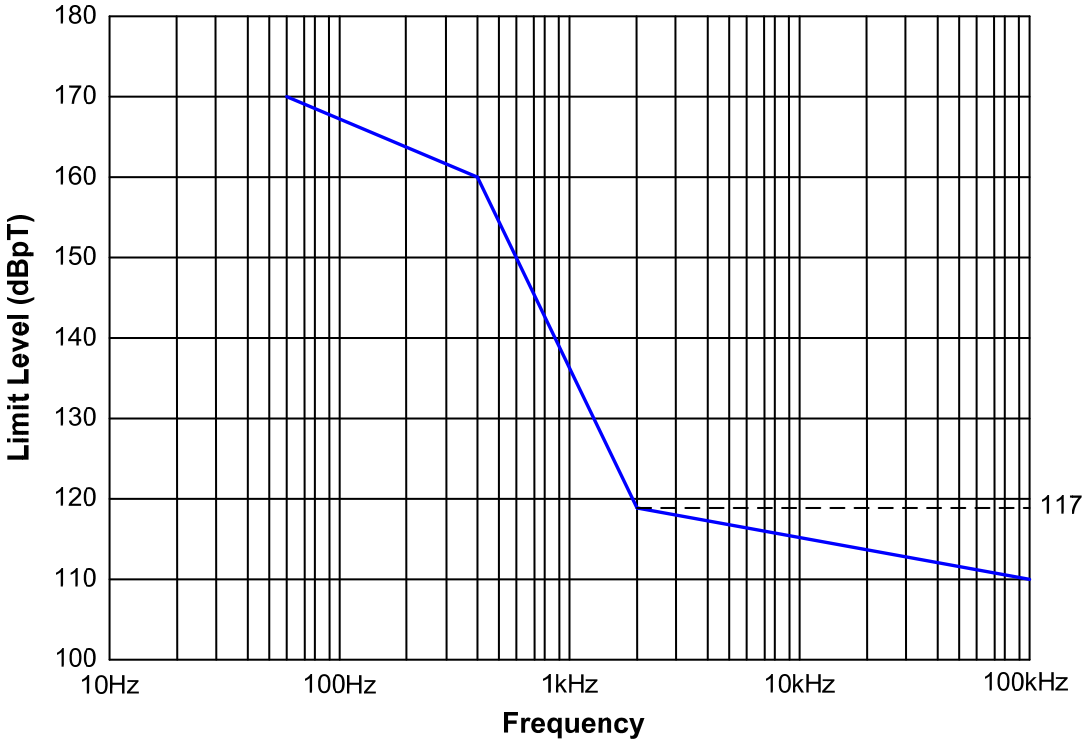

Figure 255-1 LF Fields Below Deck and all Air Applications

3.4. Environments

3.4.1. Shipboard DC Magnetic Fields:

Expected shipboard DC magnetic fields for equipment operating below decks (other than weather decks) within North Atlantic Treaty Organisation (NATO) are given in **Table 255-1**.

The maximum expected shipboard steady state field strength is 1600 A/m. Its maximum rate of change is 1600 A/m per second. No particular orientation of the magnetic field direction may be assumed. Separate values for fields from degaussing, deperming and flashing are provided so that this may be allowed for on ships where deperming does not occur or when

equipment is removed prior to deperming.

Table 255-1 Typical Shipboard DC Magnetic Fields

EQUIPMENT	PARAMETERS	
	Steady State Magnetic Field (A/m)	Changing Magnetic Field (A/m)
DEGAUSSING	1600	1600/second
DEPERMING	1600	1600/second
FLASHING	1600	1600/second

3.4.2. LF Magnetic Fields:

Figure 255-1 shows expected LF fields for shipboard equipment operating below decks and for equipment on all air platforms within NATO.

Figure 255-2 shows expected LF fields for NATO land based systems and equipment.

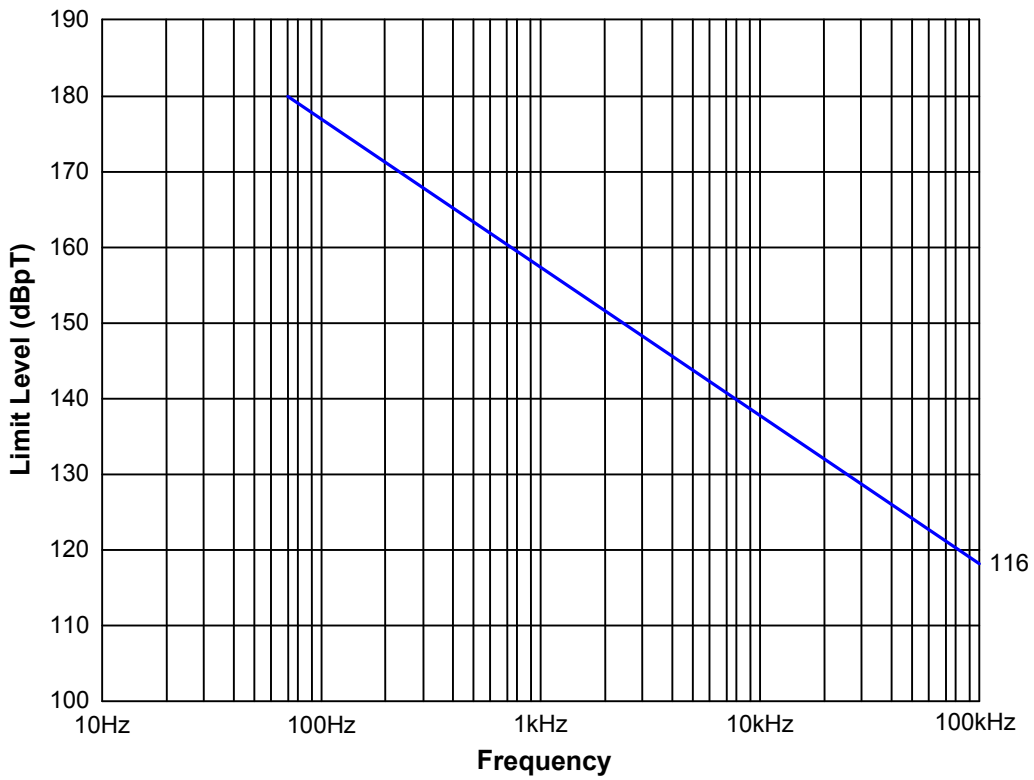

Figure 255-2 LF Fields for Land Systems and Equipment

LEAFLET 256

NUCLEAR ELECTROMAGNETIC PULSE

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LEAFLET 256

NUCLEAR ELECTROMAGNETIC PULSE

1. INTRODUCTION

Nuclear electromagnetic pulse (NEMP, also called EMP) is a term commonly used to identify electromagnetic signals resulting from a nuclear detonation. The purpose of this leaflet is to describe in simple terms the origin of an NEMP/EMP pulse, its basic characteristics and methods by which it couples onto platforms and systems. The description given here is unclassified, however reference to classified definitions are given. For a further description of the radiated EMP environment in an unclassified form see IEC 61000-2-9 [A1]. An unclassified description of the conducted EMP environment is provided in IEC 61000-2-10 [A2].

2. APPLICATION

While EMP has no known short term or long term effects on biological systems, EMP is capable of causing temporary upset and even catastrophic failure to modern electronics and electrical systems over considerable geographic areas of the Earth. Fixed facilities, mobile ground based equipment, aircraft, satellites and missiles and naval equipment could be affected and therefore must be prepared to perform their critical missions in these severe electromagnetic environments (EMEs).

Because of the complex nature of its origin, burst altitude and location and the effect the equipment-to-detonation distance has on signal strength and waveshape, it is convenient to separate EMP into high-altitude EMP (HEMP), source-region EMP (SREMP) and system-generated EMP (SGEMP).

Classified definitions for the HEMP and SREMP are defined in STANAG 4145) [A3]. Both criteria are electromagnetic fields resulting from detonation products (x-rays, gamma rays and neutrons) interacting with, in one case, the *Earth's upper atmosphere* (HEMP) and, in the other case, the *Earth and its adjacent atmosphere* (SREMP).

SGEMP, on the other hand, does not occur until equipment is introduced. It is the coupled signal resulting from detonation products interacting directly with the *equipment*. Because SGEMP signals vary so strongly with equipment topology, *no SGEMP voltage or current criteria are specified by the North Atlantic Treaty Organization (NATO)*. It is the responsibility of the nation to define those values for their facilities, aircraft, ships, satellites or vehicles using available information. Typically, when coupling occurs with equipment near the surface of the Earth, SGEMP levels unique to that equipment are calculated from [A3] initial nuclear radiation (INR) levels. When coupling occurs with orbiting satellites, satellite SGEMP levels are calculated from AEP-50 [A4] INR levels.

3. ENVIRONMENTS

A general, unclassified description of HEMP, SREMP and SGEMP, including their origins and characteristics, is now provided.

3.1. EMP Origin

First, consider what occurs at the detonation point. Kinetic energy is released in the form of both chemical (i.e.: high explosives) and nuclear energy. Most of that energy is in the release of subatomic particles (neutrons) and electromagnetic energy (x-rays and gamma rays). These nuclear "particles" move radially away from the source and eventually interact with surrounding materiel, such as the Earth's atmosphere, the Earth itself and even equipment. When these interactions take place in the atmosphere, they create free electrons and positively charged ions in what is called a source region. When these interactions take place in the Earth or equipment, they create currents and voltages. EMP is thus a generic term that refers to the resultant electromagnetic fields caused by the deceleration of the electrons (called Compton electrons) by the Earth's geomagnetic field (to cause HEMP) or by different electron recombination processes that result in electromagnetic fields (HEMP, SREMP and SGEMP).

3.2. HEMP

In the case of HEMP, the primary interactions are gamma ray (shown as γ in **Figure 256-1**) interactions with the Earth's upper atmosphere in a source region approximately 20-40 kilometres (km) above the Earth. The by-product Compton electrons move in a straight line until they "see" the geomagnetic field lines (not shown) and then coherently precess about them until they finally recombine with the atmosphere. During this precession, the electrons radiate a coherent electromagnetic pulse. When observed on the ground (along the tangential radius R_t), it is a simple radiated field that can be described by just the electric field strength in volts per metre (V/m).

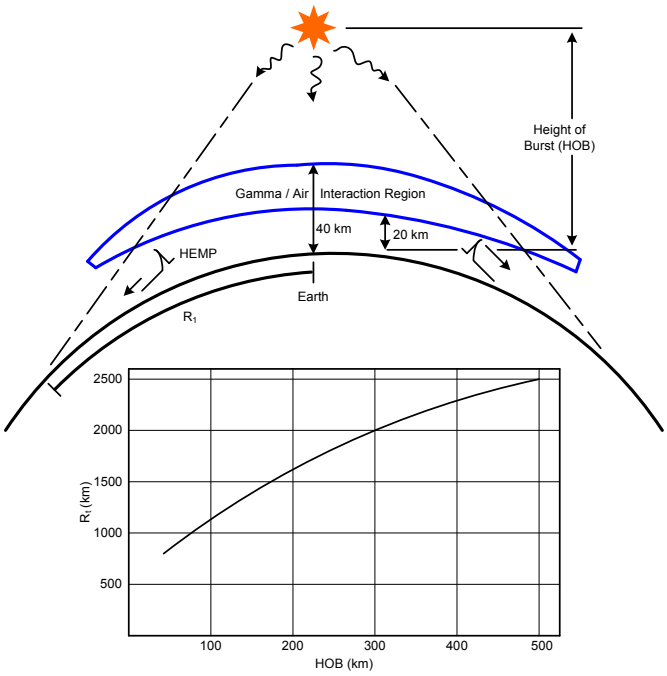

Figure 256-1
General Description of HEMP Phenomenology and HEMP Coverage on Earth

3.3 SREMP

If the nuclear fireball touches the Earth, the signal just outside the fireball is in the source region and is called SREMP. In that case, the electric and magnetic fields do not have the same waveshape, and therefore one must identify the electric field in units of volts per metre (V/m) and the magnetic field in units of amps per metre (A/m).

Figure 256-2 illustrates the origin of the primary (vertical electric field) SREMP component from a ground burst. It shows free electrons created by detonation-air molecule interactions moving radially away from ground zero in a hemispherical geometry, creating a source region of high air conductivity. In this region, the *net* electron flow is vertically upward from the ground burst (all other contributions cancel). This electron flow gives rise to a net near electric field vertically polarized with respect to the Earth. As the distance continues to increase, the electrons curve back into the Earth and return to ground zero. Finally, the remaining free electrons in the air recombine with positively charged air molecules, and the air impedance returns to its ambient level (essentially the free space value of 377 ohms). The dominant field in this range reduces to a low amplitude radiated far field. The electromagnetic signals are characterized by early time electric and magnetic fields of fast risetime, high peak amplitude and significant energy under the curve.

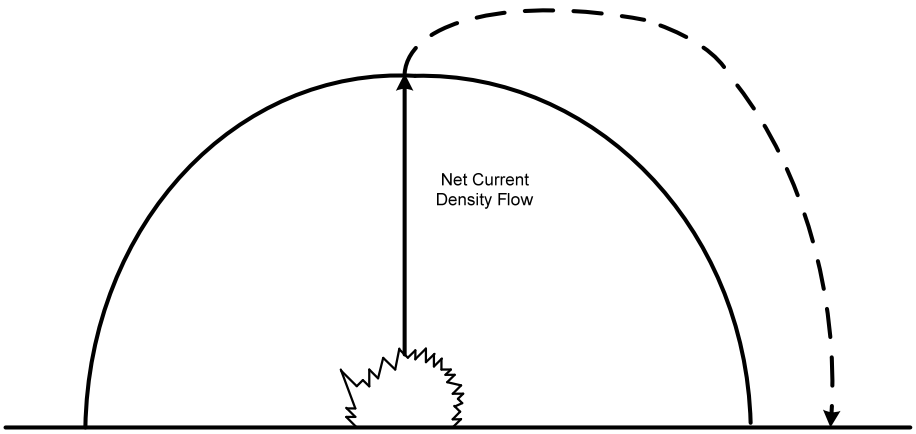

Figure 256-2 Origin of Dominant SREMP Vertical Electric Field

The region where the greatest damage can be produced from a SREMP is from about 3 to 8 km from ground zero. In this same region, structures housing electrical equipment are also likely to be severely damaged by blast and shock.

3.4. SGEMP

SGEMP is different from SREMP. It is the pulse caused when gamma rays, neutrons and in particular X-rays interact with the system causing electrons to be excited and released. The electron charge causes currents to flow on the system skin thus giving rise to an EMP. When equipment is close to the detonation, direct interactions with the equipment can be significant. For Earth-based equipment, gamma ray and neutron interactions give rise to SGEMP, an effect that increases with equipment volume. In this case, x-rays do not contribute to SGEMP; they are absorbed close to the detonation by the surrounding atmosphere and give rise to radially expanding thermal and airblast pulses. X-ray contributions to EMP are significant only in the outer atmosphere, where x-rays interact directly with space-based equipment (usually satellites) causing SGEMP. Originally, satellite

SGEMP was called internal EMP (IEMP).

3.5. EMP Characteristics

Consider the *mathematical representation* of the total electric field:

$$E_{total} = E_{far} + E_{near} = A/r + B/r^2 + C/r^3 + \ldots, \qquad \text{(equation 3.1)}$$

where A, B, C, … are constants.

The far field, E_{far}, is represented by a component that drops off as 1/r, where r is the distance between the source and the observer. When the detonation occurs in the upper atmosphere, this term corresponds to the electric field component of HEMP observed on the Earth (E_{near} is negligible). When the detonation occurs near the Earth, E_{far} is very small and typically ignored; the near field, E_{near} (the electric field component of SREMP), is represented by those components that drop off as $1/r^2$ or higher and can be significant. Mathematically, this means SREMP is more localized and severe around the source than HEMP.

Figure 256-3 identifies the primary cause of HEMP as prompt gamma rays (E1), followed in time by slower neutron and secondary gamma ray interactions (E2). The Magneto hydrodynamic (MHD) signal forms the final component (E3). It is the signal that results from geomagnetic field compression and heave. In the figure, E1, E2 and E3 refer to early-time, mid-time and late-time characteristics of the HEMP electric field:

$$E_{far} = E_{HEMP} = A/r = E1 + E2 + E3 \qquad \text{(equation 3.2)}$$

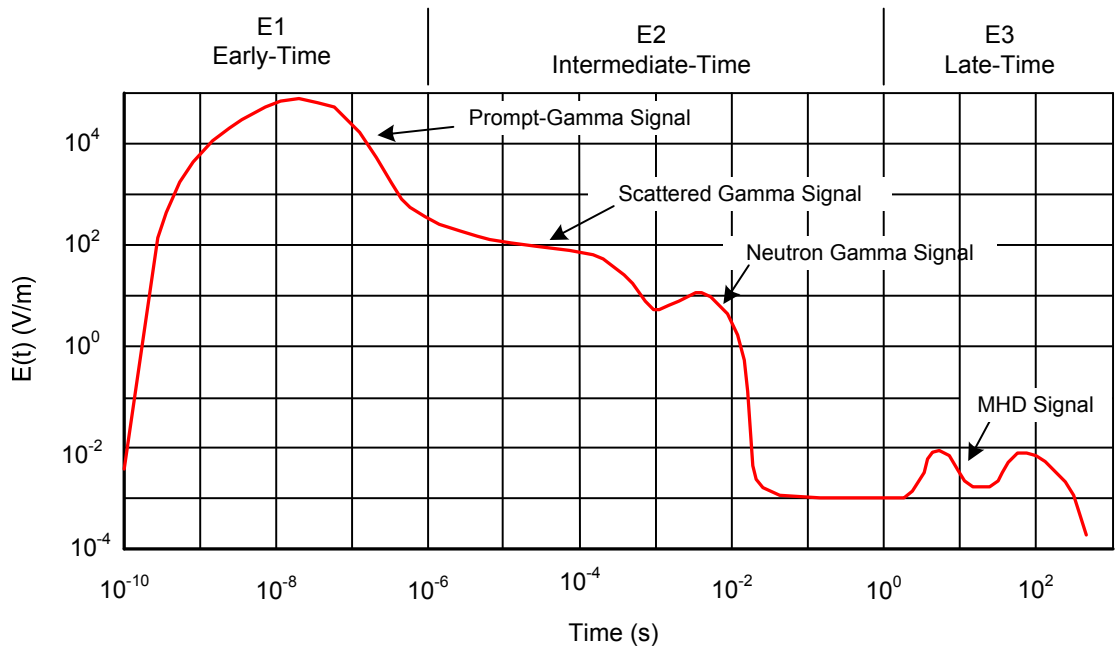

Figure 256-3 Principal Contributions to the Origin of HEMP

E1 couples onto virtually all equipment. The typical risetime is a few nanoseconds (ns), peak amplitude is several tens of kV/m and the pulse width at half max is several tens of ns wide. E2 and E3 coupling, on the other hand, only becomes significant on extremely long conductors (ie: power grids) due to its long duration (up to minutes for E3) and low amplitude

(in units of V/km for E2 and E3). The general rule of thumb is that systems and platforms much less than 1 km need only consider E1; anything greater should consider all three. A more specific description of the unclassified HEMP waveshape E1, E2 and E3 is found in MIL-STD-464 [A5].

In *engineering terms*, one can relate E_{far} (HEMP) and E_{near} (SREMP) around the detonation to the signals around a radiating antenna: signals near the antenna are near fields, characterized by extremely high amplitude field levels near the antenna that drop off at higher orders of magnitude than 1/r, where r is the distance between the antenna and the equipment. Such a complex field is found around a ground burst and is called SREMP, or sometimes low-altitude EMP (not to be confused with lightning EMP (LEMP)). While the range is smaller than HEMP from a high-altitude detonation, SREMP dominates beyond the range of blast and thermal effects. It is extremely high in amplitude (higher than HEMP) within an annulus around the burst point, eventually dropping off to a low amplitude radiated field that then goes as 1/r (**Figure 256-4**).

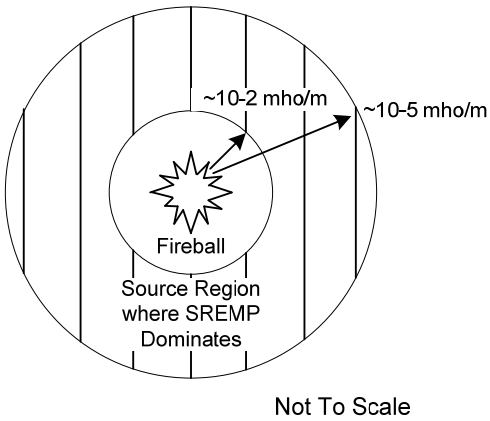

Figure 256-4 Relative Region around Detonation Point where SREMP Dominates

The early-time (E1), HEMP *or* unclassified free-field EMP environment is shown in **Figure 256-5**.

3.6. Test Considerations

Since E_{far} (HEMP) is equivalent to the far field surrounding a radiating antenna, HEMP testing often uses radiating or bounded wave simulators to simulate one or more of the vertically and horizontally polarized fields. (Note that use of only a vertically polarized simulator would not be valid for many systems). If the system is simple enough to identify all the coupling ports by which electromagnetic energy enters the equipment, the calculated signal(s) coupled onto the equipment can be driven using current injection techniques. In the time domain, HEMP is characterized by electric (E) and magnetic (H) fields having the same waveshape. They are related to each other by the constant impedance of free space (377 ohms) and are perpendicular to each other and to the direction of the radiating wave. Both travel through air or free space at 3×10^8 m/s, and they carry with them energy in the form of a radiated energy density. Most (about 90%) of that radiated energy is in the frequency range of tens of kilohertz (kHz) to a few hundreds of megahertz (MHz). A comparison of the HEMP electric field to other high power EMEs is shown in **Figure 256-6** as a function of frequency.

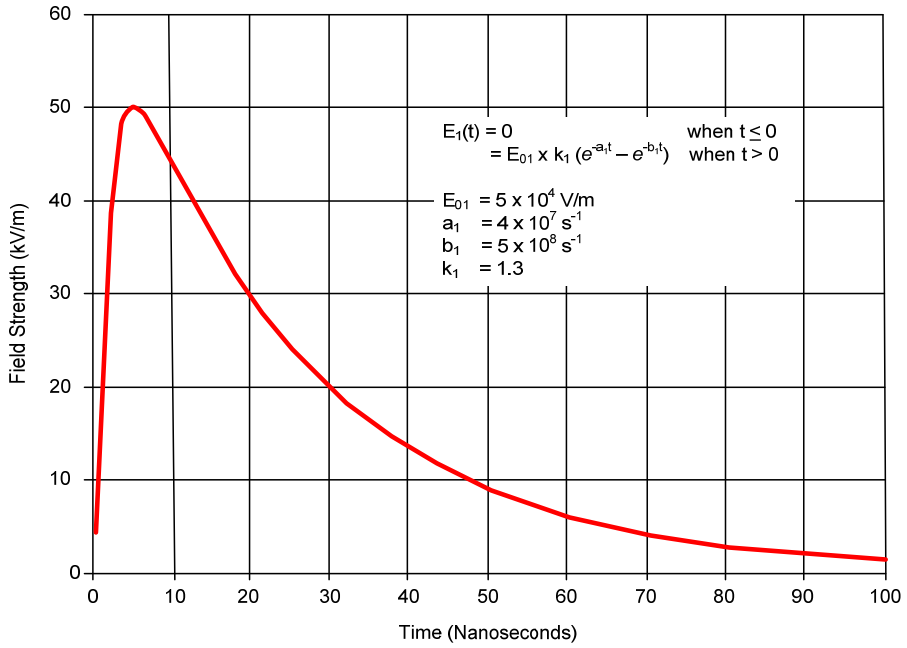

Figure 256-5 Unclassified Free-Field NEMP Environment

For a typical detonation, one can calculate the available HEMP average energy density to be between 0.1 and 0.9 joules/m^2. For a piece of equipment with a surface area of several square metres, the energy coupled to the equipment surface can be several joules. From early component damage testing, one learns only a few microjoules of that energy need couple into input/output ports of equipment electronics to cause component upset or failure via thermal breakdown.

In summary, it is important to emphasize the two primary differences between HEMP and SREMP criteria for test and analysis purposes. The first is the relationship of the electric and the magnetic fields. As mentioned earlier, HEMP E and H have the same waveshape and differ in amplitude by just a constant. This relationship allows for straightforward HEMP test simulation and coupling calculations. In the case of SREMP, E and H are radically different in both shape and amplitude. It is therefore essential that coupling calculations and testing account for this fact. The second criteria difference is that HEMP couples in regions with ambient air impedance while SREMP does not. In the near field region, the increased electron flow causes the impedance of the surrounding air to increase with range from low to ambient air impedance levels. This time and distance variation of the air impedance further complicates coupling calculations and testing. SREMP simulators do not exist; however, vertical bounded wave simulators have been used to approximate the vertical electric field component in ambient air. Current injection techniques can also be used; however, in both instances, substantial analysis is required to account for imperfect simulation.

Finally, SGEMP for ground based equipment is the result of direct interaction of the weapon prompt gammas and neutrons with the equipment itself. SGEMP is therefore described by the waveshape and amplitude of the coupled voltage and current signals. Although no NATO criteria exist, it can be of the order of thousands of volts depending on equipment volume and construction details. For space based equipment, SGEMP is caused by the direct interaction of the weapon x-rays with the equipment. Current injection techniques are the only simple way to drive predicted currents onto the equipment under test.

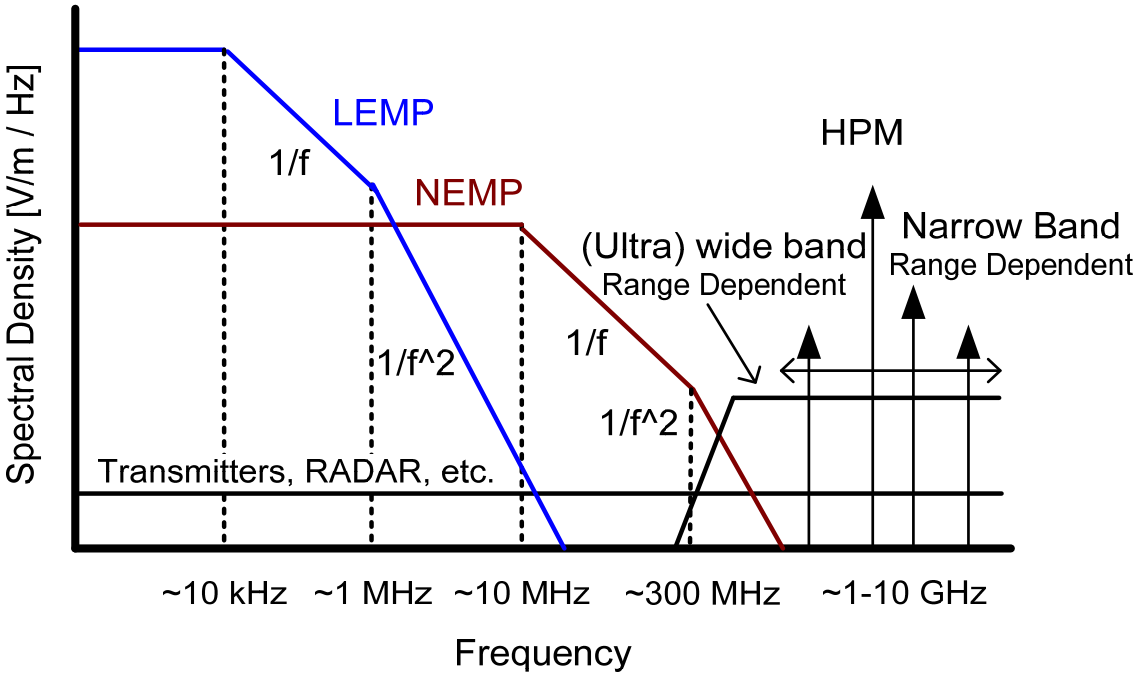

Figure 256-6 Comparison of Typical High Power Electromagnetic Environments

ANNEX A

REFERENCES

A1	IEC 61000-2-9	Electromagnetic Compatibility (EMC) – Part 2: Environment – Section 9: Description of HEMP environment – Radiated disturbance. Basic EMC publication
A2	IEC 61000-2-10	Electromagnetic Compatibility (EMC) – Part 2: Environment – Section 10: Description of HEMP environment – Conducted disturbance.
A3	STANAG 4145	Nuclear Survivability Criteria for Armed Forces Materiel and Installations
A4	AEP 50	Space and Nuclear Radiation Hardening Guidelines for Military Satellites, Electronics and Photonics
A5	MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems

LEAFLET 257

HIGH POWER MICROWAVE

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LEAFLET 257

HIGH POWER MICROWAVE

1. BACKGROUND

Relatively new threats for military and civil systems in the higher frequency spectrum (> 200 MHz) are high-power microwave (HPM) sources. An attack with this kind of source is typically defined as Intentional Electromagnetic Interference.

Technological developments within the area of high-power microwaves have made it possible to produce more powerful microwave sources for illuminating large operational installations. At the same time, it is possible to generate relatively strong fields with compact systems that can be contained, for example, in a briefcase.

Therefore, the potential threat from HPM has increased. Moreover, if an HPM system is fielded by a North Atlantic Treaty Organisation (NATO) country, there may be a need to design co-located systems against the fields produced. However, the actual threat that may exist from friendly or hostile sources in any particular scenario has not yet been fully defined by any NATO nation. The information provided below is therefore general and unclassified. National Authorities should be consulted to determine if an HPM environment needs to be specified for any particular system or equipment.

HPM energy can be radiated in the air or conducted through wires/cables to reach its intended target. The two main ways that radiated energy can penetrate into electronic systems are through the “front door” (antennas) or the ”back door” (cables and apertures). The induced currents and voltages can ultimately cause effects in the targeted electronics.

Unprotected electronic components can be damaged at distances up to kilometres, and possible disturbances with fatal consequences are considered realistic in operational scenarios, including critical elements of civilian infrastructure, where the possibility of sabotage and terrorism is a serious concern. Potential attack and collateral impact with currently and generally available technology may need to be taken into account in any scenario where malfunction of electronic systems could have fatal consequences. Examples include computers locking up; electronic valves opening/closing without being commanded; data being corrupted; communications being lost; and power being lost. Effects range from interference, which disappears when the source is deactivated, to permanent damage. On the other hand, HPM sources belong to the more general class of non-lethal weapons that can be used to eliminate hostile capabilities with a minimum of casualties and collateral damage. Today, these activities are gathered under the umbrella of HPM, which includes sources, wave propagation, reaction of the electronics and system hardening against this threat.

2. ENVIRONMENT

While the effects of high-power electromagnetic environments (HPEM) like lightning (LEMP) and nuclear (NEMP) electromagnetic pulse have been studied thoroughly in the past and characteristics are readily available, HPM is a relatively new research area.

Hostile source characteristics are difficult to predict and possible “friendly” sources are subject to security issues and have yet to be defined in a meaningful manner, which make defining the HPM environment very difficult or even impossible.

Criminals, terrorists, disgruntled employees/customers, hostile military/special forces and competitors are all potential HPM attackers. The potential scenarios are comparable. A disgruntled employee may bring a small, improvised device into the facility to simply cause some trouble. A terrorist may use a truck-mounted source to cause havoc. A military approach may be to use an airborne system to cause damage.

The characteristics of the threat environment are limited by the attacker's technical skill, technology level and access to technological means.

The power of radiated HPM sources ranges from kilowatts to gigawatts (peak). In general, the frequency ranges from tens of MHz up to several GHz. **Figure 257-1** represents a frequency relation between LEMP, NEMP and HPM sources adapted from IEC 61000-2-13 [A1].

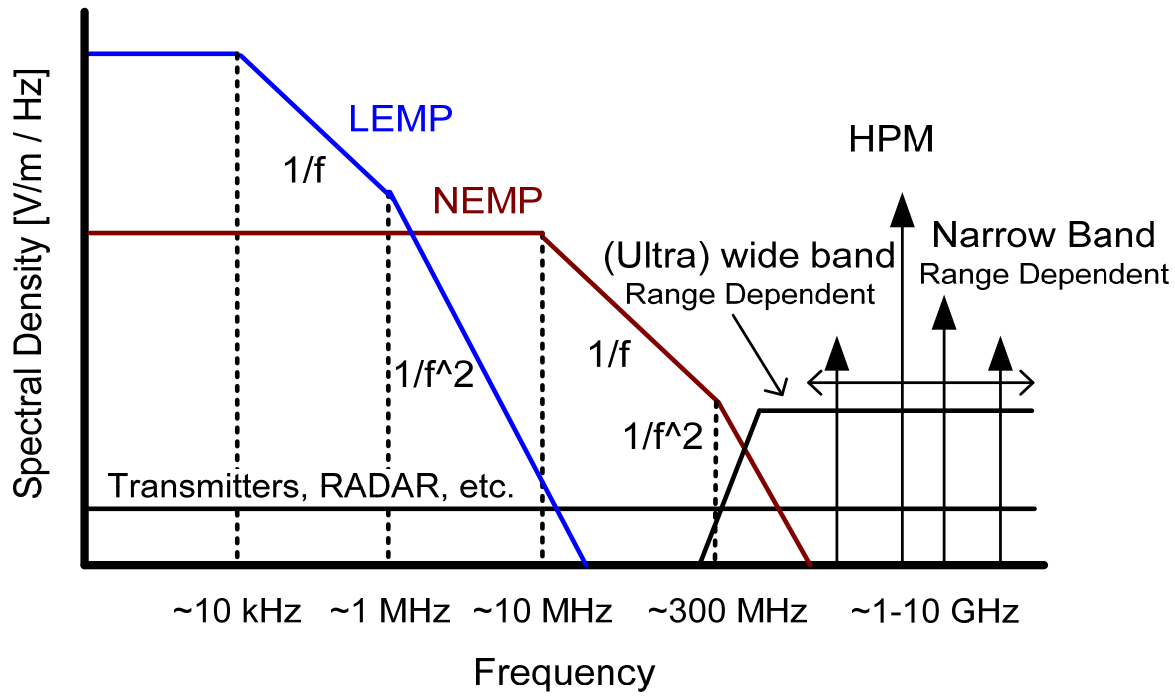

Figure 257-1 Comparison of Typical High Power Electromagnetic Environments

Depending on the objective and the knowledge of the target, the attacker will select a type of HPM source with the most effective waveform to reach the objective and cause maximum effect. The types of HPM sources and the possible waveforms are described in the following paragraphs. The energy levels at the location depend on a wide range of parameters.

2.1. Types of HPM Sources

HPM sources can be divided into four categories. They include:

a. Mobile/platform HPM source – An HPM source generally radiates fields toward targeted infrastructure facility equipment from an area that is not controlled by the targeted infrastructure facility, such as outside a fenced area. A truck-mounted source is, in this situation, more likely than a man-pack source because the power required to produce effective field levels at the intended target from a standoff distance translates into a large heavy device. Airborne sources are also possible.

b. Portable HPM source – A portable HPM source can be carried into the interior of the target, concealed under clothing or inside a briefcase, a purse or even a soda can. The proximity to the targeted electronics could make the small source even more dangerous than a larger one at a greater distance because shielding and standoff attenuations have been bypassed.

c. Conducted HPM source – An HPM source could directly inject energy into a conductor leading into the infrastructure facility, such as power or communications lines. This may be done either through the exterior or interior of the facility.

d. Projectile-based HPM source – A projectile-based HPM source radiates the entire facility with an electromagnetic pulse. This also causes large electrical surge currents passing into the facility through external conductors, such as power or communications lines, water pipes, etc.

The details of the scenario will depend on the infrastructure topology, nature of the attacker and other variables. In general, once a source has been defined, the scenario should be defined using worst case conditions.

2.2 HPM Waveforms

In general, the number of HPM waveform types is limited to four. The parameters of the waveform such as frequency, power, etc. depend on the source type.

a. Continuous wave (CW) – An HPM system that produces a CW waveform generally includes a resonant microwave tube like a magnetron. This signal is most efficient when the frequency is tuned to the most vulnerable frequency of the target. All of the HPM energy is concentrated into one frequency. CW can be characterized by its frequency and power. **Figure 257-2** illustrates a CW waveform.

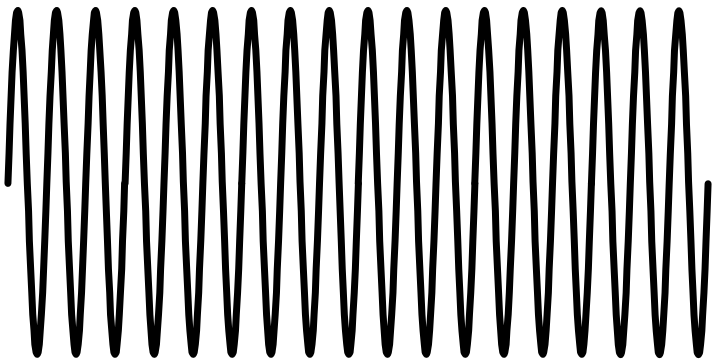

Figure 257-2 Continuous Wave Waveform

b. Pulsed CW Narrowband (NB) – A NB pulsed CW waveform is a typical HPM waveform. The Fourier spectrum of this waveform shows a narrow envelope around the "center frequency". This waveform can be characterized by its carrier frequency, peak power, pulse width and pulse repetition rate and derived parameters such as duty cycle, average power, etc.

The advantage of this NB waveform is that a low average power is used to generate efficient high peak power; consequently, high energy pulses are used to upset or damage electronic equipment. The highest peak powers are to be expected from these narrowband sources. This signal is most effective when the target is vulnerable to peak signal at the most vulnerable frequency. The signal can be designed to couple to antennas or antenna-like structures ("front door" coupling) to cause damage to the target. They can also be designed to couple to the target through unintentional paths ("back door" coupling) to cause damage to the electronics. **Figure 257-3** illustrates a NB waveform.

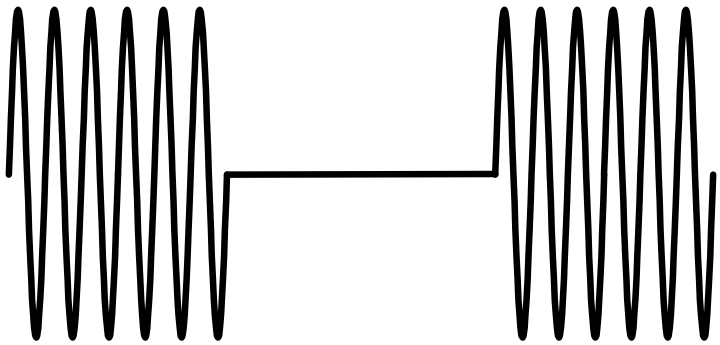

Figure 257-3 Narrow Band Waveform

c. Damped sinusoid (DS) – A DS waveform is characterized by its dominant frequency, peak power, damping rate and energy in the pulse.

The DS has a "center frequency" and some bandwidth to increase the likelihood of causing "back door" effects.

The advantage of the DS waveform is a wider bandwidth than a CW or NB waveform; typically one octave. **Figure 257-4** illustrates that DS waveform.

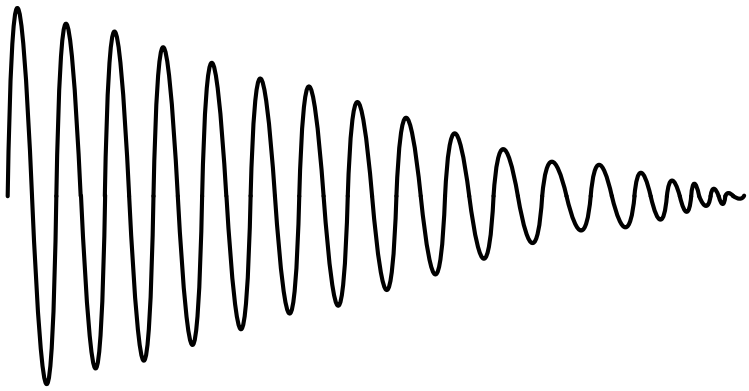

Figure 257-4 Damped Sinusoid Waveform

d. Ultra wideband (UWB) - An UWB waveform is characterized by its peak power, rise time, decay time, bandwidth and pulse repetition frequency. See **Figure 257-5**.

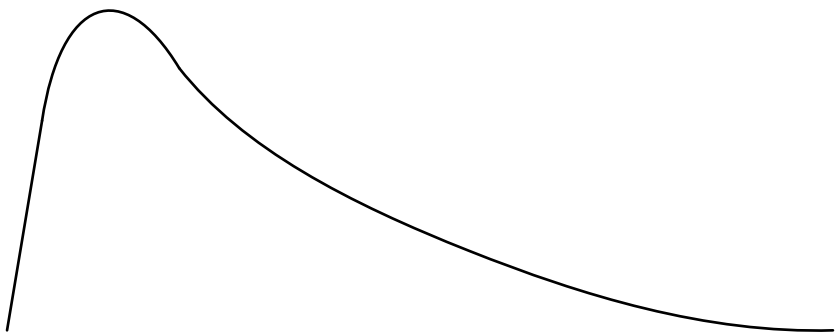

Figure 257-5 Ultra Wide Band Waveform

UWB pulses have the ability to excite many resonant modes in an object or target. However, the power that is present in a small portion of the frequency range is relatively low, as well as the total energy in one pulse and therefore less suitable to put high field strength in a resonant target for upset or damage. For UWB to be effective, much more power is needed than with NB at the right frequency.

2.3. HPM Levels

The (environment) level of the field strength and currents depends on various parameters. There are too many variables to define levels in general.

There are a number of analysis and modeling tools that can be used to provide first-order approximations for the determination of the transfer of electromagnetic energy to the point of interest. These techniques are the fundamental tools used in radar, communications and electromagnetic interference/electromagnetic compatibility.

The maximum peak radiated power of an antenna structure is limited by the breakdown field strength of air (~ 1 MV/m) at the surface area (A) of the radiating section. A rule of thumb of the maximum peak radiated power of an antenna structure with a cosine illumination is P_{peak} ~ 1 GW / m^2. In general, the available power of CW sources varies from kWatts (magnetrons) to tens of MWatts (radar tubes). Pulse power sources go up to hundreds of MWatts or higher.

A rough estimation of the local field at some distance from the source can be made by applying equations 2.1 and 2.2.

The field strength (E_a) at the surface of the antenna can be calculated when the radiated power (P), the area (A) of the aperture and the (free-space) impedance (Z) are known. The peak electric field must be lower than the air breakdown field strength of ~1 MV/m.

Peak Electric Field on the Radiating Aperture

$$E_a = \sqrt{\frac{P \cdot Z}{A}} \ldots [V/m] \qquad \text{(equation 2.1)}$$

The magnitude of the electric field (E) at a certain distance (R) in the far-field can be calculated by using equation 2.2 (assuming no multi-path effects, no intervening walls/barriers or other effects).

Peak Radiated Electric Field

$$E = \frac{E_a A}{R\lambda} \ldots [V/m] \qquad \text{(equation 2.2)}$$

The local electromagnetic field levels can be refined by taking the shielding effectiveness of the building walls or other barriers into account. A first-order approximation could be found by assigning a representative building shielding effectiveness based on some reference, though aperture penetrations should still be considered. Building attenuations are typically from 5 to 25 dB.

Examples of sources can be found in [A1].

ANNEX A

REFERENCES

A1 IEC 61000-2-13 Electromagnetic compatibility (EMC) – Part 2-13: Environment - High-power electromagnetic (HPEM) environments – radiated and conducted

LEAFLET 258

RADIO FREQUENCY ELECTROMAGNETIC ENVIRONMENTS

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LEAFLET 258

RADIO FREQUENCY ELECTROMAGNETIC ENVIRONMENTS

1. GENERAL

This leaflet addresses the Radio Frequency (RF) Electromagnetic Environment (EME) produced by various emitter sources such as communication and radar transmitters likely to be encountered by materiel of any service during North Atlantic Treaty Organisation (NATO) operations.

The objective of this leaflet is to provide an overview discussion, typical requirements, and definitions of the operational EME against which NATO military hardware must be protected in order to operate and survive. The EME levels can then be used as design criteria for all new platforms, equipments, and systems intended for use by NATO Forces.

Defining the EME levels that military hardware are expected to encounter is only the first step as these levels must be considered in all four phases of the acquisition lifecycle (i.e. design, engineering development, production and deployment), particularly when defining test requirements and mitigating issues once deployed. After the operational EME levels have been defined, EME certification requirements can be derived and other publications can be referenced as design guides and procedures for managing the operational EME. For example, AEP 41 Unified Electromagnetic Effects (UE^3) Protection [A1] provides the philosophy and methodology for achieving Unified Electromagnetic Environmental Effects (UE^3) protection and hardening of all NATO military platforms, systems and equipments (hardware) against Electromagnetic Environmental Effects (E3) and provides information concerning the different functional areas required to achieve, produce and sustain UE^3 protection and survivability. AECTP 500 Electromagnetic Environment Tests [A2] contains generic test procedures for ensuring the resistance of materiel to Electromagnetic (EM) effects. AECTP-2(B) NATO Naval Radio and Radar Radiation Hazards Manual [A3] provides procedures for mitigating Hazards of Electromagnetic Radiation to Ordnance (HERO) in the NATO Naval environment through the use of Susceptibility Radiation Hazard (RADHAZ) Designator and Transmitter RADHAZ Designator codes.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1. Sources

The EME in which an item is most likely to operate must be defined early in the acquisition process; otherwise, the burden of managing inter-system Electromagnetic Compatibility (EMC), HERO and Electromagnetic Vulnerability (EMV) issues will be placed on the service personnel which may hinder operational effectiveness. Individually, NATO Nations have captured and addressed their own operational EMEs through varying philosophies and methodologies; however, materiel intended to be used in the more dynamic NATO environment need to consider more than just the EMEs defined within National Standards. Hence, the initial step is to identify the NATO platforms and operational scenarios in which NATO materiel will operate. Once identified, the types and characteristics of any spectrum-dependent item present or planned that could possibly interact with the proposed item should be identified. This identification must address both the military and commercial EMEs alike. The information on interacting items will be used as an initial input for frequency

allocation and E3 analyses. Although the EME is defined early in the program, continuous update of the EME is necessary throughout the entire lifecycle because the environment is not static. Other entities (friendly and hostile) will be simultaneously developing or fielding items that will operate within the same EME. Data concerning these "new" items must be sought out and added to the EME definitions.

In addition, the original mission requirements of the proposed item may be changed, forcing additional geographic regions, countries, host platforms and nearby equipment to be considered. As EME definitions are updated, they should be used to refine E3 analyses and frequency allocation requests. This leaflet and other national publications such as Mil Std 464 [A4], GAM DRAM 01 [A5], GAM DRAM 02 [A6],GE DIN VDE 0848 [A7] UK Def San 59-411 Part 2 [A8] and VG 95373 [A9] describe various land-based, ship-based, airborne and battlespace environments that may be encountered by an item during its lifecycle. One of the difficulties encountered when specifying the performance requirements of an item is that, in many cases, the intended operational EME characteristics are quantitatively unknown. Factors identified/evaluated in this leaflet should be considered when defining the anticipated operational EME of an item.

In all likelihood, each item will be exposed to several different EME levels during its lifecycle. Specifying an EME level that is too stringent may result in unnecessary additional costs. Each distinctive EME that an item will be exposed to during its lifecycle should be defined before specifying its performance requirements. For example, a missile will be exposed to different EME levels during transportation/storage, assembly/disassembly, handling/loading, staged, platform-loaded and immediate post-launch conditions and on the approach to a target. The specified E3 control performance requirements should ensure the item's performance is not affected by any EME levels encountered during its stockpile-to-target sequence.

2.2. Characterization of the Electromagnetic Environment

Deliberately generated RF emissions are the usual threat to weapon systems. These external EME sources continue to change due to technology advancements, proliferation of more powerful emitters, and expanded use of the spectrum worldwide (usually at higher frequencies). Therefore, it is essential that the expected EMEs be defined and used to establish inter-system EMC, HERO and EMV design requirements. Many NATO Nations have developed National Standards that outline the EMEs to which ordnance and materiel will be evaluated, and these standards are based on the EMEs, either measured or calculated, that exist within their specific military environments. The intent of this leaflet is to present the cumulative NATO EMEs (i.e. land, sea and air) that are expected to exist such that individual Nations can procure and/or establish design requirements to ensure ordnance and materiel can operate as intended in a NATO environment.

2.3. Calculation Methodology

All participating NATO countries agreed to compute the EME levels using the same computation methodology and assumptions. The computation methodology is provided in Annex B and the assumptions are contained in the following clauses.

3. NATO EME

3.1 General

The ensuing NATO EME tables document the EMEs most likely to be encountered during

NATO operations aboard ship (flight deck, weather deck, main beam, 500 feet and 1000 feet from transmitting/antenna system), on the ground, in the air, and in space. In addition, a worst-case NATO EME table was developed that combines all of the aforementioned EMEs. Hostile EMEs (i.e. from intentionally hostile RF jammers or from hostile transmitters likely to be encountered close to a target) were not included as part of this document. The objective of gathering these measured and calculated values from each participating NATO Nations is twofold: characterize the operational EME to establish the criteria for E3 design and testing that will ensure equipments will operate satisfactorily in the true NATO operational EME; and compile the EMEs that exist during NATO operations so that better operational guidance may be provided to the warfighter to mitigate E3 issues. The latter, of course is in recognition of the fact that materiel could be exposed to EM field strengths higher than current test standards and operational limits must be set by Nations in order to address E3 issues. A separate restricted document [A10] contains the EME from each contributing Nation as well as all assumptions related to the distances used to calculate the EME levels.

3.2. Assumptions

In order for any of the EME tables to have any meaning, it must be fully understood how the data were derived and what guidelines were followed. The following is a list of basic assumptions made during the development of the EME tables. Although most of these assumptions are basic, they are provided to document all possible assumptions for the reader:

a. All calculations consider only free space loss between the emitter and the platform (i.e. no losses due to atmospheric effects).

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

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

d. The land environment consists of military fixed and mobile emitters located on military facilities and those emitters that can be deployed to the battlefield.

e. Antenna heights above ground due to antenna towers that are not part of the basic equipment package were not considered. Flat earth is assumed; i.e. terrain was not included.

f. Modulation was not considered for the non-pulsed emitters; therefore, peak field strength and average field strengths were set to be the same.

g. The field strength levels are based on the maximum authorized power level of the transmitter and antenna gain for the frequency range. The average field strength is based on the maximum average field strength (peak output power of the transmitter times the maximum duty cycle) for the frequency range. The field strengths used in the environments for peak and average may or may not be from the same driver emitter.

h. The antenna side lobes and rotation rate were not used for any of the calculations.

i. The maximum antenna gain was taken from the 3 dB beam width.

j. The units used to define the field strength of the environment are in terms of rms. All measurements or calculations of the EME are derived/computed in terms of the power density in watts per square metre (W/m^2), either peak or average then converted to electric field strength in volts per metre (V/m_{rms}). The rms units for electric field strength or power density are to be omitted since they are assumed to be understood without restatement in the units. The true electrical peak will not be used for expressing the field strength.

k. Pulse-modulated signals, such as from a radar, have differences between peak and average power density. The ratio between the peak and average values is the duty cycle for pulse-modulated or gated signals. The maximum duty cycle is to be used to calculate the environment. For pulsed emitters when the signal is on, the peak field is the value of the electric field for the time that the signal is on. When the signal is off, the field strength is zero.

l. All field strength values have been rounded to up or down to the nearest 10 except for those values less 30.

3.3. NATO EME Tables

3.3.1. NATO Ship EME:

Each contributing Nation conducted an examination of shipboard transmitters' field strength levels on the flight deck, weather deck, main beam, and at distances of 500 and 1000 feet from the transmitting antenna of all classes of Naval vessels. Nation-specific EME tables are based on both measured and calculated data and are provided in the separate restricted document discussed in **Clause 3.1**. **Table's 258-1A** and **258-1B** provide a "roll-up" of the maximum EME levels for all participating Nations with respect to each frequency band presented. **Table 258-1A** provides the worst-case flight-deck and weather-deck EME based on two criteria:

a. Measured data or calculated levels based on shipboard transmitters and

b. EMEs for personnel based on STANAG 2345 [A11] and DOD Instruction 6055.9 [A12] criteria for Permissible Exposure Limits (PELs). The greater level is incorporated in **Table 258-1A**.

Table 258-1B applies to aircraft landing on NATO ships (see note below) and is the combined EME level for ships that are rotary wing capable only and ships that are both rotary and fixed wing capable. It provides the main-beam EME levels for shipboard emitters and was computed based on the following distances:

a. 3 metres from communication transmitter/antenna systems and 15 metres from radar transmitter/antenna systems;

b. 500 and 1000 feet from both communication and radar transmitter/antenna systems. In general, the EME levels are based on calculations using the far-field Friis free-space transmission formula. However, for the worst-case main-beam environment, near-field effects were considered as discussed in **Annex B**.

Note: It must be noted that there will be exceptions where some transmitter/antenna systems on certain classes of Naval vessels will be able to illuminate systems at closer distances or, for some transmitter/antenna systems, the main-beam distance may be greater than 15 metres. In particular it is recognized that fixed wing aircraft which only operate from aircraft carriers will not experience some of the main beam worst case levels (e.g. 2.7-3.6 GHz band). Consequently, a more detailed examination of EME data may be necessary for specific classes of Naval vessels in order to tailor design requirements or manage specific operations as the probability of occurrence will be a function of the ship-class and complexity of the battlegroup around which one is operating.

Table 258-1A
NATO Ship Operation EME Field Strength Levels (Flight Deck and Weather Deck)

Frequency Range (MHz)	Weather Deck		Flight Deck	
	Average (V/m)	Peak (V/m)	Average (V/m)	Peak (V/m)
0.01 - 2	--	--	--	--
2 - 30	200	200	160	160
30 - 150	60	60	60	60
150 - 225	60	60	60	60
225 - 400	60	60	60	60
400 - 700	70	410	70	180
700 - 790	100	160	100	160
790 - 1000	240	1,300	100	1,130
1000 - 2000	180	550	110	550
2000 - 2700	160	180	160	180
2700 - 3600	180	2,030	180	2,030
3600 - 4000	200	1,860	200	300
4000 - 5400	200	290	200	290
5400 - 5900	240	710	210	450
5900 - 6000	240	350	210	350
6000 - 7900	240	350	210	350
7900 - 8000	200	350	200	350
8000 - 8400	200	350	200	350
8400 - 8500	200	480	200	480
8500 - 11000	200	1,130	200	510
11000 - 14000	200	830	200	790
14000 - 18000	200	830	200	790
18000 - 40000	200	200	200	200
40000 - 45000	200	200	200	200

Table 258-1B
NATO Ship Operation EME Field Strength Levels for Rotary and Fixed Wing Aircraft Landing Aboard a Ship (Main Beam Worst-Case, 500 and 1000 Feet)

Frequency Range (MHz)	Main Beam		Distance (500 ft)		Distance (1000 ft)	
	Average (V/m)	Peak (V/m)	Average (V/m)	Peak (V/m)	Average (V/m)	Peak (V/m)
0.01 - 2	200	200	--	--	--	--
2 - 30	200	200	2	2	1	1
30 - 150	50*	50*	1	1	--	--
150 - 225	50*	50*	1	1	--	--
225 - 400	50*	50*	2	2	1	1
400 - 700	270	1,870	30	200	15	100
700 - 790	20*	20*	2	2	1	1
790 - 1000	490	2,530	100	550	50	280
1000 - 2000	600	7,000	120	3,000	60	1500
2000 - 2700	10*	10*	2	2	1	1
2700 - 3600	2,620	21,050	1,500	11,500	750	5750
3600 - 4000	270	8,550	40	1,300	20	650
4000 - 5400	140	450	40	40	20	20
5400 - 5900	350	7,100	160	5,100	100	2550
5900 - 6000	270	270	100	100	50	50
6000 - 7900	400	400	100	100	50	50
7900 - 8000	400	400	120	210	60	110
8000 - 8400	750	3,210	120	320	60	160
8400 - 8500	400	400	120	120	60	60
8500 - 11000	1,940	10,000	500	4,030	250	2020
11000 - 14000	680	3,630	400	400	200	200
14000 - 18000	680	6,000	380	1,200	190	600
18000 - 40000	170	3,640	140	2,100	70	1050
40000 - 45000	580	580	140	140	70	70

Note: * These levels are lower than weather-deck and flight-deck levels since no account has been taken for the personnel PELs.

3.3.2. NATO Ground EME:

Each of the contributing Nations conducted an examination of transmitters' field strength levels that exist for ground-based systems located at forward deployed areas (e.g. airfields, battlefields, command posts, etc.). **Table 258-2** provides a roll-up table with the highest EMEs presented for each frequency band for all ground-based systems using the following assumptions:

An analysis of ground-based transmitter-to-ordnance locations was performed to determine standoff distances for calculating field strength levels. The analysis was based on system parameters such as radiation cut-outs, beam widths, transmit power, antenna gain and antenna location. As a general rule, all calculations were made at distances of 3 metres from communication systems and 400 metres from radar and Satellite Communication (SATCOM) systems with exception to the US data where it is based on the EME levels of reference [A4] Table 1D. Again, it is important to note that this distance may not always apply, as the distance may vary between transmitter/antenna systems and specific operations involving ordnance, equipment, ground vehicles and aircraft on the ground.

Table 258-2 NATO Ground EME Field Strength Levels

Frequency Range (MHz)	Average (V/m)	Peak (V/m)
0.01 - 2	200	200
2 - 30	200*	200
30 - 150	100*	100
150 - 225	100*	100
225 - 400	100*	1,500
400 - 700	50	1,500
700 - 790	50	1,500
790 - 1000	50	1,500
1000 - 2000	50	2,500
2000 - 2700	50	2,500
2700 - 3600	50	2,500
3600 - 4000	50	2,500
4000 - 5400	50	2,500
5400 - 5900	50	2,500
5900 - 6000	50	2,500
6000 - 7900	50	2,500
7900 - 8000	50	2,500
8000 - 8400	50	2,500
8400 - 8500	50	2,500
8500 - 11000	60	2,500
11000 - 14000	60	1,500
14000 - 18000	60	1,500
18000 - 40000	50	1,500
40000 - 45000	--	--

Note: * These EME levels represent values that exist close to mobile communication systems and exceed continuous PEL levels of [A11]. However, these EMEs will not present a hazardous environment for personnel because normal emitter operation limits personnel exposure time and hence the total energy is within acceptable levels.

3.3.3. NATO Air EME:

Table 258-3A provides the assumptions used to develop the field strength levels in **Table 258-3B**, which vary depending on the source used to populate the table. **Table 258-3B** provides the maximum EME field strength levels for two different aircraft operations: Fixed wing and rotary wing aircraft involving non-ship operations (i.e. these aircraft will not be landing directly on a ship but will be flying in close proximity to the ship). Refer to **Table 258-1B** for the maximum EME for both fixed and rotary wing aircraft involving ship operations.

Each contributing Nation conducted a study of military and commercial standards, regulations and guides on the anticipated EME for both military and civilian aircraft operations. As a result of these studies, the following documents were used to develop the NATO air operation EME: [A4], EUROCAE ED 107 [A13] STANAG 3614 [A14] and FAA doc [A15]. **Table 258-3B** provides a roll-up table with the worst-case EMEs presented for each frequency band. **Table 258-3B** Fixed Wing Aircraft field strength levels are similar to [A13] Fixed Wing Severe HIRF environment.

Fixed Wing Transport Aircraft acquired as civilian transport aircraft are assumed to be qualified to field strengths levels similar to the civilian Certification HIRF Environment (HIRF Environment 1) with the assumptions used for calculation of the Certification HIRF Environment.

Table 258-3A Assumptions Used for Developing Air Operations EME

Location	Type of Transmitter	Fixed Wing Strike Aircraft[1]	Fixed Wing Transport Aircraft	Rotary Wing Aircraft
Airport Transmitters (within 5 nautical miles of an airport runway)	Airport and Air Route Surveillance	500 ft slant range	500 ft slant range	300 ft slant range
	All Other Fixed Transmitter	250 ft slant range	250 ft slant range	100 ft direct range
	Aircraft Weather Radar	150 ft direct range	150 ft direct range	150 ft direct range
	All Other Mobile Transmitter, Including Other Aircraft	50 ft direct range	50 ft direct range	50 ft direct range
Non-Airport Transmitter		500 ft slant range[2]	500 ft slant range[2]	100 ft direct range
Offshore Platforms		N/A	N/A	100 ft direct range
Shipboard Transmitter[3]		500 ft slant range	500 ft slant range	500 ft direct range
Air – Air Transmitters	Non-Interceptor With All Transmitter Operational	500 ft direct range	500 ft direct range	N/A
	Interceptor Aircraft With All Non-Hostile Transmitter Operational	100 ft direct range	100 ft direct range	N/A

Note: [1] For purposes of this document, the Transport Aircraft assumptions are applied to the Strike Aircraft. The user is warned that the operational scenario for Strike Aircraft may result in higher EMEs than quoted below.

Note: [2] Assumes a minimum flight altitude of 500 ft, avoiding all obstructions (including transmitter antennas) by 500 ft.

Note: [3] A distance of 500 ft was used for both fixed and rotary wing aircraft for non-ship operations.

The terms slant range and adjusted slant range, are defined as follows:

a. Slant range: The line-of-sight distance between the transmitter and the aircraft.

b. Adjusted slant range: This term is used when, due to the limitation of the maximum elevation angle of the antenna, the aircraft will encounter the main lobe (maximum field strength) at a greater distance than the specified slant range. If the maximum elevation angle was not available, 90 degrees was assumed, which is a slant range of 500 ft.

Figure 258-1 illustrates the slant range.

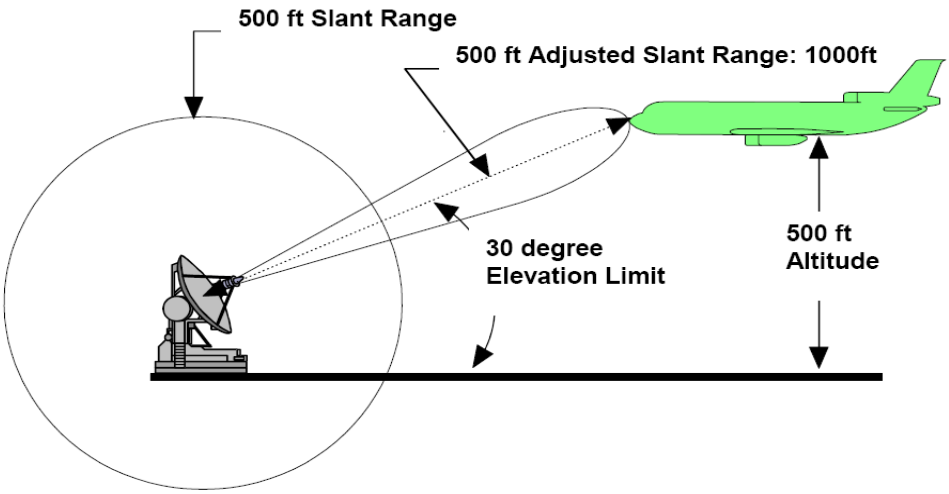

Figure 258-1 Illustration of Slant Range

Table 258-3B NATO Air Operations EME Field Strength Levels

Frequency Range (MHz)	Fixed Wing Aircraft Non Ship Operations		Rotary Wing Aircraft Non Ship Operations	
	Average (V/m)	Peak (V/m)	Average (V/m)	Peak (V/m)
0.01 - 2	70	70	200	200
2 - 30	200	200	200	200
30 - 150	50	50	200	200
150 - 225	100	100	200	200
225 - 400	100	100	200	200
400 - 700	80	730	200	730
700 - 790	240	1,400	240	1,400
790 - 1000	240	1,400	240	1,400
1000 - 2000	200	3,300	250	5,000
2000 - 2700	490	4,500	490	6,000
2700 - 3600	490	4,500	490	6,000
3600 - 4000	490	4,500	490	6,000
4000 - 5400	300	7,200	400	7,200
5400 - 5900	300	7,200	400	7,200
5900 - 6000	300	7,200	400	7,200
6000 - 7900	200	1,100	170	1,100
7900 - 8000	200	1,100	170	1,100
8000 - 8400	330	3,000	330	5,000
8400 - 8500	330	3,000	330	5,000
8500 - 11000	330	3,000	330	5,000
11000 - 14000	330	2,000	330	2,000
14000 - 18000	330	2,000	330	2,000
18000 - 40000	420	1,000	420	1,000
40000 - 45000	--	--	--	--

3.3.4. NATO Space EME:

Table 258-4 applies to space and launch vehicle systems and was taken directly from [A4]. These EMEs are considered adequate for NATO operations.

Table 258-4 NATO Space EME Field Strength Levels

Frequency Range (MHz)	Average (V/m)	Peak (V/m)
0.01 - 2	20	20
2 - 30	20	20
30 - 150	20	20
150 - 225	100	100
225 - 400	100	100
400 - 700	100	100
700 - 790	100	100
790 - 1000	100	100
1000 - 2000	200	200
2000 - 2700	200	200
2700 - 3600	200	200
3600 - 4000	200	200
4000 - 5400	200	200
5400 - 5900	200	200
5900 - 6000	200	200
6000 - 7900	200	200
7900 - 8000	200	200
8000 - 8400	200	200
8400 - 8500	200	200
8500 - 11000	200	200
11000 - 14000	20	20
14000 - 18000	20	20
18000 - 40000	20	20
40000 - 45000	--	--

3.3.5. NATO Worst-Case EME:

Table 258-5 is a compilation of the maximum field strength levels from **Tables 258-1** through **258-4**. It is intended to be used for safety related evaluations, such as HERO and intra-system EMC.

Table 258-5 Worst Case Operational EME Field Strength Levels

Frequency Range (MHz)			Average (V/m)	Peak (V/m)
0.01	-	2	200	200
2	-	30	200	200
30	-	150	200	200
150	-	225	200	200
225	-	400	200	1,500
400	-	700	270	1,860
700	-	790	240	1,500
790	-	1000	480	2,530
1000	-	2000	600	7,000
2000	-	2700	490	6,000
2700	-	3600	2,620	21,050
3600	-	4000	490	8,550
4000	-	5400	400	7,200
5400	-	5900	400	7,200
5900	-	6000	400	7,200
6000	-	7900	400	2,500
7900	-	8000	400	2,500
8000	-	8400	750	5,000
8400	-	8500	400	5,000
8500	-	11000	1,940	10,000
11000	-	14000	680	3,630
14000	-	18000	680	6,000
18000	-	40000	420	3,640
40000	-	45000	580	580

ANNEX A

REFERENCES

A1 AEP-41: *Unified Electromagnetic Effects (UE^3) Protection.*

A2 AECTP 500: *Electromagnetic Environmental Tests.*

A3 AECP-2(B): *NATO Naval Radio and Radar Radiation Hazards Manual*.

A4 MIL-STD 464: *Electromagnetic Environmental Effects Requirements for Systems*.

A5 FR GAM DRAM 01: *General Specification for Electro Explosive Devices and their Integration in Munitions against the Effect of Non-Ionising Electromagnetic Radiation*

A6 FR GAM DRAM 02: *Security Instructions to be established under various conditions of use for Systems and Munitions containing Electro-Explosive Devices in the Electromagnetic Environment*

A7 GE DIN VDE 0848: *Safety of EM Fields, Procedures for Measurement and Calculation*

A8 UK Defence Standard 59-411 Part 2: *The Electric, Magnetic, and Electromagnetic Environment*

A9 VG 95373: *Electromagnetic Compatibility-Electromagnetic Compatibility of Equipment*

A10 Rationale for the AECTP 258 Leaflet EME Tables

A11 STANAG 2345: *Evaluation and Control of Personnel Exposure to Radio Frequency Fields – 3 KHz to 300 GHz*.

A12 DOD 6055.9-STD: *Ammunition and Explosives Safety Standards*.

A13 EUROCAE ED 107: *Guide for the Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment*.

A14 STANAG 3614: *Electromagnetic Environmental Effects (E3) Requirements for Aircraft Systems and Equipment*.

A15 FAA Doc Certification of Aircraft Electrical/Electronic. Systems for Operation in the High Intensity Radiated Fields (HIRF) Environment

A16 NAVSEA OP 3565/NAVAIR 16-1-529, Volume I: *Electromagnetic Radiation Hazards (Hazards to Personnel, Fuel, and Other Flammable Material)*.

A17 NAVSHIPS 0900-006-5250: *On-Axis Power Density in the Fresnel and Fraunhofer Regions of Large Aperture Circular Antennas*.

A18 NAVSHIPS 0900-006-5240: *On-Axis Power Density in the Fresnel and Fraunhofer Regions of Large Aperture Rectangular Antennas*.

ANNEX B

METHODOLOGY FOR CALCULATING THE NEAR-FIELD AND FAR-FIELD EME FOR APERTURE AND WIRE ANTENNAS

This annex provides a discussion on the calculation technique used to predict the EME levels produced by a radiating source as a function of distance from the source's antenna. In addition, discussions are provided on near-field and far-field boundaries, antenna efficiency (K) limits, estimating the antenna illumination constant and near-field corrections for both circular and rectangular aperture antennas.

The clauses below describe the method to calculate the power density/electric field strength at a given distance from the transmitting source antenna. For near-field environments, calculations should be performed at more than one distance from the antenna in order to determine the maximum value for a system. This is suggested because of the null points associated with the near-field environment.

B.1. Near-Field and Far-Field Boundaries

The electromagnetic fields around an antenna are divided into three regions: The reactive near-field, the radiating near-field or Fresnel region and the far-field or Fraunhofer region. The approximations of the boundaries for these field regions are defined in equations B.1 through B.3:

$$NF_r \leq 0.62 \times \sqrt{\frac{L^3}{\lambda}} \quad \text{reactive near-field boundary} \qquad \text{(equation B.1)}$$

$$0.62 \times \sqrt{\frac{L^3}{\lambda}} \leq NF_{rad} \leq \frac{2 \times L^2}{\lambda} \quad \text{radiating near-field boundaries} \qquad \text{(equation B.2)}$$

$$FF \approx \frac{2 \times L^2}{\lambda} \quad \text{far-field boundary} \qquad \text{(equation B.3)}$$

where

NF_r	=	the reactive near-field region (metres)
NF_{rad}	=	the radiating near-field region (metres)
FF	=	the far-field region (metres)
λ	=	the wavelength (metres)
L	=	the largest dimension of antenna (metres)

Note: For a wire antenna where the antenna dimension is small compared to the wavelength ($\lambda > 10L$), the radiating near-field does not exist.

B.2. Far-Field Power Density Calculation Method

In the far-field region, the power density for both aperture and wire antennas can be calculated using the Friis Free-Space equation provided below. All power density levels are calculated using the maximum output power of the transmitter and the antenna gain relative to the 3 dB beam width of the main beam lobe.

$$PD = \frac{P_T \times G}{4 \times \pi \times d^2} \qquad \text{(equation B.4)}$$

where

PD	=	The power density (watts/metre^2)
P_T	=	The average or peak transmitter output power (watts)
G	=	The numerical antenna gain (unitless)
D	=	The distance or range from the antenna (metres)

The electric field strength is related to the power density by the following equation:

$$E = \sqrt{PD \times Z_0} \qquad \text{(equation B.5)}$$

where

E	=	The maximum electric field strength (V/m-rms)
Z_0	=	The intrinsic impedance of free space (120π or approximately 377 Ω)
PD	=	The power density (watts/metre^2)

In the near-field region, an antenna's electric and magnetic fields do not exhibit a constant ratio of 120π (approximately 377 Ω), the intrinsic impedance of free space. Depending on the source antenna's terminal voltage, impedance and driver current, the electric and magnetic fields at one point will vary at different rates where one field becomes dominant. As the far-field region is approached, the ratio of the electric and magnetic fields begins to approximate 377 Ω; variation between the fields becomes less and any dominance of one field is reduced. Although there are variations in the impedance within the near-field, equation B.5 was used as the convention to convert power density levels to electric field strength levels.

B.3. Peak/Average Power Calculation

Typically, communication systems are capable of modulation techniques such as Amplitude Modulation (AM), Frequency Modulation (FM) and Pulse-Code Modulation (PCM), or Continuous Wave (CW). In order to determine the Root Mean Squared (RMS) peak power for FM and PCM, a worst-case approach is used where the peak power is equal to the unmodulated carrier peak power. However, the peak envelope power of a 100 percent modulated AM signal is twice the carrier peak power and, therefore, is used to provide the worst-case scenario from AM signals. Also, the duty cycle of a CW signal equals unity and the average and peak RMS power are the same. The aforementioned rationale was used because of the randomly changing nature of true peak power over a specific interval.

Pulse-modulated signals, typically from radar transmitters, have differences between peak and average rms power. The average power is determined by the ratio of time on to time off over an interval. This time on/off ratio is the duty cycle and can be calculated (equation B.6). The average power can be calculated by the product of peak power and duty cycle as shown (equation B.7).

$$d.c. = \frac{pw}{pri} \quad \text{or} \quad d.c. = pw \times prf \qquad \text{(equation B.6)}$$

$$P_a = P_p \times d.c. \qquad \text{(equation B.7)}$$

where

d.c	=	The duty cycle (unitless)
pw	=	The pulse width (sec)
pri	=	The pulse repetition rate interval (sec)
prf	=	The pulse repetition rate frequency (Hz)
P_a	=	The average power (watts)
P_p	=	The peak power (watts)

B.4. Near-Field Power Density Calculation Method

The method used to calculate the power density along the propagation axis of a large aperture circular or rectangular antenna source in the “radiating” near-field region (Fresnel region) is provided in **Clauses B.4.1**and **B.4.2** Antenna gain and beamwidth are both degraded in the Fresnel region; therefore, the far-field power density equation (B.4) is modified to account for the near-field antenna correction factor (NCF).

The near-field power density calculation method used in calculating the NATO EMEs was derived from NAVSEA OP 3565 [A16], NAVSHIPS 0900-006-5250 [A17] and NAVSHIPS 0900-006-5240 [A18]. It is based on a consistent approach for estimating the antenna illumination and calculating/verifying the antenna efficiency; and does not consider the following: mismatch (Voltage Standing Wave Ratio) loss derived from the reflection at the antenna feed port because of impedance mismatch, RF losses between the antenna and the antenna feed point, spillover loss and phase error loss resulting from the fact that the antenna aperture is not a uniform phase surface. **Clause B.4.1** provides the method for calculating the power density for a circular aperture in the near-field and **Clause B.4.2** provide the method for calculating the power density for a rectangular aperture in the near-field. The two methods are slightly different in that the rectangular aperture method computes a gain reduction value for the antenna whereas the circular method computes a near-field correction factor that includes both a gain reduction value as well as the space loss value.

B.4.1 Near-Field Power Density Calculation Method for Circular Aperture Antenna

The equation used to calculate the power density along the propagation axis of a large aperture circular antenna source in the "radiating" near-field region is provided in equation B.8. The antenna gain and beamwidth are both degraded in the Fresnel region; therefore, the far-field power density equation (B.4) is modified to account for the near-field antenna correction factor (NCF_{circ}).

$$PD = \frac{P_T \times G}{4 \times \pi \times d_{ff}^{\ 2}} \times NCF_{circ} \qquad \text{(equation B.8)}$$

where

PD	=	The average or peak power density (watts/metre^2)
P_T	=	The average or peak transmitter output power (watts)
G	=	The numerical antenna gain (unitless)
NCF_{circ}	=	The near-field correction factor (unitless)
d_{ff}	=	The distance from antenna to the far-field using equation B.3 (metres)

Steps for computing the near-field power density:

a. Compute the power density at the far-field boundary using the Friis transmission formula

b. Calculate the illumination constant (R) using equation B.9

c. Estimate the antenna illumination and antenna factor using the illumination constant and **Table 259-B1**

d. Check to see if the antenna illumination is reasonable by computing the antenna efficiency (K) using equation B.10

e. Calculate the normalized distance from the antenna and then determine the NCF using the appropriate antenna illumination in **Figure258-B1**

f. Multiple the power density (at far-field boundary) computed in step (a.) by the NCF determined in step (e.).

The following provides the details for calculating the near-field correction factors for the Fresnel region of a circular aperture antenna. As stated above, the near-field correction factor depends on the type of antenna illumination and the distance from the antenna. If the antenna illumination is not known, it can be estimated by the following method. First, calculate the illumination constant (R) using equation B.9.

$$R = 5.817 \times 10^{-5} \times (f) \times (BW) \times (L) \qquad \text{(equation B.9)}$$

where

R	=	Constant for estimating illumination
f	=	Frequency in megahertz (MHz)
BW	=	Beamwidth in degrees (horizontal or vertical) at 3 dB points
L	=	diameter of circular antenna or largest horizontal or vertical dimension of rectangular antenna in metres (m)

After calculating R as shown in equation B.9, the antenna illumination can be estimated from **Table 258-B1**.

Note; Illuminations above $(1-r^2)^4$ are purposely omitted since the gain reduction in the Fresnel region would be almost negligible.)

Table 258-B1 Circular Aperture Antenna Illuminations $(1-r^2)^\rho$

Limits of R	Estimated Illumination	Po	Antenna Illumination Factor (F)
1.02 to 1.27	Uniform	0	1.00
1.27 to 1.47	$(1-r^2)$ Taper	1	0.75
1.47 to 1.65	$(1-r^2)^2$ Taper	2	0.56
1.65 to 1.81	$(1-r^2)^3$ Taper	3	0.44
> 1.81	$(1-r^2)^4$ Taper	4	0.36

When the illumination constant (R) is determined to be borderline between two orders of illumination (**ρ**), the higher order is selected because it will produce the maximum field strength. However, the antenna efficiency should be checked to determine if it is reasonable for this antenna type and illumination using equation B.10. Should the higher order illumination cause the antenna efficiency to be too high then the next lower order should be selected. An antenna efficiency (K) within the limits of 0.3 and 0.9 is considered reasonable.

$$K = \frac{G(\lambda^2)}{4\pi(A)(F)} \qquad \text{(equation B.10)}$$

where

K	=	Antenna efficiency (unitless)
G	=	Far-field antenna gain (unitless)
A	=	Antenna aperture area (square metres)
λ	=	Wave length (metres)
F	=	Antenna illumination factor (Derived from **Table 258-B1**)

Once the illumination factor (F) has been determined and the efficiency verified to be reasonable, then the appropriate gain correction factor can be applied to calculations in the near-field for a circular antenna of a specific illumination type.

Now that the illumination type (ρ = 0,1,2,3,4) has been determined, the near-field correction factor can be selected by calculating the normalized distance from the antenna using equation B.11 and then selecting the appropriate correction factor (NCF) based on the illumination type from **Figure 258-B1**.

$$x = \frac{d}{2\times(L^2/\lambda)} \qquad \text{(equation B.11)}$$

The near-field power density level at given distance (*d*) from the antenna can be determined by computing the power density at the far-field distance and multiplying this value by the correction factor (NCF).

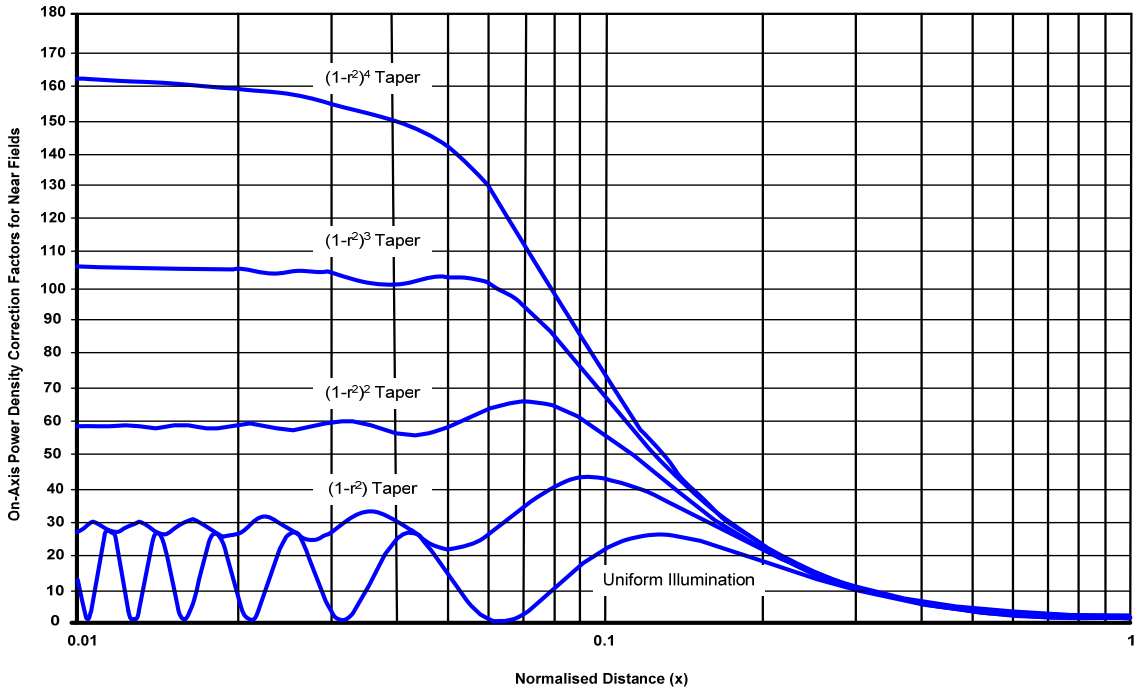

Figure 258-B1 Near-Field Correction Factors for Circular Aperture Illumination

B.4.2 Near-Field Power Density Calculation Method for Rectangular Aperture Antenna

The equation used to calculate the power density along the propagation axis of a large aperture rectangular antenna source in the "radiating" near-field region is provided in equation B.12. The antenna gain and beamwidth are both degraded in the Fresnel region; therefore, the far-field power density equation (B.4) is modified to account for the near-field antenna gain reduction factor (NGF_{rect}).

$$PD = \frac{P_T \times G}{4 \times \pi \times d^{\,2}} \times NGF_{rect} \qquad \text{(equation B.12)}$$

where

PD	=	The average or peak power density (watts/metre^2)
P_T	=	The average or peak transmitter output power (watts)
G	=	The numerical antenna gain (unitless)
NGF_{rec}	=	The near-field gain reduction factor (unitless)
d	=	The distance from antenna (metres)

Steps for computing the near-field power density:

a. Compute the power density at the specific distance of concern using the Friis transmission formula

b. Calculate the illumination constant (R) for both the horizontal and vertical plane using B.9

c. Estimate the antenna illumination and antenna factor using the illumination constant and **Table 258-B2.**

d. Check to see if the antenna illumination is reasonable by computing the antenna efficiency (K) using equation B.10

e. Determine the NGF_{rect} using the distance from the antenna (in wavelengths) and antenna length (in terms of wavelength using the appropriate antenna illumination graph from **Figures 258-B2** through **258-B6**.

f. Multiple the power density (at the distance of concern) computed in step (a.) by the NGF_{rect} determined in step (e.).

The following provides details for calculating the near-field gain reduction factors NGF_{rect} for the Fresnel region of a rectangular aperture antenna. As stated above, the near-field gain reduction factor depends on the type of antenna illumination and the distance from the antenna. A gain reduction factor for both the horizontal as well as the vertical axis/plane must be determined in order to compute the power density for a rectangular antenna. If the antenna illuminations are not known for each axis/plane, they can be estimated by the method described in **Clause B.4.1**. First, calculate the illumination constant (R-value) using equation B.9 and determine the illumination type and factors (F_h and F_v) using equation B.13 and **Table 258-B2** for each axis/plane. Illuminations above $\cos^4$ are purposely omitted since the gain reduction in the Fresnel region would be almost negligible.

Table 258-B2 Rectangular Aperture Antenna Illuminations

Limits of R	Estimated Illumination	F_h and F_v
0.88 to 1.2	Uniform	1.00
1.2 to 1.45	Cos	0.810
1.45 to 1.66	$\cos^2$	0.667
1.66 to 1.93	$\cos^3$	0.575
1.93 to 2.03	$\cos^4$	0.515

When the illumination constant (R) using equation B.9 is determined to be borderline between two orders of illumination, the higher order is selected because it will produce the maximum field strength. However, the antenna efficiency should be checked to determine if it is reasonable for this antenna type and illumination using equation B.10.

$$F = (F_h \times F_v) \qquad \text{(equation B.13)}$$

where:

F = Illumination factor,

F_h = Horizontal illumination factor,

F_v = Vertical illumination factor.

Should the higher order illumination cause the antenna efficiency to be too high then the next lower order should be selected. An antenna efficiency (K) within the limits of 0.3 and 0.9 is considered reasonable. Now that the illumination type (uniform, cos, $\cos^2$, $\cos^3$, $\cos^4$) has been determined, the near-field gain reduction value can be selected by normalizing the distance from the antenna and the antenna dimension (L_h and L_v) in terms of wavelength (λ).

$$\lambda = \frac{300}{f} \qquad \text{(equation B.14)}$$

where:

f = Frequency in megahertz (MHz)

$$x_{rect} = \frac{d}{\lambda} \qquad \text{(equation B.15)}$$

Figures 258-B2 through **258-B6** provide graphical curves of the gain reduction [in decibels (dB)] versus distance (x_{rect}) from the antenna (in terms of wavelength) relative to the antenna dimension (in terms of wavelength) for each of the illumination types (uniform, cos, $\cos^2$, $\cos^3$, $\cos^4$). Define the aperture dimensions (a_h and a_v) normalised to wavelength as:

$$a_h = \frac{L_h}{\lambda}, \qquad a_v = \frac{L_v}{\lambda} \qquad \text{(equation B.16)}$$

Once the two appropriate gain reduction values have been selected for each plane, the combined near-field gain reduction factor can be computed. To do this, add the two gain reduction values and convert the units from dB to a numerical value. The near-field power density level at given distance (d) from the antenna can be determined by computing the power density and multiplying this value by the near-field gain reduction factor (NGF_{rect}) using equation B.13 and B.12.

$$NGF_{rect} = 10^{\frac{NGR_v + NGR_h}{10}} \qquad \text{(equation B.17)}$$

Where: NGR_v and NGR_h are the near field gain reductions for vertical and horizontal axes in dB's derived from **Figures 258-B2** through to **258-B6**

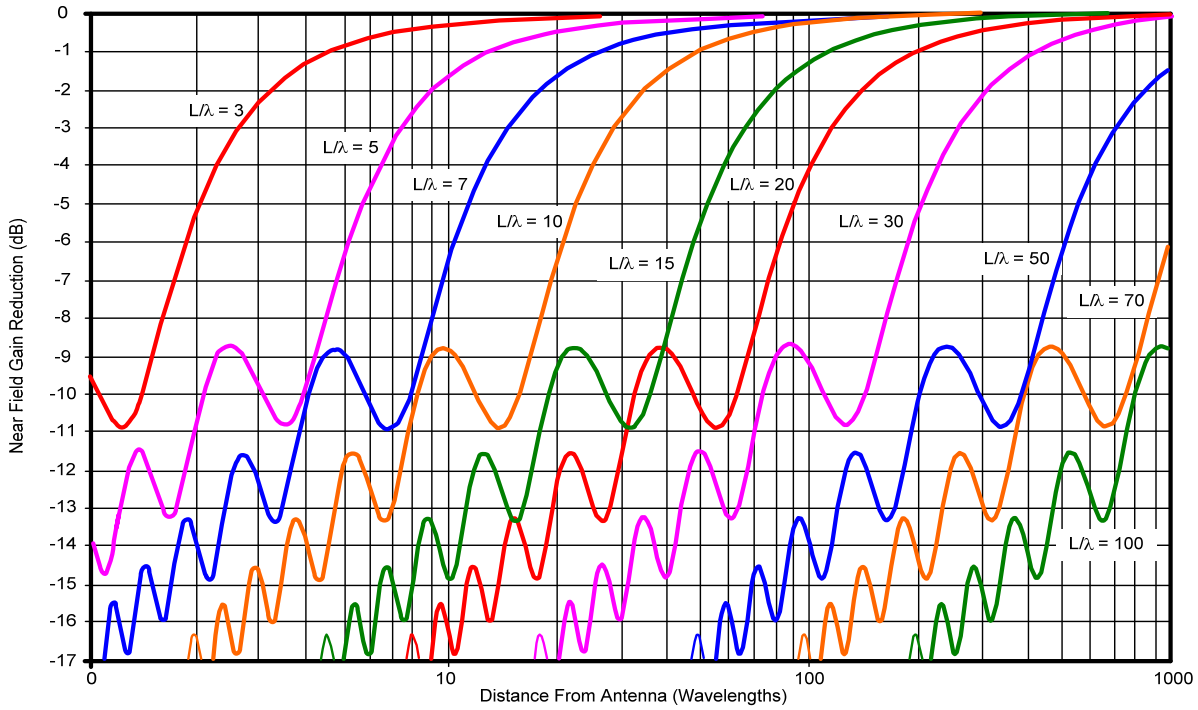

Figure 258-B2
Fresnel Region Gain Reduction for Uniform Illumination (Rectangular Aperture)

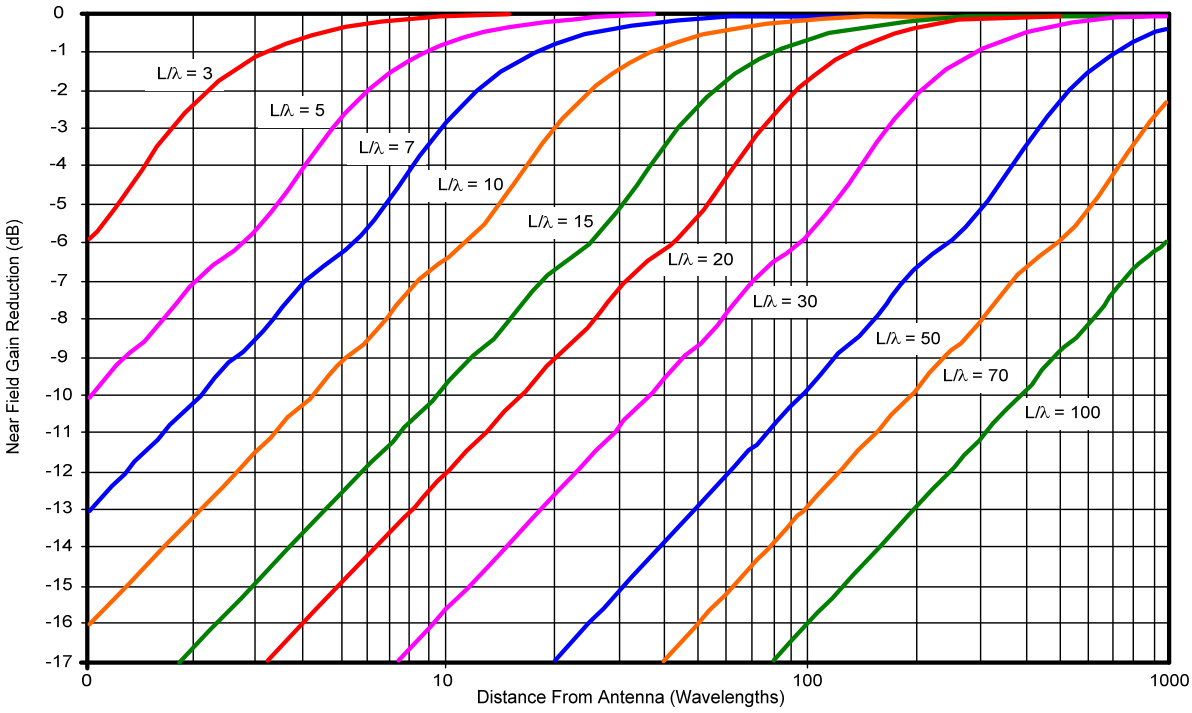

Figure 258-B3
Fresnel Region Gain Reduction for Cosine Illumination (Rectangular Aperture)

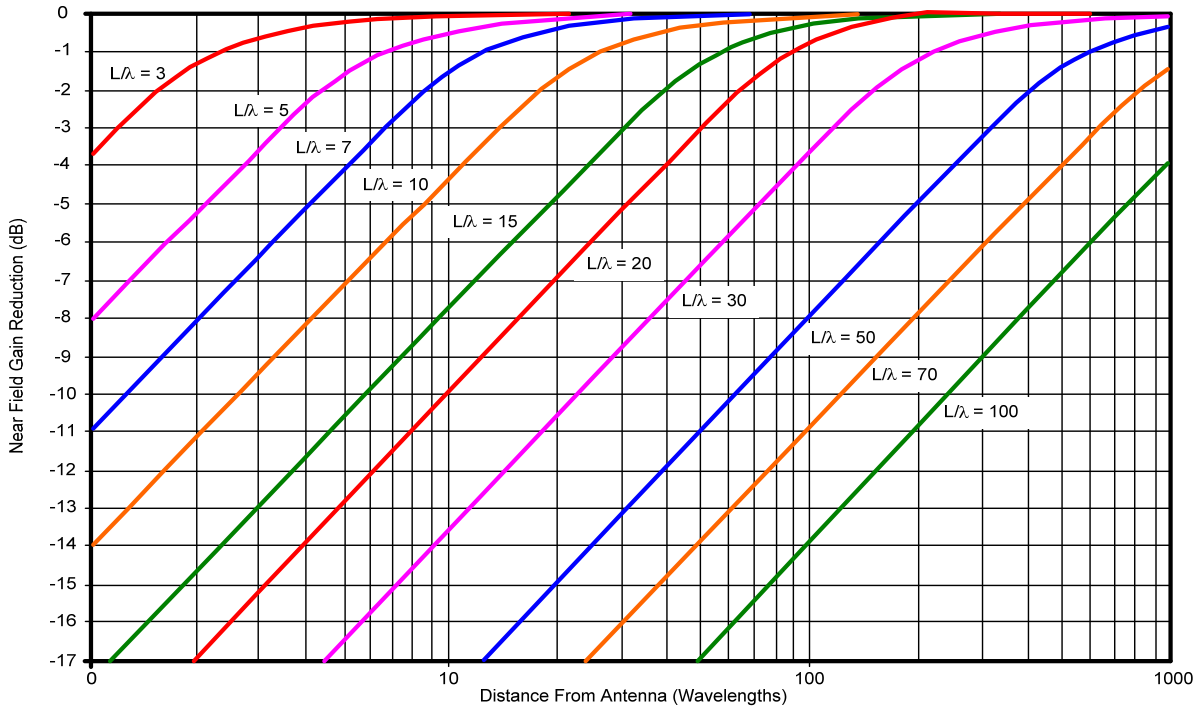

Figure 258-B4
Fresnel Region Gain Reduction for Cosine Square Illumination (Rectangular Aperture)

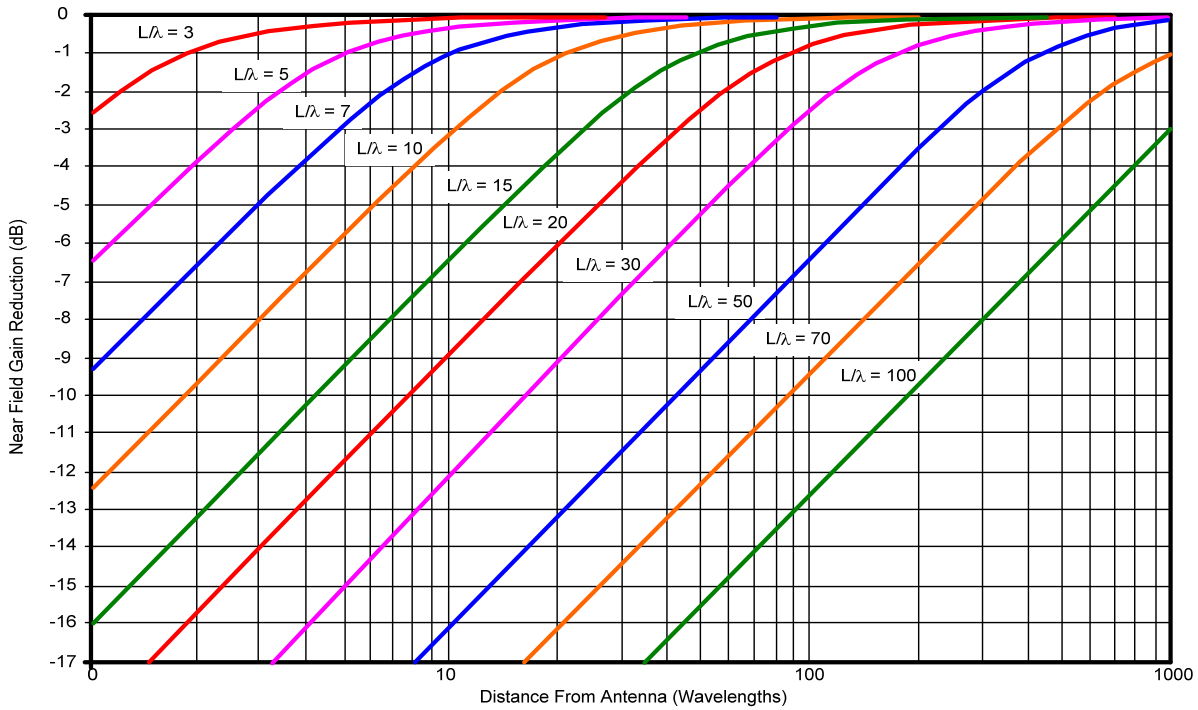

Figure 258-B5
Fresnel Region Gain Reduction for Cosine Cubed Illumination (Rectangular Aperture)

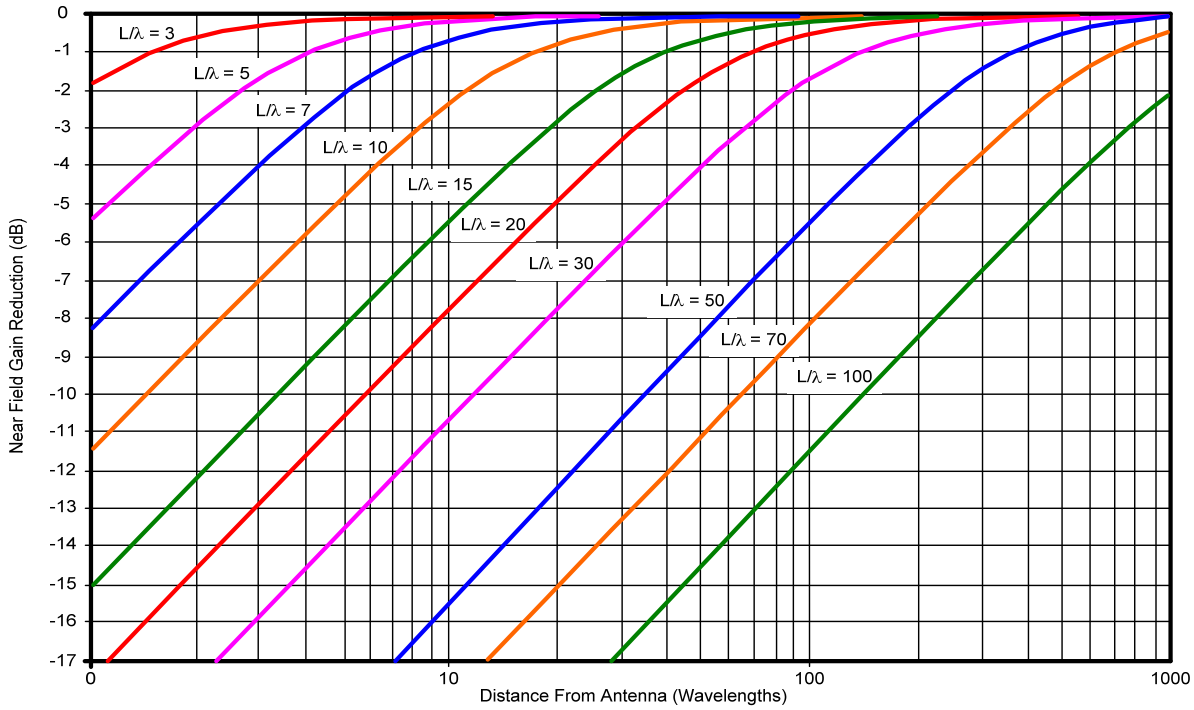

Figure 258-B6
Fresnel Region Gain Reduction for Cosine Fourth Illumination (Rectangular Aperture)

LEAFLET 259

INTRA-SYSTEM ELECTROMAGNETIC ENVIRONMENTS - ELECTRICAL POWER QUALITY

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LEAFLET 259

INTRA-SYSTEM ELECTROMAGNETIC ENVIRONMENTS - ELECTRICAL POWER QUALITY

1. GENERAL

This leaflet addresses the radio frequency (RF) conducted environments that may be encountered by materiel due to alternating current/direct current (AC/DC) power system disturbances when installed in weapon system platforms or land based communication-electronic facilities and shelters.

The objective of this leaflet is to ensure that the design and engineering of the required electrical power system architecture can meet acceptable performance levels in order to protect military communications and electrical/electronic equipment.

1.1. Distinction Between Electrical Power Quality and EMI/C

Electrical power quality is not always associated as part of an electromagnetic environmental effects (E3) framework, which typically focuses on controlling the effects of electromagnetic interference (EMI). However the two are very closely linked and should not be managed in isolation from each other.

The EMI test procedures of AECTP 501 [A1] address electric power quality issues from the perspective of controlling EMI (specifically conducted emissions) from AC/DC power leads and cables and signal leads and cables at the equipment level. These tests include both conducted emissions testing (see **Clause 4** for a detailed listing) and radiated emissions testing (NRE02) at the higher frequencies.

However this leaflet addresses electrical power quality issues from an interface perspective. That is, the control of additional electrical disturbances that can occur when electrical power terminals are shared between equipment or between equipment and the weapon system platform. These additional electrical disturbances are not entirely addressed by [A1] requirements. Where necessary, additional control may be needed to address phase load balancing and current load balancing at those terminals; the need for electrical isolation and methods to control ground loops and common mode interactions, all from an interconnection perspective.

1.2. Impact to NATO Interoperability

Addressing electrical power quality issues is a necessary condition to support interoperability within the North Atlantic Treaty Organisation (NATO). There are many situations where Nations share or require the provision of electrical power to sustain operation of their weapon system platforms during operational missions. For example, the aircraft of one nation may require connection to electrical support equipment after landing at an airfield of another nation. A command post or tank of one nation may be supplied electrical power by the generator of another nation during a Joint NATO deployment.

1.3. Impact to Operations

Military operations increasingly centre about Information Operations and Information Management. This has heralded a massive transformation from the mechanized military systems and platforms of the past to systems that are now fully electronic and computerized. Typical equipment construction is now based on sensitive circuits that are required to operate with ever decreasing electrical Noise Margins. In addition, circuit designs are predominantly digital and therefore susceptible to broadband EMI, disturbances and distortions. Switching effects, whether as a result of equipment turn ON/OFF, the use of switch mode power supplies or of ever-increasing clock speeds, greatly enhance the probability of undesired broadband signals being generated and present. This has led to militarised equipment being more susceptible to changes in the steady state power condition and to EMI in general. It is increasingly necessary for the electrical power system to be stable, reliable and without distortions or disturbances. In summary, electrical power quality and the reliability of supply are crucial for military operations.

2. CHARACTERISTICS OF THE ENVIRONMENT

2.1 Environmental Description

Electrical power systems operate with a constant line voltage, supplying power to a wide range of electrical loads. Weapon system platforms require the provision of electrical power that is free of interruptions, sags, surges and harmonic waveform distortions. The need exists to define acceptable power system operating environments to achieve improved and effective equipment operating efficiencies and reduced EMI. Power system disturbances often appear as transient voltage or current disturbances or as waveform distortions, and can be caused by lightning surges, load switching, power system faults, non-linear loads and electromagnetic pulse (EMP).

2.2. Differential Mode versus Common Mode Interference

Power system disturbances are often classified by their coupling mode into or out of electrical equipment, as either Differential (or Normal) Mode or Common Mode Interference. These are described as follows:

a. Differential Mode Interference causes the potential of one side of the transmission path to be changed relative to the other side, and

b. Common Mode Interference appears between both leads and a common reference plane (ground). This causes the potential of both sides of the transmission path to be changed simultaneously and by the same amount relative to the common reference plane (ground).

2.3. Harmonic Spectrums

Harmonic currents distort the AC waveform through the source and distribution system impedance. There are several undesirable effects of excessive harmonic voltage distortion. The distorted voltage can cause problems in poorly designed electronic equipment, increased power losses in motors and other magnetic devices, reduced torque in high-efficiency induction motors or excitation of undesirable vibration modes through electrical-mechanical couplings. Furthermore, a distorted waveform can act as a driving source for hull currents in ships. (See **Clause 2.5**.) Similar problems can be created by low frequency

harmonic line-currents generating magnetic fields which couple into other lines or equipment.

2.4. Damped Sine Waves

Damped sine waves (sometimes complex combinations) are a common occurrence on platforms from both external stimuli, such as lightning and EMP and from platform switching phenomena. Waveforms appearing on cables can be due to the cable itself resonating or due to voltage and current drives resulting from other resonances on the platform. Transients caused from switching actions within the platform can also result in similar waveforms [A1].

2.5. Structure (Hull) Currents

Structure currents can cause problems with sensitive equipment, particularly in ships. Although rectification currents appear to be the major source of structure currents, switching-frequency harmonics, if present, will also cause structure currents.

2.6. Probability of Occurrence

Ideally, electrical power would be distributed to equipment loads at a constant voltage and frequency with system impedances that are balanced and equal at all circuit phases and branches. Different phases of strategic and tactical operations necessarily require different equipment to come into use and under various operating modes as the operation or operational scenario evolve. Electrical power system and waveform disturbances of weapon system platforms and communication-electronic facilities can be expected to occur on a near continuous basis. The need for electrical power quality requirements arises from the recognition that the previously mentioned ideal conditions do not exist in real-world military installations.

2.7. Adverse Impacts

Adverse impacts to weapon system platforms and communication-electronic facilities and shelters are produced as a result of power system disturbances. They can appear in the form of poor electrical power stability, waveform distortions and inadequate voltage regulation. Examples include sags, surges, dropouts (ie: blackouts) and interruptions (ie: brownouts) resulting from changes in the power system impedance as new loads are connected or by disconnection of existing electrical loads. Adverse impacts can also appear as transients (including damped sinusoids), or ripples, or in the form of changes to the power factor.

The stability of line currents can be affected due to equipment switching which produces inductive changes to the power system impedance. This can happen when inductive loads such as motors, solenoids or relays are switched ON or OFF.

Other adverse impacts can appear as:

a. *Differential Mode Interference* due to changes in user electrical loads,

b. *Common Mode Interference* due to common mode voltages and impedances,

c. Harmonic Spectrums due to imperfect sources and electrical power supply switching and

d. Structure currents on ship hulls due to improper control of load and currents.

3. POWER QUALITY STANDARDS

3.1. General

Power Quality Standards (ie: allowable voltage distortion standards) are used to govern the characteristics of output power. They have evolved taking into account factors such as those described above. These standards largely centre on four power system parameters that serve as a framework to classify the power system's operating environment. They include:

a. frequency variations,

b. amplitude variations,

c. waveform variations and

d. symmetry.

Examples of Power Quality Standards to control the supply voltage within specified limits for weapon system platforms and utilisation equipment include:

a. STANAG 1008 [A2]

b. STANAG 2601 [A3]

c. STANAG 3456 [A4]

d. STANAG 3457 [A5]

e. STANAG 4133 [A6]

f. STANAG 4134 [A7]

g. STANAG 4135 [A8]

3.2. The Operational Versus Test Environment

Power system characteristics defined by the above standardization agreements (STANAGs) serve as both a description of the electrical power system operational environment to be encountered by platforms, facilities and utilisation equipment and of the test environment. As such, this leaflet does not detail operating environments or test environments as they are one and the same and are adequately addressed by the above STANAGs.

4. TEST SELECTION

Tests can be performed to verify the requirements of the above STANAGs.

AECTP 500 – Leaflet 501 also provides test procedures intended for utilisation equipment and subsystems that may be used to simulate transient disturbances and waveform distortions introduced onto the power system, as follows:

a. NCS01 Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz,

b. NCS02 Conducted Susceptibility, Control and Signal Leads, 20 Hz to 50 kHz,

c. NCS06 Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz,

d. NCS07 Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 400 MHz,

e. NCS08 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation,

f. NCS09 Conducted Susceptibility, Damped Sinusoid Transients, Cables and Power Leads, 10 kHz to 100 MHz,

g. NCS10 Conducted Susceptibility, Imported Lightning (Aircraft) and

h. NCS11 Conducted Susceptibility, Low Frequency Power Leads (Sea Systems)

ANNEX A

REFERENCES

A1	AECTP 501	Electrical/Electromagnetic Environmental Tests and Verifications, Equipment and Sub-System Tests
A2	STANAG 1008	Characteristics of Shipboard Electrical Power Systems in Warships of the North Atlantic Navies
A3	STANAG 2601	Standardization of Electrical Systems in Tactical Land Vehicles
A4	STANAG 3456	Aircraft Electrical Power System Characteristics
A5	STANAG 3457	Ground Electrical Power Supplies for Aircraft
A6	STANAG 4133	Method of Specifying Power Supplies, Standard Types of Electrical Power.
A7	STANAG 4134	Electrical Power Characteristics of Rotating 28 Volt DC Generating Sets
A8	STANAG 4135	Electrical Characteristics of Rotating Alternating Current Generators

Other Relevant National/International Standards

STANAG 4074	Auxiliary Power Unit Connections for Starting Tactical Land Vehicles
STANAG 4334	Electrical Power Conditioners, Solid State, General Purpose for Interoperability
STANAG 7039	Test Procedures to Ensure Compatibility of Equipment with Aircraft Electrical Power Systems
DEFSTAN 61-5	Electrical Power Supply System Below 650 Volts
MIL-STD-704	Aircraft Electrical Power Characteristics
MIL-STD-1275	Characteristics of 28 Volt DC Electrical Systems in Military Vehicles
ISO 7637	Road Vehicles – Electrical Disturbances from Conduction and Coupling