

Australian/New Zealand Standard™

Radiofrequency fields

Part 2: Principles and methods of measurement and computation—3 kHz to 300 GHz



AS/NZS 2772.2:2016

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee TE-007, Human Exposure to Electromagnetic Fields. It was approved on behalf of the Council of Standards Australia on 31 May 2016 and by the New Zealand Standards Approval Board on 2 June 2016.
This Standard was published on 24 June 2016.

The following are represented on Committee TE-007:

Australian Centre for Radiofrequency Bioeffects Research
Australian Communications and Media Authority
Australian Industry Group
Australian Mobile Telecommunications Association
Australian Radiation Protection and Nuclear Safety Agency
Communications, Electrical and Plumbing Union—Electrical Trades Division
Department of Defence (Australian Government)
Electrical Compliance Testing Association
Electricity Engineers Association of New Zealand
Local Government New Zealand
Ministry of Health, New Zealand
National Measurement Institute
National Radiation Laboratory, New Zealand
New Zealand Telecommunications Forum
Victoria University of Wellington, New Zealand
Wireless Institute of Australia

Additional Interests:

Telstra Corporation

Keeping Standards up-to-date

Standards are living documents which reflect progress in science, technology and systems. To maintain their currency, all Standards are periodically reviewed, and new editions are published. Between editions, amendments may be issued. Standards may also be withdrawn. It is important that readers assure themselves they are using a current Standard, which should include any amendments which may have been published since the Standard was purchased.

Detailed information about joint Australian/New Zealand Standards can be found by visiting the Standards Web Shop at www.saiglobal.com or Standards New Zealand web site at www.standards.govt.nz and looking up the relevant Standard in the on-line catalogue.

For more frequent listings or notification of revisions, amendments and withdrawals, Standards Australia and Standards New Zealand offer a number of update options. For information about these services, users should contact their respective national Standards organization.

We also welcome suggestions for improvement in our Standards, and especially encourage readers to notify us immediately of any apparent inaccuracies or ambiguities. Please address your comments to the Chief Executive of Standards Australia or the New Zealand Standards Executive at the address shown on the back cover.

This Standard was issued in draft form for comment as DR AS/NZS 2772.2:2015.

Australian/New Zealand Standard™

Radiofrequency fields

Part 2: Principles and methods of measurement and computation—3 kHz to 300 GHz

Originated in Australia as AS 2772.2—1988.
Jointly revised and designated as AS/NZS 2772.2:2011.
This edition AS/NZS 2772.2:2016.

COPYRIGHT

© Standards Australia Limited/Standards New Zealand

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of the publisher, unless otherwise permitted under the Copyright Act 1968 (Australia) or the Copyright Act 1994 (New Zealand).

Jointly published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001 and by Standards New Zealand, PO Box 10729, Wellington 6011.

ISBN 978 1 76035 510 4

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee TE-007, Human Exposure to Electromagnetic Fields, to supersede AS/NZS 2772.2:2011.

The objective of the Standard is to specify commonly accepted processes for assessing compliance with the exposure limits of radiofrequency (RF) safety standards such as ARPANSA Standard RPS3 and New Zealand Standard NZS 2772.1. It includes methodologies for reliably assessing human exposures to radiofrequency electromagnetic fields by measurement or computation, which form part of any compliance assessment.

Significant changes incorporated in this edition include the following:

- (a) Calculation, reporting and application of uncertainty in RF exposure assessments.
- (b) Guidance on spatial averaging provided along with instrumentation selection and calibration for new technologies, such as 4G.
- (c) A review of the harmonization with other international standards, and new case studies relating to Wi-Fi and smart meters.

The term ‘informative’ has been used in this Standard to define the application of the appendices to which it applies. An ‘informative’ appendix is only for information and guidance.

CONTENTS

	<i>Page</i>
FOREWORD.....	5
SECTION 1 SCOPE AND GENERAL	
1.1 SCOPE.....	6
1.2 REFERENCED DOCUMENTS.....	7
1.3 DEFINITIONS.....	8
1.4 ACRONYMS AND SYMBOLS	16
SECTION 2 SUMMARY OF PROVISIONS	
SECTION 3 GENERAL ASSESSMENT PROCESSES	
3.1 GENERAL.....	19
3.2 ASSESSOR COMPETENCY	19
3.3 ASSESSMENT PROCESS OVERVIEW	20
3.4 DEFINITION OF ASSESSMENT TASK.....	20
3.5 DETERMINATION OF SOURCE AND PHYSICAL ENVIRONMENTAL CHARACTERISTICS	21
3.6 DETERMINATION OF APPLICABLE EXPOSURE LIMITS	22
3.7 PRELIMINARY ASSESSMENT	22
3.8 CHOICE OF ASSESSMENT METHOD (MEASUREMENT OR COMPUTATION)	23
3.9 ASSESSMENT BY MEASUREMENT	23
3.10 ASSESSMENT BY COMPUTATION	25
3.11 REPORTING OF RESULTS	26
SECTION 4 POST-PROCESSING	
4.1 GENERAL.....	28
4.2 SPATIAL AVERAGING FOR DEMONSTRATING COMPLIANCE.....	28
4.3 SIMULTANEOUS EXPOSURE TO MULTIPLE FREQUENCY FIELDS.....	29
4.4 EXTRAPOLATION	29
SECTION 5 CALIBRATION AND VALIDATION	
5.1 GENERAL.....	31
5.2 RADIOFREQUENCY TEST INSTRUMENT CALIBRATION REQUIREMENTS.....	31
5.3 CALIBRATION LABORATORY REQUIREMENTS	31
5.4 RECOMMENDED INTERVALS OF CALIBRATION.....	32
5.5 PERIODIC CHECKING OF INSTRUMENTATION.....	32
5.6 VALIDATION OF COMPUTATIONAL TOOLS.....	32
5.7 CHECKING AND REVERIFICATION OF COMPUTATIONAL TOOLS	33
SECTION 6 UNCERTAINTY ESTIMATION	
6.1 REQUIREMENT FOR UNCERTAINTY ANALYSIS.....	34
6.2 REPORTING OF ASSESSMENT RESULTS AND UNCERTAINTY ANALYSES	34
6.3 THE ROLE OF UNCERTAINTY IN COMPLIANCE ASSESSMENTS	34

APPENDICES

A RADIOFREQUENCY MEASUREMENT INSTRUMENTATION AND
DESIRABLE PERFORMANCE CHARACTERISTICS 36

B FIELD REGIONS 45

C MEASUREMENT 46

D UNCERTAINTY ESTIMATES 58

E RADIOFREQUENCY COMPUTATIONAL TOOLS 82

F FACTORS INFLUENCING MEASUREMENT ACCURACY 96

G OTHER HAZARDS AND SAFETY CONSIDERATIONS 100

H EXAMPLE RF MEASUREMENT OF AN RF WELDER 103

I EXAMPLE MOBILE TELEPHONE BASE STATION ASSESSMENT 106

J EXAMPLE REPORT MAXIMUM EXPOSURES FROM A HOME
WI-FI ROUTER 119

K EXAMPLE—AMI METER ELECTROMAGNETIC FIELD SURVEY 123

FOREWORD

The reliable evaluation of radiofrequency (RF) electric and magnetic field exposures and the subsequent assessment of compliance with relevant RF safety exposure standards are complex and specialized tasks. Users of this Standard should be aware that a full understanding of its content requires a well-developed knowledge of RF field theory and practice, and the potential hazards associated with exposure to RF fields. It also requires knowledge of the limitations of the measurement techniques, instrumentation and computational methods used.

For safety compliance assessments, the assessor should be aware of the exposure limits set out in the relevant RF safety standards such as ARPANSA Standard RPS3 or New Zealand Standard NZS 2772.1, and be in possession of appropriate skills, knowledge and understanding. Notwithstanding these requirements, this Standard will also be of use to anyone wishing to better inform themselves in this area.

STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

Australian/New Zealand Standard
Radiofrequency fields

Part 2: Principles and methods of measurement and computation—3 kHz to 300 GHz

SECTION 1 SCOPE AND GENERAL**1.1 SCOPE**

This Standard specifies requirements for, and provides guidance on, assessing compliance with the exposure limits of radiofrequency (RF) safety standards such as ARPANSA Standard RPS3 or New Zealand Standard NZS 2772.1. This includes methodologies for making an assessment (by measurement or computation) of human exposure to ambient RF fields and induced body currents in the frequency range of 3 kHz to 300 GHz.

This Standard also sets out processes for calculating the basic restrictions' quantities (such as specific absorption rate and induced current density) in the relevant standards, but does not address their measurement.

This Standard provides appropriate methodologies for measurement techniques and instrumentation selection, computational techniques and the determination of the uncertainty of exposure assessments and its use in assessing compliance with applicable exposure limits.

The assessment methodologies provided in this Standard may be applied for all types of RF exposure situations including exposure to—

- (a) leakage fields;
- (b) radiated fields; and
- (c) reactive fields.

NOTE: Leakage fields generally imply unintentional leakage of energy, whereas radiated fields are considered primarily to be intentionally radiated RF fields. Reactive fields are present in the immediate vicinity of all sources or re-radiating objects.

This Standard is applicable to the compliance assessment of RF exposures from most kinds of RF sources including—

- (i) broadcast installations;
- (ii) cellular base stations;
- (iii) radio-communications facilities;
- (iv) radar installations;
- (v) medical applications such as diathermy machines;
- (vi) industrial applications, including RF welders, heaters and induction heaters; and
- (vii) scientific applications.

This Standard may also be used as a guide for making low-level environmental exposure assessments in areas around RF sources listed above, as well as other sources such as Wi-Fi devices, smart meters and baby monitors.

NOTES:

- 1 Assessment methodologies may vary for different frequency ranges.
- 2 While this Standard applies to frequencies from 3 kHz to 300 GHz, it should be noted that most measurements are likely to be made at frequencies between 100 kHz and 60 GHz.

1.2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS ISO/IEC

17025 General requirements for the competence of testing and calibration laboratories

NZS

2772 Radiofrequency fields

2772.1 Part 1: Maximum exposure levels 3 kHz to 300 GHz

IEC

60215 Safety requirements for radio transmitting equipment

62209 Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices—Human models, instrumentation, and procedures

62209-1 Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)

62232 Determination of RF field strength and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure

62479 Assessment of the compliance of low-power electronic and electrical equipment with the basic restrictions related to human exposure to electromagnetic fields (10 MHz to 300 GHz)

EN

50383 Basic Standard for the Calculation and Measurement of Electromagnetic Field Strength and SAR Related to Human Exposure From Radio Base Stations and Fixed Terminal Stations for Wireless Telecommunication Systems (110 MHz – 40 GHz)

JCGM

100 Evaluation of measurement data—Guide to the expression of uncertainty in measurement

101 Evaluation of measurement data—Supplement 1 to the “Guide to the expression of uncertainty in measurement”—Propagation of distributions using a Monte Carlo method

ARPANSA

RPS3 Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields—3 kHz to 300 GHz

EURACHEM/CITAC Guide

Use of uncertainty information in compliance assessment

FCC

OET Bulletin 65 Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Health Canada

Safety Code 6: Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz

IEEE

Anderson, V., 'Estimating uncertainty in calculated ambient RF field levels for hazard assessments', Electromagnetic Compatibility Symposium Adelaide, 2009, pp 102–108

IEEE

C95.1 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

C95.3 IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz–300 GHz

1.3 DEFINITIONS

For the purpose of this Standard, the following definitions apply.

1.3.1 Antenna

A device that serves as a transducer between a guided wave (e.g. coaxial cable) and a free space wave, or vice versa. It can be used to emit or receive a radio signal.

1.3.2 Antenna aperture

An aperture in the plane surface near the antenna, perpendicular to the direction of maximum radiation, through which the major part of the radiation passes.

1.3.3 Antenna array

A system of antennas coupled together for the purpose of enhancing radiation in one or more directions, and reducing radiation in other directions.

1.3.4 Antenna directivity

The ratio of the transmitted RF radiation intensity in a specified direction to the radiation intensity averaged over all directions. The average radiation intensity is equal to the power radiated by the antenna, divided by 4π .

1.3.5 Antenna-effective aperture or effective area

In a given direction, the ratio of the power available at the terminals of a receiving antenna to the power flux density of a plane wave incident on the antenna from that direction, the wave being polarization-matched to the antenna.

NOTE: A plane wave of given power flux density and from a given direction is polarization-matched to an antenna if its polarization results in maximum power at the antenna terminals. The (total) effective aperture of an antenna may be decomposed into the sum of two partial-effective apertures referred to two specified, orthogonal polarizations.

For a lossless and perfectly matched antenna, the effective area in a given direction is equal to the square of the operating wavelength, times the gain in that direction, divided by 4π .

1.3.6 Antenna factor

The ratio of the electromagnetic field-strength incident upon an antenna to the voltage produced across an impedance connected to the antenna's terminals (e.g. $50\ \Omega$ input impedance of a receiver).

1.3.7 Antenna gain (absolute gain in a given direction)

The ratio of the radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. Gain does not include losses arising from impedance and polarization mismatches. The radiation intensity corresponding to the isotropically radiated power is equal to the power accepted by the antenna divided by 4π . If an antenna is without dissipative loss, then in any given direction its gain is equal to its directivity. If the direction is not specified, the direction of maximum radiation intensity is implied. The term ‘absolute gain’ is used in those instances where added emphasis is required to distinguish gain from relative gain (e.g. absolute gain measurements).

1.3.8 Antenna gain, partial (for a given polarization)

In a given direction, that part of the radiation intensity corresponding to a given polarization, divided by the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. The (total) gain of an antenna, in a specified direction, is the sum of the partial gains for any two orthogonal polarizations. The gain of aperture antennas, e.g. parabolic reflectors, is usually referenced to an isotropic radiator. The gain of linear antennas, dipoles and colinear arrays is usually referenced to a half-wave dipole.

1.3.9 Antenna lobe

A part of the antenna radiation pattern between adjacent minima.

1.3.10 Antenna pattern

The spatial distribution of a quantity that characterizes the electromagnetic fields (EMF) radiated by an antenna.

NOTES:

- 1 The distribution can be expressed as a mathematical function or as a graphic representation.
- 2 The quantities that are most often used to characterize the radiation from an antenna are proportional to, or equal to, power density, radiation intensity, directivity, phase, polarization and field strength.
- 3 The spatial distribution of the electromagnetic field characteristics over any surface is also an antenna pattern.
- 4 When the amplitude or relative amplitude of a specified component of the electric field vector is plotted graphically, it is called the amplitude pattern, field pattern or voltage pattern. When the square of either the amplitude or relative amplitude is plotted, it is called a power pattern.

1.3.11 Assessment

The level of exposure at a specific location to RF fields determined by measurement or calculation, expressed in the metric and in accordance with the methodologies specified for an exposure limit in the appropriate RF safety standard.

Compliance (or non-compliance) assessments refer to assessments conducted for the purpose of determining compliance (or non-compliance) with a specific exposure limit from an appropriate RF safety standard.

Environmental assessments are intended to be informative about the level of RF exposure in the general environment around an RF source, and usually entail assessed levels which are far below the relevant exposure limit.

1.3.12 Basic restrictions

The limiting values for human RF exposure expressed in metrics that closely match the biophysical interaction mechanisms of the known adverse health effects. Depending on the frequency of the fields, the metrics used to specify basic restrictions are: current density (J), specific absorption rate (SAR), incident power flux density (S_{inc}) and specific absorption (SA).

1.3.13 Compliance

Conformity with the exposure limits of RPS3 or NZS 2772.1, or other relevant exposure standard.

1.3.14 Compliance boundary

A boundary determined around a fixed or mobile RF source outside which exposure from the source has been assessed to comply with the relevant exposure limits (e.g. occupational or public).

1.3.15 Conductivity (σ)

The ratio of the conduction-current density in a medium to the electric field strength. The unit of conductivity is siemens per metre (S/m).

1.3.16 Contact current (I_c)

The rms magnitude (I_c) of RF current flowing through a biological medium (typically the wrist) when making point contact (e.g. fingertip) with an RF-energized surface. It is expressed in amps (A) or, more commonly, milliamps (mA).

1.3.17 Coverage interval

An interval containing the value of a quantity with a stated probability.

This Standard refers to one-sided and two-sided 95% coverage intervals for uncertainty distributions of RF assessments.

A two-sided 95% coverage interval is defined as a probabilistically symmetric range extending between lower and upper bounds and encompassing 95% of all expected values. When using the JCGM 100 approach for estimating uncertainty, the coverage interval is the expanded uncertainty for a coverage factor of 1.96 (assuming a normal uncertainty distribution).

A one-sided 95% coverage interval is defined as encompassing 95% of all expected values which either fall below the upper bound of the interval (for compliance assessments) or above the lower bound of the interval (for non-compliance assessments). The upper/lower bounds are located 1.64 standard deviations above/below the mean of a normally distributed uncertainty.

The coverage interval may be specified in terms of the assessment values or relative to the best estimate using dB notation, e.g.:

- (a) 1.5 to 6 W/m² which is equivalent to 3 W/m² $\pm$ 3 dB.
- (b) Up to 6 W/m² (for a one-sided coverage interval).
- (c) 4 W/m² +2 dB, -4 dB (for a two-sided asymmetric coverage interval).

1.3.18 Current density (J)

The magnitude (J) of a vector ($\mathbf{J}$) of which the integral over a given surface is equal to the rms current flowing through the surface. Current density is expressed in rms amps per metre squared (A/m²). It may be derived from the internal electric field strength (E_{int} , in rms volts per metre (V/m)) and the electrical conductivity of the medium (σ in siemens per metre (S/m)) by the following relation:

$$J = \sigma E_{\text{int}}$$

1.3.19 Current probe

A clamp-on 'loop' current transformer for measuring current through the ankle or wrist.

1.3.20 Decibel (dB)

A logarithmic unit of measurement that expresses the power magnitude of an RF exposure quantity relative to a specified level. Decibel may be a dimensionless unit or may be suffixed to indicate it is referenced to a base unit (e.g. dBm, referenced to 1 mW).

If L represents the ratio of an RF exposure value P_1 to another value P_0 , then the ratio expressed in decibels (L_{dB}) is calculated using the following formulas:

$$L_{dB} = 20 \log_{10} \left(\frac{P_1}{P_0} \right) \text{ for } P = E, H, I_c, I_L \text{ or } J$$

$$L_{dB} = 10 \log_{10} \left(\frac{P_1}{P_0} \right) \text{ for } P = E^2, H^2, I_c^2, I_L^2 \text{ or } J^2, S_{eq}, S_{inc}, \text{SAR and SA}$$

1.3.21 Diode

A semiconductor device having two terminals and exhibiting a non-linear voltage-current characteristic. In more restricted usage, a semiconductor device that has the asymmetrical voltage-current characteristic exemplified by a single p-n junction.

1.3.22 Dipole

A linear radiator, usually fed in the centre, producing a maximum of radiation in the plane normal to its axis. The length specified is the overall length. A dipole antenna is considered to be a metal radiating structure that supports a line-current distribution similar to that of a thin straight wire, a half-wavelength long, so energized that the current has a node only at each end.

1.3.23 Duty factor

The ratio of the pulse duration to the pulse period of a periodic pulse train. For example, a continuous transmission corresponds to a duty factor of 1.0. Also referred to as 'duty cycle'.

1.3.24 Electric field strength (E)

The rms magnitude (E) of the electric field vector ($\mathbf{E}$) expressed in volts per metre (V/m).

1.3.25 Electromagnetic energy (EME)

Electromagnetic energy (EME) and electromagnetic radiation (EMR) are terms used to interchangeably describe electromagnetic fields and waves, and the associated electromagnetic energy.

1.3.26 Electromagnetic field (EMF)

A time and space varying field associated with electric and magnetic forces on electric charges as described by Maxwell's equations. It can be characterized at any instant by electric ($\mathbf{E}$) and magnetic ($\mathbf{H}$) field vectors.

1.3.27 Electromagnetic radiation (EMR)

Electromagnetic radiation (EMR) and electromagnetic energy (EME) are terms used interchangeably to describe electromagnetic fields and waves, and the associated electromagnetic energy.

1.3.28 Equivalent plane wave power flux density (S_{eq})

An expression of the intensity of EMR in units of power flux density (W/m^2) assuming plane wave conditions.

For electric field strength (E in rms volts per metre (V/m)), it is calculated as—

$$S_{\text{eq}} = \frac{E^2}{377} P$$

For magnetic field strength (H in rms amps per metre (A/m)), it is calculated as—

$$S_{\text{eq}} = 377 \times H^2$$

1.3.29 Finite Difference Time Domain (FDTD)

A numerical analysis technique used for modelling computational electrodynamics. It employs finite differences as approximations to both the spatial and temporal derivatives that appear in Maxwell's equations to produce a solution in the time domain.

1.3.30 Finite Element Method (FEM)

A numerical technique for finding approximate solutions to boundary value problems for partial differential equations. The method involves connecting simple element equations over subdomains, to approximate a more complex equation over a larger domain.

1.3.31 Fixed RF source

A source of RF exposure that is established for use in a fixed location and which falls within the scope of RPS3 or NZS 2772.1.

1.3.32 Half-power beamwidth

In a plane containing the direction of the maximum lobe of the antenna pattern, the angle between the two directions in which the far-field power flux density is one-half the maximum value of the lobe.

1.3.33 Impedance (Z)

The ratio of the electric field strength (E in V/m) to the magnetic field strength (H) of a propagating electromagnetic wave—

$$Z = \frac{E}{H}$$

Impedance is expressed in ohms (Ω). The intrinsic impedance of a plane wave in free space, Z_0 , is equal to $120 \pi \Omega$ (approximately 377Ω).

1.3.34 Incident power flux density (S_{inc})

The power flux density of an RF exposure incident at the surface of the body. It does not include the contribution of reflected RF fields from the surface of the body.

1.3.35 Integral antenna

An antenna that is—

- (a) permanently attached to equipment; or
- (b) intended for direct attachment to a fixed connector on equipment, without the use of an external cable.

1.3.36 Internal electric field strength (E_{int})

The electric field strength induced inside a human body from RF exposure.

1.3.37 Isotropic

Having the same properties in all directions. Isotropic electric and magnetic field probes provide the same total field response (within tolerance) regardless of the orientation of the probe.

1.3.38 Limb current (I_L)

The rms magnitude of RF current flowing in a wrist or ankle that has been induced by an RF exposure. It is expressed in amps (A) or, more commonly, milliamps (mA) (see definition of contact current (I_c) in Clause 1.3.16).

1.3.39 Linearity

The extent to which a measuring instrument responds linearly to the measured input.

1.3.40 Localized SAR

The RF power absorbed in any 10 g of tissue in the shape of a cube divided by the 10 g mass of the cube, expressed in watts per kilogram (W/kg).

1.3.41 Magnetic field strength (H)

The rms magnitude (H) of the magnetic field vector (H), expressed in amps per metre (A/m).

1.3.42 Method of Moments (MoM)

A full-wave numerical computation method that discretises the integral equations of electromagnetic (EM) fields and solves Maxwell's equations in the frequency domain.

1.3.43 Microwaves

A commonly used term signifying radio waves in the frequency range from about 300 MHz upward.

1.3.44 Mobile or portable radio communication device

A radiocommunications transmitter that is established for use—

- (a) in motion, on land, water or in the air; or
- (b) in a stationary position at unspecified points on land, water or in the air.

Examples of such devices include mobile phones, wireless modems in laptops and vehicle-mounted, radio-communication systems.

1.3.45 Modulation

The process, or result of the process, in which some characteristic (phase, frequency or amplitude) of one wave is varied in accordance with another wave or signal.

1.3.46 Monte Carlo Method (MCM)

A repeated random sampling method for calculating uncertainties based on the propagation of distributions.

1.3.47 Multi-path transmission (radio propagation)

The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths.

1.3.48 Occupational limits

The occupational basic restrictions and reference levels defined in RPS3 or NZS 2772.1.

1.3.49 Permittivity (ϵ)

The ratio of the electric flux density in a medium to the electric field strength at a point. The permittivity of biological tissues is frequency dependent. Permittivity is expressed in farads per metre (F/m).

1.3.50 Phantom

A physical representation or numerical model that is intended to be representative of a defined human population group in the way that RF fields are induced in the body, or parts of the body. The important characteristics of phantoms are their shape and dielectric composition. Phantoms that are used for measured evaluations are usually composed of a homogeneous liquid material contained within a plastic shell. Phantoms used for numerical calculations may be homogeneous or heterogeneous.

1.3.51 Polarization (radiated wave)

That property of a radiated electromagnetic wave describing the time varying direction and amplitude of the electric field vector. Specifically, the figure traced as a function of time by the extremity of the E-field vector at a fixed location in space, as observed along the direction of propagation.

1.3.52 Power flux density (S)

The rate of flow of RF field energy through a unit area normal to the direction of the wave propagation, and is expressed in units of W/m^2 .

1.3.53 Poynting vector (S)

The vector cross product (S) of the electric (E) and magnetic (H) field:

$$\mathbf{S} = \mathbf{E} \times \mathbf{H}$$

1.3.54 Probe

The electric or magnetic field sensor of an RF field strength meter (see definition of RF field strength meter in Clause 1.3.63).

1.3.55 Public limits

The public basic restrictions and reference levels defined in RPS3 or NZS 2772.1.

1.3.56 Radiation

The propagation of radiofrequency electromagnetic field energy through space.

1.3.57 Radiofrequency (RF)

A frequency of electromagnetic field oscillations that is useful for radio transmission and which for the purpose of this Standard extends between 3 kHz and 300 GHz.

1.3.58 Reactive field

Electric and magnetic fields surrounding an antenna or other electromagnetic devices that result in storage rather than propagation of electromagnetic energy.

1.3.59 Reference levels

Human exposure limits derived from the basic restrictions such as prescribed in ARPANSA RPS3 and NZS 2772.1. They are provided as a simpler, but more conservative, alternative approach for determining compliance with the basic restrictions. Specifically, they include limits on instantaneous and time averaged exposure to ambient electric (E) and magnetic (H) fields, as well as induced body currents (limb and contact currents).

1.3.60 Re-radiated field

An electromagnetic field generated from currents induced in a passive secondary radiator which is excited by exposure to a primary source. Re-radiated fields can be considered as 'reflected' or, more correctly 'scattered fields'. The scattering object is sometimes called a 're-radiator' or 'secondary radiator'.

1.3.61 RF emitter

A fixed RF source, or a mobile or portable radio device.

1.3.62 RF exposure

The subjection of a person to ambient RF fields or contact with an RF energized conductor. RF exposure induces RF EMF inside a person, which is limited by the basic restrictions of exposure safety standards such as RPS3 or NZS 2772.1.

1.3.63 RF field strength meter

An RF survey instrument that is capable of measuring spatially localized electric and magnetic field strengths under near-field and far-field conditions. The instrument consists of a probe sensor with an antenna suitable for the wavelength under study, plus a means for transmitting information from the sensor to a suitable field-strength indicator.

1.3.64 RF personal monitor

An RF field monitoring device carried on a person that is designed to alert the user when ambient E or H field exposures exceed some designated levels, usually some fraction of the relevant exposure limits.

1.3.65 Root mean square (rms)

The square root of the mean of the square of a time variant function, $f(t)$, over a specified time period from t_1 to t_2 . It is derived by first squaring the function and then determining the mean value of the squares obtained, and taking the square root of that mean value:

$$f_{\text{rms}} = \sqrt{\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} f(t)^2 dt}$$

1.3.66 Specific Absorption (SA)

The energy absorbed per unit mass of biological tissue during an RF EMF pulse. It is expressed in units of joule per kilogram (J/kg). SA is the time integral of the specific RF energy absorption rate during a pulse.

1.3.67 Specific Absorption Rate (SAR)

The rate at which RF energy is dissipated in a defined mass of body tissue expressed in units of W/kg. It may be calculated at any point in the body from the internal magnitude of the electric field (E_{int} in rms V/m) by the following relation—

$$\text{SAR} = \frac{\sigma E_{\text{int}}^2}{\rho}$$

where σ is the electrical conductivity (S/m) and ρ is the mass density (kg/m^3) of the tissue.

In RPS3 and NZS 2772.1, SAR is specified for a 10 g mass (localized SAR) and for the whole body (whole body average SAR) (see definitions of localized SAR in Clause 1.3.40 and whole body average SAR in Clause 1.3.71).

1.3.68 Standing wave

A spatially periodic or repeating field pattern of amplitude maxima and minima that is generated by two equal-wavelength propagating waves travelling in different directions. For any component of the field, the ratio of the amplitude at one point to that at any other point does not vary with time.

1.3.69 Uncertainty

A parameter associated with a measurement or computation that characterizes the dispersion of the values that could reasonably be attributed to the measurand (e.g. value of field strength or attenuation). Uncertainty is generally quantified by the extent of its coverage interval.

1.3.70 Unperturbed field

The ambient RF field levels at the assessment point that are unperturbed by the presence of any person. Unperturbed fields are specified for the assessment of electric and magnetic reference levels and the power flux density basic restriction. All other exposure limits specified by RPS3 and NZS 2772.1 entail assessments that incorporate the interaction of the RF field with a human body.

1.3.71 Whole body average SAR (WBA SAR)

The RF power absorbed in the body divided by the mass of the body, expressed in watts per kilogram (W/kg).

1.4 ACRONYMS AND SYMBOLS

The following list of acronyms is a selection of those in common use in the context of this Standard.

95% CI	95% Coverage Interval of the uncertainty for an RF exposure assessment
ϵ	Permittivity (see definition)
λ	Wavelength (m)
ρ	Mass density (kg/m ³)
σ	Conductivity (see definition)
a	Semi-span of a probability distribution, such as rectangular, triangular or U-shaped distribution
CW	Continuous Wave
dB	Decibel (see definition)
D	Largest linear dimension across the effective aperture of the antenna
E	Electric field vector
<i>E</i>	Electric field strength (see definition)
E _{int}	Internal electric field vector
<i>E</i> _{int}	Internal electric field strength (see definition)
FM	Frequency Modulation
H	Magnetic field vector
<i>H</i>	Magnetic field strength (see definition)
HF	High Frequency—3 MHz to 30 MHz
<i>I</i> _C	Contact current (see definition)
<i>I</i> _L	Limb current (see definition)
J	Current density vector
<i>J</i>	Current density (see definition)
MCM	Monte Carlo Method
MF	Medium Frequency—300 kHz to 3 MHz
PM	Phase Modulation
RF	Radiofrequency (see definition)
rms	Root mean square (see definition)
<i>s.d.</i>	Standard deviation

S	Power flux density (see definition)
S_{inc}	Incident power flux density on the body (see definition)
S_{eq}	Equivalent plane wave power flux density (see definition)
SA	Specific Absorption (see definition)
SAR	Specific Absorption Rate (see definition)
u	Standard uncertainty calculated by the JCGM 100 methodology
U	Expanded uncertainty calculated by the JCGM 100 methodology
U_0	Uncertainty allowance for U_{up} as specified in Table 6.1
U_{up}	Upper bound (in dB) of a one-sided 95% coverage interval for an uncertainty distribution
UHF	Ultra High Frequency—300 MHz to 3 GHz
VHF	Very High Frequency—30 MHz to 300 MHz
WBA SAR	Whole Body Average SAR (see definition)

SECTION 2 SUMMARY OF PROVISIONS

The following is a summary of the provisions of this Standard, reproduced here for convenience, each of which needs to be read within the context of the specific clause reference:

- (a) The assessor, or assessment team, shall, as individuals or when considered together, have the necessary skills, knowledge and understanding to prepare for, carry out, report on and explain the components of the assessment, as described in this Standard (see Clause 3.2).
- (b) Due consideration shall be given to ensuring the safety of the assessor(s) and any other nearby persons during the evaluation of RF exposures. This would ordinarily entail approximate preliminary assessments of the anticipated exposures (see Clause 3.7).
- (c) RF measurement instruments shall be fit for purpose and calibrated (traceable to national standards) appropriately for the mode of use (see Section 5).
- (d) Computational tools shall be fit for purpose and appropriately validated for the circumstance being assessed (see Section 5).
- (e) RF exposure assessments shall be accompanied by a statement of estimated uncertainty (see Section 6).
- (f) The assessment task should be clearly defined and should be planned and executed in a manner that achieves its objectives (Section 3).
- (g) RF exposure assessments should be qualified by appropriate information on instrument settings (e.g. detection mode such as averaging, peak hold, CDMA decoding), computational assumptions and post-processing (e.g. spatial or temporal averaging, extrapolation to unmeasured conditions) (see Clause 3.11).
- (h) Documentation for the RF safety compliance assessment of an RF exposure scenario should contain the information detailed in Clause 3.11.

Examples which meet these provisions are given in the case studies in Appendices H and I.

SECTION 3 GENERAL ASSESSMENT PROCESSES

3.1 GENERAL

This Standard may be applied to a wide range of assessment scenarios. There may be variations between specific assessment scenarios, but the general assessment process that should be followed is essentially the same and is described in this Section.

Pre-inspection topics include defining the actual assessment task, determining source and environmental characteristics and conducting a preliminary evaluation of expected RF exposures.

Details of measurement types, instrument considerations, post-processing, calibration uncertainty and reporting are covered in greater depth in later Sections and Appendices.

3.2 ASSESSOR COMPETENCY

The performance of an RF exposure assessment by measurement or computation involves steps that each require certain knowledge, technical and mathematical skills and experience. These may be demonstrated in different ways, with reference to educational qualifications, generic or specific training, and relevant practical experience. This Standard does not prescribe any specific educational qualifications, but notes that many aspects of an RF exposure assessment require an understanding equivalent to that obtained through tertiary training in a scientific or technical discipline.

The level of understanding necessary depends on the details of the assessment performed. Generally, a higher level of mathematical and physical understanding would be required for a computational assessment than for a measurement. A higher level of relevant practical experience and familiarity with the source of the RF fields would be required for a near-field hazard assessment than for an environmental measurement at distance.

If the assessment is performed by a team, no single individual need have all the necessary skills. For example, the uncertainty analysis may be performed by someone with the necessary mathematical understanding not held by other members of the team.

In order that an assessment may be performed in accordance with this Standard, there shall exist appropriate records of educational qualifications, training, experience and other competencies to be able to demonstrate that the people involved are able to perform and understand the necessary processes.

In particular, assessor(s) should have—

- (a) a knowledge of relevant sections in this Standard;
- (b) a knowledge of relevant sections of the appropriate human exposure Standards, such as ARPANSA Standard RPS3 in Australia or NZS 2772.1 in New Zealand;
- (c) a knowledge of the calibration circumstances and status of all critical equipment used for measurement assessments;
- (d) an understanding of the uncertainty estimate and the conditions under which it may be applied; and
- (e) a knowledge of the radiation source and of the measurement equipment or computational tool.

3.3 ASSESSMENT PROCESS OVERVIEW

Figure 3.1 illustrates the general process that shall be followed when undertaking an RF exposure assessment. The following clauses provide an overview of each of the numbered stages of the process shown in Figure 3.1.

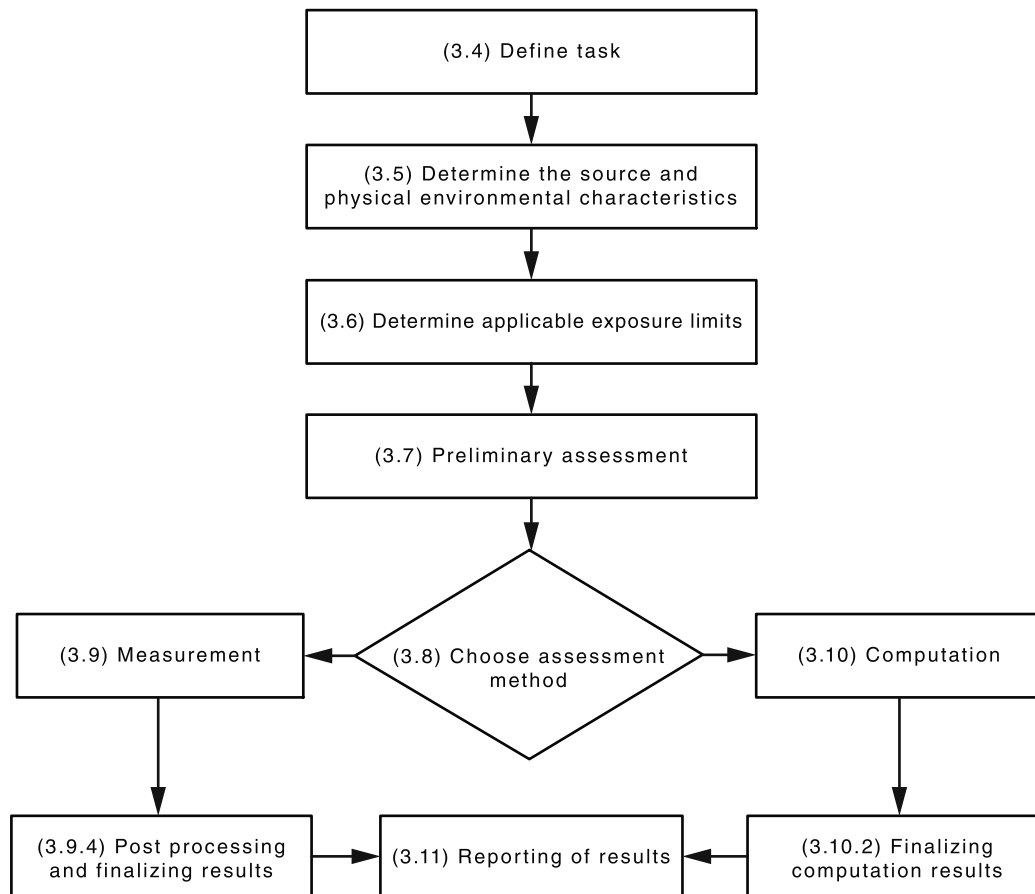


FIGURE 3.1 ASSESSMENT FLOWCHART

3.4 DEFINITION OF ASSESSMENT TASK

The first stage in an assessment is to determine the exact requirements of the client. To achieve this, information will usually be required from the key stakeholders, including the client, site operators, owners and tenants, if applicable. The assessment may include determination of compliance with regulations, OHS management and environmental surveillance or monitoring. For each aspect of an assessment task, an appropriate evaluation method that is fit for the purpose should be chosen.

Some of the factors that may influence the choice of assessment method include—

- (a) the acceptable uncertainty in the results, which may depend on the margin between compliance limits and expected values (see Clause 6.3);
- (b) regulatory requirements;
- (c) client requirements;
- (d) whether identification of the source of RF exposure is necessary;
- (e) access and safety matters; and

- (f) access to resources, RF survey instruments and computational tools, which are fit for purpose.

For example, at sites where compliance with public exposure limits is required and exposure levels are expected to be low in comparison with the limits (i.e. higher ratio between assessment result and reference level), a method with higher uncertainty may be chosen. In contrast, when determining a compliance boundary around a high-power source (i.e. comparable exposures to the reference level) where OHS management is of prime concern, a method that has a lower uncertainty should be chosen to allow more reliable definition of compliance boundary that is not overly conservative (i.e. not unnecessarily large). Similarly, a method with lower uncertainty may be necessary when monitoring small changes in low levels in the environment.

3.5 DETERMINATION OF SOURCE AND PHYSICAL ENVIRONMENTAL CHARACTERISTICS

Before conducting an exposure assessment, it is useful to determine the known characteristics of the sources, and their likely propagation characteristics. Such knowledge will permit a better estimate of the expected RF exposures and, consequently, lead to a more appropriate selection of test instruments and test procedures. A checklist of source (transmitter), propagation and physical environment characteristics should include the following:

- (a) Output power, including signal duty factor and pulse structure if applicable.
- (b) Carrier frequency or frequencies.
- (c) Modulation characteristics, e.g. peak and average values and waveform.
- (d) Intermittency, e.g. scanning beams and operational duty factors.
- (e) Number of sources and the possibility of creating complex field patterns.
- (f) Spurious frequencies including radiated harmonics.
- (g) Distance of source(s) to assessment site.
- (h) Type of antenna and properties including gain, beam-width, orientation, scanning program and physical size with respect to the distance to the area being assessed.
- (i) Characterization of the field regions: near, near-radiating or far-field.
- (j) Polarization of the electric and magnetic fields.
- (k) Existence of absorbing or scattering objects likely to influence the field distribution at the test site.
- (l) Unintended (leakage) fields.
- (m) Any previous evaluations or estimates of the same or similar RF exposure scenarios.
- (n) Presence of other sources nearby, that may affect safety and the choice of assessment technique.

NOTE: Such a checklist is useful for avoiding some simple, but often surprising, errors in exposure assessment scenarios. For example, it is necessary to know the location of the source and RF propagation path to account for the presence of the assessor's body when conducting hand held RF E or H field measurements. Another example is the possibility that the modulation of the RF field levels may produce electromagnetic interference in the survey instrument electronics if it was not designed for operation in the presence of such fields.

3.6 DETERMINATION OF APPLICABLE EXPOSURE LIMITS

RF assessments generally require a comparison of evaluated RF exposures with limits in human exposure standards. Knowledge of such limits is not only important for conducting a competent assessment, but is also necessary for the protection of the assessor during the exposure assessment.

RF safety standards such as ARPANSA RPS3 and NZS 2772.1 specify a range of basic restriction and reference level limits. Before conducting any compliance assessment, the assessor shall determine which combination of these limits shall be adhered to in order to demonstrate acceptable compliance with the relevant exposure standard. In many cases compliance can only be confidently demonstrated by observing several different limits. An RF assessor should be familiar with the physical quantities and associated limits of relevant standards, and how these quantities and limits apply to particular RF sources.

NOTE: For example, under RPS3 and NZS 2772.1, a radar transmitter operating in a microwave frequency band may require assessments against both time averaged, and instantaneous electric and/or magnetic field strengths in an occupational environment.

3.7 PRELIMINARY ASSESSMENT

3.7.1 General

The assessor should conduct a preliminary assessment to—

- (a) estimate RF exposure levels from all sources relevant to the exposure assessment;
NOTE: See Clause 3.5 and Appendix E—simplified techniques are sufficient for a preliminary assessment.
- (b) establish the quantity (e.g. field, power flux density, current) to be assessed based on the frequency of the sources and where the exposure is evaluated;
NOTE: See Appendix B.
- (c) select an appropriate measurement or computational approach; and
NOTE: See Clause 3.8.
- (d) select appropriate instrumentation or computation tool.
NOTE: See Appendices A and E.

This information, along with safety considerations (see Clause 3.7.2), allows the assessor to decide upon the type of assessment the situation requires. The options include circumstances that do not require RF exposure evaluation and those that do, both of which are described below.

3.7.2 Safety requirements

The safety of the assessor and other persons in the near vicinity shall be considered prior to performing an RF exposure assessment by measurement.

NOTE: See Appendix G.

3.7.3 RF exposure evaluation not required

In some circumstances an RF exposure evaluation may not be required. This is the case with low-power devices whose nominal average RF radiated power output does not exceed 20 mW and which do not produce exceptionally high instantaneous fields. Such devices are not capable of exceeding RF safety exposure limits under any conditions of use. RPS3 summarizes the compliance requirements for low-power devices in Table S1 (similar guidance is given in Table 11 of NZS 2772.1). IEC 62479 also gives guidance when low-power devices need not be considered for assessment. Common examples where individual assessment may not be required include—

- (a) low-power wireless devices such as some Bluetooth devices and radio remote controls for domestic devices; and

- (b) older models of cordless phones (<20 mW).

Devices with higher power outputs may be declared compliant for use under specified operating conditions, e.g. stipulating a minimum separation distance between the device and the user. In such cases, the assessor shall record the relevant operational modes of the device that are required to ensure compliance (e.g. a wireless router that assumes greater than 10 cm separation from the user under normal conditions of use).

NOTE: Consumer appliances that are used close to the body are often assessed against IEC 62209 before being placed on the market. IEC 62209 does not involve demonstrating compliance by measurement of external fields.

3.8 CHOICE OF ASSESSMENT METHOD (MEASUREMENT OR COMPUTATION)

RF exposure assessments may be performed by direct measurement of the fields of interest under actual operating conditions, or may be based on measurements that are later adjusted to account for other operating conditions. Furthermore, the results of measurements may be subject to averaging and other mathematical operations. This Standard considers all such procedures as assessment by measurement.

Alternatively, the RF exposure assessment may be achieved by a mathematical computation based on input parameters such as power, antenna gain and distances. These parameters may be measured or obtained by other means. This Standard considers such procedures as assessment by computation.

In most cases an assessment by measurement should be checked against a simplified computation, and computational assessments should be validated by prior comparison with measurements for comparable situations. Computation can also be checked against measurements at key locations and then used to provide complete coverage of a site where measurements would be impractical.

Subject to client agreement, an assessor may choose to undertake an assessment by either measured or computational means. Often, however, the particular circumstances will dictate which option is chosen. The assessor should ensure that the means chosen is suitable for the task and meets the client's requirements.

3.9 ASSESSMENT BY MEASUREMENT

3.9.1 General

Assessment by measurement is usually preferred in the following circumstances:

- (a) *Complex environment with secondary radiation* Secondary radiation can occur when RF fields from an active radiator induces currents on objects, such as metal flag poles, window frames and fences. The resulting current produces its own electric and magnetic fields (secondary radiation) that will combine with the incident field to alter the fields close to the object's surface. The fields close to the re-radiating object do not have a free space impedance and may have a high electric field (high impedance) or high magnetic field (low impedance). These enhanced fields generally diminish to the surrounding levels within very short distances of the secondary source. For geometrically complex environments (e.g. inside a ladder cage of a TV tower) reradiated fields may be difficult to predict by computational methods, in which case assessment by measurement may be preferred.
- (b) *Leakage radiation (unintended)* Leakage radiation generally entails very localized RF exposures from small gaps in RF shields, e.g. from electronic equipment casings (e.g. power amplifiers), a crack in a shielding cabinet or conduit, or from a joint between transmission cables or sections of waveguides. These are unintended emissions which are very difficult to evaluate by calculation and should generally be assessed by measurement.

- (c) *Client requirements* Regardless of differences in the technical merit of calculated versus measured assessment, the assessor may be constrained to using one or the other depending on the requirements of the client. Client needs may be dictated by other considerations such as regulatory requirements or end user preferences. Assessors should always be aware of the purpose of an assessment report requested by a client before selecting a particular assessment approach.
- (d) *Confirmation of computational assessment* When a computational assessment is to be prepared for a non-technical end-user, measurements at a number of locations may be required by the client to validate the assessment.

NOTE: Assessment by measurement of SAR is outside the scope of this Standard.

3.9.2 Choice of measurement technique

There are many different measurement techniques and the selection of the most appropriate method for an assessment will depend on many factors. Key factors in the choice of method, instrumentation and technique include—

- (a) the purpose of the measured assessment;
- (b) whether overall exposure levels are to be determined or whether the contribution from a particular source is required;
- (c) field strength levels in the environment; and
- (d) presence of intermittent or modulated signals with high peak to average powers.

For example, if the objective of the program is to perform a comprehensive environmental survey to determine the individual level of every RF source, then frequency-selective measurement techniques will be appropriate. If the objective of the program is to compare the result of measurement of combined sources against a pre-determined 'decision' exposure level (not necessarily a defined RPS3 or NZS 2772.1 exposure limit), then either broadband or frequency selective techniques may be appropriate.

NOTE: Details on the choice of instrumentation are given in Appendix A, specific details about measurement techniques are provided in Appendix C and Appendix D outlines factors that can influence the measurement accuracy.

3.9.3 Measurement procedures

Before finalizing any measurements at an assessment site, the RF assessor should consider the following:

- (a) Confirm site information needed for the report—geographic, electromagnetic (e.g. antennas) and physical (e.g. towers).
- (b) Ensure that data required for post-processing (e.g. spatial averaging, assessment of simultaneous exposure to multiple frequency fields and transmitter extrapolation) has been acquired.
- (c) Compare measured results with other independent checks (e.g. simple calculations, previous assessments or assessor experience of the same or similar exposure scenarios) to assess confidence.
- (d) Verify instruments are appropriately calibrated and working correctly.
- (e) Repeat a sample of measurement to assess reproducibility or changed circumstances.
- (f) Confirm data is stored and secure.

3.9.4 Post-processing and finalizing results

Post-processing is an integral part of the site assessment process. Often conclusions about exposure levels relative to the standard can only be reached after the actual measurement has been further processed.

Post-processing can include the following:

- (a) Spatial averaging.
- (b) Time averaging to deal with duty cycle and modulation variations in fields.
- (c) Spatial interpolation.
- (d) Extrapolation or scaling of measurements to full-power or other power levels.
- (e) Allowances for uncertainties where required.
- (f) Combining of field levels at different frequencies from multiple frequency sources to provide overall comparison with exposure limits.

The effects of spatial averaging, assessment of exposure to multiple frequency fields and extrapolation of transmitter powers are each important parts of the post-processing regime.

NOTE: Section 4 discusses these concepts in greater detail.

Finally, the assessor should evaluate the uncertainty in the measured values and compare the results to human exposure limits or other pre-determined exposure levels where appropriate.

NOTE: See Section 6 and Appendices D and F.

3.10 ASSESSMENT BY COMPUTATION

3.10.1 General

If the necessary input data are available, assessment of RF exposure levels through computation is nearly always possible. Appendix E provides a summary of the factors that need to be known before a computational assessment is attempted.

Computational tools can often play a useful role in RF field evaluations. Such tools vary in complexity from numerical calculations based on empirical antenna patterns and theoretical propagation formulas, to comprehensive full wave numerical solutions of Maxwell's electromagnetic equations modelling of the fields around an antenna and absorbing materials. Numerous methods and software packages exist for computing the RF field environment produced by antennas. While Appendix E addresses this topic in greater detail, the selection of an appropriate method will depend on the following factors:

- (a) The nature of the field region (i.e. near-field, far-field, etc.) where the exposure assessment is required.
- (b) The quantities being evaluated (e.g. internal fields/SAR versus external fields/reference levels).
- (c) The topography of the environment and geometrical arrangement of antennas where the exposure occurs.

For many RF sources, the field levels fall below exposure limit values at a short distance from the source, away from the influence of environmental scatterers. In these situations, computational techniques for the estimation of electric fields, magnetic fields and power flux density can provide very efficient and accurate evaluations of RF exposure. When assessing RF exposures in complex scattering environments, calculated assessments may become more problematic than measurements.

It is important that assessors understand the function and limitations of their equipment. In the case of computational tools, the assessor shall have sufficient knowledge about the RF computational software to assess its suitability for the assessment being undertaken. This may be obtained through knowledge of the algorithm and approximations used, or through access to a comprehensive suite of validation results relevant to the assessment task. In some cases, third-party certification of the method, such as by a regulating authority, may be appropriate. In particular, the assessor should be mindful of—

- (i) the limitations of the software in regard to frequency range and field region;
- (ii) limitations of the calculation algorithms;
- (iii) the accuracy, completeness and variability of source data and its impact on the site assessment; and
- (iv) software approximations and assumptions both in calculation and graphical output (e.g. smearing).

After considering all of the above, the RF assessor should decide on the computational techniques and tools to be used, and record the rationale for the choices made. These should include, in brief, the evidence by which the computational software can be judged suitable for purpose.

3.10.2 Finalizing computation results

Before finalizing any computations the RF assessor should—

- (a) confirm site information needed for the report—geographic, electrical (e.g. antennas) and physical (e.g. towers);
- (b) check the validity of the software tool (e.g. against canonical models);
- (c) compare results with one or more sets of measured data from previous assessments or other assessments for similar sites;
- (d) where possible, compare results with similar sites using alternative assessment methods;

NOTE: See Appendix E.

- (e) check the stability of critical calculated values against reasonable variations in input parameters;
 - (f) calculate uncertainty of the assessment; and
- NOTE: See Section 6 and Appendix D.
- (g) compare to human exposure limits where applicable.

3.11 REPORTING OF RESULTS

Having completed the site RF evaluation and post-processing, the final component of the site assessment process is reporting the results. Sufficient information needs to be provided in the report to enable another surveyor to perform a similar assessment and make a meaningful comparison of results, taking into account uncertainties. For example, where manual searching for a maximum has been carried out, the location where it was found should be documented.

Assessors should give consideration to existing reporting methods, and the format and content of results.

NOTE: For exposure standards, see RPS3 and NZS 2772.1; for accreditation requirements, see ISO 9000 or the National Association of Testing Authorities (NATA); and for regulatory and customer requirements, see Australian Communications and Media Authority (ACMA).

Reports should contain a range of information including the following:

- (a) The purpose of the assessment program.
- (b) The client for whom the work was undertaken.
- (c) The name of the assessor or the person taking responsibility for the assessment.
- (d) For assessments involving measurement—
 - (i) details of time and date;

- (ii) operating conditions;
 - (iii) details of equipment used (make, model, serial number);
 - (iv) calibration status of the equipment;
 - (v) environmental conditions; and
 - (vi) any other factors that may be expected to influence the results.
- (e) For computational assessments—
- (i) the software; and
 - (ii) version number.
- (f) A general description of processes and methods used to assess exposure. For measurements this should include details of the operating modes of equipment, such as peak-hold, time-average etc. Details of instrument settings and firmware versions should be provided in order to allow the results to be reproduced should this be required. For computational assessments, critical software parameters and any assumptions made should also be listed.
- (g) If post-processing has been carried out—
- (i) details of the processing; and
 - (ii) any assumptions made.
- (h) Uncertainty of results.
- (i) Summary of the key outcomes.

NOTE: Some examples of reports that meet these requirements are presented in Appendices H and I.

SECTION 4 POST - PROCESSING

4.1 GENERAL

In some cases it may be premature to reach conclusions about assessing exposure levels relative to the Standard limits such as those in ARPANSA Standard RPS3 and NZS 2772.1 prior to post-processing. Important concepts such as duty factor, extrapolation, spatial averaging of fields and assessment of simultaneous exposure to multiple frequency fields are all elements that could impact on the final outcome of a site assessment.

4.2 SPATIAL AVERAGING FOR DEMONSTRATING COMPLIANCE

4.2.1 General

Both RPS3 and NZS 2772.1 recommend schemes for spatial averaging. For compliance evaluations against these standards, the spatial averaging schemes they recommend are acceptable. These are intended to be conservative and ensure that exposures do not exceed the basic restrictions on localized SAR, as well as the WBA SAR. Other averaging schemes have also been proposed, for example in IEC 62232.

4.2.2 Other spatial averaging schemes and further detail

Electric and magnetic reference levels such as those in Tables 7 and 8 of RPS3 and Tables 6 and 7 of NZS 2772.1 were derived from the basic restrictions using simple models of humans exposed to uniform fields under conditions of maximum coupling. In most situations, exposures are not uniform across the body and measurement of the spatial peak RF field strength may give an unnecessarily conservative indication of how exposures relate to the basic restrictions. Spatial averaging can provide a more realistic value of the exposure for comparison against the reference level.

However, since spatial averaging of the field over the entire body is only suited for demonstrating compliance with the whole body average SAR basic restriction, a constraint is required on the spatial peak field strength to limit localized SAR.

In general, an assessor should perform a search for the spatial peak field over the position of the body and compare this value with the reference levels. Spatial averaging is not necessary if the spatial peak field complies with the reference level.

There are many technical considerations when deciding upon the suitability of a spatial averaging scheme, including the following:

- (a) The extent to which the scheme meets recommendations of requirements in a mandatory exposure Standard or regulation.
- (b) Whether the area/volume over which exposures are averaged coincides with where someone might be exposed (e.g. seated, standing) or takes into account their physical stature (child versus adult).
- (c) The extent to which it ensures that the basic restrictions on WBA SAR and localized SAR will be met. Exposure standards allow compliance to be demonstrated based on field strength measurements (or calculations) not exceeding the reference level fields.
- (d) The complexities of the scheme and practicality of its implementation (for example, how many points need to be averaged). Spatial averaging schemes in RPS3/NZS 2772.1, IEC 62232 or IEEE C95.1 and IEEE C95.3 are examples that may be directly adopted or modified to suit.

- (e) Whatever choice of spatial average scheme is adopted by an assessor, the limit on the spatial peak field (whether explicit or implicit) shall be observed in accordance with the exposure standard applicable to the assessment (e.g. a three-point averaging scheme (that includes the spatial peak) implies that the spatial peak exposure cannot be more than three times the reference level).

NOTE: The RPS3 standard defines different methods of spatial averaging for above and below 100 MHz. This frequency represents an inconvenient break-point for sites hosting FM radio services as it falls within the allocated transmission band. It is therefore possible that there will be services above and below this frequency coupled into one antenna. To simplify the measurements at such sites, the RPS3 spatial averaging scheme for frequencies below 100 MHz may be used for the entire FM band (87.5–108 MHz).

4.3 SIMULTANEOUS EXPOSURE TO MULTIPLE FREQUENCY FIELDS

Radiofrequency safety standards such as ARPANSA Standard RPS3 or New Zealand Standard NZS 2772.1 require that aggregate exposure of multiple RF signals at different frequencies shall be considered when making comparison to basic restrictions and reference levels. These standards provide specific rules for aggregating RF exposure levels which shall be implemented when making compliance assessments (e.g. Section 3 of RPS3 or Section 7 of NZS 2772.1).

4.4 EXTRAPOLATION

Extrapolation is required when the configuration of the site during an assessment (measurement or computation) differs from the required assessment configuration. Extrapolation can be applied to E and H fields, induced currents, power flux density and SAR.

Common reasons for extrapolating results include—

- (a) when it would be hazardous for the assessor to enter the measurement area under full power conditions;
- (b) where the operating conditions at the time of the assessment do not represent the full power (or any other power level of interest) operating conditions;
- (c) where the modulation, antenna directivity, duty factor or other characteristics of the equipment during the evaluation differ from normal operating conditions; and
- (d) where the measured field level of a base-station control channel can be used to assess the field level for the full output power from all transmitted signals.

Extrapolation to the required assessment configuration requires the determination of an extrapolation factor. The factor can be determined as follows:

- (i) The assessor shall determine the values for parameters that together represent the operating conditions of the equipment during the evaluation (e.g. transmitter power (P_{eval}), directivity (D_{eval}), signal amplitude modulation (M_{eval}), duty factor (DF_{eval})).
- (ii) The assessor shall derive the values for the parameters for the required assessment configuration (e.g. transmitter power (P_{ass}), directivity (D_{ass}), signal modulation (M_{ass}), duty factor (DF_{ass})).

The extrapolation factor (F_{ext}) is given by—

$$F_{\text{ext}} = P_{\text{ass}}/P_{\text{eval}} \times D_{\text{ass}}/D_{\text{eval}} \times M_{\text{ass}}/M_{\text{eval}} \times DF_{\text{ass}}/DF_{\text{eval}} \times \dots$$

NOTE: ‘×...’ represents other parameters that may be important for determining the extrapolation factor.

The extrapolated levels can be determined as follows:

$$K_{\text{ass}} = K_{\text{eval}} \times \sqrt{F_{\text{ext}}}$$

$$S_{\text{ass}} = S_{\text{eval}} \times F_{\text{ext}}$$

where

K_{ass} = the assessment field (electric or magnetic) or current

K_{eval} = the evaluated field (electric or magnetic) or current

S_{ass} = the assessment power flux density or SAR

S_{eval} = the evaluated power flux density or SAR

For example, the extrapolation factor for the situation where only the transmitter power differs between evaluation (P_{eval}) and during normal operation (P_{ass}) can be expressed as—

$$F_{\text{ext}} = \frac{P_{\text{ass}}}{P_{\text{eval}}}$$

SECTION 5 CALIBRATION AND VALIDATION

5.1 GENERAL

Calibration and validation of RF test instruments and computational software allows for results to be determined with the lowest levels of uncertainty (given the limitations of the assessment tools) and provides stakeholders with a degree of confidence in the assessment outcomes. In this Section the calibration and validation requirements are described along with recommended calibration intervals and direction on calibration laboratory accreditation.

The process of calibration, validation and ongoing checking shall be documented by the assessor.

5.2 RADIOFREQUENCY TEST INSTRUMENT CALIBRATION REQUIREMENTS

For an assessment to be conducted in accordance with this Standard the following criteria shall be adhered to:

- (a) All RF test equipment used for assessments, which could have a significant effect on the accuracy or validity of the result of the assessment (known as the test equipment), shall have valid calibration certification.
- (b) The test equipment shall be calibrated by an accredited calibration laboratory in accordance with the criteria described in Clause 5.3.
- (c) The time since last calibration of test equipment shall not exceed the calibration interval requirements described in Clause 5.4.
- (d) Once in service, the test equipment shall be periodically checked in accordance with the requirements described in Clause 5.5.
- (e) When conducting computational-based RF site assessments, assessors shall have an understanding of the modelling software accuracy in accordance with the requirements described in Clause 5.6.

5.3 CALIBRATION LABORATORY REQUIREMENTS

The calibration of RF test and measurement instrumentation is a highly specialized field. Assessors are responsible for ensuring that their instruments are calibrated by a testing laboratory with appropriate credentials.

The calibration laboratory shall have an established program and procedure for the calibration of its own equipment. Such a program shall include a system for selecting, using, calibrating, checking, controlling and maintaining measurement standards, and measuring test equipment used to perform tests.

In order that an assessment may be performed in accordance with this Standard, test and measurement equipment used in the assessment that have a significant effect on the reported results and associated uncertainties of measurement shall be calibrated by one (or more) of the following:

- (a) National Association of Testing Authorities (NATA) accredited calibration laboratories with the results reported on a NATA-endorsed document.
- (b) National metrology institutes that are signatories to the Comité International des Poids et Mesures (CIPM) or International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA).

- (c) Laboratories with traceability to a national metrology institute, provided the institute has demonstrated adequate performance in relevant international comparisons.
- (d) A laboratory performing its own calibrations subject to proficiency testing and technical assessment to ensure all the relevant requirements of AS ISO/IEC 17025 are met (e.g. adequately documented procedures, procedures to estimate the uncertainty of measurement, complete records of calibration data).

Calibration reports from organizations claiming traceability to a national metrology institute, but not endorsed by a laboratory meeting one or more of the above requirements or those bearing only an ISO 9000 series certification endorsement, are not acceptable.

5.4 RECOMMENDED INTERVALS OF CALIBRATION

The objective of a stated calibration interval is to provide reasonable assurance that the instrument performance has not deviated from its specification or initial calibration status within the calibration interval. The calibration interval depends on the individual instrument and is commonly recommended by the equipment manufacturer. The calibration interval may be changed based on the results of 'as received' measurements and the procedures contained in an applicable calibration control standard (e.g. Section 4 of AS ISO/IEC 17025).

The calibration interval may need to be changed, if over time, a drift in instrument response has been identified. Once this drift has been established, it is simply a matter of deciding how long it will take before the uncertainty in the latest calibration certificate has expanded to the maximum acceptable for the testing being done. Immediately after recalibration the results should be compared with the previous results. If the change produces a difference greater than the desired uncertainty then the calibration interval should be shortened.

5.5 PERIODIC CHECKING OF INSTRUMENTATION

It is important that RF assessors complement traceable calibrations with more frequent instrument checks. These checks can be non-traceable as long as correct technically sound and reproducible procedures are used.

The instrument should be checked before and after each use against at least one known value to confirm that it has not been damaged.

Reduced intervals between calibrations and checks are required when the equipment operates under less than ideal conditions. For example, if the equipment is damaged, or is likely to have been damaged, then it shall be recalibrated immediately and thereafter at reduced intervals until the stability of the equipment is confirmed.

5.6 VALIDATION OF COMPUTATIONAL TOOLS

Validation of a computational assessment is necessary in order to provide an estimate of the uncertainty in the result. An uncertainty statement shall accompany the results of every computational assessment.

Validation may be assured by external checks whereby the calculated results are compared against the results of other independent means of evaluating the same exposure scenario. Possible sources of external checks include measured assessments, calculated assessments using different numerical methods, and reliable reports (e.g. manufacturer specification sheets) of evaluated results (e.g. the gain of an antenna). Internal consistency checks are also useful, such as checking for reciprocity and energy conservation, and examining how well the boundary conditions are satisfied. For full wave computational analyses, the results may be scrutinized for what appears to be 'non-physical' behaviour, e.g. whether the solution converges as the number of unknowns is increased and whether small changes in the numerical model produce small changes in the results.

NOTE: Paragraph D3 of Appendix D provides specific guidance on validating and estimating uncertainty for calculated assessments.

5.7 CHECKING AND REVERIFICATION OF COMPUTATIONAL TOOLS

Checking is important to confirm continued operation of computational tools over time. Re-verification shall be performed when moving RF computational software between computers or installing tools on a different computer. This can be achieved by the use of standard test cases that can be routinely reprocessed for comparison with solutions stored from previous results. Standard test cases are obtained from previous, validated assessments, comparisons with published literature or analytic solutions.

SECTION 6 UNCERTAINTY ESTIMATION

6.1 REQUIREMENT FOR UNCERTAINTY ANALYSIS

All reported assessments of measured or calculated RF field levels shall include an estimate of the uncertainty of the assessment. Unless otherwise specified by the client, a two-sided 95% coverage interval should be provided for environmental assessments (specified by a lower and upper bound), and a one-sided 95% coverage interval for compliance assessments (specified only by an upper bound). One-sided 95% coverage intervals with a lower bound should also be provided if requested by the client or regulator for non-compliance assessments.

NOTE: Guidance on performing uncertainty analysis is provided in Appendix D.

6.2 REPORTING OF ASSESSMENT RESULTS AND UNCERTAINTY ANALYSES

Assessment results should generally be provided as the best estimate of each evaluation incorporating corrections for any known systematic errors, unless otherwise specified by the client. For measured assessments, the best estimate value will usually be the level indicated on the instrument meter after adjustment for calibration factors. For calculated assessments, the value will usually be the calculated estimate adjusted for various system losses.

All reporting of assessment results and uncertainty shall be accompanied by a description of the context of the assessment. The description of the context should include any relevant circumstances of the assessment that may significantly affect the evaluated levels, such as—

- (a) the operational state of the RF source (e.g. transmitter power for normal operating conditions or maximum possible power level);
- (b) whether the evaluation includes a consideration of field scattering in the environment;
- (c) RF sources that may or may not have been included in the exposure evaluation; and
- (d) spatial averaging schemes that were applied.

6.3 THE ROLE OF UNCERTAINTY IN COMPLIANCE ASSESSMENTS

The uncertainty of an assessment (with due consideration of each of the relevant input quantities) shall be considered when determining compliance or non-compliance with an RF exposure limit. In general, different decision rules can be formulated to determine whether an assessment result is determined to comply or not with a limit (for example, EURACHEM/CITAC Guide: Use of uncertainty information in compliance assessment and IEC 62232). The choice of rule should be based on the circumstances.

The relevant regulator or client may specify a decision rule to be followed when using the result of an exposure assessment (including its uncertainty coverage interval) to determine whether the exposure complies with an exposure limit or other prescribed level. In the absence of any such external guidance, the following approach should be taken using the upper bound, U_{up} (expressed in dB relative to the assessment result), of the one-sided 95% coverage interval for the uncertainty of the exposure assessment:

- (a) If U_{up} is less than or equal to the uncertainty allowance, U_0 , compliance is demonstrated if the assessment result does not exceed the limit.
- (b) If U_{up} is greater than the uncertainty allowance, U_0 , compliance is demonstrated if the assessment result increased by $(U_{up} - U_0)$ does not exceed the limit.

Table 6.1 specifies the uncertainty allowance, U_0 for basic restrictions and reference levels.

NOTE: Appendix D provides example templates for the classic calculation of the uncertainty of the assessment, U , for measurement and computation.

TABLE 6.1
UNCERTAINTY ALLOWANCE

Limits (see Note)	Uncertainty allowance (U_0) dB
Basic restriction	1.2
Reference level	3

NOTE: For example, a list of basic restrictions and reference levels is given in Table 1, RPS3 (2002).

APPENDIX A

RADIOFREQUENCY MEASUREMENT INSTRUMENTATION AND DESIRABLE PERFORMANCE CHARACTERISTICS

(Informative)

A1 PERSONAL MONITORS

Personal monitors are typically small, portable broadband detectors, suitable for attachment to workers' clothing, which are equipped with an alarm feature for alerting the wearer to the presence of high-level RF fields that may approach the relevant maximum permissible exposure (reference level).

Some personal monitors provide an alarm with an adjustable or preset threshold, e.g. 50% of the applicable reference level. In the region between 1 GHz and 100 GHz, resistive thermoelectric dipoles are used as sensors with a background of lossy material to reduce the effect of scattering from the body. Electrically short dipoles with diode detectors as sensors may cover a portion of this range.

In the range of 0.1 MHz to 30 MHz, surface charge detection is used and the monitors, therefore, respond to the radial fields that predominate near re-radiators in this frequency range. In the frequency range of 3 MHz to 1000 MHz, personal monitors may incorporate sensors for both electric and magnetic fields, and some contain frequency-dependent sensors that automatically weight the detected RF fields in accordance with frequency-dependent RF exposure limits. Although magnetic field sensors are less susceptible to the effects of scattering from the body, various techniques may be employed with E-field monitors to reduce their susceptibility to these effects. This feature makes them especially useful in multiple frequency environments such as broadcast and wireless telecommunications antenna sites.

Because personal monitors respond to the RF fields at the position where the monitor is located on the body, some care should be used in its placement and interpreting exposure during an alarm condition. For example, wearing a belt-mounted personal monitor when the predominant exposure is at eye level may not provide sufficient warning of excessive exposure. Conversely, when used in non-uniform RF field environments, such as VHF and UHF broadcast facilities, an alarm condition may be a very conservative indication of potential excessive exposure, since the reference levels of several exposure standards and guidelines are based on spatial averages over the projected area of the body. Encountering fields that trigger the alarm at one point in space may not ultimately lead to whole body average exposures exceeding the reference level value.

It is also quite common for personal monitors worn on the body to be very sensitive to VHF frequencies, due to the body acting as a coupling antenna, and to lead to false triggering. The most accurate reading is taken when the personal monitor is insulated from the body and placed closest to the radiating source. For example, when climbing a tower, the personal monitor can be held above the head prior to entering a platform or hazard zone.

Personal monitors can form a valuable component of an RF safety program. However, it is important that they are recognized as monitors and not as calibrated hazard meters. It is desirable that they have isotropic characteristics, be self-checking and indicate battery condition. Additionally, they should be calibrated at defined intervals and exposed to a known RF field source to check their correct operation. Instruction in their use should be an integral part of any RF safety-training program.

A2 E, H AND S BROADBAND MEASUREMENT INSTRUMENTATION

A2.1 Instrumentation for external field measurements

An RF survey meter can be divided into three basic parts—probe (sensor), leads and metering instrumentation. The probe consists of an antenna in combination with a sensor or detector. The design and characteristics of the probe determine to the greatest extent the performance and application of the unit. The detected output from a probe with a flat frequency response is a direct measure of the RF field strength. The leads refer to that part of the instrument that carries the detected signal to the metering instrumentation. To accomplish this without causing perturbation of the field, the leads may take the form of high-resistance wires, or if they are metallic they should be carefully oriented so they minimize coupling with the field. They may also take the form of an optical fibre. Metering instrumentation includes signal-conditioning circuitry and display devices.

A2.2 Field strength power density meters

Power density meters measure either the electric or magnetic field strength and then display the measured level in equivalent power density, assuming a wave impedance of 377Ω . The electric and magnetic probes are generally isotropic and broadband devices. Most meters allow the measured field to be displayed in field strength units and power density units. However, there are conceptual differences among these devices in the way the fields are detected and processed. The instruments described in the following sections have essentially the same basic components (i.e. a probe, a connecting cable and a conditioning display unit). They are limited to those types that are currently available and that can provide reasonable accuracy in both near-field and far-field situations. Measurements conducted with a power density meter may produce erroneous readings when the connecting cables are inadvertently aligned with the electric field. This is due to the fact that high resistance leads carrying the signal act as a more efficient antenna at low frequencies (such as in AM broadcasting band) than the short dipoles in the probe.

A2.3 Instrument types for external field measurements

The instruments described in the following sections are limited to those types that can provide reasonable accuracy in both near-field and far-field situations. Instruments that have large scattering areas (in terms of wavelength) are not included.

A2.4 Diode rectifier

In these instruments, small antennas are terminated by single or multiple diodes. Multiple diodes and antenna elements arranged in suitable configurations can be used to sum all field components and enable measurements to be made independent of polarization and direction of incidence. A minimum of three elements in an orthogonal arrangement is required for an isotropic instrument that can be used in any orientation with respect to the field.

A crossed-dipole or multiple dipoles arranged in a single plane will respond correctly to signals arbitrarily polarized in the plane of the sensor, but not to the total field. Such units should be oriented so that the resultant (maximum) field vector is in the plane of the sensor.

Diode instruments are basically non-linear with respect to power flux density or field strength. At low levels, the rectified voltage is proportional to power flux density, or the square of E (or H). At higher levels, the rectified voltage becomes directly proportional to E (or H). This change in characteristic means that the instrument only provides a valid indication of power flux density when used in its specified range of operation.

Diode instruments are well-suited for measurements of simple signals, but should be used with caution for intermittent signals and signals with high peak-to-average ratios (PARs); and only relied upon if suitable correction charts are available from the manufacturer or other reliable sources.

Diode detectors, depending on design, may exhibit a marked dependence upon ambient temperature. Variations in output with ambient temperature will typically be of the order of 0.05 dB per degree Celsius, which may become significant for large temperature variations.

There are a number of possible spurious response effects that can occur with diode detectors. The following are the most common:

- (a) *Multiple signals* Diodes act as a square-law detector only at low signal levels, tending to a linear detector at high signals, with an intermediate characteristic at moderate signal levels. In association with a resistor capacitor circuit, a diode detector tends to act as a peak detector. Where there are two or more (in band) signals of similar amplitude (e.g. FM plus TV in one antenna) the instrument will tend to read higher than true.

It is preferable to measure each signal separately, either by turning off all except one signal, or by making frequency selective measurements.

- (b) *Modulated signals* Diode units also may be modulation sensitive if the square-law region is exceeded, resulting in errors dependent upon the form of modulation.
- (c) *Pulse modulation* When diode instruments are used in pulsed fields they usually change from an average to a peak detecting device and, hence, measurement errors may be large in fields of high peak to average ratio (low duty factor). The reading may be many times higher than the actual time-averaged level, approaching the instantaneous peak. This is of particular importance in radar measurements and sometimes TV. This effect will vary when saturation of the diode takes place at very high peak field strengths.
- (d) *Light sensitivity* Schottky diodes, in general, exhibit some photovoltaic effect. Beam-lead hybrid types exhibit this effect to a much greater extent and may produce erroneous readings when illuminated by sunlight or strong incandescent light. This effect may produce a reduction in the reading. Therefore, optically opaque encapsulation is required to eliminate this effect. If making measurements in bright light, check for increases in the reading by shading the probe, taking care that the field is not altered by the action of shielding the probe from the RF source.

A2.5 Thermocouple devices

Thermocouple-type radiation monitors generally utilize thin-film thermocouples as the detection elements. Parts of the film perform the function of the antenna element. These units exhibit extremely good adherence to square-law characteristics in that the d.c. output from the thermocouple is proportional to the square of the electric field strength. These units, while relatively independent of ambient temperature, are generally less stable than diode-type detectors. Hot and cold junctions of the couple are in close proximity to reduce the drift due to variations in ambient temperature. Variation in sensitivity is of the order of 0.1% per degree Celsius. The major limitation of the element is the burnout characteristic which, in terms of average values, is typically approximately three times full scale. The full-scale ratings depend on the basic probe sensitivity. The utilization of thin resistive films provides very broad bandwidth.

Some commercial probes arrange alternate hot and cold thermocouple junctions in a continuous-series linear arrangement to form a dipole, or in a circular arrangement to form a loop. If any single thermocouple junction fails because the probe is subjected to fields well in excess of the maximum rating of the probe, the probe will be non-usable.

Some thermocouple devices utilize dual modes of operation for extreme bandwidth. They may function as a linear-resistive dipole at frequencies typically below 18 GHz, and as a travelling wave or phase effect antenna above 18 GHz. Such devices have an upper frequency limit that exceeds 40 GHz.

A2.6 Continuous film type devices

Two other types utilizing bolometric principles are liquid crystal and gas pressure devices. These devices are not widely used. The bolometric elements in these devices are thin, resistive films of relatively large area. In the gas-pressure device, the thin resistive film encloses a gas-filled sphere. As energy is absorbed in the thin film, the gas is heated by conduction and a resultant increase in pressure is attained. This increase in pressure is a measure of the energy absorbed. Units of this type exhibit large bandwidths but suffer from relatively low sensitivity to RF energy. Compensation for variations in ambient temperature can be accomplished by using a second gas sphere that has no resistive film surface. The absorbed energy is indicated by the difference in gas pressure of the two spheres.

The liquid-crystal type unit uses a thin resistive film in contact with a liquid-crystal film. As the resistive film is heated by the electric component of the field, a variation in colour of the liquid crystal occurs. This technique has relatively low dynamic range and indications are not absolute, requiring calibration by substitution power methods. It does provide an indication of relative power flux densities over large areas. Wide frequency ranges may be attained, dependent on film resistivity.

A2.7 Active antenna

It is difficult to make accurate, broadband *E*-field and *H*-field probes that cover the long-wavelength region (frequencies of around 3 MHz), using the conventional means cited in Paragraphs A2.4 to A2.6. This is due to the fact that the source-impedance of an electrically-small (10 cm) dipole antenna is extremely high and, also, the sensitivity of a small (5 cm to 10 cm diameter) loop antenna is very low. In order to provide a flat frequency response and adequate sensitivity in a dipole probe, the load impedance of the detector in combination with the high-impedance lead should be greater than the antenna (source) impedance. One solution is to provide a high-impedance RF buffer amplifier that is connected directly to a monopole or loop antenna and that acts as the load. This is accomplished by placing the amplifier and battery in a metal enclosure that serves as a cubical 'ground plane' or asymmetric dipole element. In commercially available units, the size of this cube is small enough (10 cm to 15 cm on a side) so as to not unduly perturb the field under test or the receiving-pattern of the device. This is practical for frequencies between 10 kHz and several hundred MHz. Commercially available magnetic and electric field probes, using active electronics, operate at frequencies as low as 60 Hz.

A second problem associated with probes without active electronics is that of isolating the signal-carrying leads from between the combined antenna and detector. This problem may become severe below about 100 MHz, and particularly below 10 MHz. This is due to the fact that the typical high-resistance signal-carrying leads serve as a low-pass filter, and their ability to separate the low-frequency signal detected from the RF field being measured becomes more difficult as the two frequencies approach each other. This results in excessive sensitivity and poor antenna patterns in passive probes. Finally, at frequencies above about 300 MHz, when 'free space' or uniform irradiation conditions exist, both the sensor and the metal enclosure of the survey instrument can be exposed to similar levels of RF, and scattering from the enclosure to the sensor (probe) can cause significant measurement errors.

Active electronic probes eliminate the use of such leads entirely by including the visual display (readout) with the metal box containing the active electronics. A fibre-optic data link can be provided for a remote readout.

A2.8 Displacement current sensors

In addition to short dipoles and monopoles, a form of parallel plate capacitor called a displacement-current sensor can be used to measure electric fields normal to its surface or normal to any large conducting surface. Displacement-current sensors are typically used at frequencies in the LF and VLF regions, e.g. from d.c. to a few hundred kilohertz, but may effectively be used at frequencies as high as a few hundred megahertz.

A2.9 Electro-optical (photonic) sensors

This type of RF field sensor utilizes a non-metallic, passive sensing element (electro-optic modulator) with a very broadband response (d.c. to 20 GHz) that converts radiofrequency field strength information to instantaneous modulation of a laser beam. The laser energy is transmitted via fibre optics to a modulator. The modulator impresses amplitude modulation on the laser beam, in proportion to the instantaneous amplitude of the RF field to which the modulator is exposed. The amplitude-modulated laser beam is then carried from the modulator to a photo-detector that converts the modulated optical beam to an electrical signal, which represents the instantaneous amplitude of the RF field strength.

A2.10 Combined electric and magnetic field probes

Methods for the simultaneous and mutually-independent measurement of RF electric and magnetic field strengths have been developed. A broadband isotropic probe system for measuring the *E*-field and *H*-field simultaneously can be produced with a set of three mutually orthogonal dipole elements and a set of three mutually orthogonal loops that are physically located within the same very small (compared with wavelength) volume. Each antenna has associated circuitry comprised of a detector and an optional frequency response-shaping filter to provide a frequency response that is flat over the desired frequency range. The lengths of the dipoles are kept electrically short so that the fields are not perturbed and the diameters of the loops are kept electrically small so that the *E*-field pickup of the loop will be negligible. Mutual coupling between any of the probe elements is also minimized by the use of electrically small antennas. Detectors based on the use of square-law operated diodes or thermocouples are used to provide a signal to the electronic circuits, which include an arrangement for analogue or digital summing and data processing. An analogue or digital display, data logger and recorder can be incorporated as part of this system. If three loop antennas are arranged with a common centre, this also provides an isotropic response. This type of probe is commercially available and is used in personal monitors.

A2.11 Shaped-frequency response

Safety limits for field strength and power density in Australia and throughout the world are frequency dependent. Probe designs, which rely on dipole-diode elements separately or in conjunction with thermocouple elements, may be designed to have a 'sensitivity versus frequency' characteristic that is the inverse of the standard. This allows the summation and weighing of multiple frequency signals in conformity with the frequency-dependent safety limits. The readout of such devices is in percentage of the standard. Conversion from percentage back into field strength units is only possible for single known frequencies. Shaped-frequency response probes may cover only a portion of the frequency range of the standard. Additional probes may be used to complement each other and provide a wider measurement range. When complementary probes are used, each should exhibit good rejection of out-of-band signals.

A3 E, H AND S FREQUENCY SELECTIVE MEASUREMENT INSTRUMENTATION

A3.1 Receivers and spectrum analysers

Frequency-selective RF field strength measurement is characterized by an antenna and a calibrated receiver, such as a spectrum analyser or frequency-selective field strength meter.