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Permitted Noise Above 1 GHz: Final Report

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Summary

The Office for Communications (Ofcom) contracted a consortium led by ERA Technology and including Aegis Systems Ltd and QinetiQ to perform a study into Permitted Interference and EMC limits above 1 GHz. The main aims of the work were to try to identify the risk to Ofcom of the increasing use of electronic equipment and radio devices in the home, office and other environments. Ofcom want to ensure that there are sufficient standards in place to ensure that emissions from all noise sources do not degrade the quality of the spectrum.

CISPR published proposed EMC emission limits for 1 to 6 GHz during 2005. It is expected that EN 55022 will be upgraded with the latest approved amendments to CISPR 22 for emissions above 1 GHz. Normally that would be completed in about 2 years after CISPR publication. It is possible that certain electronic system manufacturers could still look to oppose the EN 55022 changes but this is more likely to result in delays in the implementation.

The sources of unwanted emissions included unintentional emissions from electronic equipment, UWB, and spurious emissions. The assessment method used laboratory measurements to characterise EMC and spurious emissions in an anechoic chamber. This input data was combined with data and for the victim radio systems and for UWB emissions and input into a Monte-Carlo simulation which allowed a statistical approach to predicting interference in a range of scenarios. The Monte-Carlo modeling method was compared to the CISPR methodology and proposed limits.

Seven radio systems were simulated using the Monte-Carlo in this study, T-DAB, GSM, FWA, FSS ES, GPS, RSA, and 802.11b. These simulations predicted that for a methodology similar to the CISPR method, assuming a single interferer at the CISPR limit but with realistic probabilities of interference being present in the receiver channel, four out of the seven radio systems did not experience any interference issues. For the remaining systems, the predicted interference was relatively significant. For T-DAB the probability of interference occurring was about 30% and for FWA this figure was about 15%. For GPS there was about a 40% probability of the interference power exceeding the acceptable level. Although considerable effort was made to ensure that the assumptions were not too worst-case, there may in practice be some further relaxation of the parameters used and this would require some additional work.

The practical experience of many countries seems to indicate that there are currently no significant problems with EMC interference above 1 GHz. However, as indicated by the measurements, actual EMC emissions at present are typically some 10 to 15 dB below the CISPR average limit. Although it is difficult to use the practical experience of the lack of instances of interference from existing equipment which operate significantly below the CISPR limit as proof that equipment operating at the CISPR limit causes no problems, it may be a good indication that there are not likely to be any significant EMC interference issues in the near future.

The Monte-Carlo modeling based on actual measured electronic equipment emission levels, instead of CISPR emission limits, predicted no interference issues from current devices. As the EMC emissions

are not expected to get significantly worse in the near future, it is likely that there will be no significant EMC interference issues, although this may be very system dependent.

Although CISPR considers interference from just a single device, it was shown that aggregate EMC emissions may need to be considered where the density of interferers increases considerably, as has been suggested for future potential home and office usage. For the scenarios considered the increase in interference levels in the receiver bandwidth varied between about 3 dB and 11 dB more than for the single interferer case.

The proposed CISPR levels appear to be set at a sensible level to protect radio receivers above 1 GHz with a practical balance with the constraints that more stringent limits would place on manufacturers. There is protection, in that, if interference levels are reported then mitigations will be sought, either by reducing the emissions from particular items of equipment or by reconsidering the CISPR limit. The Monte-Carlo modelling performed in this study predicted some possible interference to some of the radio systems when assuming equipment emissions at the CISPR level. However, it is possible that although care was taken to not over-predict the likelihood of interference, some relaxation of the modelling criteria might remove this predicted interference and this should be investigated further.

Interference from EMC emissions was compared to interference from UWB, spurious emissions and thermal noise. It was seen that spurious emission levels tended to be the highest, with thermal noise next highest, then EMC emissions and finally UWB emissions. Potential interference from spurious emissions appears limited to high powered transmitters such as broadcast transmitters and radars for example. For general communications systems, although the level of spurious emissions is high compared to other sources of unwanted emissions such as EMC and UWB, the probability of a spurious emission falling in any given band are quite low.

Including the probability of the occurrence of interference, a comparison was made between EMC, UWB and thermal noise. It could be seen that, for a 1 MHz receiver bandwidth, the probability of the aggregate interference levels from three UWB devices being higher than thermal noise was less than 0.1%. In the case of EMC emissions, this probability was up to 1%. This was based on an FWA configuration and further work is required to determine these figures for more general services.

It was determined that the definition and implementation of a Permitted Noise Metric is practical. This may not be a single absolute measure and could consist of simple graphs containing:

- the probability of any given interference power level;
- for a specified group of frequency ranges (e.g. 1 to 2 GHz, 2 to 4 GHz etc);
- for a range of specified bandwidths;
- aggregated over thermal noise, EMC emissions and UWB emissions.

Examples of a permitted noise metric are given for a range of bandwidth. This was calculated for the 3 to 4 GHz band and has a number of underlying assumptions that required further investigation and agreement.

It was seen that it would be practical to include UWB in the permitted noise metric. It is not seen as appropriate to include spurious emissions in a generic permitted noise metric as the harmonic frequencies are predictable and the potential level of interference could be significant compared to other sources of interference but with quite a low probability of occurrence. However, it may be beneficial to include specific high powered emitters such as radars.

Using this approach of characterising interference from equipment in the laboratory and then using those values as building blocks to put into a Monte-Carlo simulation is advantageous as it does not rely on the devices being present in large numbers throughout the UK. Simulations can be predictive of future situations and can allow what-if scenarios to be carried out. Using this combination of modelling and measurements can allow a large number of scenarios to be determined using practical data in a manageable amount of time and is very cost effective.

Validation measurements were carried out in the laboratory for interference to GSM phones and Wi-Fi from single and aggregate EMC emissions and UWB emissions. Interference could be caused to the GSM phones and Wi-Fi, but only under worst-case conditions where the wanted received carrier levels were low, the channel had been selected to be at the worst-case EMC emissions and the separation distances were of the order of centimetres. For aggregate effects, the measurements showed that the single worst-case interferer tended to dominate.

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Abbreviations List

EUT	Equipment Under Test
FAR	Fully Anechoic Rooms
ISM	Industrial, Scientific and Medical
OATS	Open Area Test Site
MMN	Man Made Noise
MSC	Mode-Stirred Chamber
RMS	Root Mean Square
SRD	Short Range Devices
UWB	Ultra Wide Band
GSM	Global System for Mobile communications
PMSE	Programme Making and Special Events
WLAN	Wireless Local Area Network
DECT	Digital Enhanced Cordless Telephone
UMTS	Universal Mobile Telecommunications System
W-CDMA	Wideband Code Division Multiple Access
DAB	Digital Audio Broadcast
DTH	Direct to Home
T-DAB	Terrestrial Digital Audio Broadcasting
FSS ES	Fixed Satellite Service Earth Station
GPS	Global Positioning System
FWA	Fixed Wireless Access
RAS	Radio Astronomy

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1 Introduction

The Office for Communications (Ofcom) contracted a consortium led by ERA Technology and including Aegis Systems Ltd and QinetiQ to perform a study into Permitted Interference and EMC limits above 1 GHz. The main aims of the work were to try to identify the risk to Ofcom of the increasing use of electronic equipment and radio devices in the home, office and other environments. Ofcom want to ensure that there are sufficient standards in place to ensure that emissions from all noise sources do not degrade the quality of the spectrum.

Ofcom wish to identify if they can establish a "permitted noise metric" which Ofcom stakeholders might use to quantify expected interference in their licensed radio spectrum allocations, and recommend the level of this metric for various frequency bands. As demand for spectrum usage in the UK increases, this work will help Ofcom to guarantee a certain quality of the radio spectrum to the radio community in order to allow radio users to develop the maximum range of services in the limited spectrum available. In particular, Ofcom is increasingly being asked to keep the spectrum clean, define what interference can be expected in a piece of spectrum, and determine the causes of noise in a spectrum band. Spectrum liberalisation will increase the need to better define the quality of spectrum.

Ofcom's strategy of spectrum liberalisation as defined in the Spectrum Framework Review (SFR)[1] is based on allowing market forces to drive improved efficiency of this scarce resource. Spectrum will change hands through spectrum trading, bandsharing, spectrum clearance programmes and auctions. Efficiency will be driven by pricing. In turn, spectrum users will be protected from increases in interference through the use of spectrum rights. In order to properly define these spectrum rights for each frequency band, information about the existing and future levels of both interference from intentional transmissions and background noise from unintentional emissions such as EMC is required.

It is not completely clear to what extent the radio spectrum is being polluted by unintentional emissions at present. There have however, been several studies that help indicate the contribution from Man Made Noise (MMN). ITU-R P.372 defines expected noise limits in a number of environments versus frequency. ITU-R P.372 is based on data gathered in the 1970s and is now the subject of several studies to update it to identify if there is increased background noise levels due to increasing amounts of MMN.

Over the last ten years there have been developments in CISPR to produce test methods and limits for emissions from ITE, and in 2005 CISPR Sub-committee I approved an amendment to CISPR 22, CISPR/I/151/FDIS [3] containing emission limits and methods over the frequency range 1-6 GHz which shortly is likely to be a European harmonized standard applicable to all information technology and multi-media equipment placed on the market in Europe.

[1] "Spectrum Framework Review", Ofcom, 23rd November 2004

At higher frequencies, electronic devices may radiate from many parts of the equipment and can act like an antenna array, creating narrow beams of emissions in particular directions. Electronic equipment is continuing to operate at faster clock speeds with PCs now operating at speeds exceeding 3 GHz. It is envisaged that clock speeds may continue to increase up to the 10 to 20 GHz range. Future developments such as Ultra-Wide Band (UWB) and increased use of Short Range Devices (SRDs) will also add to the need to define and control the quality of the spectrum above 1 GHz.

There are only generalised maximum limits for spurious emissions from radio transmitters and many radio standards and ITU recommendations allow spurious and out-of-band emissions above 1 GHz at fairly high levels.

As opposed to measuring a very large number of locations with no known information about the specific sources at each location, a different approach to characterising background noise levels has been taken here. A range of electronic and radio devices have been measured in the laboratory to identify typical levels of EMC and spurious emissions, and probabilities of emissions occurring in any given band. These levels have then been input into a Monte-Carlo simulation. This simulation runs through a number of scenarios for the home, office and outdoor environments assuming a given density of devices.

Definition of the noise environment and ongoing monitoring should use the strengths of both modelling and measurements. It is more appropriate to measure very complex radiators such as electronic equipment. However, modelling can provide statistics over very wide areas, considering future systems that are not yet implemented, and covering a large array of scenarios within practical cost and time budgets.

1.1 Sources of Interference

Figure 1 below shows the different types of contributors to the electromagnetic noise environment [1].

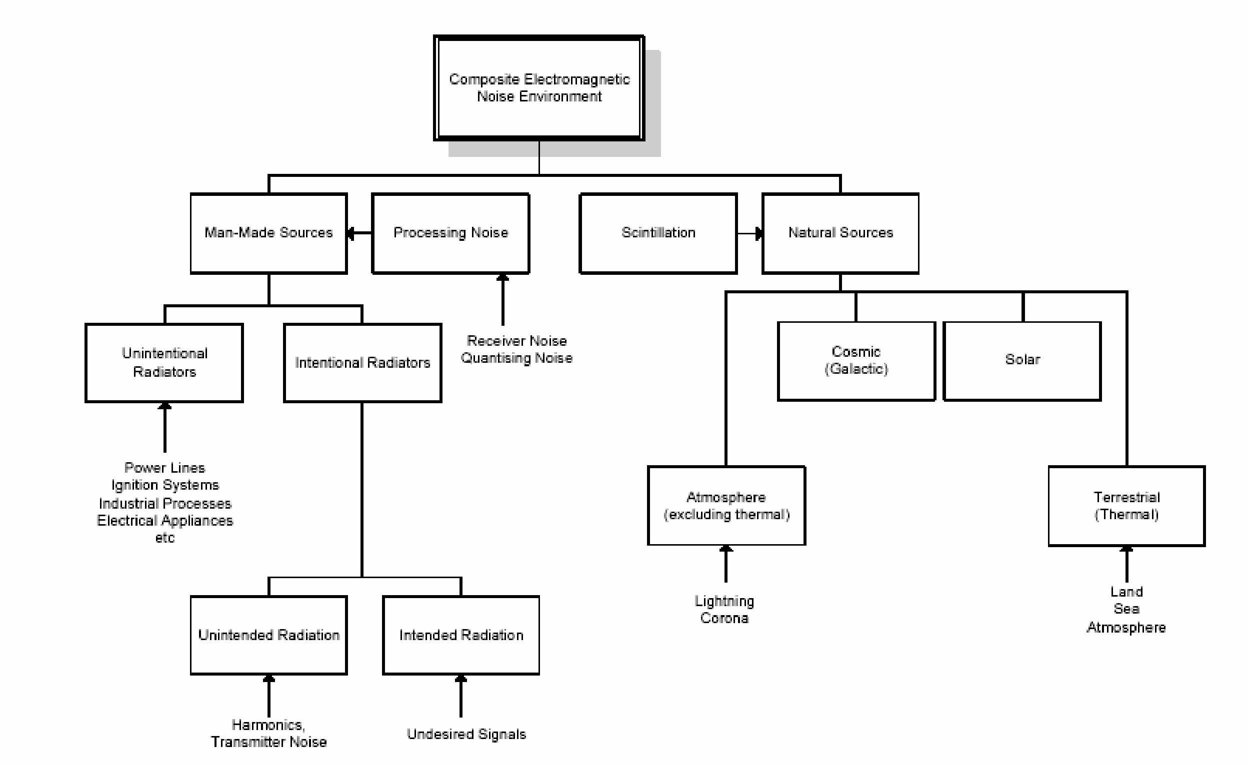

Figure 1: Noise source contributors

For the purpose of this study, the types of noise can be divided up into the following categories:

- Man-Made Noise (MMN) sources
    - Electrical and electronic equipment: e.g. computers, motors etc
    - Narrowband radio-communications: spurious and out-of-band emissions
    - Broadband radio-communications: e.g. UWB
- Natural sources
    - Thermal noise, lightning etc.

ITU-R Recommendation P.372-8 provides median values of man-made noise power (relative to the noise floor) based on measurements carried out in 1970s below 250 MHz in a number of environments including business, residential, rural and quiet rural, Figure 2. Measurement results indicate that the man-made noise power (dB) decreases linearly with log(frequency).

A contribution from the UK to ITU-R Working Part 3J (Document 3J/15, November 2003) reports on man-made noise measurements in the UK. An example of low frequency noise is given in Figure 3. Measurements of both White Gaussian Noise (WGN) and Impulsive Noise (IN) are reported. WGN results are plotted up to 1 GHz and show that F_a (defined as the mean man-made noise power relative to the noise floor) decreases linearly with log(frequency), which agrees with Rec.372. The results also show that the man-made noise power values are higher than those given in Rec.372.

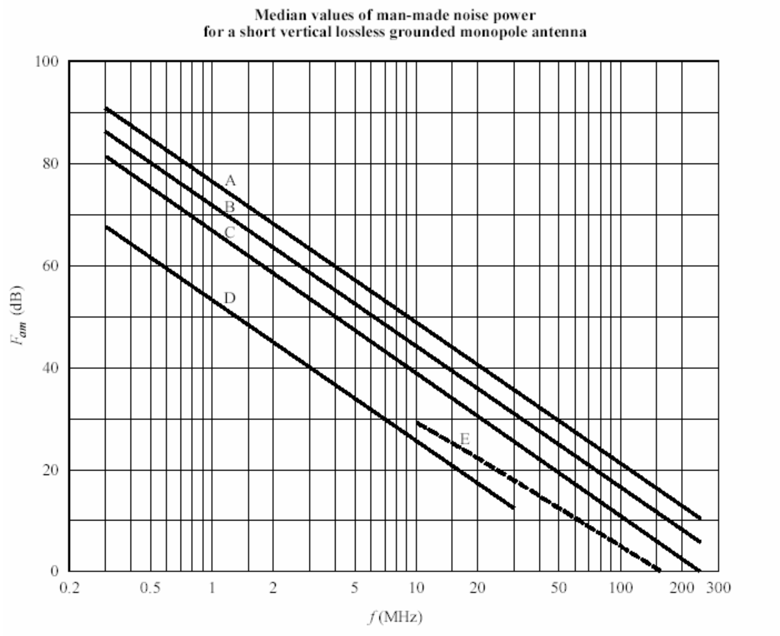

Figure 2: Man-made noise levels in current version of P.372

The mean and standard deviation of the IN voltage measurements are presented in units of dB(µV/MHz) up to 3 GHz. It is suggested that both parameters fall-off with log(frequency) following a linear relationship, similar to the F_a.

A more recent contribution to ITU-R Working Party 3J (Document 3J/94, September 2005) outlines the results of man-made noise measurements below 1 GHz in business, residential and rural environments in Germany. Similar to the UK study, both WGN and IN measurement results are reported. Results indicate that, for example at 918 MHz, the median WGN power is measured to be in the range 0 - 2 dB above the noise floor. In the same document, Amplitude Probability Distribution (APD) graphs are provided to show the combined WGN and IN statistics. For example, at 980 MHz, plots indicate that the relative noise power is 3 – 5 dB above the noise floor.

FIGURE 12

F_a versus frequency

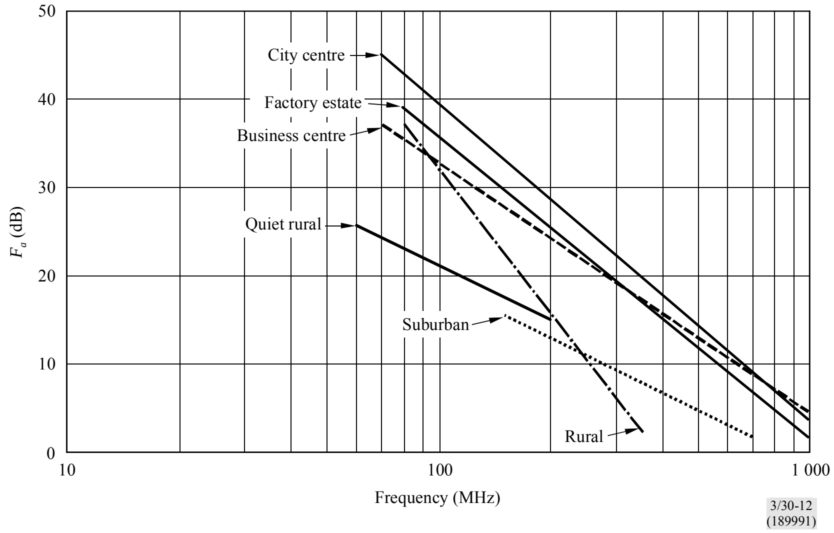

Figure 3: Data on man-made noise in proposed revision of P.372 (ITU-R Document 3/30)

1.2 Methodology Used in this Work for Estimating Noise Levels

It is thought that increases in background noise are most likely to be due the increased use of electronic equipment and radio equipment. There is an increased use of digital processor based electronic equipment used in the home, office, and other environment. This equipment also tends to operate at increasing clock speeds with 3 GHz processors now quite common. This could lead to increased EMC emissions. The increased use of radio devices e.g. mobile handsets, wireless LANS, DECT phones etc, may in addition lead to an increase in spurious emissions. There is also likely to be an introduction of broadband radio devices in the form of Ultra Wideband (UWB) devices which are intended to work at low power levels for short range high data applications such as wireless video streaming e.g. between a DVD player and a TV.

As opposed to measuring a very large number of locations with no known information about the specific sources at each location, a different approach has been taken here. A range of electronic and radio devices have been measured in the laboratory to identify typical levels of EMC and spurious emissions. These levels have then been input into a Monte-Carlo simulation. This simulation runs through a number of scenarios for the home, office and outdoor environments assuming a given density of devices. In addition, the emission limits in the various standards were used as an input to the simulations as well as the measurements for comparison.

Figure 4 shows the process for combining the input data from measurements and standards with the Monte-Carlo modelling.

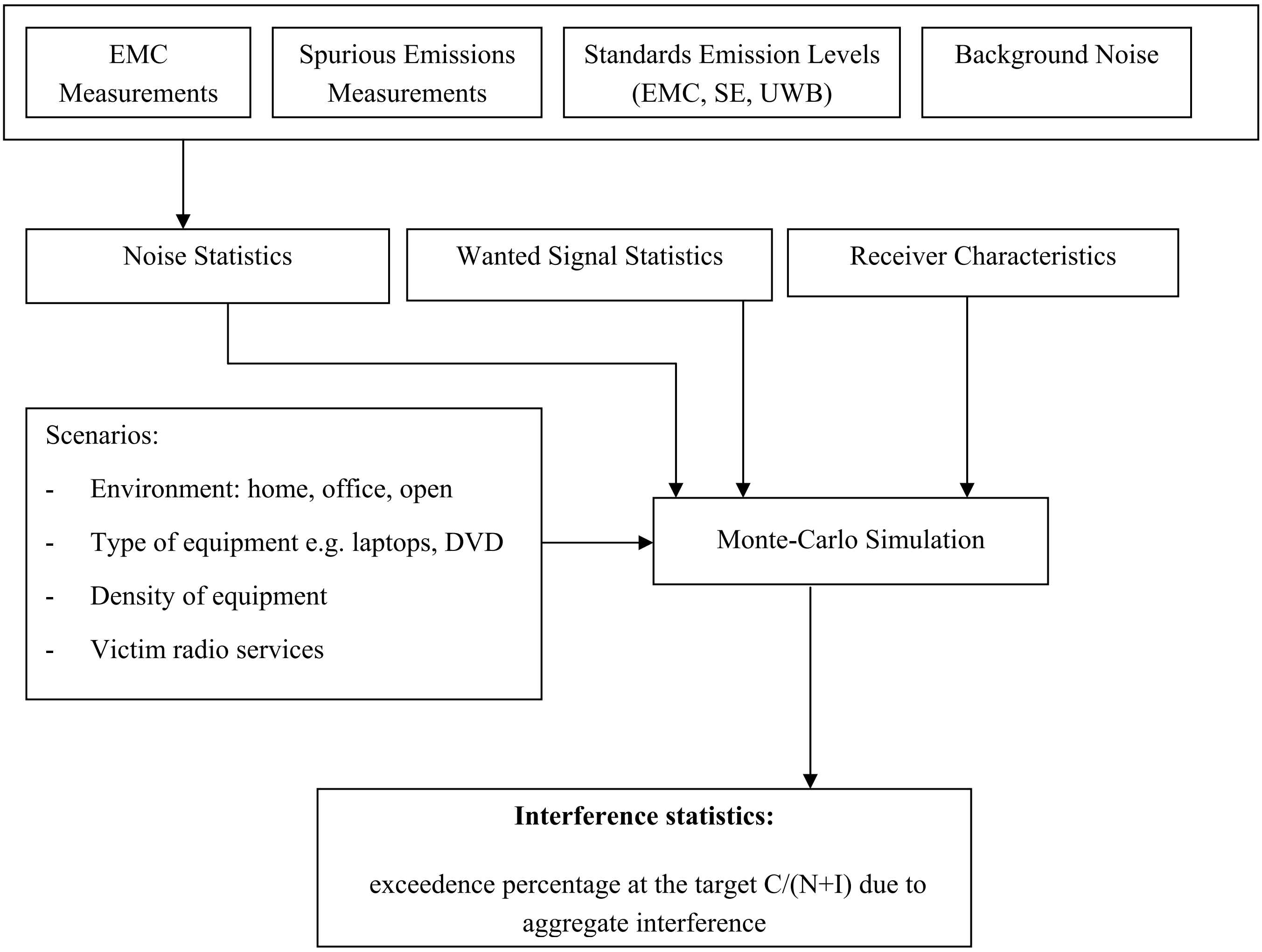

Figure 4: Overview of methodology combining measurement of electronic and radio equipment with Monte-Carlo modelling

2 Standards

There are a range of standards applicable to this study covering the areas of:

- EMC
- Spurious emissions
- UWB

These standards are reviewed in the following sections.

2.1 EMC Standards for Emissions Above 1 GHz

The main interest for the protection of radio services operating at frequencies above 1 GHz is associated with the interference that could be caused by information technology and multi-media equipment that could have widespread use. Electronic equipment (ITE, TV, etc) is continuing to operate at faster clock speeds with PCs now operating at speeds exceeding 1 GHz and it is envisaged that clock speeds may continue to increase up to the 10 to 20 GHz range.

Over the last ten years there have been developments in CISPR to produce test methods and limits for emissions from ITE, and in 2005 CISPR Sub-committee I approved an amendment to CISPR 22, CISPR/I/151/FDIS [3] containing emission limits and methods over the frequency range 1-6 GHz which shortly is likely to be a European harmonized standard applicable to all information technology and multi-media equipment placed on the market in Europe. The proposed radiated emission limits are presented in Table 1.

Table 1:
CISPR 22 amendment, proposed limits above 1 GHz

Frequency range	Average limit, dB(uV/m)		Peak limit, dB(uV/m)	
	Class A ITE	Class B ITE	Class A ITE	Class B ITE
1-3 GHz	56	50	76	70
3-6 GHz	60	54	80	74

Note: Class A ITE are for commercial and industrial use, Class B is for residential use.

The CISPR test method above 1 GHz, which is basically similar to those at frequencies below 1 GHz, will be applied until more applicable methods are approved. Figure 5 shows a general description of the proposed CISPR A radiated field measurement method above 1 GHz.

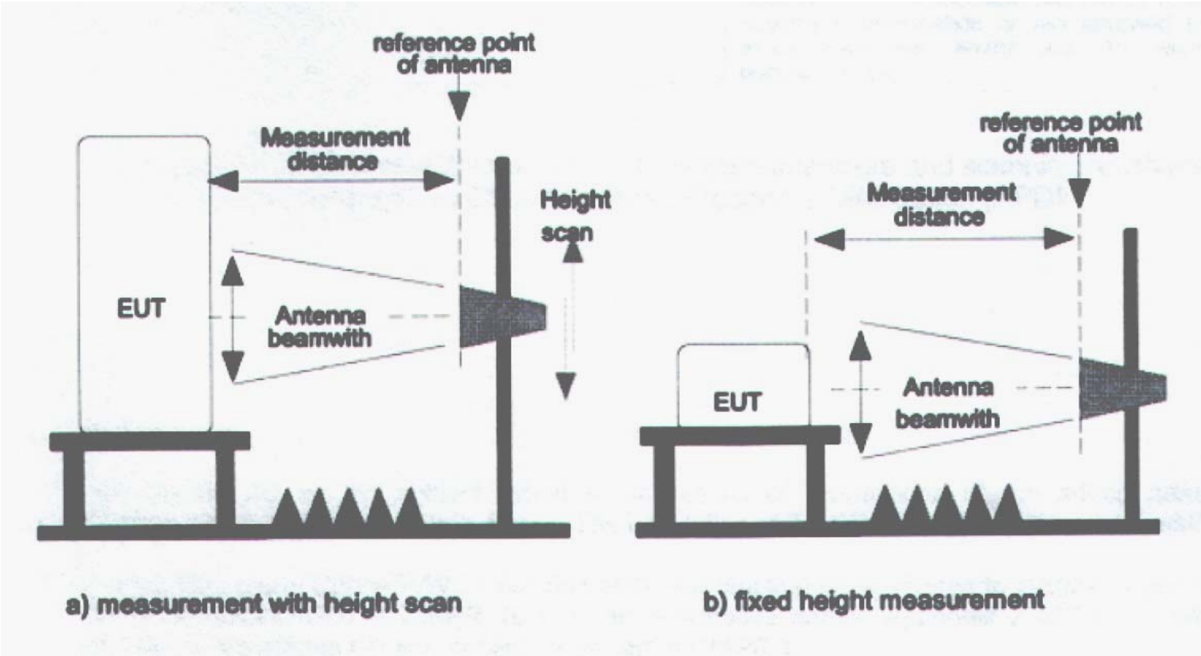

Figure 5: Typical EUT measurement set-up

The test facility is calibrated for a defined cylindrical space termed the "validated test volume" over which a calibrated energised antenna is placed and the observed fields determined by the measuring antenna are to be within a defined range. The directional properties of the measuring antenna are taken into account by determining the width of the main lobe at the location of the EUT. For EUTs, which are not encompassed by the 3dB beamwidth of the measuring antenna at the fixed height, h, the antenna shall be height scanned in order that the radiated emissions from the upper sections of the EUT are covered by the beamwidth dimensions. No such allowance is necessary for the horizontal direction because the search for maximum emissions is based on rotation of the turntable.

A 1 MHz resolution bandwidth is proposed for all measurements, with peak and average detectors. On a spectrum analyser, average measurements are made with a reduced video bandwidth.

The preferred test distance is 3 m provided the far field conditions are achieved, ie $d > D^2/2\,\lambda$, where D is the maximum aperture dimension of the measuring antenna and λ is the wavelength of the measurement. Measurements may be made at 1 m or 10 m and the data would be adjusted to the 3m values using free space propagation conditions.

Similar limits and test methods have been in force in the USA for a number of years as part of the Federal Communications Commissions (FCC) Code of Federal Regulations. The FCC limits for frequencies above 1 GHz, which are stated in Part 15, Sec. 15.109, are presented below in Table 2; this covers equipment categories of PC, computers and other digital devices.

Table 2:
FCC limits for digital devices

Frequency range, GHz	Field strength limit, dB(µV/m)			
	Class A (at 10m)		Class B (at 3m)	
	Peak	RMS Average	Peak	RMS Average
Above 0.96	N/a	49.5	N/a	54

For Class B equipment, e.g. residential PCs, the field strength limit is 7 dB more relaxed than the 37 dBµV/m limit of EN 55022 (at 10 m), at frequencies below 1 GHz.

FCC measurements are performed on an open area test site (OATS) or can be performed in an absorber lined shielded enclosure provided it can be demonstrated that reflections do not adversely affect accuracy. The measurements are made with a receiver or spectrum analyser having a bandwidth of 1 MHz and an average detector. There is also a limit on the radio frequency emissions, as measured using instrumentation with a peak detector function, corresponding to 20 dB above the maximum permitted average limit for the frequency being investigated. This applies unless a different peak emission limit is specified in the Rules, e.g. Sec. 15.255, Operation within the band 57 – 64 GHz; Sec.15.509, (Technical requirements for ground penetrating radars and wall imaging systems), and Sec 15.511, (Technical requirements for surveillance systems). The average detector used has a long time constant and significantly reduces the measured levels for any short duration transients.

Table 3 presents a comparison of the CISPR and FCC emission limits at 3m.

Table 3:
Comparison of limits at 3 m

Frequency range	CISPR Average limit, dB(uV/m)		FCC Average limit, dB(uV/m)	
	Class A ITE	Class B ITE	Equivalent Class A ITE	Class B ITE
1-3 GHz	56	50	60	54
3-6 GHz	60	54	60	54

At frequencies above 3 GHz the limits are identical and below 3 GHz the CISPR limits are 4 dB more severe. It is likely that these limits, (if fully agreed) will be retained until there is strong pressure in the form of feedback from the manufacturers, or the operators. Any proposals would take several years to be implemented.

In terms of European standards for EMC above 1 GHz, other than the standard for microwave ovens, (EN 55011), there are currently no harmonized standards published in the OJEC for unintentional electromagnetic (EM) emissions from ITE and other equipment above 1 GHz in Europe. However the recent amendment to CISPR 22 for emissions measurements at frequencies above 1 GHz are likely to be presented to CENELC TC 210 for consideration as a harmonized standard relevant under the EMC Directive 89/336/EEC.

Countries such as Canada, Australia and Japan are likely to update their standards according to the proposed changes to CISPR 22.

Any limits developed should provide, with reasonable probability, adequate protection to radio services. Furthermore there needs to be an acceptable cost to manufacturing industry who have to meet the emission limits in terms of the costs of design to comply and the costs of testing to demonstrate compliance. However, designing for EMC at the early stages of product development usually deals with design cost issues since low cost options can be chosen.

Complaint statistics in the radio service bands at frequencies above 1 GHz are somewhat minimal. These would be useful to establish a balance between protection requirements and manufacturing costs, and the established emission limits based on compromise.

The measurement test method should be capable of determining the interference potential of emissions from the EUT to a reasonable (or known) degree of accuracy. Previous work on emissions from products at frequencies above 1 GHz [2] indicated a field strength measurement uncertainty of 4-6 dB even under well controlled conditions and the method applied has to be sufficiently well designed to ensure repeatability and reproducibility of results from different laboratories. There is a possibility that high gain lobes will be observed at higher frequencies and could impact on probabilities of encountering maximum radiation. A measurement of a devices total power radiated has some advantages. The reverberation chamber technique, described in Section 4, does provide a measure of the devices total radiated power and thus has encouraged the use of this method in addition to an expansion of the standard CISPR field strength measurement techniques that have proved effective for many years.

In the future, there are likely to be some considerations given to convergence of the test facilities for all EMC radiated emission (and immunity) measurements and there is likely to be convergence on two basic facilities, Fully Anechoic Rooms (FAR) and Mode-Stirred (Reverberation) Chambers (MSC). In IEC/CISPR there have been several attempts at a unified test facility for both emissions and immunity testing where a single set up and EUT configuration for both tests would be used. This would be valuable where existing commercial facilities can be updated with minimal changes.

The mode-stirred (reverberation) chamber has significant advantages for some EMC work, mainly in the military sector where very high fields are required to simulate the effects of powerful transmitters at close distances. Work has been done to investigate the possibility of emissions measurements and the main advantage is that the results are in the form of the total effective radiated power from an

EUT which can be interpreted to assess the possible interference potential of the equipment. These limits have yet to be fully developed but will permit an effective assessment of a product which does not require a search for high gain lobes and should give more accurate assessments. The disadvantage is that the facility costs are quite high and will not be appealing to commercial businesses.

2.2 Spurious Emissions Standards

The spurious emission levels for the radio devices to be considered are defined by ETSI standards. Examples of the spurious emission levels detailed in the standards are given here.

Spurious emission limits for T-DAB transmitters shall not exceed the values set out in Table 4 for the frequency range 9 kHz to 1 GHz or 3rd harmonic whichever is higher.

Table 4:
Spurious emission limits for T-DAB transmitter

Frequency range of the spurious emission (MHz)	Limits of the spurious emission	Reference bandwidth (kHz)	Figure
9 kHz - 174	-36 dBm (250 nW)	100	4.1
> 174 - 400	-82 dBm, for P ≤ 25 W -126 dBc, for 25 W < P ≤ 1 000 W -66 dBm, for 1 000 W < P	4	4.2
> 400 - 1 000	-36 dBm (250 nW)	100	4.1
> 1 000 - 1 452	-30 dBm (1 μW)	100	4.1
> 1 452 - 1 492	-62 dBm, for P ≤ 25 W -106 dBc, for 25 W < P ≤ 1 000 W -46 dBm, for 1 000 W < P	4	4.2
> 1 492	-30 dBm (1 μW)	100	4.1
NOTE: P = mean power of the transmitter.			

As defined in EN 301 511 [10] and TS 151 010-1 [11], the spurious emissions limits for a GSM base station transmitter are shown in Table 5, and the limits for the mobile handset in Table 6.

Table 5:
Requirements for DCS BSS transmitter spurious emissions in receiver bands

	GSM BSS receive band (dBm)	DCS 1800 BSS receive band (dBm)
Normal BTS	-98	-98
Micro BTS M1	-91	-96
Micro BTS M2	-86	-91
Micro BTS M3	-81	-86

Table 6:
MS allocated channel spurious emission power levels

Frequency range		Power level in dBm		
		GSM 400, GSM 700, GSM 850, GSM 900	DCS 1 800	PCS 1 900
30 MHz to	1 GHz	-36	-36	-36
1 GHz to	4 GHz	-30		-30
1 GHz to	1 710 MHz		-30	
1 710 MHz to	1 785 MHz		-36	
1 785 MHz to	4 GHz		-30	

The spurious emissions from a wireless LAN transmitter are covered by EN 300 328 v 1.6.1 (2004-11) [12] and shall not exceed the values in the indicated bands as shown in Tables 7 and 8 below, for narrowband and wideband emissions.

Table 7:
RLAN transmitter limits for narrow band spurious emissions

Frequency range	Limit when operating	Limit when in standby
30 MHz to 1 GHz	-36 dBm	-57 dBm
above 1 GHz to 12,75 GHz	-30 dBm	-47 dBm
1,8 GHz to 1,9 GHz 5,15 GHz to 5,3 GHz	-47 dBm	-47 dBm

Table 8:
RLAN transmitter limits for wide band spurious emissions

Frequency range	Limit when operating	Limit when in standby
30 MHz to 1 GHz	-86 dBm/Hz	-107 dBm/Hz
above 1 GHz to 12,75 GHz	-80 dBm/Hz	-97 dBm/Hz
1,8 GHz to 1,9 GHz 5,15 GHz to 5,3 GHz	-97 dBm/Hz	-97 dBm/Hz

2.3 UWB Standards

2.3.1 FCC and NTIA recommendations

In the United States, the FCC, in co-ordination with the National Telecommunications and Information Administration (NTIA), have developed rules for unlicensed UWB devices under 47 Code of Federal Regulations Part 15 [13]. The regulation sets out guidelines under which an intentional, unintentional, or incidental radiator may be operated without an individual license. Part 15 stipulates that unlicensed devices are subject to the condition that no harmful interference is caused to licensed services and that harmful interference to unlicensed devices must be accepted. It is recognised and stated in Part 15.5 (c) that; “the limits specified in this part will not prevent harmful interference in all circumstances.”

The FCC has defined a UWB device to be any intentional radiator of RF energy, which has a 10 dB bandwidth of 25% of the strongest frequency within that 10 dB bandwidth or a 10 dB bandwidth of equal to or greater to 500 MHz [13]. These devices do not conform to the usual frequency allocation table and associated FCC regulations, because of these extremely large bandwidths.

The FCC regulation sets out a "mask" with an upper limit of –41.3 dBm/MHz as the amount of power that can be radiated at any particular frequency by a UWB device within the core band of 3.1-10.6 GHz. The FCC UWB limits are shown in Figure 6.

2.3.2 ECC recommendation

Decision ECC/DEC/(06)04 on the harmonised conditions for devices using UWB technology in bands below 10.6 GHz has been finally adopted by the European Communications Committee (ECC) at its meeting 20 – 24 March 2006 in Oulu (Finland).

The baseline solution for UWB operation in Europe is twofold and is based on a consensus reached between Conference of Postal and Telecommunication administrations (CEPT) administrations:

- Operation in band 6 – 8.5 GHz, subject to maximum power density levels and without requirement for additional mitigation.

- Operation in band 3.1 – 4.8 GHz, subject to maximum power density levels and to the implementation of adequate mitigation techniques, which requirements are to be defined and effectiveness is to be validated.

No consensus has been reached on the inclusion of regulatory provisions for a phased approach in the band 4.2 – 4.8 GHz without mitigation techniques.

Draft ECC Decision ECC/DEC/(06)EE has been developed in complement to Decision ECC/DEC/(06)04 and is currently focused on the principle of a possible harmonised transition measure applicable to frequency band 4.2 – 4.8 GHz since no technical requirements are currently available for mitigation techniques considered in the frequency band 3.1 – 4.8 GHz.

Additionally, new UWB devices are exceptionally permitted until [30 June 2010/2012] to operate in the frequency band 4.2 - 4.8 GHz with a maximum mean EIRP density of –41.3 dBm/MHz and a maximum peak EIRP density of 0 dBm/50 MHz without the requirement for additional mitigation

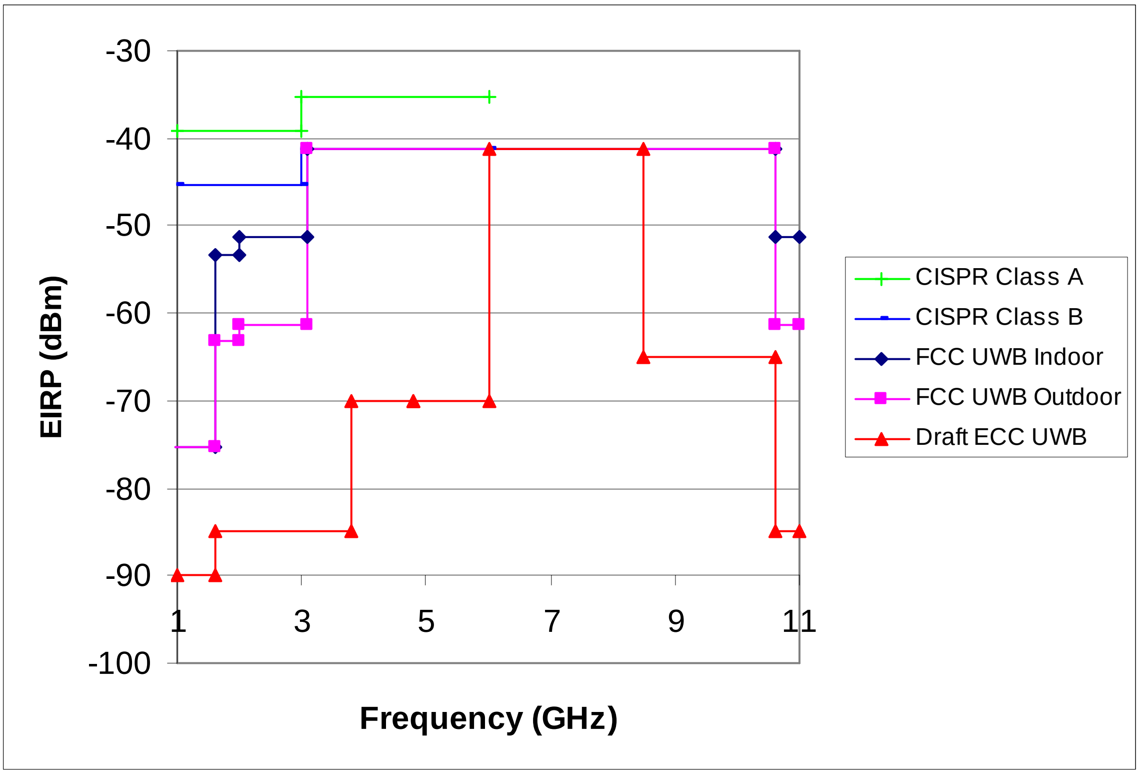

Figure 6: FCC and draft ECC UWB mean EIRP limits compared with CISPR average emission limits in a 1 MHz band

Figure 6 above shows the comparison between CISPR average emission limits above 1GHz for Class A (Industrial) and Class B (Residential) and mean UWB limits set by the FCC and proposed by the ECC.

3 Review of Existing Research Studies for Noise Above 1 GHz

ERA carried out a programme of work for the Radiocommnications Agency, now Ofcom, in 2002 [2] with the objective of developing test methods and limits for emissions tests to provide adequate protection for radio services above 1 GHz, suitable for submission to CISPR. The test method should be acceptable, pragmatic, and relatively economical in terms of facilities that give repeatable and reproducible results. To address concerns that EUT emissions above 1 GHz are likely to be directional, the RF emissions were measured using a Hemispherical Measurement Range shown in Figure 7.

Figure 7: The Hemispherical Measurement Range

Examples of measurements made with the Hemispherical Measurement Range are shown below for frequencies of 1 GHz and 10 GHz. The results show that the emissions become increasingly directional with increasing frequency above 1 GHz, Figure 8. These are in the form of Logarithmic Spherical Plots at frequencies of 1GHz, 3GHz and 10 GHz.

(a) (b) (c)

Figure 8: EMC emissions a) at 1 GHz; (b) at 3 GHz; (c) at 10 GHz)

Limits were derived from the work of CISPR and research papers. A limit of 57 dB(μV/m) was proposed for the frequency range 1 to 2.7 GHz, and a limit of 65 dB(μV/m) over the range 2.7 to 6 GHz. The measurement uncertainty budget for the measurement chain of the proposed test method was approximately + /-5 dB to a 95% confidence level, following the procedures of the UKAS document Lab 34 [15]. Overall the uncertainty budget is only slightly greater than the typical values (+/-4 dB) for measurement at frequencies below 1 GHz.

The ERA/BT proposal to CISPR I was rejected but the latest CISPR I proposal is a watered down approach and may give rise to lower levels of control as a result of the low probability of capturing the maximum fields of the high gain lobes.

The Man Made Noise Measurement Programme [16] carried out by MASS Consultants developed a methodology and gathered measured data for updating ITU-P.372. The MASS measurement system was tested at 8 sites and it was proposed that a large number of measurements should be made using the test jig developed in order to gather a more statistically relevant set of data. A range of noise metrics was measured. It was noted that there appears to be evidence showing an increased level of MMN over the last few decades, although this is to be confirmed.

A study by Quotient [17] into the potential economic impact on the UK spectrum of Ofcom not undertaking technical research and standards work in the area of EMC, considered the probability of interference in office and home environments to LW/MW/FM radio, DAB radio, PAL, DVB-T, mobile services, etc. This work details a range of sources that were considered for different environments and estimates of the percentage of the environment that could be affected by different levels of interference, although the work concentrates on frequencies below 1 GHz.

York EMC Services developed a mathematical model [18] to try and predict the radiation patterns from typical EUTs. A simple generic EUT shielded box with slots containing a Comparison Noise Emitter source was used. York EMC Services then performed a second study using the same simple EUT and undertook detailed electromagnetic modelling to try to reduce measurement times for EMC tests, particularly above 1 GHz. A simple point source model was used, and it was shown that even with a simple source it proved difficult to accurately model the statistics of the EUT emissions under consideration due to the complexity of the interactions.

4 Measurements

Laboratory measurements were made of the EMC emissions and spurious emissions from a range of modern electronic equipment and radiocommunications equipment. These measurements provided data on the actual emissions of typical equipment such as emission levels and the probability of emissions occurring from 1 to 6 GHz.

Emission measurements were made in both a fully anechoic room (FAR) and a stirred-mode chamber. The new CISPR standards specify the use of a fully anechoic chamber. The stirred-mode chamber was used in addition as it might be considered in the future as an alternative technique and can easily capture emissions in all directions which was seen as a potentially attractive solution due to the increased directionality of emissions from equipment at higher frequencies.

The fully anechoic room consists of a shielded metallic room which has RF absorber on all internal walls which minimises the reflections in all directions. An example of the fully anechoic room is shown in Figure 9. The equipment under test (EUT) is rotated and the measurement antenna height varied to allow the worst-case emissions to be captured. This method gives a direct measure of absolute field strength.

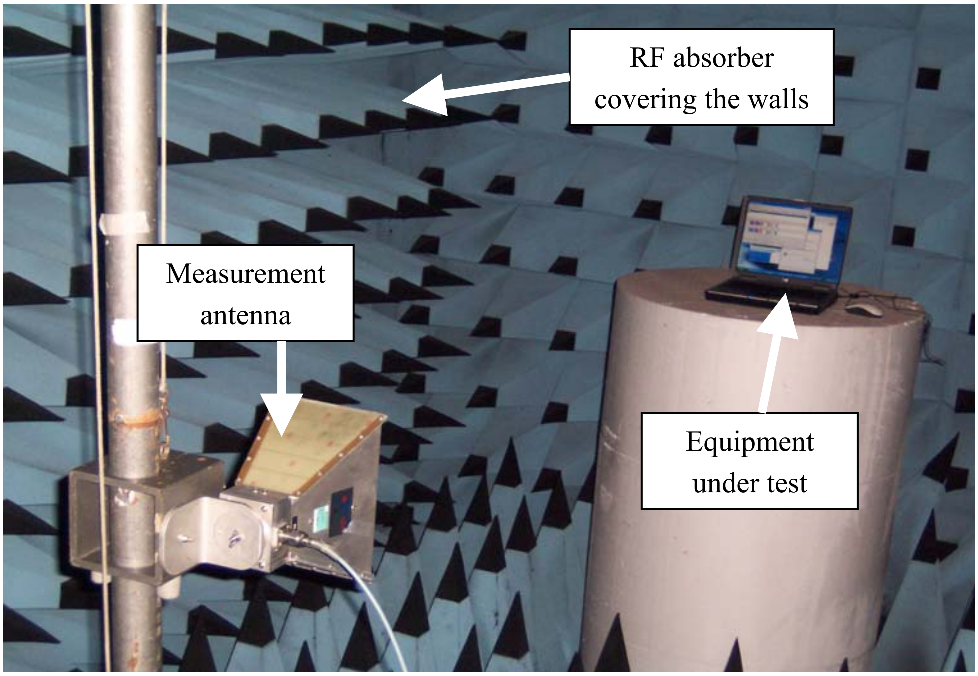

Figure 9: The fully anechoic room

The mode-stirred chamber is also called a reverberation chamber and this is because it makes use of the reflections off the metal walls of the chamber, Figure 10. However, the path loss between the EUT and the antenna will vary with frequency and location of the EUT and the antenna. For this reason, a paddle wheel is used which rotates and "mode-stirs" the chamber by continually changing the direction of the reflections within the chamber removing the dependence on the location of the EUT and the antenna and allowing a repeatable measurement. As opposed to the fully anechoic room measurement described above which gives a direct measure of field strength in the absence of reflections from a particular part of the EUT, the received field strength for the stirred-mode chamber is an instantaneous combination of multiple reflections from all parts of the EUT, and the absolute field strength needs to be calculated by comparison to a reference transmitter such as a dipole antenna, which can lead to errors. It should be noted that an alternative reverberation chamber technique to mode-stirring is mode-tuning.

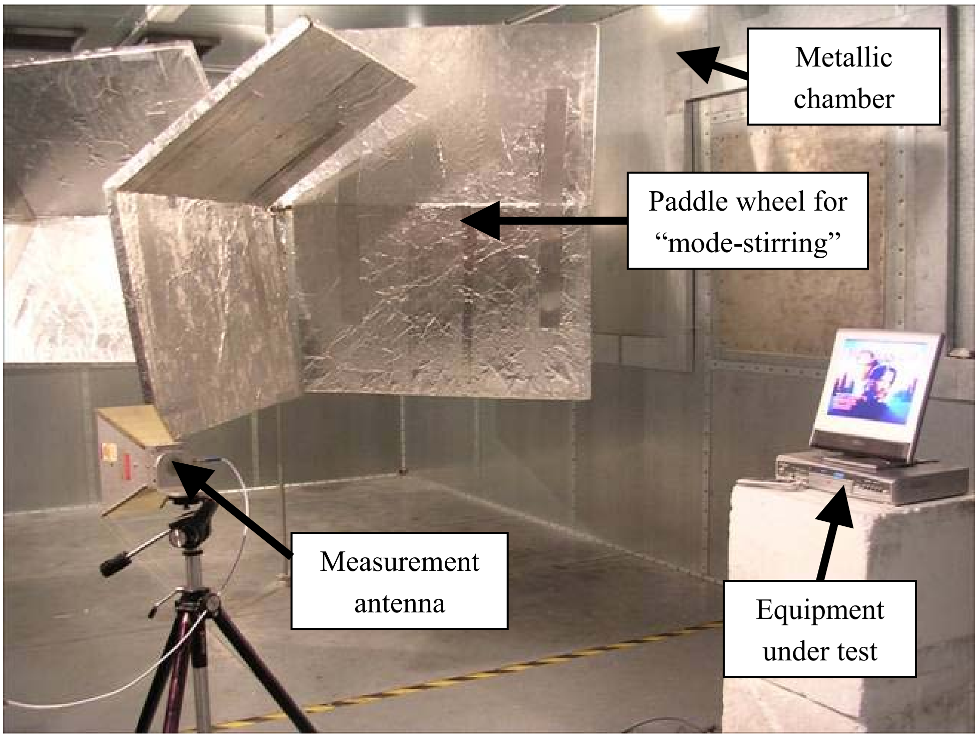

Figure 10: The stirred-mode chamber

4.1 Products Tested

The types of product to be examined were based on the fact that large market entry would give rise to widespread potential interference problems if not adequately protected. The products listed below were selected on that basis and have been tested with their operating conditions set to represent the most typical configurations, i.e. normal operating mode and worst-case scenario if the set-up allows.

1. **DVD Player – Goodmans X-Pro.** Tested in normal operating mode, playing DVD and displaying the output on LCD TV.

2. **DECT Phone – Twin Set Digital Cordless Phone.** Tested in intercom mode – dialling an internal call between the two handsets.

3. **Desktop PC – Packard Bell I Media Pentium 4 - 2.9GHz CPU – 512M RAM.** Tested in worst-case scenario using special software that exercises the CPU usage to up to 95%.

4. **HP Laptop – Compaq nx9010 – 2.6GHz CPU – 512 RAM.** Tested in worst-case scenario using special software that exercises the CPU usage to up to 95%.

5. **Multimedia System – Philips.** The wireless transmitter was enabled to allow multimedia file streaming between the product and the laptop PC. The output of the received files was displayed on the LCD TV.

6. **XBox 360 Core system.** Tested in normal operating mode – Using a demo game that exercises the CPU, graphic cards and input and output ports.

4.2 The Fully Anechoic Room (FAR) Measurement Configuration

Figure 11 shows the basic CISPR standard test set up for the measurement of emissions from the six equipment systems examined. The equipment under test was placed on an insulating support of 1.7 metres height and the receive antenna was placed at a height, h, of 1.9 metres.

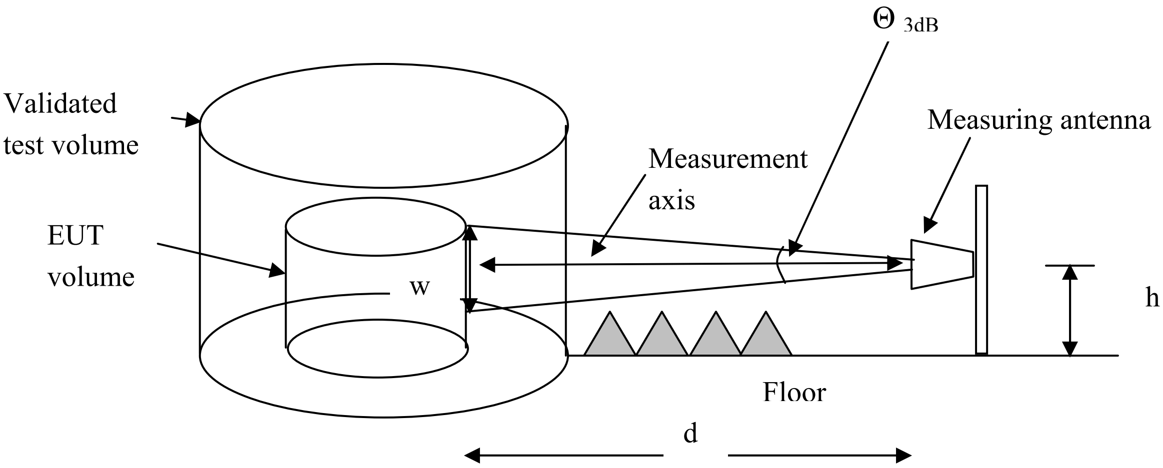

Figure 11: CISPR validated test volume measurement set-up

As the antenna 3 dB beamwidth is finite, the area of the equipment under test (EUT) that it covers, shown as “w” in Figure 11, may be smaller that the EUT dimensions. As the EUT will be rotated, emissions from all sides of the EUT will be captured. However, if the EUT height is larger than the antenna beamwidth “w”, then the measurement antenna would have to be scanned with height. For the equipment tested during this study, no antenna height scanning was required in the frequency range of concern (1 to 6 GHz) due to the small dimensions of the EUTs used.

The sweep time of the spectrum analyser was set such that the selected frequency span can be swept within a time that is equal or less than the time needed for the turntable to rotate 15 degrees. The product under test was then rotated from 0 to 360 degrees; this enabled the spectrum analyser to capture the maximum peak emissions from the EUT in the frequency ranges of 1 to 6 GHz. This method was then repeated for other orthogonal scans, resolution bandwidths and antenna polarisations.

The products under test (operating in normal mode or worst case scenario) were placed on a turntable at 3m distance from the measuring antenna, for peak measurements, the spectrum analyser is set to peak detector with max hold set-up to detect the maximum emission profiles generated by the EUT.

The emission measurements have been carried out with spectrum analyser resolution bandwidths (RBW) of 1 MHz, 300 kHz and 100 kHz, using both peak and average detectors. The CISPR method requires a resolution bandwidth of 1 MHz but additional bandwidths were used in order to determine the preferred options for radio service protection. Field strength measurements were made in both vertical and horizontal antenna polarisations.

The EUT was tested with the vertical axis of the equipment placed in three orthogonal axes, X, Y and Z as shown in Figure 12.

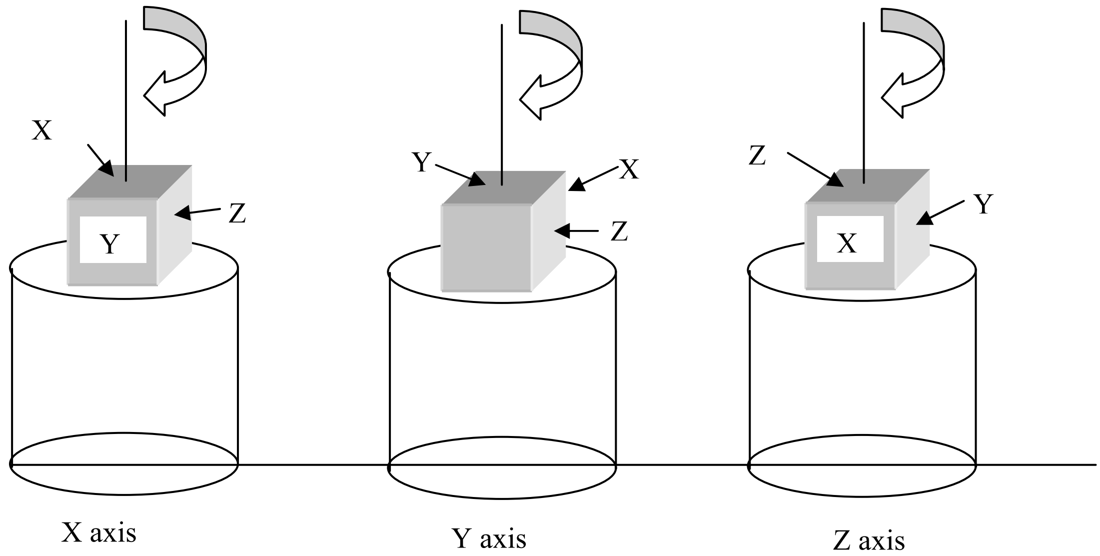

Figure 12: EUT configurations for the X, Y and Z axis measurements

For each axis the EUT was rotated through 360 degrees by the operation of the turntable so that information was obtained on two vertical scans through 360 degrees in addition to a single horizontal rotation. Only one (X axis) rotation is required by CISPR; the aim of this assessment was to determine whether the CISPR method fully captured the maximum radiation levels.

4.3 The Reverberation Chamber Measurement Configuration

The EUT radiated emissions were measured over the required frequency range, in this case 1 to 6 GHz. Each EUT was set-up using a non-conductive support with the EUT positioned at least λ/4 from the chamber boundaries and paddle wheel/tuner, where λ is the wavelength at the lowest measured frequency. In this case 1 GHz relates to a full λ of 30 cm, thus the EUT must be greater than 7.5cm from all boundaries and any conductor within the chamber. For all EUT radiated emissions measurements the receive antenna was directed towards the paddle wheel or tuner, to avoid direct illumination from the EUT.

Within an anechoic chamber or OATS the measured radiated emissions parameter is in terms of E-field (dBμV/m) with limits based on defined EUT to antenna distances, measurement bandwidths and receiver detectors. Conversely, within the reverberation chamber the parameter measured is the antenna base voltage (dBμV). Using the corrected antenna base voltage measurement it is possible to determine the amount of total radiated power ($P_{radiated}$) radiated by the EUT. During this investigation the paddle wheel/tuner was rotated for a minimum of 5 complete rotations per measurement band for the continuous mode stirred method, to ensure the maximum total radiated power was detected. For the two devices tested employing mode-tuned methods, 30 discrete paddle or tuner steps were employed over 1 rotation of the paddle/tuner.

4.4 Fully Anechoic Room (FAR) Test Results

The complete fully anechoic room (FAR) test results are reported in Annex A. A selection of the results is shown below. Figures 13 and 14 show the emission from the laptop using a peak and average detector, respectively. Figures 15 and 16 show the peak emissions from the desktop PC, and the X-box, respectively. The X-box has an in-built Wi-Fi system which can clearly be seen. All of the results are compared to the CISPR limit lines. It can be seen that in all cases the measured emission levels are well below the CISPR limit lines. For the peak detector measurements, the emissions from all of the equipment measured are typically 15 to 20 dB below the limit line, except for the 2.6 GHz clock emission for the laptop which is about 13 dB below the peak limit line. For the average measurements the emissions were typically 10 to 15 dB below the limit line, except for the 2.6 GHz clock emission for the laptop which is about 6 dB below the average limit line.

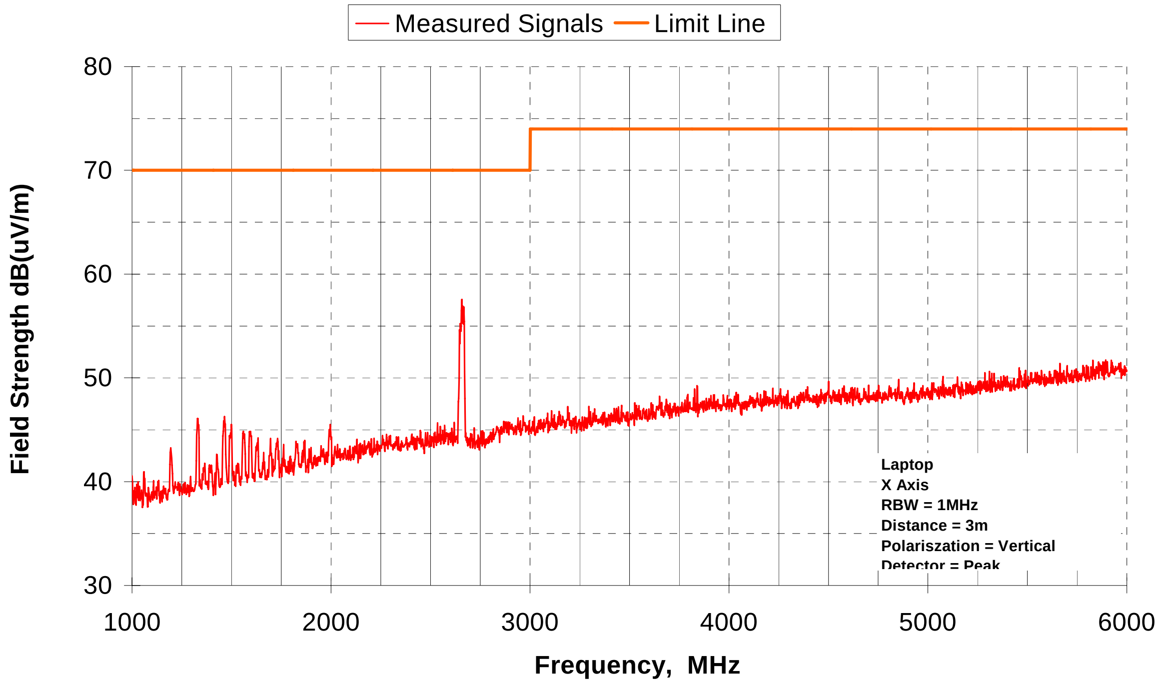

Figure 13: Emissions from laptop with 1 MHz bandwidth and peak detector

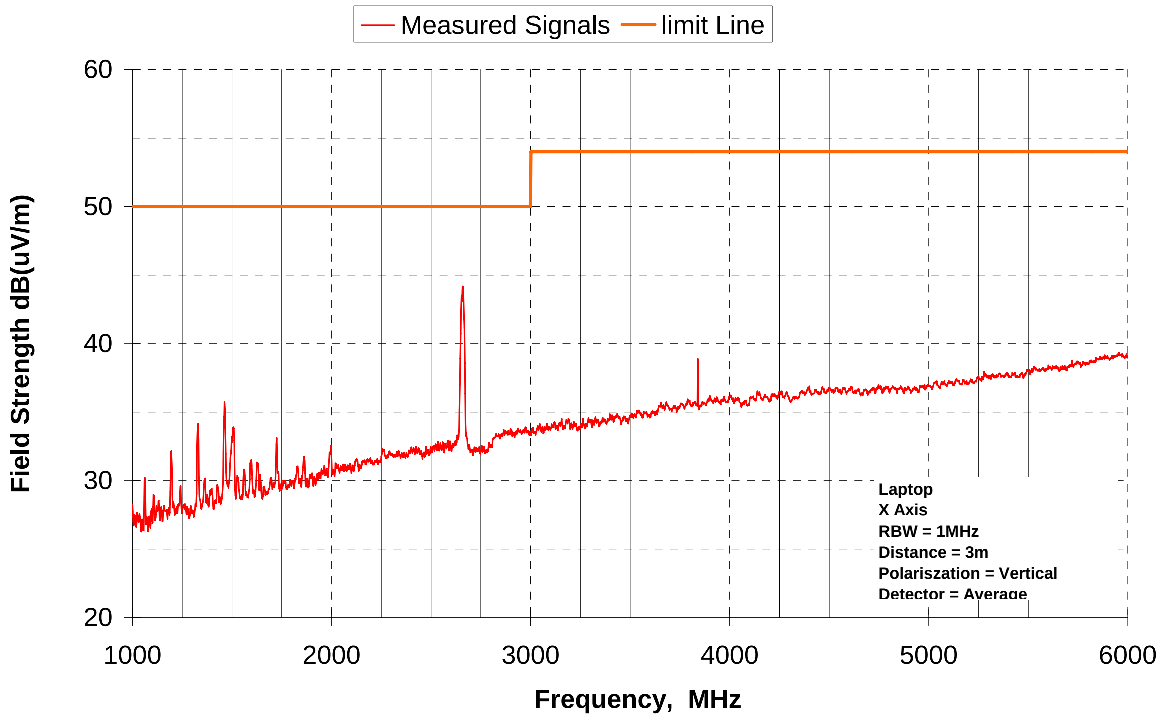

Figure 14: Emissions from laptop with 1 MHz bandwidth and average detector

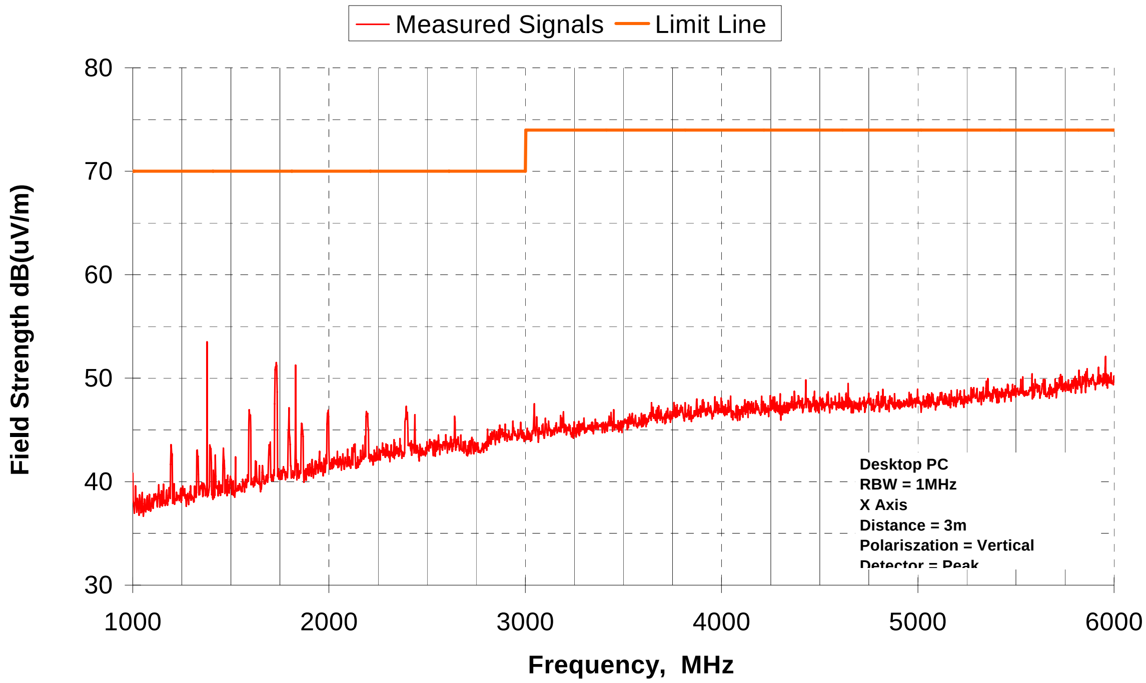

Figure 15: Emissions from desktop PC with 1 MHz bandwidth and peak detector

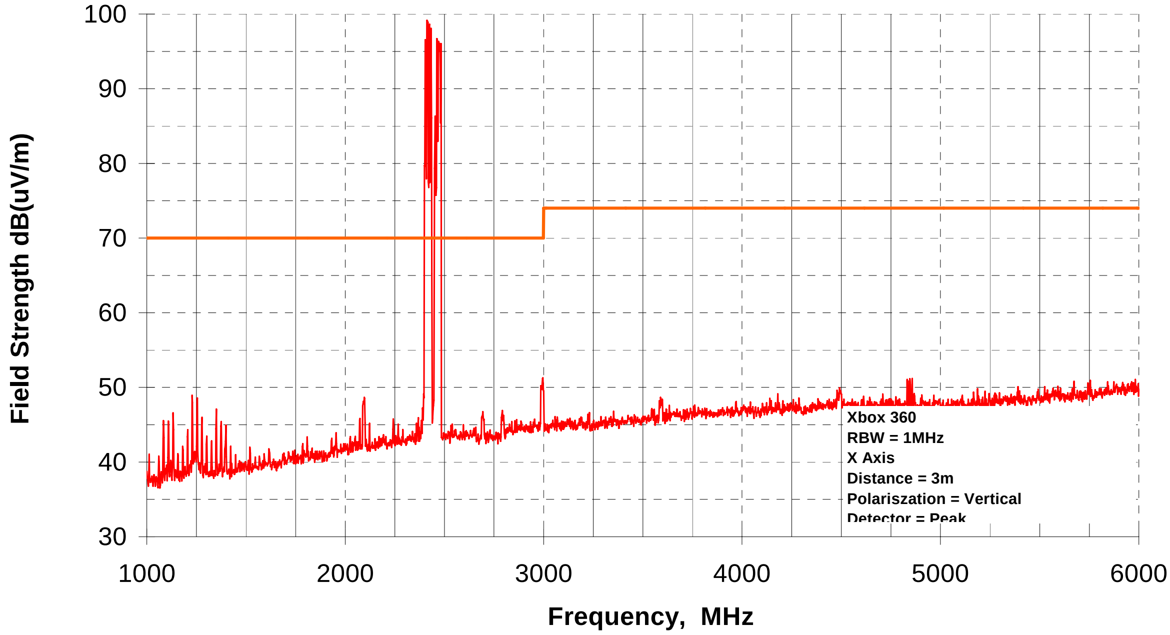

Figure 16: from X-Box with 1 MHz bandwidth and peak detector

4.4.1 Field strength polar distribution

The products under test were also scanned to detect the field strength distribution from all orthogonal planes (X, Y, Z). Different frequencies at high field strength levels were measured for each product. The complete measurements results are presented in Annex A.

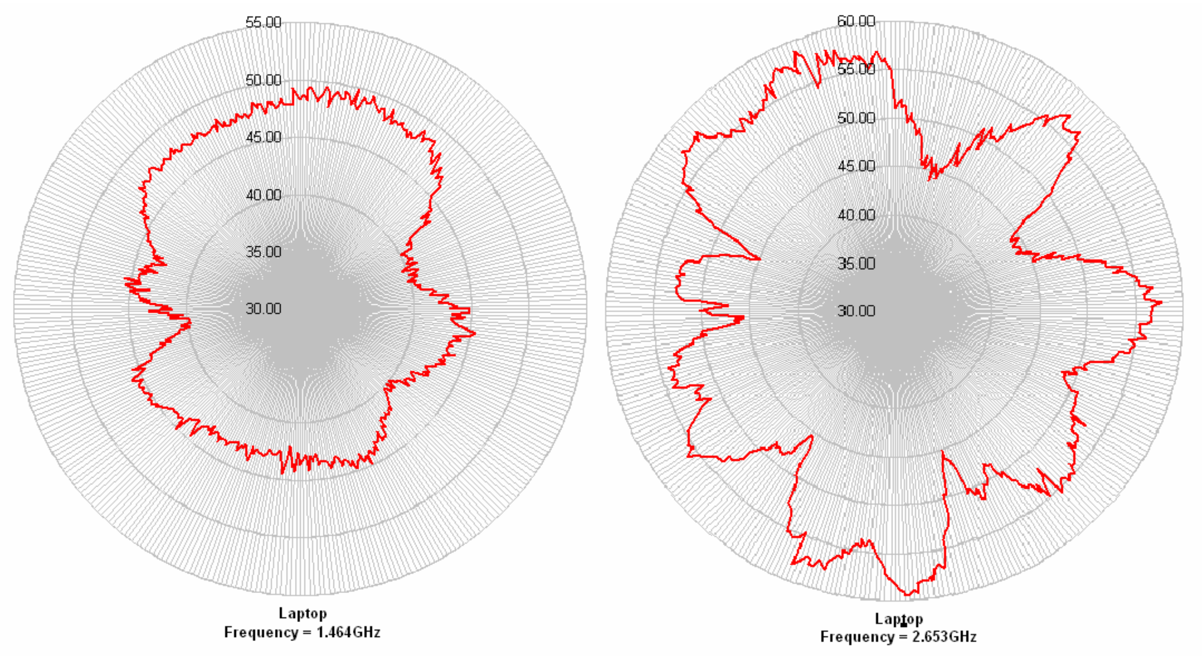

Figure 17: Polar distribution of the laptop emissions in the x-axis: (a) at 1.464 GHz and (b) at 2.653 GHz

The radiation patterns at higher frequencies had a number of very directional peaks.

4.5 Reverberation Test Results Assessment

The results of the reverberation chamber measurements performed by Qinetiq are presented in Annex A and a summary is given here. When making comparisons it must be considered that the directivity of the devices was not known when calculating the equivalent radiated field. Unless the device tested was purely isotopic, the estimated E-fields from the reverberation chamber method may be 'artificially' lower than the 'worst case' value measured within the FAR. There are a number of other factors that could impact the comparison between measured emissions, some of these can also exist within conventional techniques, for example, turntable rotation speed, cable layout, antenna scan rate, equipment cycle/dwell time.

An example of the mode-stirred chamber results is given in Figure 18 for the laptop. The main CPU clock frequency and second harmonic are clearly measured. The CPU fundamental frequency of 2.6 GHz, is over 20 dB below the peak limit defined.

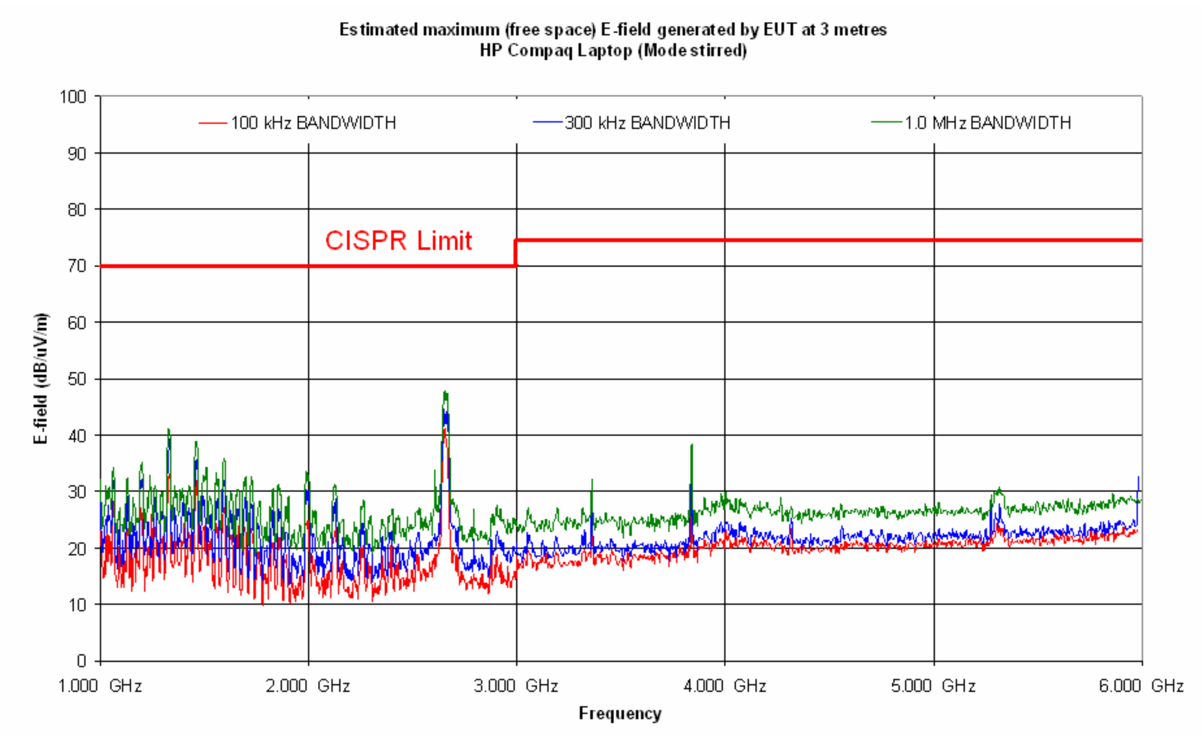

Figure 18: Laptop – Mode Stirred

4.6 Comparison of FAR and Reverberation Measurements

Figure 19 shows the comparison between the radiated emissions from the desktop PC measured in the reverberation chamber compared with those measured on the same item of equipment in the Fully Anechoic Room.

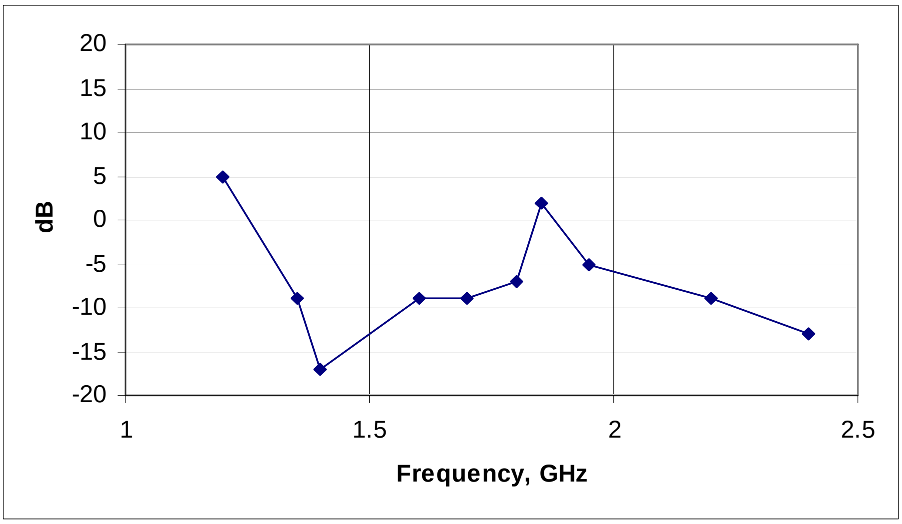

Figure 19: Desktop PC reverberation chamber radiated emission results relative to FAR results

The reverberation chamber gave an average reduction in field of 7 dB but there was clear and apparently uniform frequency dependence. This difference is due to fundamental differences in the methods, with the FAR giving a direct measure of field strength, whereas the reverberation chamber requires a calculation from a total received power which includes multiple reflections off the chamber walls. This difference could lead to a factor, which could be included in EN 61000-4-21 to obtain representative fields when using the reverberation chamber, but further work is required to determine the value and precision of the gain figure to be applied. The same outline analysis was performed for the DVD/TV system that was measured using both facilities. The results are presented in Figure 20. The mean value is again in the order of about 10 dB with a +/-5 dB variation about the mean.

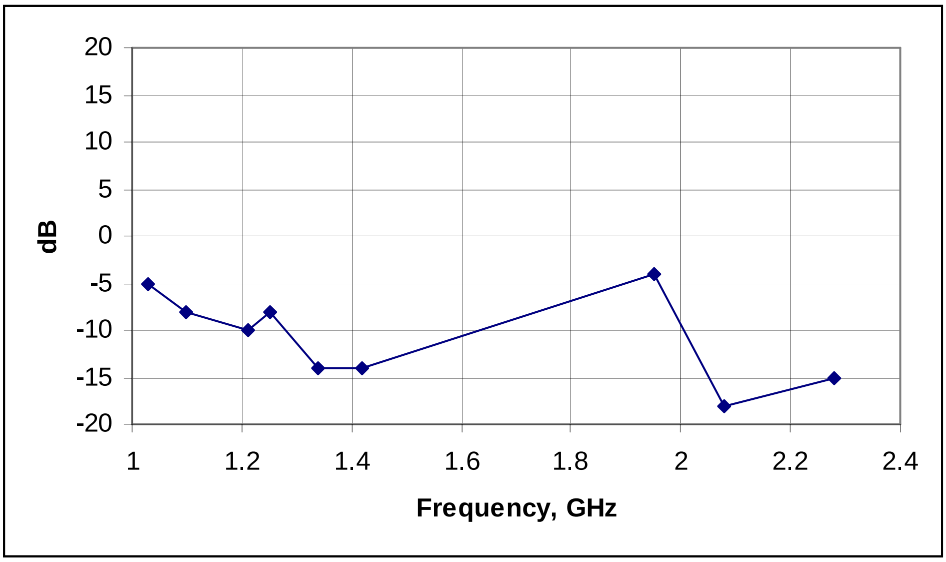

Figure 20: DVD/TV reverberation chamber radiated emission results relative to FAR results

Both of these results imply that the reverberation chamber directivity factor of 1.7 would probably need to be adjusted in order to realise a more representative reverberation chamber result closer in value to those determined in the FAR for these types of product. It is encouraging that the differences do not vary significantly with frequency since this could be an expected effect where the EUT are omni-directional radiators at low frequencies but have higher gain lobes at higher frequencies.

4.7 Extraction of Measurement Data for Input to the Modelling

The anechoic measurement results were used to provide an input to modelling work, as the results available were more extensive than the reverberation chamber results and use a CISPR accepted methodology. The full list of extracted data is shown in Tables 9 and 10. An investigation of the types of emissions from the different products showed that there are typically two types of signal emitted from electronic / radio equipment: wideband signals, e.g. from dithered clocks, and narrowband harmonic signals. Figure 21 illustrates example field strength measurements from a desktop PC from 1 to 1.5 GHz.

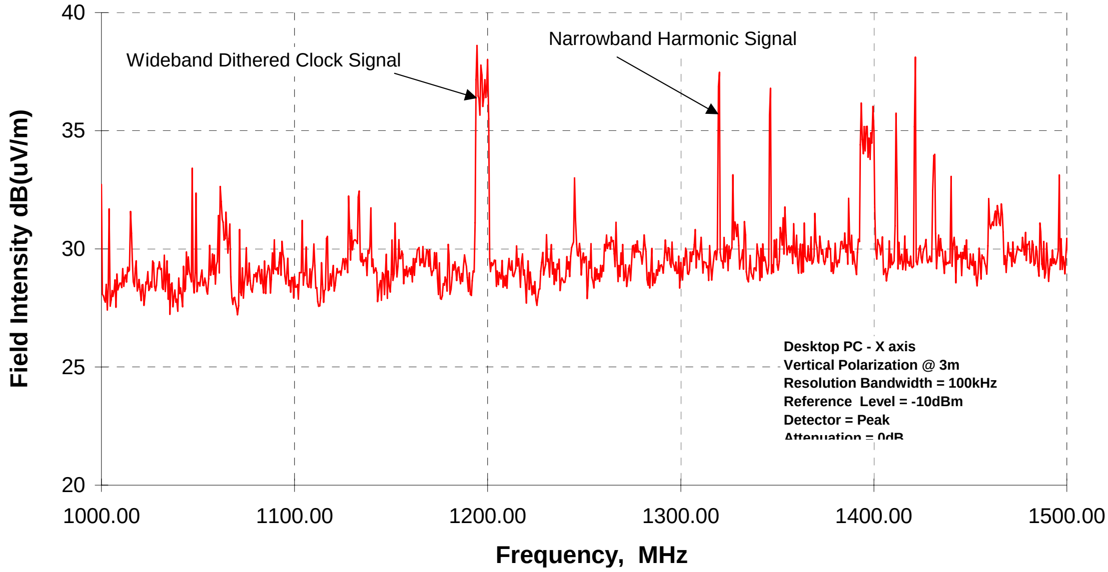

Figure 21: EMC Measurements from a Desktop PC

An Excel module was developed which automatically processed the measured data according to a set of functions. Firstly, only those emissions that were 2 dB or greater above the noise floor were extracted. The data then contained both narrowband and broadband emissions and these needed to be first identified and then separated. Figure 22 show this process for the DVD+TV combination for frequencies from 1 to 2 GHz. This process worked very well in the majority of cases and gave quite reliable data for the modelling.

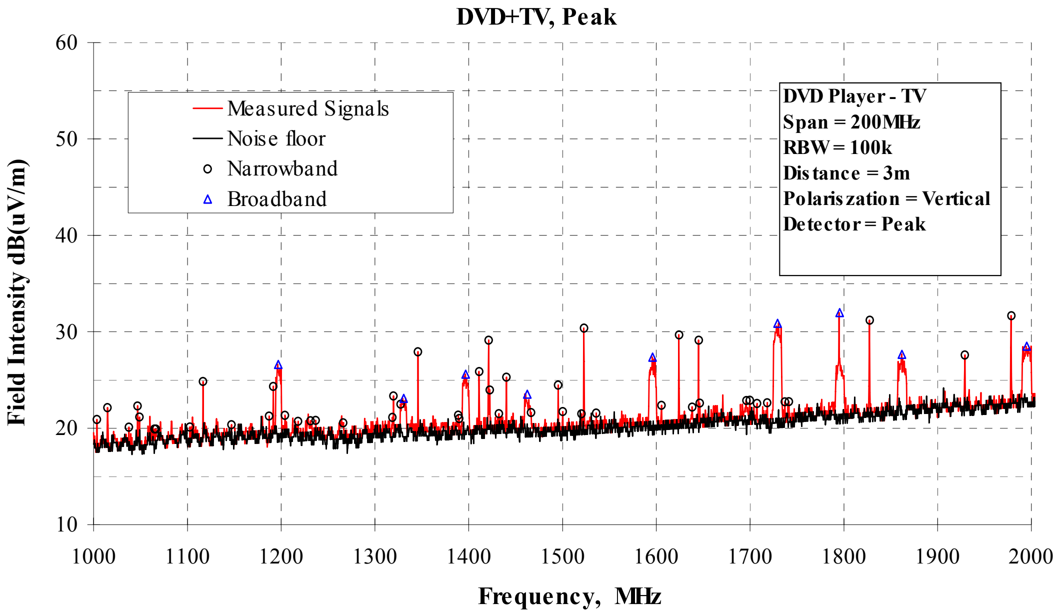

Figure 22: Automatic extractions of narrowband and broadband data, DVD+TV, 1 to 2 GHz

The separated narrowband and broadband emissions data was then further processed to provide statistical information. Figure 23 shows processed narrowband data in the form of the percentage of the sampled data versus the emission level, and also the number of occurrences, for 3 frequency bands.

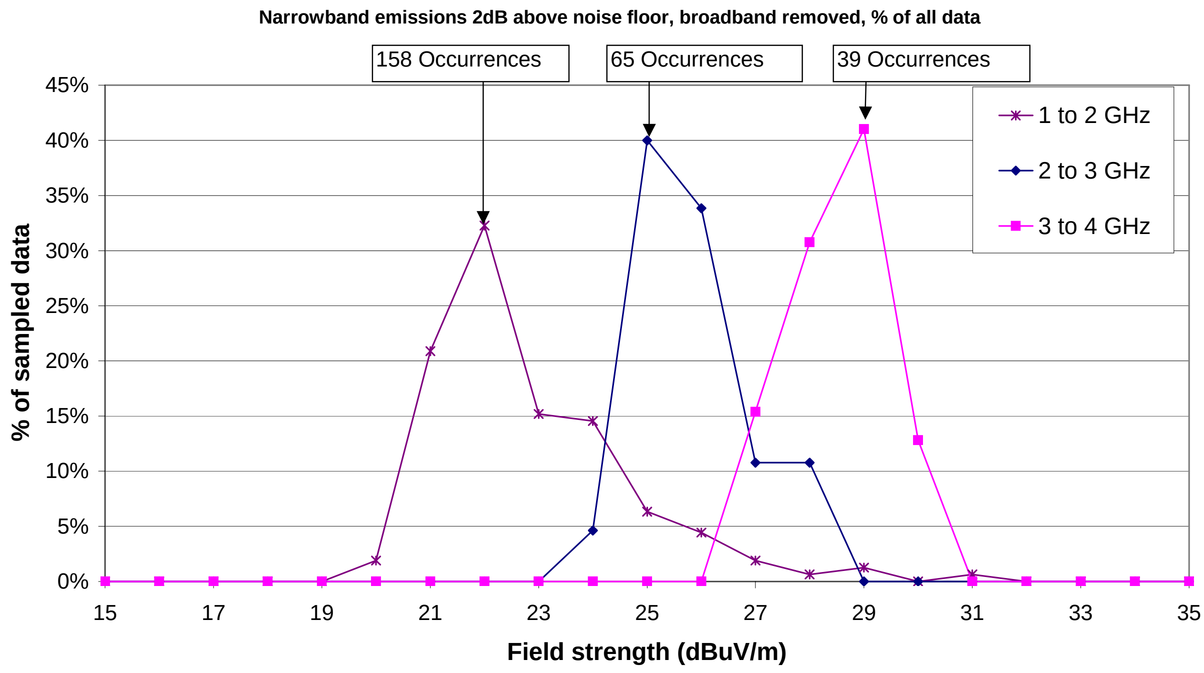

Figure 23: Extracted narrowband statistics (% of sampled data plus number of occurrences)

It should be noted that above about 2 to 3 GHz the emissions were largely below the noise floor. For this reason, where the noise floor dominated the emissions, the actual measured levels were used but some statistical information such as number of occurrences was used from lower frequency bands. The assumption is that the probability of occurrence of narrowband and broadband emissions is similar at higher frequencies but the levels are lower. If anything, this is a slightly worst-case as it also assumes that some of the emissions are at the noise floor level whereas they could be considerably below.

In addition, the following information was used. At each frequency where an emission is detected, the maximum field strength and the field strength variation with the orientation of the measured equipment have been determined.

In addition to the field strength levels and the number of occurrences, the bandwidths were also determined. Tables 9 and 10 summarises the measured emission characteristics for all equipment considered in this study. The results are obtained from an average detector with 100 kHz resolution bandwidth.

Table 9: Measured Emission Characteristics

Equipment	Frequency Band	Emission Type	Mean of Measured Maximum Emission Levels (dBμV/m)	Standard Deviation of Measured Maximum Emission Levels (dB)	Difference Between Maximum and Mean of Measured Emission Variation with Orientation (dB)	Standard Deviation of Measured Emission Variation with Orientation (dB)	Number of Occurrence	Mean Emission Bandwidth (MHz)
Laptop	1 – 2 GHz	Narrowband	22	3.44	-4	2.3	225	0.69
		Wideband	28	0.53	-4	2.3	14	10.61
	2 – 3 GHz	Narrowband	26	2.14	-9	3.0	71	0.46
		Wideband	32	0.53	-9	3.0	2	15.9
	3 – 4 GHz	Narrowband	29	0.80	-9	3.0	74	0.4
		Wideband	32	0.53	-9	3.0	2	15.9
PC	1 – 2 GHz	Narrowband	23	1.93	-9	3.5	48	0.52
		Wideband	28	1.71	-9	3.5	9	7.0
	2 – 3 GHz	Narrowband	26	1.35	-8	4.2	22	0.53
		Wideband	29	1.85	-8	4.2	2	7.8
	3 – 4 GHz	Narrowband	28	0.96	-8	4.2	9	0.48
		Wideband	29	1.85	-8	4.2	2	7.8
TV+DVD	1 – 2 GHz	Narrowband	22	2.27	-8	5.3	158	0.57
		Wideband	31	2.27	-8	5.3	28	3.49
	2 – 3 GHz	Narrowband	25	0.88	-8	3.0	65	0.46
		Wideband	30	0.94	-8	3.0	8	2.95
	3 – 4 GHz	Narrowband	29	0.84	-8	3.0	39	0.42
		Wideband	30	0.94	-8	3.0	8	2.95

Table 10: Measured Emission Characteristics (continued)

Equipment	Frequency Band	Emission Type	Mean of Measured Maximum Emission Levels (dBμV/m)	Standard Deviation of Measured Maximum Emission Levels (dB)	Difference Between Maximum and Mean of Measured Emission Variation with Orientation (dB)	Standard Deviation of Measured Emission Variation with Orientation (dB)	Number of Occurrence	Mean Emission Bandwidth (MHz)
X-Box	1 – 2 GHz	Narrowband	25	2.27	-7	3.6	63	0.84
		Wideband	33	5.16	-7	3.6	3	3.7
	2 – 3 GHz	Narrowband	26	1.46	-6	2.2	32	0.76
		Wideband	33	2.24	-6	2.2	2	18.64
	3 – 4 GHz	Narrowband	29	0.87	-6	2.2	17	0.59
		Wideband	33	2.24	-6	2.2	2	18.64
WML	1 – 2 GHz	Narrowband	22	3.44	-10	4.1	67	0.96
		Wideband	35	0.53	-10	4.1	2	3.47
	2 – 3 GHz	Narrowband	28	2.15	-7	3.3	14	1.25
		Wideband	35	0.53	-7	3.3	2	3.47
	3 – 4 GHz	Narrowband	28	0.8	-7	3.3	2	0.4
		Wideband	35	0.53	-7	3.3	2	3.47

4.8 Spurious Emission Measurements in FAR

Spurious emission measurements were made to identify if the actual measured values were significantly below the ETSI limits or whether they tended to radiate up to the limits. Three products were tested:

- DECT phone
- 802.11b/g wireless router
- Three GSM mobile phones (Nokia 6310i, Motorola V3, Nokia 1100)

The resulting field strengths and effective EIRPs are compared to the allowable spurious emission limits in Table 11. The measured spurious emissions were between 3 and 12 dB below the limits.

Table 11:
DECT spurious emission levels

Harmonic Frequencies, GHz	Equivalent measured EIRP, dBm	Equivalent allowable EIRP, dBm
DECT		
3.76	-36.62	-30.00[1]
Wireless Router (Wi-Fi)		
4.91	-42.15	-30.00[2]
GSM900		
1789.97[3]	-33.74	-30.00[6]
1789.97[4]	-33.19	-30.00[6]
1789.97[5]	-35.13	-30.00[6]

[1] ETSI 300 176-1; [2] ETSI 300 328; [3]Nokia 6310i; [4]Motorola V3; [5]Nokia 1100