- Aggregate EMC effects
- CISPR methodology for derivation of the new EMC limits
- Should Ofcom support the proposed CISPR limits?
- The way forward for the EMC standards process
- Are spurious emissions a threat to radio services?

- How do the different noise sources compare?
- How should a permitted noise metric be defined

These are discussed in the following sections.

7.1 Are Future EMC Emissions a Threat to Radio Services?

7.1.1 Current and future EMC emission levels from single items of equipment

The EMC emissions measured from a number of modern items of electronic equipment showed that the actual emission levels were typically 15 to 20 dB below the CISPR limit for a peak detector, although a clock frequency was measured 13 dB below the limit. The measured emissions were typically 10 to 15 dB below the CISPR limit for an average detector, although a clock frequency was measured only 6 dB below the limit. There is no indication that emissions above 1 GHz will increase significantly in the near future. From the devices measured it was observed that good design features to limit emissions, such as shielding, had been implemented.

As clock frequencies continue to increase, the resulting harmonics become more widely-spaced and this may limit to some extent the emissions content above 1 GHz. For example, one of the devices measured has a clock frequency of 2.6 GHz and therefore the first harmonic was at 5.2 GHz so not much energy appears between 1 and 6 GHz. Much of the existing emissions above 1 GHz result from fundamental clock frequencies that are below 1 GHz. The limits below 1 GHz have been in place for many years and manufacturers are used to designing equipment to ensure that emission limits are met.

7.1.2 Aggregate EMC effects

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 modelling identified that 4 out of the 7 radio systems modelled could potentially experience some level of interference for equipment operating at the CISPR limit and assuming the aggregate effect described above. However, when taking into account the existing and likely future levels of EMC emissions the actual predicted potential for interference is somewhat less onerous.

In addition, the effect on any given receiver is very system dependent. For example, for a voice-based system such as GSM, any instantaneous interference could have an immediate impact on the quality of the service. However, for a wideband data-based system such Wi-Fi, information is buffered and although the throughput may reduce considerably for a small period of time, this may not be observed by the user. Some systems employ methods such as frequency hopping and dynamic frequency selection which further reduce the probability of an interference problem.

The aggregate modelling was done on the assumption of five items of electronic equipment in a domestic premise which could be considered a fairly large number of electronic items within one room. In addition, many of these items are gradually being integrated into single multi-media devices, whether based on a dedicated multi-media device.

The effective C/Is appropriate for a more accurate prediction of the potential for interference may differ somewhat from those available in ITU documentation, due to the nature of the interference. Further investigation of this aspect would provide valuable data for future modelling studies of this nature.

7.1.3 CISPR methodology for derivation of the new EMC limits

The Monte-Carlo simulations were performed using assumptions that were as close as possible to the assumptions used by CISPR for the derivation of the CISPR limits. However, the derivation of the CISPR limit is likely to have included a degree of relaxation factors and negotiation with manufacturers. Although the Monte-Carlo modelling did predict some interference for 4 of the 7 radio systems, there could potentially be a further relaxing of various factors in the modelling which would bring the potential for interference down further. However, this would need to be investigated in more detail.

The Monte-Carlo modelling based on existing measured EMC emission levels 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.

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 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.

7.1.4 Should Ofcom support the proposed CISPR limits?

The proposed CISPR levels appear to be set at a sensible level to protect radio services above 1 GHz. 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, that some relaxation of the modelling criteria might remove this predicted interference and this should be investigated further.

7.1.5 The way forward for the EMC standards process

Ofcom have a committee representative for GEL 210 and therefore already have some involvement in technical development of the standards, although the role of the Ofcom representative is not known, and it may be that a high level input is also required on an occasional basis to provide an objective input for the formation and monitoring of EMC strategy.

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.

Under the European Commission's Global Approach, compliance with a relevant harmonised standard such as EN 55022 is voluntary, however compliance with the essential requirements of the EMC Directive is mandatory. The manufacturer or supplier has the option of the method of assessment which could be compliance with a relevant standard published in the OJEC or some other method, e.g. preparation of a Technical Construction File. Most of the major suppliers go down the compliance with relevant standards route. The relevant standards are approved under the mandate CENELEC have from the Commission and the standards are obtained from either CISPR for emissions or IEC for immunity. Many of the CENELEC committee members also participate in CISPR and IEC work so there are usually few technical issues that cause any significant debate, the main concerns are usually related to the implementation dates for new test methods and limits/levels, where there has been some inconsistency in the Commission's activity in the past.

7.2 Are Spurious Emissions a Threat to Radio Services?

Existing 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. The spurious emissions measured for this study indicated that actual spurious emissions were typically up to the limits specified in the various ETSI standards, but did not exceed the limits for any of the equipment measured. The measurements were made with the radio transmitters operating at their maximum output power so spurious emission for a general scenario are likely to be perhaps some 10 dB or more below the specified limits.

There is an increasing usage of home and office radio-communications devices such as DECT phones, mobile phones and PDAs, Wi-Fi enabled laptops, gaming consoles and multimedia devices. However, as the number of technologies tends to be limited (e.g. DECT, GSM900, GSM1800, 3G, Bluetooth, Wi-Fi) the spurious emissions are limited and well-defined. As an example of this, the potential spurious emissions from all of the devices mentioned above were considered as threats to the 7 radio victim services used in the Monte-Carlo modelling, and it was observed that no spurious emissions fell into any of the victim bands.

There do not appear to be any existing problems from general communications systems. Spectrum liberalisation is likely to open the spectrum to technology neutral and application neutral usage and, although the probability of occurrence of spurious emissions being present in any given channel are low, the impact of the interference could be significant if it does occur and this should therefore be considered for future changes in band usage.

7.3 How do the Different Noise Sources Compare?

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. The increase in interference power in the receiver with bandwidth was assessed and it was seen that whereas thermal noise and UWB emissions both tend to increase predictably with frequency, i.e. as 10 Log10 (bandwidth), the EMC and spurious emissions tend not to increase as fast as this. Spurious emissions have the lowest probability of occurrence but if they do occur they might tend to have the most significant impact as the levels can be quite high.

In addition, to properly judge the interference potential of these various sources, the probability of interference must also be taken into account. 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 would suggest that EMC and UWB might add only a small amount to thermal noise but more work is required to quantify this more precisely.

7.4 How Should a Permitted Noise Metric be Defined?

One of the main aims of the work was to determine whether a permitted noise metric could be defined and implemented. Spectrum quality can be divided up into two main categories:

- Interference from intentional radiocommunications: co-channel geographic spillover, adjacent channel spillover, spurious emissions, UWB

- Background noise levels from unintentional emissions: thermal noise, EMC

Figure 43 shows a summary of the various interference sources that might need to be included in an interference simulation.

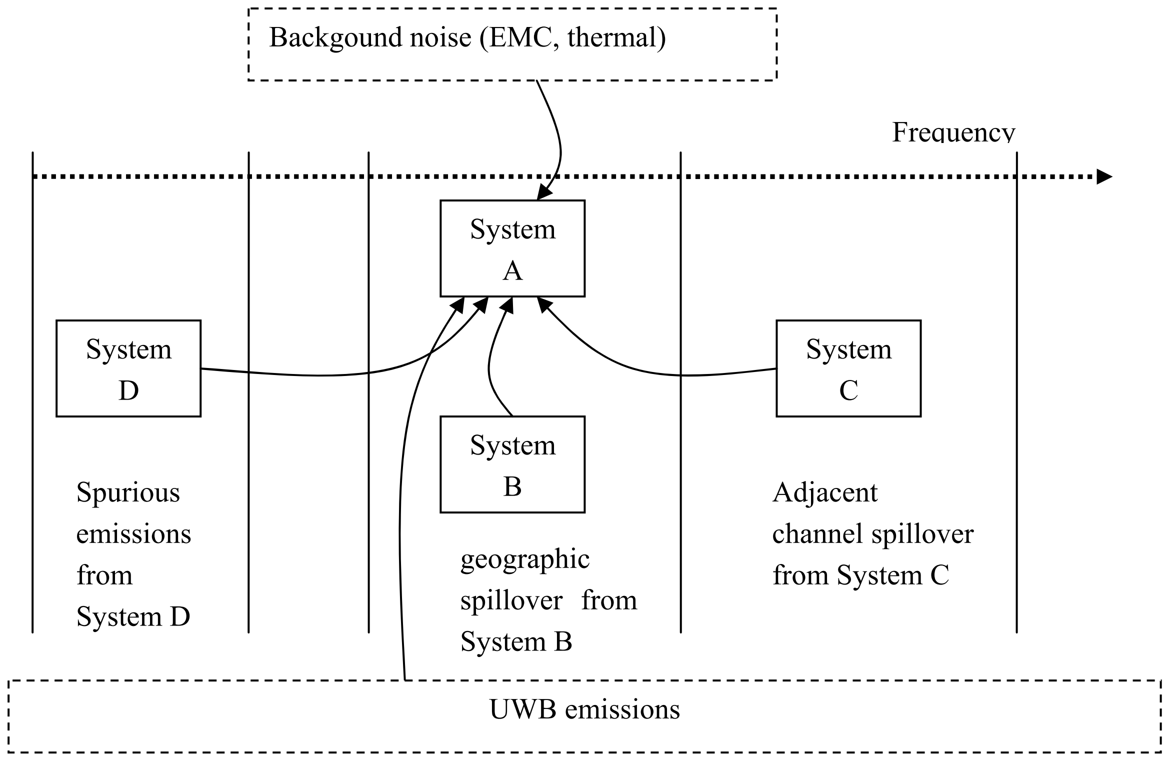

Figure 43: Summary of sources of interference

In interference simulations, other radio-communications services which are in-band and in the adjacent bands are included. In addition, thermal noise is included usually as a system noise factor.

Spurious emissions do not tend to be included unless this includes high power transmitters such as broadcast transmitters or radars. If spurious emissions are considered significant for future interference simulations, particularly with the potential for technology and application neutral usage, spurious emissions harmonics that appear in-band could easily be identified and included. However, this would require a database that includes complete data on systems across the spectrum. It is not seen as appropriate in general 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 appropriate to include spurious emissions from high-powered emitter such as radars in a generic permitted noise metric.

UWB is now often included in interference simulations as a specific radio-communications system. However, there is the potential to include UWB emissions in a permitted noise metric. This is because the emissions are continuous across a wide area of the spectrum and are relatively low level. An agreed model for the density, antenna characteristics and activity factors of UWB devices could be agreed which would allow a "one-off" calculation of the contribution of UWB emissions to the total permitted noise metric.

EMC can readily be included in a permitted noise metric and in fact this is the only practical way to include such unintentional emissions. Emissions from any given piece of equipment are essentially random and this study has shown how aggregate emissions can be developed by combining both laboratory measurements and Monte-Carlo simulations.

It may not be practical to have a single absolute measure of permitted noise metric and the permitted noise metric 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, and possibly spurious emissions from high powered emitters such as radars.

An example permitted noise metric has been calculated from the Monte-Carlo simulations and is shown in Figure 44. This was calculated for the 3 to 4 GHz band and has a number of underlying assumptions that required further investigation and agreement.

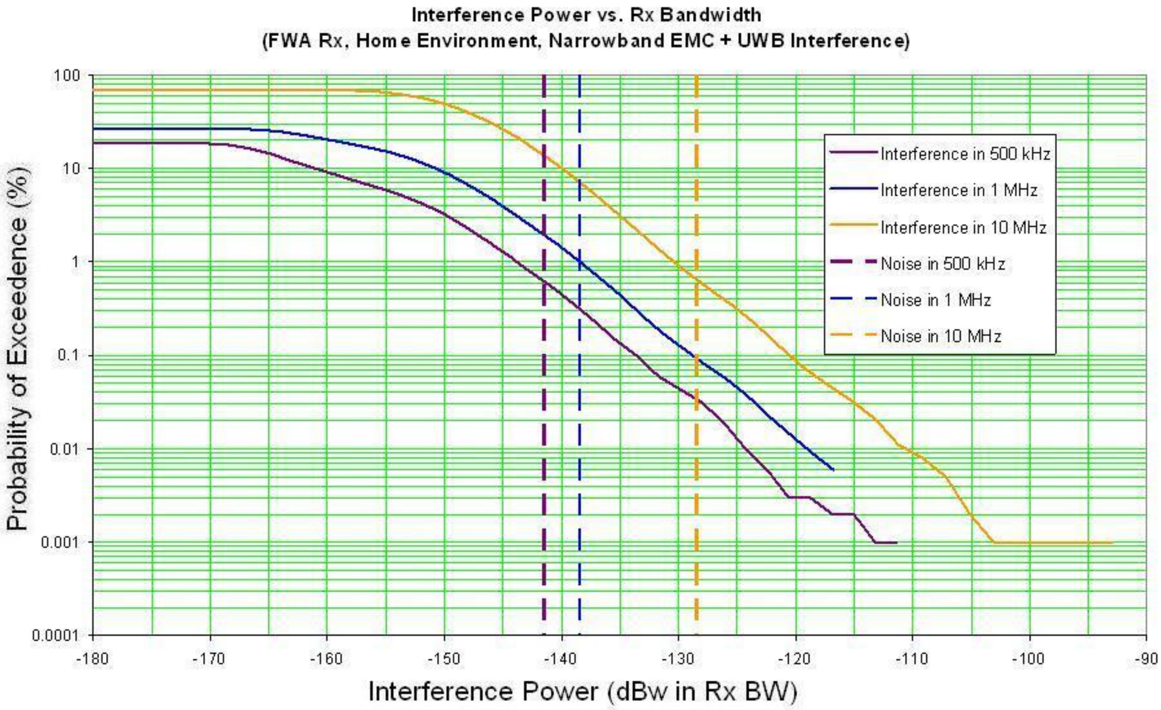

Figure 44: Example of potential Permitted Noise Metric measure

7.5 Interference Monitoring

Using this approach of characterising interference from equipment in the laboratory and then using those as building blocks to put into a Monte-Carlo simulation has the following advantages:

- 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 a what-if scenarios to be carried out.
- This approach can be done quickly and very cost effectively, and updated very easily.

Some practical verification could be carried out periodically.

8 Conclusions

This study looked at the levels of unwanted emissions and the resulting risk to the quality of the radio spectrum due to the increasing use of electronic equipment and radio-communications, particularly in the home and office environments, but also in outdoor environments. Additionally, how these levels of unwanted emissions could be captured in a Permitted Noise Metric were investigated.

The sources of unwanted emissions included EMC emissions, UWB, and spurious emissions. The assessment method used laboratory measurements to characterise EMC and spurious emissions in an anechoic chamber. The measurements gave the mean and the standard variation of the emission levels and the emission bandwidths. In addition, for the EMC emissions, this also gave realistic statistics for the probability of occurrence of emissions and also the variation in emission level with equipment orientation. This input data was combined with data and for the victim radio systems and for UWB emissions and input into a Monte-Carlo simulation.

The Monte-Carlo simulation allowed for a number of factors which tried to ensure that the simulations were not too worst-case. Statistical information was input for the propagation in urban/suburban environments, interferer and victim receiver locations, emission level variations with orientation, probability of emissions occurring, shielding, etc.

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.

An investigation of the CISPR methodology was made. Many statistical factors similar to the Monte-Carlo modelling used in this study were used in the CISPR model, but one main difference is that the CISPR model assumed a single interferer whereas the Monte-Carlo used both single and multiple interferer scenarios. In addition, the CISPR limits may have been subject to additional relaxation parameters, and negotiation with manufacturers based on practical experience. It was difficult to obtain sufficient information to make a like for like comparison between the CISPR method and the Monte-Carlo method used for this study.

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.

However, there is still an element of worst-case in these assumptions as the results are for the receiver operating at the edge of the cell. Assuming an increase in the typical carrier level, above that at the edge of the cell, of about 10 dB, T-DAB would still experience a small level of interference, the FWA system would not experience any interference. In order to reduce the impact on the GPS system, the density of interferers operating at the CISPR level would need to be further reduced below that assumed which was 2 pieces of electronic equipment per household and a homogenous distribution of 50,000 households in a 2 km radius.

Therefore, the Monte-Carlo predictions in this study suggest that there could be some interference to radio systems. 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 modelling based on existing measured EMC emission levels 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.

In addition, the effect on any given receiver is very system dependent. For example, for a voice-based system such as GSM, any instantaneous interference could have an immediate impact on the quality of the service. However, for a wideband data-based system such Wi-Fi, information is buffered and although the throughput may reduce considerably for a small period of time, this may not be observed by the user unless the application being used requires the transfer of data at its maximum rate. Some systems employ methods such as frequency hopping and dynamic frequency selection which further reduce the probability of an interference problem.

The effective C/Is appropriate for a more accurate prediction of the potential for interference may differ somewhat from those available in ITU documentation, due to the nature of the interference. Further investigation of this aspect would provide valuable data for future modelling studies of this nature.

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, that some relaxation of the modelling criteria might remove this predicted interference and this should be investigated further.

There is an increasing usage of home and office radio-communications devices such as DECT phones, mobile phones and PDAs, Wi-Fi enabled laptops, gaming consoles and multimedia devices. However, as the number of technologies tends to be limited (e.g. DECT, GSM900, GSM1800, 3G, Bluetooth, Wi-Fi) the spurious emissions are limited and well-defined. Spectrum liberalisation is likely to open the spectrum to technology neutral and application neutral usage and, although the probability of occurrence of spurious emissions being present in any given channel are low, the impact of the interference could be significant if it does occur and this should therefore be considered for future changes in band usage.

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 because the emissions are continuous across a wide area of the spectrum and are relatively low level. An agreed model for the density, antenna characteristics and activity factors of UWB devices could be agreed which would allow a “one-off” calculation of the contribution of UWB emissions to the total 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.

Further comparison of the suggested permitted noise metric with other measures of noise factor derivation such as that included in P.372 would need to be further investigated.

Using this approach of characterising interference from equipment in the laboratory and then using those 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 WiFi 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.

9 Recommendations for Further Work

The results and conclusions of the work undertaken have indicated the following:

- More work is recommended to investigate the comparison of reverberation chamber and FAR results so that adequate limits can be derived.
- Further investigation of the CISPR detailed assumption and investigation of what parameters could be relaxed further in the Monte-Carlo modelling in order to remove any remaining predictions of interference, if possible.
- More validation measurements on a wider range of radio products with different bandwidths would provide very useful data such as better C/I values.
- Further development of the suggested Permitted Noise Metric and comparison to ITU-R P.372 approaches.
- Investigation of how this work could contribute to the other programmes of work within Ofcom on spectrum user rights
- Further emission measurements of electronic equipment in perhaps 2 years to update the study.

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