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Study to quantify the economic impact on the UK spectrum industry and its users of Ofcom not undertaking technical research and standards work in the area of Electromagnetic Compatibility (EMC)

Final Report

A Study for

Ofcom

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EXECUTIVE SUMMARY

This is the final report of the "Study to quantify the economic impact on the UK spectrum industry and its users of Ofcom not undertaking technical research and standards work in the area of Electromagnetic Compatibility (EMC)". The project has been undertaken by Quotient Associates Limited in conjunction with York EMC Services Limited and Dr Chris Doyle of the Centre for Management under Regulation at Warwick Business School.

Most electrical/electronic equipment radiates some level of Electromagnetic Interference (EMI) and for users to enjoy full utility of other electronic equipment and radio services, the levels of this interference must be carefully managed. A regime of standards is available from various UK, European and international standards agencies covering all types of electronic equipment. In the UK, the sale of equipment is subject to the European Commission's EMC Directive, which requires that all products likely to interfere must conform to harmonised standards before being offered for sale. Compliance requires significant testing and documentation, often involving independent Competent Bodies, and it is estimated that the total cost of complying with EMC standards accounts for around 1% to 5% of the total selling price of products. In the UK this equates to between £550 million and £2.75 billion annually.

The Radiocommunications Agency[1] (and more recently Ofcom) has managed the EMC environment in the UK by dealing with interference complaints from users of the radio spectrum, funding research into levels of interference, measurement techniques and limits, and taking on formal roles within international standards bodies such as CISPR. To enable this activity, the Agency has relied on an allocation of funds to support a policy of proactive research, and sufficient staff to keep abreast of interference issues, manage the research projects and participate within the standards organisations. The levels of this funding and the staff resources that are retained by the Agency are important elements its EMC policy.

The purpose of this report is to understand how the Agency's policy has performed historically from an economic perspective by considering the economic impact of reducing the level of its research funding into EMC. This is considered in terms of net benefits to the UK and the private value of spectrum as perceived by operators of radio services. In addition, the EMC Directive is being subjected to modification as part of the Simpler Legislation for the Internal Market (SLIM) initiative. This has potential to affect all parties involved in the production, installation, certification, usage and regulation of products. The report also considers the economic impact of recent proposed modifications to the EMC Directive.

[1] The project was originally commissioned by the Radiocommunications Agency (the "Agency") prior to the transfer of its responsibilities to the Office of Communications (Ofcom), therefore the report is mainly concerned with the historical activities of the Agency. However, where it refers to the Agency in the context of EMC regulatory policy then this is intended to guide the future policy of Ofcom.

Research projects funded by the Agency are usually focussed on particular products/technologies, measurement methods or limits for standardisation. Projects can be classified as: Reactive projects that attempt to resolve a known EMC problem; and Proactive projects that investigate the need for, and methods of dealing with potential EMC problems.

Proactive EMC research funding

The Agency funds a relatively modest amount of research in comparison to the value of the systems that require protection from interference. Proactive research funding by the Agency has averaged £667,000 per year over the last three years, which is insignificant when compared to the £24 billion[2] estimated value of the radio industry to the UK economy in 2002. The focus of the Agency's research is on investigation of future interference scenarios and their impact on measurement techniques; a type of project that is unlikely to be funded in a similar form within the UK.

By its very nature much of the Agency's research work in the area of EMC is intended to assess the need for further EMC standards development, and as such has not always found that further work was necessary. Consequently, not all the EMC research undertaken can be expected to result in a net economic benefit. However, the economic benefit of individual projects cannot be known *ex-ante*. In cases where the outcomes of individual projects are uncertain, it is appropriate to select projects that yield the highest expected benefits. For the policy to be worthwhile, the overall benefits should exceed the total spent in funding the research policy.

This report considered the performance of the Agency's research policy in the three years from 2000 to 2003. It is likely that all the research will convey some economic benefit on the basis that all information removes some uncertainty and allows more appropriate decisions to be made. However, the analysis in this report concentrates on those projects likely to generate economic benefits of a scale to justify the research spending. Of the 27 projects undertaken in the period, only 3 projects[3] generated readily quantifiable economic benefits totalling £11.2 million calculated over 10 to 20 years (depending upon the project considered) and discounted at the current Treasury rate of 3.5%. This exceeds the total research spending in the three year period of £2 million and indicates that in the 3 year period considered, the EMC research policy was worthwhile from an economic perspective.

This is also indicative of benefits that might arise from future EMC research activity based on a similar policy. Technical innovation shows little sign of abating, therefore it is reasonable to assume that EMC issues will continue to arise at a similar rate into the future. Given the potential scale of the impact demonstrated by the research projects

[2] The Economic Impact of Radio – 2003 Update, The Radiocommunications Agency

[3] The 3 projects considered: the need for effective emission limits at frequencies greater than 1 GHz; the impact of advanced energy efficient lighting; and EMC issues in the railway industry.

considered, the research funding can be viewed as an insurance premium, which helps guard against extreme interference effects that could potentially devastate the operation of an entire radio service.

The role performed by the Agency's research has been to provide impartial guidance and detailed, quantitative inputs to the standards development process. This has provided two major benefits to those involved in standards development: firstly to gain an awareness of potentially damaging EMC issues where the users of radio services are not well represented within the standards committees; and secondly, to promote a better informed equitable compromise between manufacturers of interfering equipment and the users of victim systems. Although. it should be noted that this compromise is not necessarily optimal from the perspective of national economies.

Although the study found that the Agency's EMC research policy did indeed provide economic benefit to the UK outweighing the costs of research, we cannot conclude from this that the policy is optimal. Many EMC issues are undertaken in stages since the scale of the problem is not known at the outset. Hence the initial stage is often a scoping study to determine the scale of the problem and understand the broad range of remedial actions that could be undertaken. If elements of economic impact analysis were included in such studies then this would allow future funding by the Agency to be better prioritised and justified; and provide all in the manufacturing industry with an appreciation of the commercial importance of EMC issues. A clearer idea of the returns and higher participation by industry in the standards process should result in more appropriate standards.

Reactive research funding

Reactive projects undertaken by the Agency are in response to a known interference degradation to a victim system. The Agency has a statutory duty to manage spectrum so as to protect the property rights of the users of the spectrum for which licence fees are paid. In this sense the Agency has little discretion whether or not to fund research into the problem, although it must inevitably prioritise its work in response to resource constraints. It must take all reasonable steps to facilitate a solution to the problem.

To understand this aspect, the report evaluates the economic impact of one such project, the mitigation of interference on mobile phone networks due to industrial microwave ovens. It was found to have benefited producer surplus in the GSM900 mobile phone industry by £3.2 million. It also revealed that the Agency has performed an important arbitration function because of its ability to view the requirements of each party impartially. However, to perform the function correctly requires the Agency to maintain access to core EMC expertise in order to enable opportunities for arbitration to be recognised, and the management of research activities in a way that facilitates a solution to the problem.

Impact on spectrum value

Spectrum value was considered in this report as the private value to operators of services using the spectrum, since this governs the amount that could be paid in fees for

spectrum either as part of an auction or in administrative fees. The analysis shows that the economic benefits of EMC research to operators generally occurs as:

- Savings in costs (where changes to the standards enable operators to avoid additional investment that would otherwise be required to maintain the same performance);
- Avoided revenue reduction (where changes to the standards reduce interference that would otherwise result in fewer subscribers able to use the service or reduced availability of the service).

The value attached to the spectrum is governed by the profit that an operator expects to make and the returns on investment expected by the shareholders. In general the narrower the margins in an industry the lower the value attached to the spectrum. Since the economic impact is an absolute reduction in profits rather than a proportional reduction in scale of business, the economic impact of interference is magnified. At the extreme, there is potential for severe interference to render the business unviable.

The victim systems investigated in this report (FM sound broadcasting and mobile telephony) currently exhibit healthy operating profits, therefore the research projects had a modest impact on spectrum value in percentage terms. For example, without the anticipated changes to the standards, we estimate that the value of FM broadcasting spectrum would be reduced by 2.9% and the GSM1800 spectrum by 0.32%.

Economic impact of proposed amendments to the EMC Directive

The EMC Directive is the means by which the harmonised standards become implemented within the products that have potential to cause harmful interference. Implementing these measures is a significant proportion of the selling price of products therefore it is important to get the legislation right if the benefits of interference limiting standards are to be realised.

The form of the EMC Directive directly influences these costs and the proposed amendments to the directive are estimated to result in an increase in net costs to the UK of around £76 million. These are not considered significant compared to the value of products affected by the EMC Directive.

However, it was also found that a number of issues lie within the amendments that are particularly important from a UK perspective, requiring involvement in the overall process by UK government representatives, to:

- Ensure that UK industry correctly interprets the intent of the provisions;
- Lobby for clarity at European level;
- Argue against provisions that might unfairly discriminate against UK companies.

This requires expertise in EMC and its associated industries to reside in the UK either as a government department or industry organisation.

Recommendations

Our study has shown that there is an overall net benefit from the Agency funded EMC research projects, which was determined from economic analysis of selected projects. This leads to the following recommendations:

- That Ofcom continues to fund EMC research projects;
- That the EMC research policy be adjusted to include:
  - Assessment of technical impact on potential victim systems at a quantitative system level (so that the implications on commercial deployment can be clearly identified);
  - Economic impact assessment of EMC issues as part of the preliminary aspect of projects examining new and emerging interference sources;
- That sufficient expertise is retained by Ofcom to:
  - Manage and coordinate EMC research funding (to avoid duplication and highlight issues not being fully addressed within standards bodies);
  - Monitor and promote EMC issues of particular concern to the UK within international standards organisations;
  - Continue to monitor and challenge amendments to the EMC Directive as part of the coordinated UK response.

Ofcom is in a situation where the efficiency of spectrum management is being reconsidered at a fundamental level. Therefore it is appropriate that the economic benefits of its activities are scrutinised. As Ofcom undertakes a review of it's future EMC policy, then this study is supportive of continued activity in EMC.

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APPENDICES

1. OVERVIEW

1.1 Introduction

This is the final report of the "Study to quantify the economic impact on the UK spectrum industry and its users of Ofcom not undertaking technical research and standards work in the area of Electromagnetic Compatibility (EMC)". The project has been undertaken by Quotient Associates Limited in conjunction with York EMC Services Limited and Dr Chris Doyle of the Centre for Management under Regulation at Warwick Business School. The project was originally commissioned by the Radiocommunications Agency (the "Agency") prior to the transfer of its responsibilities to the Office of Communications (Ofcom), therefore the report is mainly concerned with the historical activities of the Agency. However, where it refers to the Agency in the context of EMC regulatory policy then this is intended to guide the future policy of Ofcom.

Most electrical/electronic equipment radiates some level of Electromagnetic Interference (EMI) and for users to enjoy full utility of other electronic equipment and radio services, the levels of this interference must be carefully managed. A regime of standards is available from various UK, European and international standards agencies covering all types of electronic equipment. In the UK, the sale of equipment is subject to the European Commission's EMC Directive, which requires that all products likely to interfere must conform to harmonised standards before being offered for sale. Compliance requires significant testing and documentation, often involving independent Competent Bodies, and it is estimated that the total cost of complying with EMC standards accounts for around 1% to 5% of the total selling price of products[4].

Maintaining a full set of standards covering all products is a substantial task, and one that requires constant modification as new products are introduced (often based on radically new technology and techniques), and new services are developed to make use of the radio spectrum. The range of new products and radio services was studied as part of this project and Appendix 1 provides an overview of future developments that can be expected. As each new product area is developed, then it is important to understand its implication for the EMC environment and whether the current standards provide adequate protection for radio services. This often requires specific research into the levels of emissions, methods of measurements and protection limits.

The Agency has been a strong contributor to both the standards process and the development of measurement techniques and limits, although its scope has been limited to the impact on *radio* devices. The Agency has defined EMC research as being

[4] Cost Benefit Analysis on the Draft Amendment of the EC Directive on Electromagnetic Compatibility, prepared by RPA for the European Commission Directorate-General Enterprise.

concerned with the susceptibility of non-radio devices to radio waves, and vice versa[5]. However, for the purposes of our study, the Agency's EMC research funding addresses:

- Interference from non-radio devices on users of the spectrum. The Agency's primary role is to protect users of the spectrum and therefore research into EMC issues involving interference to non-radio devices (either from radio or other non-radio devices) is not funded[6];
- Methods of resolving EMC issues by appropriate measurement techniques or limits applied to interference sources (The Agency has felt that users of spectrum should be motivated to fund their own "immunity" research into improving susceptibility measures).

The impact of interference from intentional radio use (such as Ultra Wide Band) is considered an interoperability issue and therefore not part of EMC research. Interoperability studies are undertaken before any spectrum allocation is made, to ensure that co-channel and adjacent channel interference is at an acceptable level.

The Agency has managed the EMC environment in the UK by dealing with interference complaints from users of the radio spectrum, funding research into levels of interference, measurement techniques and limits, and taking on formal roles within international standards bodies such as CISPR.

In this sense the Agency has had a reactive function which deals with complaints, a proactive function which anticipates future forms of interference, and an enacting role which seeks to ensure that interference issues with potential to affect UK industry are taken into consideration within the standards bodies and that effective protection limits are applied. To enable this activity, the Agency has relied on an allocation of funds to support a policy of proactive research, and sufficient staff to keep abreast of interference issues, manage the research projects and participate within the standards organisations. The levels of this funding and the staff resources that are retained by the Agency are important elements its EMC policy.

[5] As described on the Ofcom website (last viewed 11th January 2004), http://www.ofcom.org.uk/static/archive/ra/topics/research/topics.htm#emc

[6] It is an open question whether, with the broader remit of Ofcom, interference on non-radio communications devices will need to be addressed.

The purpose of this report is to understand how the Agency's policy has performed historically from an economic perspective by considering the economic impact of reducing the level of its research funding into EMC[7]. Where the usage of the radio spectrum is impaired by interference, there is likely to be a reduction in the value of the spectrum, therefore this report also considers what reduction might be expected in spectrum value if the funding of EMC research projects is reduced or discontinued. In addition, the EMC Directive is being subjected to modification as part of the Simpler Legislation for the Internal Market (SLIM) initiative. This has potential to affect all parties involved in the production, installation, certification, usage and regulation of products. The report also considers the economic impact of the proposed modifications to the EMC Directive.

1.2 Structure of this report

The report is structured around analysis of the Agency's role in EMC management and the economic assessment of recent research projects funded by the Agency. It is not the purpose of this report to perform an audit of research projects; rather we have evaluated a small sample of the projects that had clear potential for demonstrating net benefits for the UK economy arising from the changes to the standards prompted by the research.

Chapter 2 of the report discusses the role of the Agency and the range of research projects that have been undertaken within the last three years. In support of this, an overview of EMC standards and a future view of the interference environment was prepared and this is presented in Appendix 1. Chapter 2 also highlights the areas and specific Agency funded projects where significant economic benefits might be found, and presents an economic framework by which the economic impact of these projects might be assessed.

Chapter 3 provides an economic analysis of each of these Agency funded research projects. In some cases, specific interference evaluation was undertaken by York EMC Services Ltd and the results of these analyses are presented in Appendices 2, 3, 4 and 5 of the report.

Chapter 4 considers the structure of the EMC Directive and the economic impact of the its proposed amendments. Appendix 6 provides an overview of the EMC Directive and this has been used as the basis for analysing the economic impact of the proposed amendments.

[7] Equivalently the economic impact associated with an increase in research funding into EMC could have been analysed. By only assessing the impact of a reduction, it is implicitly assumed that for relatively small changes in research funding, the relationship between funding and economic impact is linear. However, for relatively large changes in research funding it is likely that the relationship could be non-linear.

Chapter 5 provides a summary of our conclusions from the analysis undertaken, both in terms of the numerical economic impact assessment, and our observations on the range and outcomes of the Agency funded research projects. On this basis, we have formulated a range of recommendations that should be taken into account when formulating Ofcom's future EMC policy.

2. THE AGENCY'S ROLE IN EMC

2.1 Overview of EMC research funding

We live in a less spectrally polluted world because of activity in EMC research and regulation. The money spent on undertaking these activities is varied and the research spending by the Agency forms only one part of the total expenditure. Clearly therefore when considering the economic impact of successful EMC regulation, care must be taken to attribute the benefit appropriately based on all activity that takes place. Therefore we need to understand the structure of research funding and the Agency's role within it.

Research is usually undertaken as projects that are focussed on particular products/technologies, measurement methods or limits for standardisation. Each project can be classified into two categories for the purposes of this project:

- Reactive projects that attempt to resolve a known EMC problem;
- Proactive projects that investigate the need for, and methods of dealing with potential EMC problems.

The distinction is very important when considering the actions that are necessary to embody a piece of research into legislated protection of victim systems. The generic sequence of actions to enable change to take place is detailed in Table 2.1 for both types of project.

Reactive projects	Proactive projects
Identify cause of interference	Management of research process to identify candidate issues for proactive EMC research
Quantify severity and impact of interference	Undertake a number of research projects of which some proportion will be "successful" i.e. they will identify a previously unknown EMC problem.
Undertake research to identify means of resolving problem	
Research to enable new measurement techniques and limits	
Standards effort to enact the new techniques and limits into harmonised standards	
Application of system solutions to limit interference	
Measurement undertaken to confirm that solution is effective	

Table 2.1 Process for enacting solutions to EMC problems

Reactive projects are undertaken in response to either complaints by spectrum users or direct measurement of interference during routine monitoring of the frequency environment. Therefore the validity of subsequent research activities is known *ex-ante*. Clearly reactive projects require expenditure to identify and quantify the severity of the problem before the research into solutions can be undertaken. All the steps are equally vital to ensuring adequate protection of victim systems (i.e. no individual or combination of stages affords any protection to victim systems unless all steps are undertaken). We can therefore attribute the benefits to the UK of protecting the victim systems in proportion to the costs of undertaking each stage of the process.

In contrast, proactive projects are based on intelligent selection of projects, of which some proportion result in identification of interference problems. In this sense, the success of proactive projects is only known *ex-post*, therefore we can expect that a number of projects must be undertaken for each one that results in an EMC problem to solve. The implication of this for this report is that when considering the proportion of returns to attribute to each stage of the process, this efficiency factor needs to be accommodated.

2.2 Responsibilities of the Radiocommunications Agency

The Agency has taken part in all of the activities described in Table 2.1 to some degree, however, this has varied from project to project depending upon the levels of participation by other players in the industry.

The participation with the standards bodies requires attributes for which the Agency is ideally suited:

- Because of the volume of such activity it can employ specialists for this type of work;
- As a national regulatory authority, the Agency is more likely to be regarded as impartial and its research is more likely to have integrity;
- Its research can incorporate detailed representative data on affected parties (submissions by those parties might be less detailed due to confidentiality concerns).

The Agency undertakes both reactive and proactive projects. The major differences between reactive and proactive projects can be summarised as follows:

- Reactive projects are in response to a **known** interference degradation to a victim system. The Agency has a statutory duty to manage spectrum so as to protect the property rights of the users of the spectrum for which licence fees are paid. In this sense the Agency has little discretion whether or not to fund research into the problem, although it must inevitably prioritise its work in

response to resource constraints. It must take all reasonable steps to facilitate a solution to the problem;

- Proactive projects are based on the search for previously **unknown** EMC problems usually associated with the introduction of new products or victim systems. At the time the decision is made to fund proactive research projects there is an alternative: the Agency could wait until such time as harmful interference is observed and then only spend research money on reactive research projects. Therefore the Agency has discretion over whether EMC research is funded or not. This can be likened to an option (*i.e.* the value of delay).

We have assumed that the Agency will always be obliged to provide EMC research funding for reactive projects where it has a statutory duty. Therefore the major insights provided by this report into EMC policy can be derived from investigation into the economic benefits of proactive research projects.

2.2.1 Analysis of Agency research funding

The Agency funds a relatively modest amount of research in comparison to the value of the systems that require protection from interference. Research funding by the Agency has averaged £667,000 per year over the last three years, which is insignificant when compared to the £24 billion[8] estimated value of the radio industry to the UK economy in 2002.

Table 2.2, Table 2.3 and Table 2.4 show a breakdown of the EMC research projects funded by the Agency in the financial years 2000/1, 2001/2 and 2002/3 respectively, and indicates the nature of research work that the project comprised, according to the following categories:

1. Current systems – The project considers the current situation, including current interference issues and current levels of electromagnetic noise in an environment;

2. Future interference scenarios – The project considers the effects of introducing new technologies, the increase in usage of current technologies or the development of current technologies into new areas;

3. Measurement techniques – The project considers the applicability of current measurement techniques for their current use or for future alternate uses, or investigates new or improved measurement techniques;

[8] The Economic Impact of Radio – 2003 Update, The Radiocommunications Agency

4. Interference countermeasures – The project investigates interference countermeasures, such as new shielding technologies and design or installation advice to cure current problems or prevent future incompatibilities;

5. Applicable limits – The project considers current limits applied in specifications and/or proposes new limits for existing or future specifications or standards.

The funds spent on these EMC research projects in the three years of interest were approximately £558,000, £795,000 and £649,000 respectively, totalling just over £2 million for the period.

In Table 2.2 to Table 2.4, 27 projects (in 35 project parts) are identified[9]. From the breakdown, it can be seen that the consideration of future interference issues and measurement techniques, appear most often (19 times each). Addressing future use within the research is to be expected, as the role of the Agency's EMC research activity is largely to provide protection for the future use of the radio spectrum whether this is for new services or increasing service density. Measurement techniques are closely linked to the study of future interference scenarios in 12 of these projects, which provides an overview of potential measurement techniques so that an early view of the technical implications can be established. The development of measurement techniques is important; as it is largely by measurement that EMC compliance is demonstrated worldwide.

[9] The final reports from Agency funded EMC projects are available on the Ofcom website: www.ofcom.org.uk

Report title	Status	Current issues	Future issues	Measurement techniques	Interference counter-measures	Applicable limits
Feasibility study into the measurement of man-made noise	Complete	✓	✓	✓		
Susceptibility of digital systems to electromagnetic fields	Complete			✓		
Specification of the scope of work needed to determine the technical and operational impact of emissions from unstructured telecommunications transmission networks interfering with aeronautical and maritime radio services in the UK	Complete		✓			
Practical limits for electromagnetic emission testing at frequencies above 1 GHz	Complete		✓	✓		✓
Design and development of a methodology for efficiently tracing the source of intermittent wideband electromagnetic disturbances to radio reception	Complete			✓		
Preliminary investigation into a methodology for assessing the direct RF susceptibility of digital hardware	Complete			✓		
Limits and method of measurement for emissions at frequencies above 1 GHz	Complete			✓		✓
An impulsive noise source position locator	Complete			✓		
Cumulative effect of radiated emissions from metallic data distribution systems on radio based services	Complete		✓			
An investigation into the feasibility of designing frequency selective windows employing periodic structures	Complete				✓	
Development of practical methods and equipment to facilitate both detection and measurement of radiation from, and wideband radio frequency currents in, unstructured distribution networks	Complete			✓		
A study to assess the possible effects on radio based services of electromagnetic emissions from the proposed increase of electrically powered public and private transport	Complete	✓	✓	✓		✓
Continuation of investigations into the possible effect of DSL related systems on radio services	Complete	✓	✓			
Study into the effects of deployment of ADSL	On-going		✓			

Table 2.2 Breakdown of Agency funded EMC projects for the year 2000/01

Report title	Status	Current issues	Future issues	Measurement techniques	Interference counter-measures	Applicable limits
Further work into the potential effect of the use of dithered clock oscillators on wideband digital radio services	Complete		✓	✓		✓
Development of improved test methods for assessing the electromagnetic emissions from luminaires and ancillary devices	Complete	✓	✓	✓		✓
EMC susceptibility of low power radio services	Complete	✓	✓	✓	✓	
Investigation of electromagnetic emissions from alternative powertrain road vehicles	Complete		✓	✓		
Potential electromagnetic interference to radio services from railways	Complete	✓	✓	✓		✓
Investigation of impedance and mode conversion of telecommunications cables for xDSL systems	Complete	✓	✓	✓		
Continuation of investigations into the possible effect of DSL related systems on radio services	Complete		✓			
Development of novel methodologies for measuring digital hardware for immunity to electromagnetic fields	Complete			✓		
Limits and method of measurement for emissions at frequencies above 1 GHz (continued)	Complete			✓		✓
Study into the effects of deployment of ADSL (continued)	On-going		✓			
Cumulative effect of radiated emissions from metallic data distribution systems on radio based services (continued)	Complete		✓			
An investigation into the feasibility of designing frequency selective windows employing periodic structures (continued)	Complete				✓	

Table 2.3 Breakdown of Agency funded EMC projects in 2001/02

Report title	Status	Current issues	Future issues	Measurement techniques	Interference counter-measures	Applicable limits
Study into the effects of deployment of ADSL (continued)	On-going		✓			
An investigation into the feasibility of designing frequency selective windows employing periodic structures (continued)	Complete				✓	
Research to scope any EMC implications of software radio	Complete		✓			
Investigation into the electromagnetic emissions from SMPSs and SELCs	On-going	✓	✓	✓		
Study how CISPR 14 Part 1 (Emissions from household appliances, electric tools and similar apparatus) may be improved to make it more relevant and accessible	Complete	✓	✓	✓		✓
An impulsive noise source position locator (continued)	Complete			✓		
Man-made noise measurement programme	On-going	✓	✓			
Investigation of electromagnetic emissions from alternative powertrain road vehicles (continued)	Complete		✓	✓		
Study into railway electromagnetic emission measurement techniques	On-going	✓	✓	✓		

Table 2.4 Breakdown of Agency funded EMC projects in 2002/03

The investigation of current interference scenarios formed part of 11 of the 27 projects. In all these cases, this research was part of a study that also looked towards the future interference environment. Most actual cases causing immediate concern will be the subject of rather more urgent reactive research projects or development not necessarily appearing under the banner of EMC research[10]. Within Table 2.2 to Table 2.4 the current interference scenarios are linked more closely with future changes in interference that might be expected, or to provide a baseline for measuring these changes against.

Investigation into the levels and limits to be applied appears rather less frequently (7 projects). The application of limits to measurement is a process which must necessarily be undertaken relatively late in the process of formulating a new standard (limits can only be proposed once the measurement method is agreed). It is also difficult to apply limits for the protection of technologies that do not yet exist. Hence the study of limits is less frequent than that of the associated measurement methods and this reflects the focus on *future* rather than *current* interference environments.

Projects associated with interference countermeasures appear 2 times in the list of 27 projects. These were concerned with investigating the future use of RF frequency selective optical materials for use in segregating services within buildings; and providing levels of design advice for manufacturers to improve the performance of their products. Again (as in the case of the industrial microwave ovens project) specific cases of immediate concern are more commonly dealt with either by those parties directly affected (industry or end user) or by other research areas within the Agency.

From the above we conclude that the Agency's focus is on research into possible future EMC problems arising from new technological developments in specific areas of industry. This work often includes evaluation of the current situation to set a baseline for comparison and it commonly goes on to evaluate implications for measurement methods and limits. However, it is rare for the Agency to fund specific projects that only address measurement techniques or limits. Funding for interference countermeasures, although significant in terms of value, accounted for few projects. They tend to be isolated and opportunistic, focused as they are on only two areas of interference mitigation over the past three years.

2.2.2 Impact on international standardisation

It is important that a balance is maintained between participation of manufacturers (industry) and regulatory and research organisations (public funded) in the committees that formulate standards. Technical competence of regulatory authorities'

[10] For example, the Agency funded work to investigate improvements in the design of industrial microwave cooking facilities to reduce interference with current cellular services. This project is assessed in more detail later.

representatives is particularly important as powerful commercial arguments (from industry) may have to be balanced against wider public concerns. The high degree of participation of the Agency within CISPR (in particular) is strongly supported by the research activity and the technical expertise of the Agency staff.

The Agency funding of EMC research projects has been the mainstay of basic UK government funding for EMC research into areas which will directly affect UK industry and users. These projects are short term in nature (rarely over a year in duration) and may also be used as an initial study to promote awareness or interest in the wider EMC community leading to additional or further investigations undertaken by others. For example the project that assessed emissions from energy efficient lighting has stimulated debate within the CISPR lighting committee with more than one point of view currently being held, and the projects concerning the effects of dithered clocks (or spread spectrum clocks) have resulted in one major manufacturer attending a project presentation to debate the issues investigated.

2.2.3 Rationale for reduced levels of research funding

The main factor guiding potential scenarios of reduced research funding is to understand what levels of equivalent research would be funded by other parties that also lack commercial vested interests. EMC research is also funded in the UK by the research councils, which allocate funding to UK academic institutions. In most cases, the research is rather longer term than that funded by the Agency and is focussed on matters expected to become issues even further into the future.

The EU also funds EMC research projects, however these are usually collaborative ventures (between, for example, industry, professional associations and academic institutions) and are international in nature which means that they are usually of rather larger value and more involved undertakings than the focussed research of the Agency funded projects. Other research is funded by industry (both internally and using consulting agencies) but this is focussed primarily into specific immediate problems or potential problems associated with a narrow commercial sector. The results may well be protected to prevent the wider community benefiting from the investment.

The type of project funded by the Agency would not readily fit into those of other major funding organisations concerned with EMC research. The Agency's selection of research projects is based primarily on an assessment of the issues that have potential to affect spectrum use in the UK. Where these issues are not a priority for action in the relevant standards committee through lack of awareness, or the committee's progress is hampered by a lack of objective quantitative inputs, the Agency tends to commission a research project to use as a stimulus for action. This approach is intended to discourage duplication in research efforts.

In summary, the Agency has been funding research based primarily upon protecting the radio spectrum for future use. The type of project funded by the Agency would not readily fit into those of other major funding organisations concerned with EMC

research, therefore much of this research would not otherwise have been funded in a similar form within the UK.

2.3 Benefits of proactive EMC research funding

The benefits of proactive research funding are the difference between taking a wider proactive approach and relying on the later undertaking of specific reactive projects to resolve EMC problems. The work in Appendix 1 shows that continuing innovation of both new products and potential victim radio systems can be expected, therefore EMC issues can be expected to arise into the future at a similar rate to the past. Consequently, the economic benefits arising from recent projects can be considered a reasonable indication of future benefits, if a similar EMC policy is adopted in the future.

By its very nature much of the Agency's research work in the area of EMC is intended to assess the need for further EMC standards development, and as such has not always found that further work was necessary. Consequently, not all the EMC research undertaken can be expected to result in a net economic benefit.

2.3.1 Research projects with potential for economic benefits

The Agency funded EMC research projects undertaken over the years 2000 to 2003 were assessed to understand where the conclusions of the projects had potential to influence the applications of EMC standards and limits, and there was potential for interference to victim systems. An overview of the interference environment surrounding the technologies that were the subject of the research is presented in Appendix 1. A number of projects were selected for economic impact assessment where a high potential for interference was found and the victim systems were readily identifiable.

For the indoor environment these were:

- Faster clock processors;
- Switched Mode Power Supplies (SMPS) and Switched Electronic Load Controllers (SELC);
- Lighting;

For the outdoor environment these were:

- xDSL and Power Line Communication technologies;
- Railway technologies;
- Electric vehicles.

Assessing the range of projects that have been undertaken over the last three years also revealed some reactive projects, but nevertheless have potential to illustrate the continuing economic importance of EMC. Consequently, EMI emissions from further indoor sources: household appliances and electric tools, and Dithered Clock Oscillators (DCO); and a further outdoor source, Industrial Microwave Ovens, were included within the analysis.

2.3.2 Appraisal of EMC research projects

Our approach to appraisal of the Agency funded projects is based on the construction of two scenarios:

- The Factual scenario – this is based on the consequences of the research project having taken place. To change the interference environment, it involves modification of the limits or measurement methods within the existing harmonised EMC standards, or the introduction of new standards. Adherence to the changes by manufacturers becomes mandatory after an implementation delay of typically 3 to 4 years duration[11];
- The Counterfactual scenario – this speculates on what might have happened had the research project not been undertaken. It would typically be based on either more relaxed (current) emission limits or no agreement on appropriate limits at all.

Under both scenarios the impact was considered from the perspective of both the manufacturers and suppliers of potentially interfering products, and the operators and users of potential victim radio services.

Manufacturers and suppliers

These costs are associated with the additional RF shielding required to achieve compliance with amendments to the standards. It should be noted that these costs differ depending upon how late these occur within the product lifecycle. For example, where EMC requirements are known well in advance, then they can often be accommodated at reasonably low cost in the product design. However, where products fail compliance testing and remedial actions are required subsequently, these can be far more costly. In our analysis, we have assumed that costs to manufacturers due to changes in the standards can be accommodated at an early stage in the design process.

[11] Once the standards are published they will then need to be adopted by the Official Journal of the European Communities (taking typically 6-12 months). Manufacturers will then be able to use them to claim compliance with the EMC Directive 89/336/EC. Following this there will typically be a transition period (typically 2-3 years) where manufacturers can chose to apply the old standard.

Manufacturers will continue to incur costs resulting from the amended standards as long as they sell new products that fall within the scope of these standards.

Operators and users of victim services

The impact on operators and users of potential victim radio systems were also assessed. The research is aimed at protecting the users of radio spectrum well into the future so it is appropriate to consider the economic impact in the long term as well as the short term. In calculating the nature of impact on the users and operators of victim systems, we also considered:

- The impact on revenue due to reduced availability and usage of the radio service, given the typical configuration of such systems;
- Any practical alternatives for users to obtain an equivalent service (which tends to limit the economic impact of interference);
- Any remedial measures that could be undertaken by operators to maintain system performance in the presence of interference.

In deciding what actions are taken by users and operators of radio services, we have assumed that the lowest cost option would be undertaken. Where alternative systems are available for delivery of similar services, we have assumed that users would only act where they had knowledge of the alternative system and confidence that it would not also be compromised by interference.

Modelling the costs and benefits

A model of the costs and benefits was constructed for each research project assessed. The outcome of the analysis was expressed as a Net Present Value of the difference in cash flows between the factual and counterfactual scenarios. The costs and benefits were assessed for both the producer and consumer surplus, where the overall economic impact on the UK is the sum of both. The earlier Agency work on assessing the economic value of spectrum[12] was used as the starting point for calculation. The proportion of this spectrum value that might be lost as a result of interference was then calculated.

The costs to manufacturers of potentially interfering equipment assume that all additional costs are reflected in the retail price of the product and are therefore passed onto UK consumers of products. As it is assumed that the demand is unchanged, this assumption results in a (slight) overstatement of the foregone consumer surplus. However, we believe that this is of second order significance.

[12] The Economic Impact of Radio – 2003 Update, The Radiocommunications Agency

The duration of the model varies between 10 and 20 years depending upon whether there were continuing impacts of changes to the standards, and the levels of confidence in assumptions for the longer term. All costs and benefits were modelled as real costs relative to the year 2003 and future cash flows were discounted at the recommended treasury rate of 3.5%[13].

Attributing the results to the research projects

The Agency is not the only contributor to the standards process and other parties expend money in making submissions and participating in the standards process. To correctly assess the economic benefits resulting from the Agency funded research, we must only consider the proportion that this funding represents of the total required to effect the change to the standards. To evaluate fully the proportion of funding by the Agency relative to others is a substantial task and we were not able to determine the levels of funding undertaken by other organisations.

However, there are some factors that suggest the Agency's input is substantial compared to the total spent on effecting a change to the standards. For example, the Agency:

- Funds objective quantitative studies addressing all aspects of the issue;
- Focuses on issues which it perceives as having a potentially high severity of impact in the UK, and which have not already received a high level of input by other organisations;
- Contributes in terms of manpower to the standards committees;

Therefore we consider it reasonable to assume that in these areas the Agency has incurred a large proportion of the total expenditure involved in bringing a standard to fruition. For the purposes of this analysis we have assumed that it has incurred 50% of the overall expenditure, however we have also considered the robustness of our conclusions where it might only represent 25% of the total expenditure.

The Agency undertakes many more projects under its EMC research policy that do not result in changes to standards. These can be considered a necessary cost in achieving the directly usable outputs. In the summary of research projects in Table 2.2 to Table 2.4, the 6 issues identified for economic analysis represented 48% of the total research funding over the three years. This implies that for each pound spent on research directly supporting a change to the standards, the Agency must also spend £1.08 on other research projects (an overhead of 108%). Assuming that other contributors would face similar overheads to provide similar input, the Agency's contribution to effecting a change to the standards is higher than that suggested by its spending on the directly

[13] HM Treasury in its Green Book recommends a real discount rate of 3.5%. See http://www.hm-treasury.gov.uk/media/05553/Green_Book_03.pdf

related research projects. Therefore, where the Agency contributes 50% directly, its effective contribution is 68%, given the overhead of other projects. Similarly, where the Agency contributes 25% directly, its effective contribution is 41%.

Having outlined the methodology for project appraisal, we analyse in the next section, the potential for benefits arising from each of the shortlisted Agency funded EMC research projects.

3. ECONOMIC IMPACT OF SELECTED RESEARCH PROJECTS

3.1 Agency funded research projects considered

The previous section identified nine major potential sources of EMI for which specific Agency funded research has been undertaken over the last 3 years, and where changes in the EMC standards might (or already have) resulted. It is the purpose of this report to explore the outcomes of these areas to understand the changes resulting from the research, and the changes in the interference environment that might be expected in the future from which economic benefit to the UK might be derived. To determine which research projects had potential to provide economic benefits we considered each of the areas according to the following criteria:

- Did the research result in a change (or potential change) in the EMC standards and therefore a lessening of the interference in the environment?
- Had the research not been undertaken would measures have been taken by others anyway to alleviate the problem at no cost to the Agency?
- Would the additional interference have caused degradation in real victim systems had the research not been undertaken?

In this report we have addressed the nine major sources of EMI that were identified in the previous section from the perspective of the questions above. To support our assessment of these areas of research, additional work was carried out by York EMC Services Ltd into four major environments and these are presented in Appendices 2 to 5.

In general, our approach to assessing the potential impact of EMI on radio services was to model typical environments within which EMI sources and potential victim radio services may be found. The exception to this is the work addressing emissions from industrial microwave ovens, which considers the specific impact of EMI on GSM1800 public mobile base stations.

The impact of faster clock processors, SMPS/SELCs, energy efficient lighting and DCOs were considered in Appendix 2 using three typical indoor environments classified according to the number of EMI sources having potential to cause interference:

- Office environment – Single storey with 36 m^2 floor area, having 24 energy efficient lighting devices, 16 SMPSs, 7 DCOs and 7 PCs (note that appropriate internal components of the PCs are included within the SMPS and DCO counts);
- Above average home – Two storeys with 90 m^2 floor area, having a variety of advanced entertainment and communications products resulting in 4 energy

efficient lighting devices, 15 SMPSs, 1 SELC, 6 DCOs and 6 PC-based appliances;

- Below average home – Two storeys with 90 m^2 floor area, having a basic level of entertainment and communications products resulting in 11 SMPSs, 3 DCOs and 2 PC-based appliances.

A more comprehensive description of these indoor environments can be found in Appendix 2. The same home layout was adopted for the assessment of household appliances and electric tools in Appendix 5.

The impact of EMI from railway technologies and electric vehicles was assessed in Appendix 3 on the basis of two typical buildings that might be found in close proximity to railway environments. These were:

- House – two storey dwelling with a floor area of 70 m^2;
- Office – single storey dwelling with a floor area of 100 m^2.

For each of these, it was assumed that where sound and television broadcasting is received using an outdoor aerial, this would be mounted on the roof of the building at a height of 10 metres above ground level.

Each area of potential EMC degradation is addressed in the following sections.

3.2 Faster clock processors

3.2.1 Overview

The potential for interference from faster clock processors arises because harmonised EMC standards designed to protect the domestic indoor environment[14] do not apply to frequencies above 1 GHz. In reality, processor clock speeds have already achieved 3 GHz and have potential to rise to 20 GHz in the future, thus creating a situation where fundamental frequency emissions from domestic equipment have potential to affect communications services, in particular between 1700 and 2500 MHz which include the allocations for GSM1800 and IMT-2000 Public Mobile Networks.

The Agency funded research projects found that the interference had potential to affect many radio services such as GSM1800, 3G, Bluetooth and wireless access systems using the 2.4 GHz band, although the systems at most jeopardy were GSM1800 mobile networks. The early work by the Agency helped bring this issue to the attention of CISPR, which then considered reducing the limits from the de facto levels of 70dBµV/m

[14] CISPR 22 Part B, which is adopted as a European Norm EN 55022 Part B.

set by the FCC. There was heavy representation in CISPR on this issue by both the manufacturing community and the potential victim system operators (most notably public mobile operators). The series of research projects funded by the Agency assessed the potential for degradation of all radio services above 1 GHz in the UK in a quantitative way and the most recent of these projects[15] finally recommended extension of the measurement band to 18 GHz and recommended a new limit of 56dBµV/m.

To determine the impact of the Agency funded research projects into emissions above 1 GHz, the nature of the standards development process was discussed with participants in the standards committees[16]. In October 2003, new limits were agreed between CISPR participants that have a high probability of a positive vote. They proposed a level of 50 dBµV/m between 1 and 3 GHz (which were the levels sought by the public mobile operators) and 54 dBµV/m between 3 GHz and 18 GHz. However, prior to the Agency's input, the debate over limits had been dominated by largely emotive arguments. It is likely that without the Agency's objective quantitative input to stimulate rationale debate, no agreement would have been reached. Accordingly, we have assumed that if the Agency's research projects had not been undertaken then there would have been no agreement in CISPR on this issue and therefore no change to the current standards governing emissions above 1 GHz. This means that emissions from PCs would be effectively unregulated other than as required by the FCC for the USA market (at the much higher level of 70 dBµV/m).

To understand the impact of the research project, the following factual and counterfactual assumptions were made:

Factual assumption	Counterfactual assumption
With the Agency funded research projects, the limits adopted within CISPR will be set to a level of 50 dBµV/m, which will become mandatory in 2007.	Without the Agency funded research projects, there would be no effective limits on emissions above 1 GHz and average emissions levels of 54 dBµV/m[17] would result.

[15] P S Bansal, A R Bullivant, A J Maddocks, D Carpenter, D Crosbie, C Gent and T Morsman, "Limits and Method of Measurement for Emissions at Frequencies above 1 GHz", ERA Report 2001-0489, March 2002.

[16] Including discussions in December 2003 with Peter Kerry of the Radiocommunications Agency and Chairman of CISPR.

[17] The emissions from a small sample of PCs were measured by York EMC Services Ltd in support of this study and a mean level of 54 dBµV/m was considered to be a reasonably conservative assumption for the purposes of this analysis. Note that the processor clocks in this sample were also dithered.

The impact of the research was assessed and the results are presented in Appendix 2. The volume of typical houses and offices within which mobile services could be successful, were assessed in the presence of CPU based equipment emitting at both limits.

3.2.2 Interference analysis

The analysis presented in Appendix 2 found that the broadband nature of IMT-2000 networks in the UK makes them resilient to narrowband noise sources, however GSM1800 networks remain prone to interference. Significant degradation of GSM1800 mobile phone services can be expected, with and without relaxation of the limits.

The degree of coverage degradation was studied in Appendix 2, which illustrates the cumulative percentage of volume that will experience interference above a particular noise level. It found that as the level of interference that could be tolerated within a typical home or office decreased (as a result of lower wanted mobile received field strengths), the percentage degraded volume of a building increased. The results show that if a mobile operator wished to fully compensate for the degradation then signal levels would need to be increased by 3.6 dB wherever faster clock processors were used.

The results can be related to the typical received field strength from a mobile base station as shown in Figure 3.1, which is based on:

- The 7 dB increase in interference levels for the counterfactual scenario over that used as the basis for analysis in Appendix 2[18];
- The minimum received field strength for mobile communications at 1800MHz of 40.5 dBµV/m and a required carrier to interference ratio of 9dB as indicated in Appendix 2;
- A 3dB margin for co-channel interference.

[18] The analysis in Appendix 2 was performed under early assumptions for this scenario that were different to those detailed here. It assumed that under the counterfactual assumption, the limits likely to be agreed would have been 3dB *lower* than the factual assumption, rather than 4dB higher. This means that the revised counterfactual assumption is based on noise levels 7dB higher than those detailed in Appendix 2, and the corresponding excluded volumes indicated for the counterfactual assumptions will occur at noise levels 7dB higher.

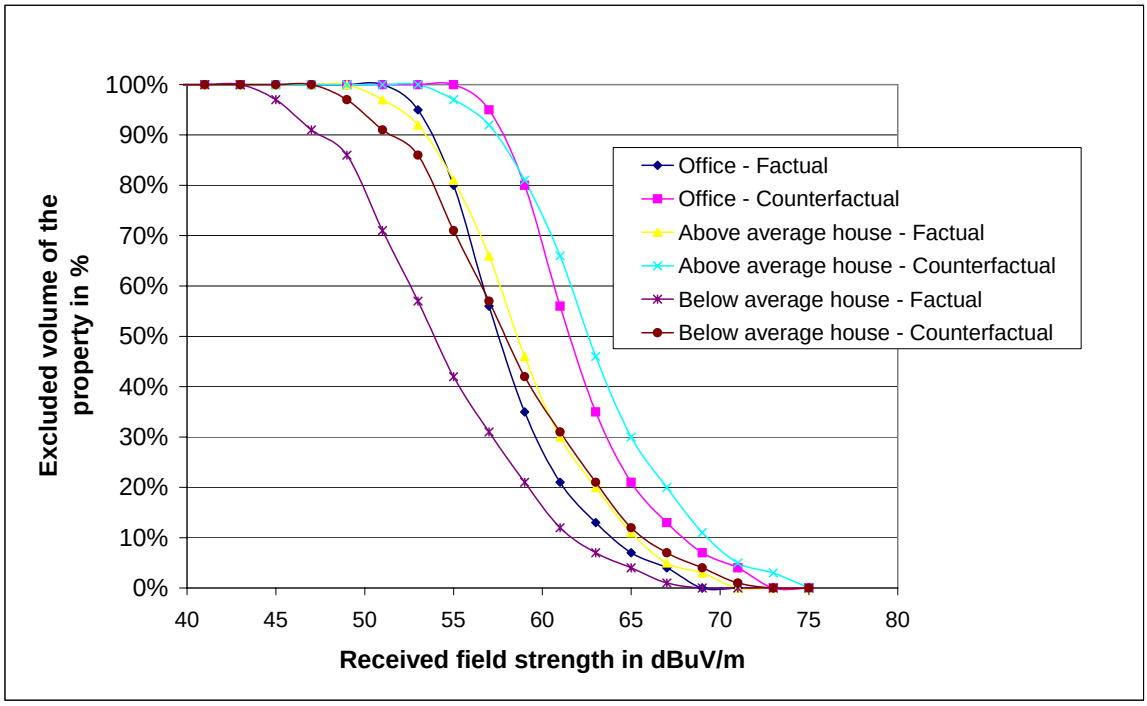

Figure 3.1 Cumulative volume of the property excluded versus received field strength

The impact of the Agency funded research is represented by the difference in excluded volume between the factual and counterfactual scenarios at each received field strength. The overall impact on mobile communications depends upon how much of the network has indoor field strengths at these levels. To determine this we calculated the proportional area of the network that lies within "rings" of coverage that corresponded to 2dB signal increments. This provided a weighting to apply to each of the excluded volumes in Figure 3.1 and from this the overall degradation to the network for both the factual and counterfactual scenarios. This is represented by the following equation:

$$\text{Proportional degradation in coverage} = \sum_{All\_coverage\_rings} \left[Area\_prop_{ring} * Vlost_{ring} \right]$$

Where: $Area\_prop_{ring}$ = proportional area of the ring
$Vlost_{ring}$ = proportional excluded volume of buildings within the ring

The mean incremental excluded volume of homes and offices across the network was found to be 13.5% for the office environment and 17.2% for the domestic

environment[19]. However, it was interesting to note that even in the factual scenario, the potential loss in coverage was 65% for offices and up to 67% for the domestic environment (if all offices and houses were equipped with radiating devices to the extent described in Appendix 2).

3.2.3 Hypothetical response to increased interference by mobile operators

In the previous section, we have determined what impairment might be expected with the introduction of interfering devices in homes and offices. To assess fully the economic impact requires us to understand the probability of equipment being introduced into the premises and operating at frequencies capable of affecting the mobile receiver of GSM1800 networks. Depending upon how likely this interference is to occur, the mobile operator may decide to upgrade the entire network to compensate for the degradation. If this were the case then the economic impact would be determined by the costs that would be incurred by the network operator in upgrading the network.

If however, the mobile network operator would consider that the degradation is infrequent enough that its market competitiveness is not unduly impaired, then they would be unlikely to make network configuration changes. In this case, the economic impact would be determined by loss of utility incurred by those users of the affected mobile phone networks who do not move to alternative networks not affected.

There are three alternative cases that might be expected depending upon the severity of the problem:

- Case 1 – if the problem is very serious and a large number of subscribers are affected, then mobile operators will be motivated to improve coverage such that service performance can be maintained;
- Case 2 – subscribers may opt to switch their subscription to a GSM900 service provider, which would be affected to a lesser extent by the interference. This relies on them being able to recognise the cause of interference and to know that switching to GSM900 might resolve the performance issue;
- Case 3 – in the event of neither of the above then some subscribers will be subjected to reduced network availability.

Each of these cases is discussed below in more detail.

[19] The calculation of the overall impact in the domestic environment was based on 50% of homes being above average and 50% of homes being below average. The overall calculation of economic impact was dominated by the office environment therefore the results were not sensitive to this assumption.

Case 1

The difference in interference between the factual and counterfactual scenarios is 4dB and the received power in all homes and offices would need to be increased by this amount to fully compensate for the performance degradation. To increase received power levels by 3.6dB across all urban and suburban areas would be a major undertaking by a mobile network operator. Assuming a propagation exponent of 35.22 (as embodied in the commonly used Okumura-Hata[20] model for mobile propagation) the effective range would be reduced by around 21%. This would equate to an increase of 60% of base stations to cover an area. With GSM1800 operators currently having in excess of 17,500[21] base stations sites and at an approximate cost of £200,000 per base station site this would cost in the region of £2.1 billion to upgrade the networks. It would clearly be a major undertaking and one that would only be embarked upon if the problem were considered substantial.

Case 2

This case relies upon the mobile subscriber being able to recognise the cause of the degradation and have confidence that switching to a GSM900 network would alleviate the problem. The subscriber would indeed be likely to recognise the cause of the problem since they would observe a marked improvement in network availability when the equipment causing the problem was switched off. However, we do not believe that subscribers would automatically be aware that switching to a GSM900 service would have potential to solve the problem. Network operators and service providers tend not promote the frequency being used in the network and therefore there is no reason for most subscribers to be aware of the technical difference between networks. Subscribers may observe that visitors to their premises with GSM900 mobile phones obtain better coverage, however this could easily be attributed to better individual mobile phone performance. For these reasons, we have assumed that most GSM1800 mobile subscribers would tend to tolerate the reduced network availability and stay with their current operator under these circumstances, rather that switching to another network. We acknowledge that some mobile subscribers would be likely to switch providers but we not able to identify any data to inform us precisely how many. For the purpose of this analysis we have assumed that 85% of the affected mobile subscribers would stay with their current provider.

[20] The Okumura-Hata model contains a distance term of $[44.9 - 6.55*\log_{10} h_b]*\log_{10} r$ where h_b is the height of the base station and r is the distance from the base station. At a base station height of 30 metres the distance exponent is 35.22. *Source: Cellular Radio Performance Engineering, by Asha Mehotra, Artech House, London*

[21] The Radiocommunications Agency estimates the total number of cellular base station sites to be 35,000 (http://www.sitefinder.radio.gov.uk). Since each GSM1800 site typically achieves less coverage than GSM900 it is probable that more than half of these are GSM1800 sites.

Case 3

The third case is based upon no action being taken by either the mobile operator or the mobile phone user to alleviate the problem. In this case the mobile phone user would experience less coverage and availability throughout the home or office. This loss of utility represents a reduction in value of the service to the mobile phone user. The loss in value would be limited to that proportion of their usage that they would have at home or in the office and in general be limited to incoming calls. In most cases it can be assumed that there will be an alternative fixed line telephone from which to make outgoing calls.

We have first addressed the severity of impact before considering the likely actions that would have been taken by mobile network operators.

3.2.4 Assessment of the severity of impact

The severity of impact depends upon the following factors:

- The proportion of households and offices likely to be installed with interfering microprocessor based equipment;
- The proportion of mobile calls made that use GSM1800 spectrum;
- The proportion of affected users that migrate to GSM900;
- The proportion of mobile usage that is indoors;
- The amount of coverage degradation within the property (as already assessed in Section 3.2.2);
- The proportion of calls for which there is no alternative (such as usage of a fixed line);
- The number of GSM channels affected by interference;
- The probability of simultaneous usage of interfering devices and mobile phones.

A model was constructed to accommodate all of these factors and calculate the economic impact over a period of 18 years. The model starts from the beginning of the year 2003 and finishes at the end of 2020, with the mandated implementation of the new limits occurring in 2007. All costs and benefits in the model are real, and therefore ignore the impact of inflation. The rationale for each factor and the values chosen are discussed below:

The introduction of interfering microprocessor based equipment

The market for PC based products in the UK is in the region of 6.8 million units per year[22] of which 68% are desktop PCs and 31% are laptops, with the remaining 1% being servers. For the current leading-edge desktop systems incorporating the latest Intel processors, the processor clock speeds have already exceeded 3 GHz; Intel is the leader in the desktop processor market with around 79.4% market share[23]. The remaining processor manufacturers, most notably AMD, are focused less on clock speed for performance and use other techniques including shorter instruction pipelines and larger caches to achieve equivalent overall system performance. AMD leading-edge desktop processors currently run at approximately 2.2 GHz which is well above the frequencies that may interfere with GSM1800 networks, but still falls within the frequency range applicable to the new RF emissions limits between 1 GHz and 3 GHz. However, we anticipate that by the time that the new limits become mandatory in 2007, AMD desktop processor speeds will also have exceeded the 3 GHz threshold.

The primary market segments using slower clock processors are laptop and notebook computers, which are attracted to slower processors because of their sensitivity to heat dissipation issues. These currently use processors running at around 1300 to 1500 MHz, which although currently below 1800 MHz, have potential to increase in speed in the coming years and interfere with GSM1800 networks. On the basis of historical growth in clock speeds for laptop and notebook processors, we have assumed that leading edge clock speeds will enter the GSM1800 mobile receive band in 2005 and will spend approximately 1 year within this range. This implies that 1 year of laptop and notebook shipments will have potential to interfere with mobile phone networks under the counterfactual scenario. However, although these are expected to find their way into high end products quickly, cheaper products will tend to use lower speed variants, therefore implementation of processors in the GSM1800 frequency range will be spread over the following years. Therefore, we have assumed that a number of units corresponding to a single year of laptop and notebook processor shipments will be spread over the years from 2005 to 2009 peaking in the year 2007. We have further assumed that the replacement period for laptops and notebooks is 5 years for business users, and 8 years for domestic users. At the end of 5 years, the business laptops and notebooks are assumed to transfer to domestic use for the remaining 3 years of their life (*i.e.* via the second hand market).

Within our model we have assumed that annual PC sales will continue at the current levels and that all PCs using processors below 3 GHz will require extra shielding as a result of the change to the standards from the beginning of 2007. Extrapolating the historical rate of increase in clock speeds results in high end processors exceeding 3

[22] Source IDC PC Tracker Quarterly Telebriefing, August 13th, 2003

[23] Intel's market share of 79.4% is based upon a news report of 15th of August 2003 from "The Register" on www.theregister.com

GHz in 2015, therefore we have assumed that all laptop and notebook computers will incur extra RF shielding costs until this time. After 2015 we have assumed that the numbers requiring extra RF shielding will decline to zero in 2020. The costs of implementing extra shielding to meet emissions limits are discussed in Appendix 2 in the context of remedial measures should a product fail compliance testing. For laptops and notebook computers this is estimated to be £5 per unit. In our model we have conservatively estimated that the cost of this extra shielding where it is applied *early* in the product design cycle, to be £2 per unit (in reality it may be much less). This cost is assumed to remain constant in real terms throughout the period.

The proportion of calls that use GSM 1800 spectrum

Of the four GSM operators, two are wholly based upon the use of GSM1800 frequencies, and the other two GSM900 operators have also been allocated some spectrum within the GSM1800 band. It is our understanding that the GSM900 operators primarily use their 1800 MHz spectrum to provide extra capacity in hot spots[24], rather than for widespread deployment across the network. Therefore we should not assume that a significant proportion of the GSM900 operators' traffic is carried on GSM1800 spectrum. Analysis of the market shares within the mobile market shows that in 2001/2002, the GSM900 operators had 56.6% and the GSM1800 operators have 43.4% of mobile revenues[25]. However, in the longer term there will be some migration from GSM to 3G networks. The Competition Commission has assumed that in the long term there would be similar market shares for each of the five mobile operators[26], which implies 40% of the market will be retained by the current GSM1800 operators. Therefore we have also assumed that 40% of the value attributed to mobile telephony may be potentially affected by interference from microprocessor based devices not controlled by the existing emissions standards. This proportion is assumed to remain constant throughout the duration of the model.

The proportion of affected users that migrate to GSM900

As discussed in the previous section we have assumed that 15% of the affected users would recognise that switching to other service providers would alleviate the problem. These users would incur a switching cost due to renewal of handsets earlier than would

[24] The disparity in range achievable from cells using 900 MHz and 1800 MHz frequencies means that most GSM900 sites are not suited for deployment of 1800 MHz transceivers.

[25] The UK Telecommunications Industry Market Information 2001/2002, Oftel, published in March 2003.

[26] Vodafone, O2, Orange and T-Mobile: Reports on references under section 13 of the Telecommunications Act 1984 on the charges made by Vodafone, O2, Orange and T-Mobile for terminating calls from fixed and mobile networks, Competition Commission, February 2003.

otherwise be necessary, but we do not consider this to be significant. The effect of this assumption in our calculation is to reduce the forgone consumer surplus by 15%.

The proportion of calls that are indoor

We were not able to identify any publicly available sources of data to indicate the proportion of calls or revenue that is derived from calls made and received indoors. However, we did find references in the news media to the proportion of traffic that is indoors and we discussed the issue with a number of professionals in the mobile communications industry. A consensus emerged from these discussions that indicated a conservative estimate of indoor traffic proportion of 30% with levels expected to rise to 65% or 70% in the future. Since a higher level for our analysis would tend to inflate the economic benefits arising from EMC research, we have used a conservative assumption for this study of 30% in year 2004 rising linearly to 45% by the end of 2012, and remaining at this level from then on.

The proportion of calls for which there is no alternative

In the vast majority of office and domestic environments, fixed line telephones are available and represent alternative methods of making outgoing calls. However the originators of incoming calls are not likely to know the mobile user's location. Therefore, we have assumed that only 50% of the value attributed to mobile phone usage is potentially degraded within buildings. This is assumed to remain constant throughout the duration of the model.

The proportion of GSM 1800 channels affected by interference

The study work in Appendix 2 assumed that only a single channel would be affected by emissions from microprocessor based devices. In view of the fact that efforts to change the standards to reduce emissions from Dithered Clock Oscillators (DCO) are not likely to be successful (see Section 3.8), then we can assume for this analysis that all future microprocessor based products will incorporate DCOs. This means that whereas a traditional microprocessor clock would only affect a single GSM carrier, clock oscillators operating at 1800MHz (with for example, 1% dither), are able to disrupt 18 MHz of bandwidth. This has potential to affect mobile phone operation in two ways:

1. Where a traffic channel is chosen for communication by the mobile phone that lies within the disrupted 18 MHz of bandwidth, the call will fail to be established. This will apply for both incoming and outgoing calls;

2. Where the BCCH signalling channel lies within the 18 MHz of disrupted bandwidth, then the majority of calls attempted from that location would fail[27].

[27] It should be noted that where there is overlapping coverage from an adjacent base station the mobile phone would seek to use the alternative base station. However, the indoor environments

With each processor being able to influence 18 MHz of spectrum, any processor clock centred within the range of 1796 MHz to 1889 MHz has potential to affect GSM1800 carriers. The probability of a typical call being affected by interference in this range is 30% including the impact on both traffic channel availability and BCCH signalling. This was based on a typical four carriers per cell positioned at 7.5MHz spacing within a single GSM1800 operator's spectrum allocation.

The probability of simultaneous usage of interfering devices and mobile phones

The probability of simultaneous use of interfering devices and mobile phones was considered for both offices and the domestic environment. In offices, we can expect PCs and mobile phones to be in use simultaneously for the entire time spent in the office giving a duty cycle of 100%. In the home, we assumed that a mobile phone might typically be switched on for a period of 14 hours, however a home PC will only be used for a portion of this time. In our analysis we have assumed that a PC might be switched on for one hour out of the 14, resulting in a duty cycle of 7.1%. These duty cycles are assumed to remain constant over the duration of the model.

3.2.5 Calculation of economic impact

The value of mobile spectrum has been assessed by the Agency in its study on the Economic Impact of Radio[28] which found that £12.6 billion was the annual contribution of mobile telephony to the UK economy. The proportion of this that can be attributed to GSM1800 spectrum is approximately 40% resulting in £5.0 billion. Of this amount £270 million was found to be producer surplus and £4,790 million was consumer surplus. The consumer surplus was further divided into £2,933 million for domestic use and £1,858 million for business use. Although we expect that there will be some migration to 3G networks and services in the future, we do not expect the value attributed to GSM1800 to reduce within the timeframe of our analysis. Therefore, we have assumed that these values will remain constant in real terms over the duration of the model.

Using the proportions established in the previous section we calculated the proportion of GSM1800 consumer surplus that could potentially be affected by interference from microprocessor based devices if all buildings are penetrated with laptop and notebook computers. This was 1.1% for the factual scenario and 1.3% for the counterfactual scenario (rising to 1.5% and 1.9% respectively in 2012 due to increased indoor usage). Since we have assumed that the consumer surplus will be reduced by proportion of lost service availability, we can also assume that overall operator revenues would be

can be considered to be at the limit of coverage and therefore, typically, there are not likely to be alternative base stations for use.

[28] The Economic Impact of Radio – 2003 Update, The Radiocommunications Agency

decreased by a similar proportion. Therefore, we have also applied the same proportions to quantify the potential reduction in producer surplus.

Our overall calculation of economic impact includes these calculated losses for both consumer surplus and producer surplus. This resulted in a potential annual loss of £53.6 million for the factual scenario and £64.9 million for the counterfactual scenario *if all buildings were penetrated with interfering laptop and notebook computers*. The difference between these losses, £11.3 million, is the potential annual benefit arising from the changes to the limits above 1GHz to limit emissions. However, the actual economic impact in each year is calculated on the basis of the forecast penetration of interfering devices in the laptop and notebook computer markets.

3.2.6 Discounted cash flow analysis

To establish the economic value arising over a period of 18 years, we used a Discounted Cash Flow (DCF) model to calculate the Net Present Value (NPV) of the benefits arising from the Agency funded research project. The analysis is based upon some important assumptions.

For the factual scenario:

- The research and standards process means that changes to the standard will not occur until the beginning of 2007;
- The interference limiting measures for all PCs having processor clocks between 1 GHz and 3 GHz will be introduced from that time;
- These measures will be necessary for all laptop and notebook PCs until 2015, and thence for a declining proportion to zero in 2020.

For the counterfactual scenario:

- Laptop and notebook computers will start to incorporate processors having clocks between 1796 MHz and 1889 MHz[29] from 2005 onwards;
- The number of homes will be penetrated by these devices at a rate of one device per building;
- The number of offices will be penetrated by these devices at a rate of one device per group of six indoor workers[30] (a group of six desks was the scenario on which the exclusion areas were calculated in Appendix 2);

[29] 1796 MHz to 1889 MHz range is the range of centre frequencies of an 18 MHz differed clock source that has potential to interfere with the GSM1800 mobile receive band.

Under the counterfactual scenario the overall economic impact on mobile network operators is a net loss having a NPV of £61.5 million. Under the factual scenario there was also a net loss having a NPV of £17.3 million. Therefore the economic impact of the change in the standards is a benefit of £44.2 million to mobile operators.

The economic impact on PC manufacturers under the counterfactual scenario is zero since there are no effective constraints on emissions. Under the factual scenario the economic impact was a net loss having a NPV of £32.9 million. Therefore the economic impact on PC manufacturers due to the changes in the standard is a net loss of £32.9 million.

Therefore the overall impact of the change to the standards is to increase value to the UK since the cost to PC manufacturers is outweighed by the benefits to mobile network operators. The NPV of the benefits are estimated to be £11.3 million. The proportion of this that can be attributed to the Agency funded research is 68% resulting in a net benefit of £7.7 million.

Our assumption of a GSM1800 operator's response

Our analysis shows that a loss of up to £61.5 million could have resulted from interference emissions from laptop and notebook computers in the office and domestic environments. This is substantially less than the estimated £2.1 billion required for network upgrade. Therefore we have assumed that a GSM1800 network operator would be unlikely to undertake alleviation measures to overcome the increase in interference.

3.2.7 Impact on spectrum value

The major effect of the change in standards for emissions greater than 1 GHz, is on the value of GSM1800 mobile spectrum. The impact on consumer surplus was calculated by estimating the reduction in usage undertaken by consumers. Since the GSM1800 mobile operators' major source of revenue is the rental and call revenues paid by mobile users, we would expect their revenues to reduce by a similar proportion.

It could be argued that subscription charges (or any bundled minutes tariff structures) would remain unaffected by the degradation, and in the market segment most affected here, (business) bundled minutes are more common. In this case, although an individual subscriber's spending on their mobile phone service might be unaffected by the presence of interference, their preparedness to use a mobile phone service would

[30] The approximate number of workers in the UK was obtained from the Annual Local Area Labour Force Survey (2000/01) available from the Office of National Statistics (www.statistics.gov.uk). The proportion of these that are indoor was assumed to be 30%, consistent with our assumption for the proportion of mobile usage that is indoor.

still be affected. Therefore there would still be a reduction in revenues caused by potential mobile users not taking up the service at all. The calculations found that there was an increase in the sum of producer and consumer surplus in GSM1800 services as a result of the change to the standards, which is estimated to have a NPV of £44.2 million.

The sum of producer and consumer surplus of GSM1800 services is estimated to be £5.0 billion per year which corresponds to a NPV of £66.8 billion discounted at 3.5% over a period of 18 years. Therefore the effect of the changes to the standards governing emissions above 1 GHz is expected to increase GSM1800 operator revenues by 0.066%. However, the impact on profits is more pronounced and it is the potential for profits that determines what a mobile operator would be prepared to pay for spectrum. Assuming a typical EBITDA of 20.4%[31], then the effective reduction in spectrum value is 0.32% (*i.e.* 0.066% divided by 20.4%).

3.2.8 Conclusions

Overall the UK economy appears to have benefited from the Agency funded research projects on this issue. The change in the standard is estimated to result in a net benefit of £11.3 million of which £7.7 million can be attributed to the Agency funded research. The case also raises some important issues for the study:

- The recommendations of the Agency funded research are not necessarily implemented within the standards;
- Both mobile phone network operators and PC manufacturers potentially face substantial costs resulting from the emissions from faster processor clocks, or the need to limit them;
- For there to be overall economic benefits arising from changes to the standards, the sum of costs incurred by both mobile operators and PC manufacturers would need to be less than the costs faced by mobile operators alone in the absence of effective standards;
- The returns from the change in the standards depend upon the objectives and criteria of participants within the standards development agencies;

It arises from this that there may be two, sometimes conflicting, objectives of setting limits within the standards. Firstly, that of achieving an equitable compromise between the needs of mobile operators and the needs of PC manufacturers. Secondly, that of

[31] Typical EBITDA figures for the UK GSM1800 mobile phone operators were obtained from the Competition Commission report "Vodafone, O2, Orange and T-Mobile: Reports on references under section 13 of the Telecommunications Act 1984 on the charges made by Vodafone, O2, Orange and T-Mobile for terminating calls from fixed and mobile networks", February 2003.

maximising the overall benefits to the economies in countries where the standards are applied. It could be that the second objective can only achieved with one of the parties incurring all the cost. With the majority of participants within the standards bodies being manufacturers and operators, it is likely that the former objective dominates the decisions that are taken. In this case, our calculations suggest that the compromise has favoured the mobile network operators (£17.3 million versus £32.9 million).

The case illustrates that the compromise achieved was better for the UK than if the mobile industry had borne all the costs. This suggests that an equitable compromise is better for the UK than no compromise at all. However, it also serves to illustrate that, although the Agency is able to promote a well-informed equitable compromise within the standard development committees, it is not able to maximise benefits for the UK or indeed national economies generally. Despite this, it should be noted that a well-informed equitable compromise between the parties affected, would tend to maximise the availability of a diverse range of products and services for consumers.

Whichever approach is undertaken within standards development, it can only be achieved by the informed and active participation of all parties affected. This means that good economic and well as technical understanding of each party's perspective is required.

3.3 SMPS and SELC

3.3.1 Overview

The research project into Switched Mode Power Supplies (SMPS) and Switched Electronic Load Controllers (SELC) has been included because the research work was commissioned within the 3 year timeframe of analysis. However, the research work is not yet completed so final results cannot be included within this study. Nevertheless, it is worthwhile to outline the EMC issues surrounding SMPS and SELCs since it is illustrative of the thinking underlying proactive EMC research undertaken by the Agency.

The current standards for indoor devices effectively limit emissions from SMPS and SELCs quite effectively, however, common to most EMC standards the limits are based on the impact of a single device under normal load conditions. With today's proliferation of computing equipment and domestic appliances a large number of SMPS in particular can be expected. In addition, some of these can be expected to be loaded differently compared to the configuration used during testing, giving rise to potentially increased emission levels which would not have been tested for compliance with the standards.

The purpose of the study in progress is to identify the potential for emissions from these devices under various loading conditions and to assess whether the current test methodology (load condition and type of testing) is appropriate for such devices. Part of

this study also involves the writing of a code of practice to enable SMPS and SELC engineers to employ better EMC practice in designing their devices.

3.4 Lighting

3.4.1 Overview

The EMC issues considered in this study surrounding lighting are a consequence of the harmonised standards governing lighting not covering the frequency range from 30 to 300 MHz within which lies the analogue FM and DAB sound broadcasting bands. There has been an increase in recent years in techniques designed to improve the efficiency of lighting. As these techniques become more innovative, they tend to involve higher frequency current switching and therefore greater levels of interference.

The Agency funded research project measured the emissions from a number of commercially available high efficiency lighting sources and proposed that a new limit consistent with CISPR 22 class B should be included within the lighting standards[32]. It was recognised that the new limit would not guarantee perfect reception for FM and DAB, but would provide superior protection to them than the current CISPR 15 affords to MW and LW. The project was funded because it was recognised that the impending European Energy Directive will increasingly cause lighting equipment to use more energy-efficient but less EMC considerate techniques, causing emissions at frequencies which are not covered by the current standard.

To understand the impact of the research project, the following factual and counterfactual assumptions were made:

Factual assumption	Counterfactual assumption
With the Agency funded research project, a practical limit on emissions was imposed that, although readily achievable by current technology, would constrain the emissions from future lighting technology between 30 and 300 MHz.	Without the Agency funded research projects, new energy efficient lighting products would be introduced with no regulated maximum emission level between 30 and 300 MHz.

[32] The RA funded research into lighting proposed that new limits be introduced in CISPR 15 (EN 55015) from 30-300 MHz. The research showed that energy efficient lighting also has a high potential to interfere with both LW and MW services, but did not propose that new limits be set below 30 MHz.

The impact of emissions from energy efficient lighting was analysed in Appendix 2, which shows the extent to which degradation to FM sound broadcasting services can be expected in the factual and counterfactual cases.

3.4.2 Findings

The research in Appendix 2 found that for the factual scenario the proposed limits are adequate to protect victim systems from individual lighting devices, however degradation to FM sound broadcasting can still be expected due to the effect of aggregation from many devices particularly within an office environment. In consequence, FM reception at the periphery of FM broadcasting coverage is likely to be affected even with the new standards in place. All FM channels are likely to be affected equally.

However, with the introduction of new devices emitting at typical levels 10dB above the CISPR 22 class B limits it is clear that FM broadcasting services would be degraded even further from the boundaries of coverage, once the use of these new devices becomes widespread. It was found that the percentage volume of the office within which FM reception would not be possible, increased by up to 70 percentage points (i.e. from 22% to 95% of office volume) within 20dB of the boundary of FM broadcasting coverage. Reduced utility of a radio service also depends upon the coincidence of both sources and victim systems. However in office environments having many energy efficient lighting devices, the lights can be expected to be switched on continuously during working hours.

The cost of compliance with the revised standard is expected to be minor. It is mainly expected to affect future products, which are yet to be developed. Where EMC requirements are built into the requirement specification at the start of development, good design practice can ensure compliance with the standard at minimal cost.

3.4.3 The value of FM sound broadcasting

If the research had not been undertaken, then there would be loss of the ability to receive FM broadcasting stations by some users in the office environment. They would then need to either find an alternative location within the office, find an alternative source for the same station (such as the internet), tune to an alternative station having higher signal or find a poorer alternative to listening to the radio. Each of these options potentially represent loss of utility for the radio listener and consequent welfare degradation. It should be noted that the majority of user benefits can be expected to arise in a domestic setting, rather than in an office where radio contributes little to the direct economic output of the business.

Our approach to assessment of this is based on the value of FM broadcast spectrum as identified by the Agency in its study on the Economic Impact of Radio[33] which found that £1.242 billion was the annual contribution of use of the radio spectrum used for sound broadcasting to the UK economy. It is useful for later analysis to separate commercial and non-commercial use of the radio spectrum and an earlier study[34] by the Agency found that 58% of the value can be attributed to BBC programming.

This figure includes all sound broadcasting sources based on use of the radio spectrum including LW, MW, FM and DAB. However the Agency study found that listeners value DAB more highly at around 2.7 times the value attributed to analogue services. We used the quarterly survey from Radio Joint Audience Research Ltd[35] (RAJAR) to isolate the proportion of listening that is attributed to FM radio stations. It was found that FM broadcasting comprises approximately 90% of all BBC listening minutes and 80% of all commercial radio listening minutes. Therefore, the estimated consumer benefit is £648 million for BBC FM broadcasting and £417 million for commercial FM broadcasting.

The locations at which radio listening occurs are also monitored by RAJAR and a useful guide to listening in the workplace is available on the Radio Advertising Bureau website[36]. It found that listening in the workplace accounts for around 14.3% of all listening minutes and that of these 34.8% was BBC broadcasting and 63.5% was commercial broadcasting. This covers all work related radio listening including for example solitary listeners in vehicles, however for the purposes of this analysis we are only interested in locations that are large enough to have multiple installations of energy efficient lighting products (the study in Appendix 2 was based on 6 units within an area occupied by 6 desks). The RAB study also found that 55% of all workplace listeners claim to listen to the radio in groups of 6 or more. Therefore we have used this proportion as the basis to attribute the economic value of FM sound broadcasting to the workplace environment potentially affected by interference from energy efficient lighting.

[33] The Economic Impact of Radio – 2003 update, The Radiocommunications Agency

[34] The Economic Impact of Radio – 2000, The Radiocommunications Agency

[35] RAJAR (Radio Joint Audience Research Limited) was established in 1992 to operate a single audience measurement system for the radio industry - BBC, UK licensed and other commercial stations. RAJAR is wholly owned by the Commercial Radio Companies Association (CRCA) and by the British Broadcasting Corporation (BBC).

[36] The RAB is funded by UK Commercial Radio stations and its aim is "to guide national advertisers and their agencies towards effective advertising on Commercial Radio". The RAB guide to Radio Listening in the Workplace is based on the June 1999 RAJAR data. It can be found at www.rab.co.uk/html/pages/Guide_Workplace.htm

The RAB study found that listening to radio stations commanded a high degree of loyalty and switching rates were low. However, it also found that although the majority of people claimed to have an influence on station choice this was usually a group decision. From this we must conclude that perceived economic value of listening to radio can be maintained if *any* radio stations are available at a location from either BBC or commercial stations. In general, people in this environment cannot expect to have automatic access to their primary choice of station.

From this we established that the consumer benefits arising from radio broadcasting to workplace environments potentially affected by interference from energy-efficient lighting is £36.2 million per annum for BBC programming and £42.3 million per annum for commercial radio.

3.4.4 Workplaces at the periphery of FM radio coverage

FM radio is transmitted from 525 transmitter locations across the UK. Of these, 107 are BBC transmitters[37] broadcasting both the national and local BBC programming. The remaining 415 locations (excluding tunnels) are commercial radio[38] transmitter locations. The transmitter locations were compared with UK population centres and were classified according to the size of population centre in which they were located as follows:

- Those that serve large metropolitan areas and individual towns and cities of population greater than 90,000 (a total population of 29.3 million). It was found that virtually all these towns and cities had one or more radio stations specifically aimed at serving its population. Since each transmitter, in general, aims to serve the same concentration of population, the coverage areas tend to be correlated.
- Those that serve towns and cities having a population between 50,000 and 90,000 (a total population of 3.4 million). It was found that 47% of these had radio stations aimed primarily at the population centres, but also served other towns and villages.
- Those that serve towns and cities having a population between 20,000 and 50,000 (a total population of 5.3 million). It was found that 25% of these had radio stations located within the population centres. In general these were wide area broadcast sites that coincidentally used the small town as a transmitter location, rather than it being the focus of their targeted coverage.

[37] The BBC transmitter characteristics and locations are available on the BBC website www.bbc.co.uk

[38] Details of commercial radio transmitter characteristics and locations are available on the Ofcom website www.ofcom.org.uk

We have assumed that all the major conurbations, towns and cities described above and having transmitters located within them, have high signal levels available to their population, and these conurbations are therefore excluded from the calculation of economic impact of interference. The remainder of the radio listening population was assumed to be evenly distributed throughout the remaining coverage area. Information on the precise locations of workplaces having more than 6 employees was difficult to obtain. For the purposes of this analysis we have assumed that they are distributed in proportion to the UK population. This is likely to result in an overestimate of economic benefit since there is likely to be a disproportionately higher concentration of larger businesses within the excluded urban areas. Therefore to consider the sensitivity of this factor we also considered the case where there is a two to one weighting of business concentration in the major cities and towns.

On the basis of the above analysis and assumptions we estimated that between 33% and 44% of radio listening minutes take place outside major conurbations having dedicated FM radio transmitter sites.

Geographic influence of lighting on radio broadcasting

The study in Appendix 2 found that lighting affects radio reception towards the periphery of the radio coverage area. As the wanted radio broadcast radio signal increases then the volume within the office within which good FM radio reception can be achieved increases. This is shown in Figure 3.2 as a function of the received field strength.

To relate this to the geographic area served by each broadcast transmitter, we interpolated the results shown in Figure 3.2 into 1 dB increments, each of which corresponds to a “ring” of coverage around the broadcast transmitter. The distance and area within each ring was calculated using ITU-R Recommendation P.1546, which presents field strength curves for terrestrial paths at 100 MHz. We also assumed a mean in-building penetration loss of 10dB consistent with the approach taken for the interference analysis in Appendix 2.

The FM broadcast transmitters vary in power and to take this variation into account the distance and area of each ring was calculated separately for each transmitter class using the mean power within that class. The distribution of FM transmitters by power class (in 10dB increments) is shown in Figure 3.3 for both BBC and commercial radio transmitters.

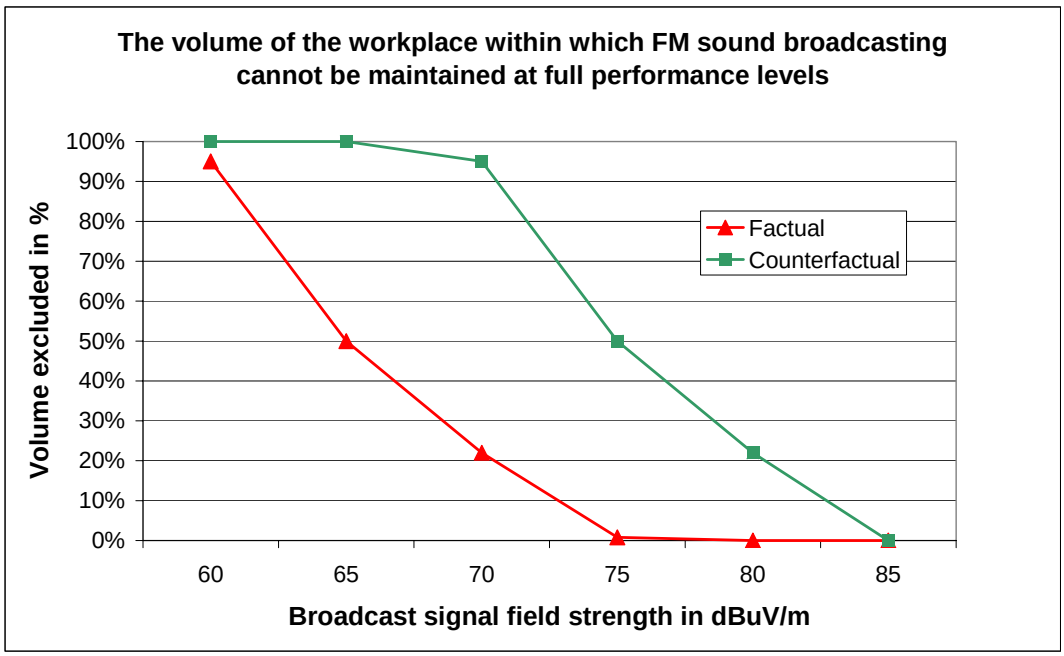

Figure 3.2 Graph of the excluded volume of the office environment as a function of the received signal strength

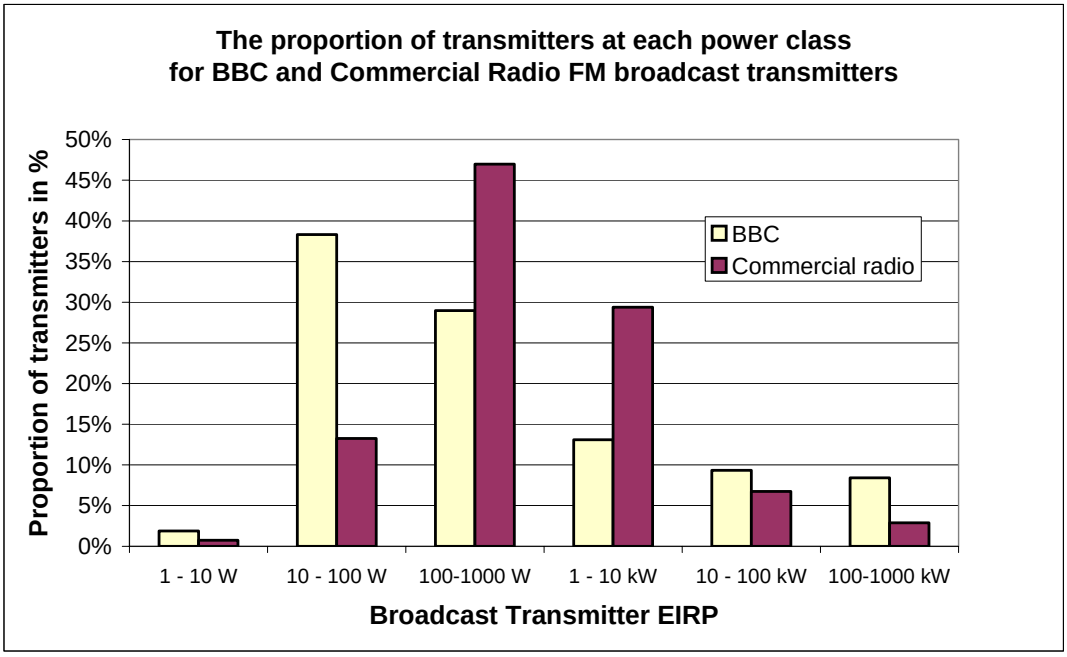

Figure 3.3 Distribution of transmitter power classes for BBC and Commercial radio

To calculate the economic value represented across the coverage area a weighted sum of all transmitter classes and rings was calculated independently for the BBC and commercial radio broadcasting.

This is represented by the following formula:

$$Economic\_Value = BBC\_value * \sum_{All\_TX\_Classes} \left(TX\_Class_{BBC} * \sum_{All\_rings} \left[\frac{A_{ring}}{A_{TX\_Class}} * Vlost_{ring} \right] \right)$$
$$+ CR\_value * \sum_{All\_TX\_Classes} \left(TX\_Class_{CR} * \sum_{All\_rings} \left[\frac{A_{ring}}{A_{TX\_Class}} * Vlost_{ring} \right] \right)$$

Where:

BBC_value = economic value of BBC radio broadcasts to the workplace
CR_value = economic value of Commercial Radio broadcasts to the workplace

All_TX_Classes = the set of transmitter power classes (TX_Class)
TX_Class_{BBC} = the proportion of BBC transmitters at each TX_Class
TX_Class_{CR} = the proportion of Commercial radio transmitters at each TX_Class
All_rings = the set of concentric rings of coverage in 1dB increments
A_{ring} = the area of a ring for the TX_Class
A_{TX_Class} = the total indoor coverage for the TX_Class
$Vlost_{ring}$ = the volume of excluded coverage within the workplace

This calculation resulted in a weighted proportion of area of 82% for the counterfactual scenario and 34% for the factual scenario. These areas are substantial because incremental changes in range at the periphery of coverage represent a large proportion of the broadcast coverage area.

This resulted in an annual economic loss of £9.4 million for the factual Scenario and £12.7 million for the counterfactual scenario. The difference between these losses is the annual value arising from the changes to the lighting standards to limit emissions, if all workplaces were affected by the changes.

Discounted cash flow analysis

To establish the economic value arising from a change to the standards governing energy efficient lighting a Discounted Cash Flow (DCF) model was used to calculate the Net Present Value (NPV) of the benefits arising from research over a period of 10 years. Our analysis is based on some important assumptions:

- The research and standards process means that changes to the standard will not occur until the beginning of 2007;

- Energy efficient products will be introduced into business lighting installations from that time. There are substantial tax benefits available for companies that install energy efficient lighting products and as a result of this, growth in energy efficient lighting installations has been consistent at 3.47% per annum since 1996[39];

- No costs are incurred by the lighting manufacturers (as discussed earlier);

- Some costs will be incurred beyond the 10 year period however, these are less certain due to the take-up of DAB and internet radio in the workplace. Consequently these have not been included within the analysis.

The cash flows arising from this analysis for the scenario where workplace listening is assumed to be distributed in proportion to the UK population are shown in Table 3.1.

Calculation of NPV	Units	Year									
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Value potentially affected by interference	£ '000s	12,718	12,718	12,718	12,718	12,718	12,718	12,718	12,718	12,718	12,718
Potentially subject to the new devices	£ '000s	0	0	0	0	441	883	1,324	1,765	2,206	2,648
NPV	£ '000s	6,967									

Table 3.1 Cashflows arising from the difference between the factual and counterfactual scenarios – assuming workplace listening is distributed in proportion to population.

This results in a NPV of benefits arising from the research of £7.0 million.

Applying the 2:1 bias applied to the workplace listening assumed to take place in cities and large towns, results in the cash flows shown in Table 3.2.

Calculation of NPV	Units	Year									
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Value potentially affected by interference	£ '000s	9,403	9,403	9,403	9,403	9,403	9,403	9,403	9,403	9,403	9,403
Potentially subject to the new devices	£ '000s	0	0	0	0	326	653	979	1,305	1,631	1,958
NPV	£ '000s	5,151									

Table 3.2 Cashflows arising from the difference between the factual and counterfactual scenarios – assuming workplace listening is biased 2:1 towards cities and large towns.

[39] The Lightswitch programme was set up as partnership between the Energy Saving Trust and the lighting industry to promote the use of energy efficient lighting by industry. The penetration of High Frequency Light fittings is charted on its website www.lightswitch.co.uk

Our conclusions are based on the more conservative assumption of a 2:1 bias applied to the workplace listening assumed to take place in cities and large towns.

This results in a NPV of benefits arising from the research of £5.2 million. Apportioning this to the Agency research funding at 68% results in a net benefit of £3.54 million.

3.4.5 Impact on spectrum value

Spectrum value as might be paid at auction or in administrative spectrum licence fees is dependent upon the producer surplus. Clearly only the commercial radio stations obtain advertising revenue, since the BBC is funded by public subscription. However, even the BBC spectrum can be valued according to the opportunity cost of it not being made available to commercial broadcasters – or other uses.

By reducing the minutes of listening, interference to FM sound broadcasting reduces the advertising value of the broadcasts by the same proportion since reduction in listening will be represented in the ratings, which in turn are used to set advertising rates. Therefore we can assumed that the FM radio spectrum will be devalued by the same proportion that £5.2 million is of the total consumer surplus.

We established that the annual consumer surplus of FM radio broadcasting spectrum is £648 million for BBC programming and £417 million for commercial radio programming. Therefore the percentage reduction in revenues that would have resulted from the counterfactual scenario is 0.5%. However, the impact on profits are more pronounced and it is the potential for profits that determines what a broadcaster would be prepared to pay for spectrum. Assuming a pre-tax profit margin of 17%[40], then the effective reduction in spectrum value is 2.9% (*i.e.* 0.5% divided by 17%).

3.4.6 Conclusions

The main findings from analysis of the lighting research project are:

- Listening in the workplace is substantial (at around 14% of total listening in the UK);
- Although the majority of the working population is not affected by the interference (being located within large towns and cities), a large proportion of the remaining coverage area would potentially have been affected by the interference;

[40] A study of the ten largest radio broadcasting groups (by turnover) revealed an approximate average profit margin of 17%, weighted by revenue.

- Even under the factual scenario, the area potentially affected is substantial (at 34%) indicating that this kind of analysis would be useful input to ensure that these issues receive appropriate attention within standards bodies;

- There are significant benefits arising from the research having an NPV of £3.54 million.

The research project into energy efficient lighting is a good example where the implementation of standards will result in benefits to radio spectrum users at little or no cost to manufacturers. The standards committees tend to be dominated by manufacturers who have little economic incentive to apply more restrictive limits, even though in doing so, they would incur little extra cost. For standards to accommodate the needs of radio spectrum users, it is important that the issues are brought to the attention of the standards committees. In this instance, the radio users are a disparate group and therefore have little consolidated representation. This suggests that the Agency has a role in promoting the interests of radio user communities that are not otherwise represented on the standards committees.

3.5 xDSL and Power Line Communication technologies

Penetration of ADSL in the UK is increasing, and is currently the subject of measurement work to assess the aggregated interference effects of this technology. Although ADSL is the system currently being deployed, HDSL, SDSL & VDSL are all likely to present threats to radio services when deployed en-mass. DSL technology has potential to cause interference primarily because of the use of unshielded twisted pair cable running to the house. The Agency commissioned a number of research projects to assess the potential impact of these services.

The research found that as the density of ADSL services increases, then the interference may aggregate to a much higher level. At levels of penetration greater than 25%, the interference can affect the operation of Non-Directional Beacons (NDB) and therefore the landing of aircraft. ADSL also has potential to affect the performance of Differential GPS and LW radio. Studies are continuing to understand better the nature of aggregation as the density of ADSL increases. A three year program of measurement funded by the Agency was due to be completed in July 2003.

We also need to consider the case where the research projects might not have been undertaken.

The factual and counterfactual scenarios are summarised below:

Factual assumption	Counterfactual assumption
As a result of research undertaken, knowledge of the potential scale of the problem and its likely effects have been established. Proactive steps could be taken to ensure that emissions are limited from ADSL installations in sensitive areas.	Potential problems would not be known. As penetration increases to >25% then degradation might occur at locations nearest the highest density of usage. The CAA would complain to the Agency, who would insist that ADSL operators cease operation in that area. CAA, the Agency or ADSL operators would then fund research into the problem and possible remedial actions necessary. Remedial actions would be taken only for those installations that are at risk of affecting other systems.

Clearly then, under both scenarios the affected services would not suffer sustained economic loss. In fact, it can be argued that since understanding of actual degradation effects will be better understood as to occur, the money spent on remedial work will be more focussed than money spent proactively as a result of the early research study. Consequently, we have not considered this area further since it is unlikely to yield significant economic benefit in terms of this analysis.

The key difference between this research project and the others considered in this report is that the Agency has the legislative power to *prevent the operator from continuing to offer services* that cause actual interference. For this reason also, we have not considered the potential degradation of victim systems from emissions by other power line communication technologies. In contrast, for interfering products that have been sold to consumers, recall of the products is usually impractical and sustained economic loss is more likely to occur.

It should be stressed that this lack of economic benefit does not mean that the research project was not worthwhile. With any new technology deployed in large numbers like ADSL, there is a possibility that users of radio services may face degradation unknowingly or attribute the degradation to other causes. Without some proactive research into new areas of technology like ADSL, the Agency would not be able to determine who might face impaired use of the radio spectrum or review methods for monitoring such interference, and therefore would not be able to best represent their interests. In this case it appears that the economic benefits may not be significant from having done the EMC research. However, the Agency could not have known this before the research work was commissioned.

3.6 Railway environment

3.6.1 Overview

Both Light Rail schemes (typically DC systems) and Main Line railways (typically AC systems) were considered in this section of the work. Examples were chosen of a 750V DC modern urban tram scheme and a 25kV AC main line railway.

Emissions from trains are usually measured using a peak detector, since the conventional time-based quasi-peak measurement is difficult to achieve in practice whilst a train is moving. The limits contained within the standard EN 50121[41] using the peak measurement are structured around emissions from the sliding contact, which due to their transient nature are less perceptible to audio and television radio services than continuous emissions. An unfortunate consequence of this is that the standard provides little protection against future equipment installed on rolling stock that emits *continuously* within the limits of peak measurement.

The Agency funded research identified in detail the nature of the interference from railway applications and considered which services might potentially be vulnerable to this interference. It also made recommendations that methods to enable measurement of both continuous and transient emissions be further investigated. Realisation of such measurement methods would allow more appropriate limits to be set within the standards.

To understand the economic impact of the research project, the following factual and counterfactual assumptions were made:

Factual assumption	Counterfactual assumption
With the Agency funded research project, a practical limit on continuous emissions from rolling stock will be imposed that reduces interference levels indoors to levels equivalent to devices emitting at the CISPR 22 Class B limits.	Without the Agency funded research projects, new equipment would be introduced onto rolling stock that emits continuously at a level 20dB below the current limits for peak emissions.

It should be noted that revision of limits for continuous emissions in the railway environment is at an early stage and more extensive study work will be undertaken before actual limits emerge. The levels assumed for the factual scenario are estimates for the purposes of economic analysis only.

[41] Note that there are currently no harmonised standards governing EMC emissions from railway applications. EN 50121 has not yet been adopted as a harmonised standard, though it is widely used within the railway industry.

The potential impact of interference emitted from both trams and mainline trains was evaluated and this assessment is presented in Appendix 3. It considered the impact of the interference on FM and DAB sound broadcasting, analogue and DVB-T television broadcasting, and mobile networks.

3.6.2 Findings

The study work in Appendix 3 found that there is likely to be a significant impact on radio services from both trams and mainline railways if the standards are not amended to the extent of the factual assumption. The emissions are expected to be a combination of wideband and narrowband sources. The calculations in Appendix 2 were based on the assumption that the interference would be wideband, and on this basis we would expect all channels within the bands used to deliver the radio services to be equally affected.

The extent of this degradation is summarised in Table 3.3.

In the case of indoor reception, extensive disturbance is expected in the factual and counterfactual scenarios and accordingly higher wanted signal levels are required to enable service reception. In Table 3.3, the indoor separation distance shown is the region within which disturbance will occur over and above that which might be expected from devices operating at the limits of CISPR 22.

It can also be seen that for FM, DAB and analogue TV radio services in the indoor environment, that the minimum separation distance is greater for the factual scenario than for the counterfactual. This is because the factual limits are derived from CISPR 22, whereas the counterfactual limits are based on what might actually be expected from unconstrained continuous emissions from rolling stock in the future. In these instances, there would be no net degradation resulting from the counterfactual scenario.

Source	Service	Minimum separation for no degradation at the limit of coverage		
		Indoor reception	Outdoor reception	
			Factual	Counterfactual
Trams and Light railways	FM sound broadcasting	Up to 5 metres	348 metres	531 metres
	DAB	No increase in degradation	119 metres	Up to 104 metres
	Analogue TV	No increase in degradation	501 metres	Up to 94 metres
	DVB-T	No increase in degradation	45 metres	No increase in degradation
	Mobile networks	No increase in degradation	No increase in degradation**	
Mainline railways	FM sound broadcasting	Up to 100 metres	348 metres	Up to 2.2 km
	DAB	Up to 30 metres	119 metres	Up to 582 metres
	Analogue TV	Up to 20 metres	501 metres	Up to 531 metres
	DVB-T	Up to 20 metres	45 metres	Up to 47 metres
	Mobile networks	No increase in degradation	No increase in degradation**	

* *Degradation is shown here at the limit of coverage of the wanted service*

** *This case was not addressed in Appendix 2, however, similar performance can be expected in the outdoor environment given that a similar carrier to interference ratio would be available*

Table 3.3 Potential degradation arising from the counterfactual scenario (services shaded in grey indicate no net degradation)

In general, the potential impact on indoor FM reception from trams and light railways is confined to the houses lining the streets along which the trams run. The potential impact from mainline railways is greater and has potential to affect residential areas and offices to a distance of 100 metres. The impact when using an external aerial is more severe for trams, light railways and mainline railways. Indoor DAB sound broadcasting is affected up to 30 metres from mainline railways, and up to 582 metres using an outdoor aerial.

The impact on indoor television reception is limited to premises very close to mainline railways. Using an external aerial, degradation might be expected within 531 metres of

a mainline railway, however degradation can be expected to 501 metres even with the revised limits assumed for the factual scenario.

The actual disruption that is likely to occur also depends upon the frequency with which trains and trams travel along the line. Clearly, this will depend upon the timetable relevant to each line. To provide some perspective on this, the work in Appendix 3 provides an indication of how intermittent the interference is likely to be. For trams, it used a duty cycle of 10 trams/hour, which showed that interference to FM sound broadcasting might occur up to 96% of the time when using an outdoor antenna. In the indoor case, where the minimum separation is only 5 metres each disturbance would be brief.

The frequency of trains on mainline railways is likely to be less homogenous, therefore Appendix 3 illustrates the typical periods of disruption that might be expected from a train travelling at 64.5 mph. Again, for the indoor cases disruption will be brief. Using an outdoor aerial, each disturbance on FM sound broadcasting might last for up to 161 seconds.

3.6.3 Prospects for economic analysis

Although the potential degradation from railway EMI sources is substantial, the difference between the factual and the counterfactual cases is made less significant by the EMC limits that might reasonably be accommodated within the standards. This means that only a few of the victim systems scenarios considered have potential for significant economic benefits arising from the Agency funded research. A further factor limiting the economic benefits is that it is more common for people to use indoor aerials for reception of sound broadcasting.

Therefore the main areas where economic benefits from the research may arise are from degradation to FM sound broadcasting using indoor aerials within 5 metres of trams and light railways, and within 100 metres of mainline railways. The economic analysis (described later) found that although there was significant economic benefit arising from the mainline railways scenario because of the impact at 100 metres from the line, there was far less at 20 metres, therefore the following analysis focuses on the mainline railways scenario.

3.6.4 Assessing the interference as a function of the received signal level

Appendix 3 found that as the signal level decreases, there are two factors that influence the probability of unacceptable interference on signal reception:

- The region of influence from the railway line increases – this increases the number of properties affected by the interference and increases the duty cycle (proportion of time that interference is present) for properties closer to the line;

- The volume of the property that is unduly affected by interference increases as does the differential volume (that is the difference between the volume affected under the factual and counterfactual scenarios).

The overall probability of interference at a property is the product of the duty cycle and the differential volume affected. The volume of properties affected by interference at various distances from the line was obtained directly from Appendix 3, which was interpolated to derive the volume at 5 metre distance increments from the line. The duty cycle was calculated for each distance using the following formula:

$$DutyCycle = \frac{2 * T * \sqrt{Dist_{\max}^2 - Dist^2}}{3600 * \upsilon}$$

where:

T	= train intensity (in trains per hour)
$Dist_{\max}$	= maximum range of influence at that signal level (in metres)
$Dist$	= distance from the line being considered (in metres)
υ	= average speed of trains using the line (in m/s)

The train intensity is typically 8.6 for the mainline routes electrified at 25kV[42] and assuming an average speed of 26.7 m/s (60 mph) for each train gives a maximum duty cycle of 1.8% for a property close to the line where the region of influence extends to 100 metres. The duty cycle reduces for properties further away from the line.

To provide a basis for later calculations the overall probability of interference was calculated for properties within 100 metres of the line at various signal levels. The probability at a single signal level was given by:

$$P100_{SigLevel} = \frac{\sum_{n=1}^{20} \left[DifferentialVolume_{(SigLevel,n)} * DutyCycle_{(SigLevel,n)} \right]}{20}$$

where:

$P100_{(SigLevel)}$	= Probability of interference within 100m at a particular signal level
n	= number of 5 metre distance increments from the line

[42] The train intensity was obtained from The Strategic Plan 2003 from the Strategic Rail Authority, which details the length of route and percentage of electrification of the UK main railway lines. From this the weighted average across 25kV electrified routes was estimated to be 103 trains per day. This translates to an average intensity of 8.6 trains per hour in a 12 hour busy period assuming that the intensity is 2 trains per hour outside the busy period.

From this the overall probability was calculated for various received signal levels. A plot of the overall probability versus signal strength is shown in Figure 3.4.

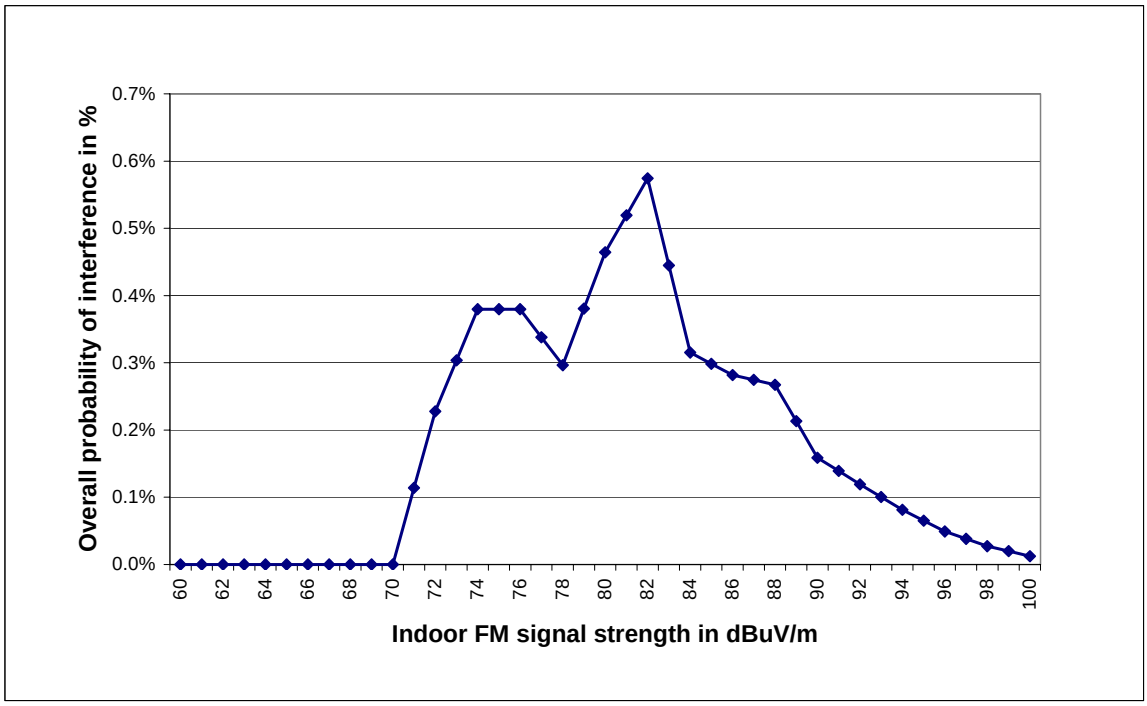

Figure 3.4 The mean probability of interference versus signal strength for FM broadcasting reception within 100 metres of a 25kV electrified mainline railway

It can be seen from Figure 3.4 that additional interference only occurs above 70 dBµV/m which is 10 dB above 60 dBµV/m (the minimum value for good reception). This is because below this level the interference is present in both factual and counterfactual cases. The peaky response of the plot is due to the non-linear nature of the affected volume of the property which has plateaus caused by the influence of internal walls.

The fact that differential degradation occurs only at field strengths above 70 dBµV/m has an impact on the geographic area of influence within FM Broadcasting coverage area. From the distribution of FM transmitter powers of BBC and Commercial Radio stations (as described earlier in the section on lighting), the weighted average area at each 1dB increment of received field strength was calculated. It was found that 72.5% of typical coverage area lies within the region 60 dBµV/m to 70 dBµV/m, and would therefore not be subject to the differential degradation between factual and counterfactual scenarios that is the subject of this analysis.

3.6.5 Overall value of FM broadcasting

The overall value of FM broadcasting was established in an earlier section which considered the impact of EMC issues in lighting. It was found to generate a consumer surplus of £1,065 million annually. We have assumed that homes and offices will be distributed alongside railway lines in the same proportion as they occur within the general urban areas of the UK. However, it is important to distinguish and isolate the listening which takes place in cars. The Radio Advertising Bureau[43] found that 24% of radio listeners consider that radio listening in cars is where they listen most often. Although this does not precisely define the extent of listening minutes that take place in cars we consider it to be a reasonable approximation for our analysis. This leaves a total consumer surplus of £809.4 million that can be attributed to listening within homes and offices.

The approach to further economic assessment was undertaken in two parts:

- Firstly to consider what proportion of the population is located in cities and towns through which electrified mainline railways run;
- Secondly to determine the degradation to FM radio services that might be expected within those cities and towns.

3.6.6 The number of properties affected

To determine the number of properties affected by the interference from mainline railway interference, UK rail network was analysed with regard to its proximity to population centres.

Approximately, 40% of the UK rail network is electrified of which:

- 63.8% is at 25KV using overhead transmission
- 36% is at 750 V DC using a third rail
- 0.2% is at 1500 VDC using overhead transmission (Sunderland Metro)

The 25 kV lines are mainly used north of London, on the West Coast and East Coast Main Lines. The 750 VDC lines are primarily located along the commuter routes of Kent, East Sussex and Hampshire, but are also used for suburban rail systems in London and Liverpool. To establish the proximity of these lines to population centres, it was assumed that all significant populations of housing and workplaces within close proximity to these lines will have a railway station associated with them. There are

[43] The Radio Advertising Bureau website is www.rab.co.uk

2,508 railway stations on the UK rail network[44], however further analysis revealed that only 278 of these are located along the 25kV electrified routes.

For further analysis, the 278 stations were divided into two groups:

- Those which are located within urban areas that also have dedicated FM radio transmitter sites. It was found that 132 of the railway stations were located within 39 population centres that have one or more FM radio transmitters. A total of 74 FM transmitters were located within these 39 population centres;

- Those that are not associated with dedicated FM radio transmitter sites. These remaining stations were assumed to be distributed randomly within the coverage area of FM transmitters.

Each of these cases are analysed in turn. It was assumed that households and offices would be distributed in a similar proportion to population.

3.6.7 Urban areas with dedicated FM transmitters

Since the railway environment in these urban centres is correlated with the locations of FM transmitters, a specific model was developed for each urban centre and its FM transmitters based on the population and area of the urban centre. This allowed the population and area of the city to be taken into account as well as the distribution of signal levels along the railway line. The model is shown in Figure 3.5.

[44] Obtained from the Department for Transport (DfT) transport statistics at www.dft.gov.uk

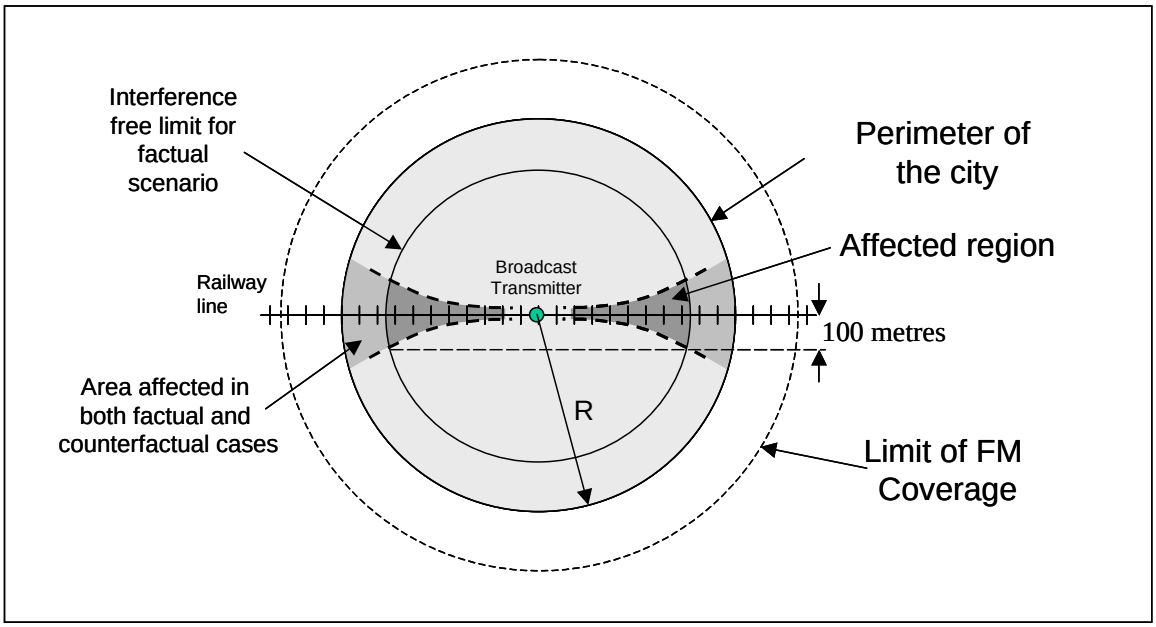

Figure 3.5 Model of interference within a city with a co-located FM radio transmitter

The study in Appendix 3 found that high levels of interference can be expected in close proximity to railway lines for both the factual and counterfactual cases. Therefore the *difference* between the two cases emerges at higher signal levels occurring closer to a broadcast transmitter. This is shown in Figure 3.5 as the region within which emissions under the factual scenario will not degrade the performance of FM radio reception. At locations closer to the broadcast transmitter under the counterfactual scenario, the area affected becomes narrower as higher wanted field strengths are available to overcome the impact of interference.

To relate this to the geographic area served by a broadcast transmitter, we interpolated the results shown in Figure 3.4 into 2 dB increments and calculated the effective reduction in range that this equates to for broadcast powers at various transmitter powers. To do this we used the propagation characteristics contained within ITU-R Recommendation P.1546, which has field strength curves for terrestrial paths at 100 MHz. We also assumed a mean in-building penetration loss of 10dB consistent with the approach taken for the analysis in Appendix 3. We then calculated the area contained within each increment for a range of transmitter powers for both BBC and Commercial Radio transmitters and used this to calculate a weighted average of the proportional volume of availability lost for each transmitter power. The overall proportional volume of availability lost was calculated as the weighted average of all transmitter classes.

From the population of each city, its area was estimated using a figure of 45.6 persons/Hectare[45]. From this the effective radius (R) of the city was calculated. For the purposes of analysis the railway line running through the city was divided into segments where each segment corresponded to 1dB difference in received signal level. From this, the population within each line segment was determined considering a region of influence extending 100 metres on both sides of the railway line. This allowed the total population within the region of influence to be weighted by probability of interference and summed for the city. Comparing the sum of these weighted populations across all cities within which the 74 transmitters are located, with the population of the UK provided the proportion of FM consumer surplus that would be lost under the counterfactual scenario in these cities.

This is represented by the following equation:

$$ValueLost = TotalFMValue * \frac{\sum_{FMtransmitters}\left[CityPop * \frac{\sum_{LineSegments} A_{LineSegment} * \Pr ob_{LineSegment}}{A_{City}}\right]}{Population\_of\_UK}$$

Where:

TotalFMValue	= the consumer surplus of FM (less listening in cars)
FMtransmitters	= the set of FM transmitters located within the cities on electrified route
CityPop	= the population of each city on electrified route
LineSegments	= the set of line segments each representing 1dB of signal strength
$A_{lineSegment}$	= Area of each line segment to a distance of 100m from the line
$Prob_{LineSegment}$	= Mean probability of interference for each line segment
A_{City}	= Area of the city (based on the generic model)

The result of this calculation was an annual loss in consumer surplus of £27,000 under the factual scenario.

3.6.8 Urban areas without dedicated FM transmitters

The remainder of the towns having stations along 25kV electrified track were assumed to be distributed at random within the general coverage area of FM radio. Therefore the overall probability of interference was calculated as the weighted sum of probabilities for each coverage "ring" where a ring of coverage is the area within a 1 dB increment of FM field strength. The mean probability of interference for houses within 100 metres of

[45] The UK Government Statistics website (www.statistics.gov.uk) gives the population density for London as 45.6 persons/hectare.

the line was as calculated earlier and the population potentially affected was calculated as by proportion of area.

This is represented by the following formula:

$$ValueLost = TotalFMValue * \frac{\sum_{Towns}\left[TownPop * \frac{Area_{100m}}{A_{Town}} * \frac{\sum\left(A_{ring} * Prob_{ring}\right)_{CoverageRings}}{A_{TXcoverage}}\right]}{Population\_of\_UK}$$

Where:

TotalFMValue	= the consumer surplus of FM (less listening in cars)
Towns	= the set of towns located on electrified route
TownPop	= the population of each town on electrified route
LineSegments	= the set of line segments each representing 1dB of signal strength
$Prob_{Ring}$	= Mean probability of interference for the coverage ring
A_{Ring}	= Area of a coverage ring
$A_{TXcoverage}$	= Total area of coverage by the transmitter
A_{100m}	= Area bounded by 100m on either side of the line
A_{Town}	= Area of the Town

The calculation was performed for the remaining towns and the resulting reduction in consumer surplus was £1,528. This low figure is due to the relatively small population of these towns and the fact that within 72.5% of the coverage area there is no net degradation between the factual and counterfactual scenarios.

3.6.9 Economic impact

To establish the economic value arising over a period of 10 years, we used a Discounted Cash Flow (DCF) model to calculate the Net Present Value (NPV) of the benefits arising from research. Our analysis is based on some important assumptions:

- The research and standards process means that changes to the standard will not occur until the year 2007;
- The new standards will apply to all new rolling stock and new equipment installations from that time. In this analysis we have assumed that rolling stock is replaced on a 30 year cycle and refits take place every 5 years. It is assumed that potentially interfering equipment would be installed as refits are performed on rolling stock;
- No costs are incurred by the train equipment manufacturers since changes can be accommodated early in the design process without cost.

The following table shows the cash flows arising from this analysis.

Year		1	2	3	4	5	6	7	8	9	10
Potential loss in consumer surplus	£	28,528	28,528	28,528	28,528	28,528	28,528	28,528	28,528	28,528	28,528
Percentage of rolling stock affected	%	0%	0%	0%	0%	20%	40%	60%	80%	100%	100%
Change in consumer surplus	£	0	0	0	0	5,706	11,411	17,117	22,822	28,528	28,528
Discount rate	%	3.50%									
Net present value	£	£86,027									

Table 3.4 Forecast cash flows arising from difference between the factual and counterfactual scenarios

The net present value of benefits arising the change to the standards is £86,027. Since 68% of this can be attributed to the Agency funded research projects, the net benefit arising from the Agency funded research is £58,498.

3.6.10 Impact on spectrum value

Like the analysis of the research project into energy efficient lighting, the potential impact on spectrum value can be calculated from the proportional decrease of consumer surplus that was avoided by undertaking the research. The potential impact on FM Broadcasting consumer surplus is 0.009%, and when expressed in terms of typical profit margins (17%) in the broadcasting industry it amounts to only 0.05%. Whilst any increase in spectrum value should be welcomed, the impact is clearly small.

3.6.11 Conclusions on railway environments

The research project into EMC issues in the railway environment identified some areas where harmful interference might occur if the EMC standards are not modified to take account of the nature of emissions from rolling stock. This interference was found to have potential to affect sound and television broadcast reception in the vicinity of railway lines. Although the research provided a great deal of insight into the nature of railway emissions and its potential to affect victim radio systems, the economic benefits arising from the research are likely to be low which is largely due to the small population of radio users affected by the interference in practical scenarios.

3.7 Electric vehicles

There are few electric vehicles deployed at the moment, however usage is expected to increase in future, and could result in large numbers in close proximity to residential areas. There are practical EMC measurement issues to ensure high emissions when accelerating or braking are taken into account when testing.

This issue was studied in an Agency funded research project undertaken by the transport research laboratory (TRL)[46], which found that current standards were adequate for electric vehicles. A later study by MIRA[47] concluded that there was possibility of some degradation to FM Broadcasting, PBR and TETRA radio services, although it considered that there was not much of a threat in the short term since the density of electric vehicles is expected to remain low for some time. It also acknowledges that the outage probabilities were evaluated under worst-case conditions for both EMI sources and victim receivers. Its main finding was that changes to the automotive EMC measurement methods are necessary to ensure that the existing limits were applied effectively to electric vehicles.

Consequently, we have not studied this further in our report since the impact on radio services appears to be slight for the foreseeable future, and we do not expect a change to the limits applied to the interference environment as a result of the Agency funded research.

3.8 Dithered clock oscillators

3.8.1 Overview

Dithered Clock Oscillators (DCO) are a consequence of a technique which enables the emitted interference power originating from microprocessor clocks to be distributed over a wider bandwidth than conventional equipment using microprocessor clocks that are not dithered. Although it means that the power is lower when measured with a conventional quasi-peak detector, the overall interference power affecting some radio services may increase. It enables a manufacturer to reduce shielding on equipment housings (thereby cutting manufacturing costs) whilst still meeting the test requirements of the standards.

However, this has three effects on the interaction with potential victim systems:

[46] L S Blanchard and D Whitehead, “A Study To Assess The Possible Effects On Radio Based Services Of Electromagnetic Emissions From The Proposed Increase Of Electrically Powered Public And Private Transport”, TRL Project Report PR/SE/186/00, October 2000.

[47] Investigation of electromagnetic emissions from alternative powertrain road vehicles, MIRA, May 2002.

- Where there is some degradation to narrowband victim systems (which might otherwise be considered acceptable), this degradation occurs over a wider bandwidth;
- Higher interference power is observed by broadband victim systems;
- Broadband victim systems such as those used for digital sound and television broadcasting generally have a higher susceptibility to broadband noise sources compared to a narrowband source with an equal noise power.

The research projects undertaken by the Agency addressed this issue and recommended modification to the standards to ensure that emissions will be constrained to a level consistent with the spirit of the narrowband limits. Although the Agency has attempted to raise awareness of the issue within CISPR, it has not yet gained the support of the relevant committee; therefore it is unlikely that action will be taken to amend standards in the near future.

To understand the technical impact of the research project, the following factual and counterfactual assumptions were made:

Factual assumption	Counterfactual assumption
With the Agency funded research project, a practical limit on broadband emissions from microprocessor based equipment will be imposed that reduces degradation to indoor use of radio services.	Without the Agency funded research projects, equipment would continue to use dithered clocks resulting in increased broadband emissions.

The issue was studied and the results are presented in Appendix 2. DCOs can be installed in a number of domestic appliances including personal computers, set top boxes, advanced home entertainment systems and intelligent appliances. The impact of the interference was studied in both office and domestic environments.

3.8.2 Findings

The study within Appendix 2 found that the use of DCO equipment has potential to affect FM sound broadcasting, DAB sound broadcasting and DVB-T broadcasting. The extent of the impact of this interference is summarised in Table 3.5.

Service	Coverage parameter	Difference in degradation between factual and counterfactual assumptions		
		Office environment	Above average home	Below average home
FM sound broadcasting	Increase in affected volume	Up to 77%	Up to 45%	Up to 17%
	% of band	5-16%	5-14%	5-14%
	Duty cycle	100%	30% to 100%	30% to 100%
DAB	Increase in affected volume	Up to 25%	Up to 65%	Up to 32%
	% of band	0-12%	12-32%	12-32%
	Duty cycle	100%	30% to 100%	30% to 100%
DVB-T	Increase in affected volume	Not applicable	Up to 18%	Up to 17%
	% of band		10-49%	10-49%
	Duty cycle		30% to 100%	30% to 100%
Notes *Degradation is shown here towards the limit of coverage of the wanted service* *Analysis of all services assumes the use of indoor aerials*				

Table 3.5 Summary of the degradation experienced by radio services due to the use of dithered clock oscillators

It can be seen that there is likely to be significant degradation of FM broadcast services in both offices and homes. In addition, DAB and DVB-T services are likely to be affected in both above average and below average homes. The actual degradation experienced by users also depends on the percentage of channels affected and the coincident duty cycle of both the interference and the victim system. The overall change in victim system availability is the product of the volume affected, proportion of the band and the coincident duty cycle.

This is summarised in Table 3.6.

Coverage parameter	Difference in service availability between factual and counterfactual assumptions		
	Office environment	Above average home	Below average home
FM sound broadcasting	3.9 to 12.3%	0.7 to 6.3%	0.3 to 2.4%
DAB sound broadcasting	0 to 3%	2.3% to 20.8%	1.2 to 10.2%
DVB-T television broadcasting		0.5 to 8.8%	0.5 to 8.3%

Table 3.6 Difference in service availability between the factual and counterfactual assumptions

The cost of implementing the additional shielding required to reduce emissions from equipment using dithered clock oscillators is estimated to lie between £3 to £5 per unit.

3.8.3 Conclusions

Dithered clock oscillators are already widely used within information technology equipment such as PCs, printers and scanners, because of the reduced EMI protection measures that are required to meet the current limits. This widespread adoption can be expected to continue into the future so long as the standards are not able to limit DCO use. The result is likely to be a worsening of the interference environment as the penetration of equipment using DCOs increases. Consequently, the utility of sound and television broadcasting services available to offices and households can be expected to suffer into the future if the penetration of DCO devices were to increase.

Since the standards are unlikely to change as a result of the Agency funded research, the degradation to radio services outlined above is unlikely to be avoided, and therefore we have not considered the economic impact further. However, the case illustrates a situation where the standards bodies were not persuaded that the impact of interference was significant enough to warrant changes to the standards.

It could be argued that the inclusion of quantitative impact assessment at the system level, such as that performed in Appendix 2 and outlined in economic terms in this report for other areas, would present a more compelling case for further action to be taken.

3.9 Industrial microwave ovens

3.9.1 Overview

Industrial microwave ovens are able to use an ISM frequency allocation in the UK that permits them to utilise 20 MHz of spectrum centred at 896 MHz. This spectrum is currently assigned to two GSM900 mobile network operators. The interference limits

applied by the Agency were originally set to be 120 dBµV/m measured at 30m from the building housing the microwave oven. However, it was found that interference into nearby mobile phone base station equipment unduly affected mobile operation and substantially reduced the range of mobile phone usage from those sites.

A series of research projects were undertaken by the Agency to assess and resolve the issue. The conclusion of this work was that a combination of lowering the interference limits to 60 dBµV/m and fitting RF chokes to the ovens, was the most effective solution to the problem.

To understand the impact of the research project, the following factual and counterfactual assumptions were made:

Factual assumption	Counterfactual assumption
With the Agency funded research project, a practical limit on industrial microwave oven emissions of 60 dBµV/m was imposed. Practical solutions limited emissions to an average of 55 dBµV/m.	Without the Agency funded research projects, mobile phone network operators would have needed to re-configure their networks to ensure adequate network operation in the vicinity of each microwave oven.

The impact on mobile phone usage and costs of remedial actions were assessed in support of this study and the results are presented in Appendix 4.

3.9.2 Findings

The study in Appendix 4 found that without the Agency funded research the impact on mobile phone networks was severe. A separation distance greater than 6 km would have been necessary to ensure that cell range was not degraded by more than 10%. This percentage reduction in cell range worsens as the separation distance between the oven and base station is reduced.

The impact on typical cell range under both factual and counterfactual assumptions as a function of separation distance between the industrial microwave oven is shown in Figure 3.6.

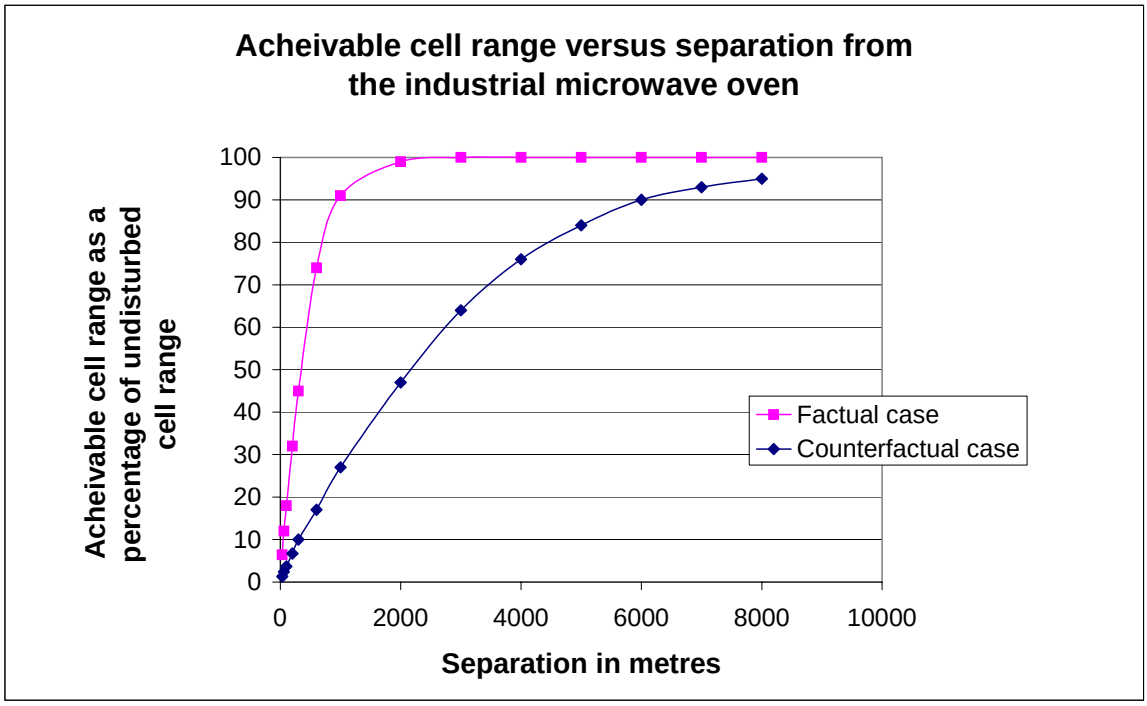

Figure 3.6 Typical impact on GSM900 cell range as the distance between base station and industrial microwave oven varies

The study in Appendix 4 also found that the separation distance required for minimal degradation with typical modified ovens (at 55 dBµV/m) were still significant at around 1 km for 10% range reduction. The original Agency funded research work indicated that a separation of around 0.19 km was required at an emission limit of 60 dBµV/m. The different results in Appendix 4 are due to a more thorough treatment of assumptions used to characterise typical mobile phone networks performed in the course of this study.

The costs of remedial action to the industrial microwave oven depended upon the age of the individual oven. The newer ovens were modified by fitting of improved chokes at an estimated cost of £30,000 per oven. Older ovens required greater modification including replacement of generators at an estimated additional cost of £140,000 per oven.

3.9.3 Impact on Mobile Phone networks

The separation distance that was computed would have been very problematic for mobile phone operators. The typical range of a suburban cell is 4km[48] which means that a separation of 6km cannot be achieved by cells pointing directly towards the interfering source. This means that the network operator would have had two options:

- To forego the coverage around the microwave oven and provide a lower quality of service for these subscribers;
- To re-locate sites so that the disruption is minimised.

We have assumed that the solution adopted by mobile operators would be to relocate a single site in the vicinity of each microwave oven installation, such that sectored antennas would be directed either side of the microwave oven site. This means that the immediate vicinity of the oven installation would still suffer some reduced performance due to the interference, but the cells would continue to operate relatively normally. This means that the costs incurred by mobile operators would be the costs associated with relocation of a single (3-sectored) site. It follows that even with the results of research in place there is also a residual impact on the mobile networks. It is likely that 10% of locations will still not achieve the separation distance and require some reconfiguration.

We have assumed that the mobile operator would have relocated the site on a minimum cost basis. This means that all equipment would be relocated where practical. In real networks, it may have suited an operator to purchase new equipment under existing contractual arrangements with the equipment supplier, however such a decision would not be a direct result of the interference and therefore should not be included in this analysis.

3.9.4 Calculation of economic impact

The main costs associated with site relocation are shown in Table 3.7. They were obtained from the Long Run Incremental Costing (LRIC) methodology as adopted by Oftel when calculating the costs of service provision to support Interconnect negotiations for fixed and mobile network operators[49].

[48] Calculated using a sample link budgets described within GSM 03:30 Radio network planning aspects (version 8.3.0 Release 1999). The calculation was also based on a 10dB in-building loss and COST 231 propagation model as applied to suburban environments.

[49] The LRIC model was developed for Oftel by Analysys Limited and is available on its website (www.analysys.com).

		Capital costs
Site costs		
Site acquisition and leasing		£25,000
Tower/Mounting		£20,000
Power		£10,000
Security		£5,000
Enclosures		£20,000
Antennas		£10,000
Cables		£5,000
Equipment installation		
Capital cost of equipment		
3 sector BTS (no TRX's)	£28,160	
TRX costs	£70,560	
2 Mbit/s microwave link	£15,000	
Equipment installation (at 15% of capital equipment costs)		£17,058
Equipment removal (at 5% of capital equipment costs)		£5,686
	Total	***£117,744***

Table 3.7 Assumed costs associates with site re-location

Assuming a total of 21 microwave ovens[50] this results in a cost to each Mobile network operator under the counterfactual scenario of £2.47 million, giving a total of £4.94 million. Assuming that 10% of the oven locations will still require remedial action even under the factual scenario, the total cost savings to mobile operators resulting from the research is estimated to be £4.45 million.

However, each oven manufacturer must implement remedial measures to reduce the interference. At a cost of £30,000 for 15 of the ovens and £140,000 for the remaining 6 ovens[51], the total cost is £1.3 million.

Therefore the overall economic benefits arising from the research are estimated to be around £3.2 million.

[50] A total of 21 industrial microwave oven sites were identified in the Agency research.

[51] Using an assumption that 20% of the ovens require the more expensive replacement of generators.

3.9.5 Impact on spectrum value

Without the Agency funded research project the value of GSM900 spectrum would have been reduced by an estimated £3.2 million.

3.9.6 Conclusions

As a result of the research projects into methods of reducing emissions from industrial microwave ovens, the Agency has been able to lower the ISM limits with a consequent reduction in interference to GSM900 network operators. As a result, the need for remedial action to maintain GSM900 performance is alleviated. The avoided costs are estimated to be £3.2 million.

This case illustrates an important arbitration function performed by the Agency. Without the Agency's intervention, neither the operators of the industrial microwave ovens nor the mobile operators were economically motivated to resolve the issue, since the mobile network operators were being compensated for the reduced service availability by a reduction in licence fees. Therefore, the actions of the Agency have served to maximise access to the radio service for consumers.

3.10 Household appliances and electric tools

3.10.1 Overview

The adequacy of CISPR14, the standard that protects services from household appliances and electric tools was called in to question when a manufacturer was taken to court for supplying a hairdryer that was capable of interfering with indoor portable TV reception, even though it complied with the standard. The defendants pleaded guilty; therefore the issue of appropriate limits was not resolved in court.

The Agency funded a research project to look at the adequacy of CISPR14. This study found the standard to be inadequate and recommended that CISPR14 be extended in frequency range from 300MHz to 1GHz. To understand the impact of the research project, the following factual and counterfactual assumptions were made:

Factual assumption	Counterfactual assumption
With the Agency funded research project, a practical limit on emissions between 300MHz and 1GHz from household appliances will be imposed that reduces degradation to indoor use of radio services.	Without the Agency funded research project, interference would be experienced by radio services between 300MHz and 1GHz within the home.

The impact of interference from household appliances was studied in Appendix 5. The main victim systems between 300MHz and 1GHz were DVB-T using indoor aerials and GSM 900 mobile phone services.

3.10.2 Findings

The study found that with typical emissions from a hairdryer, handheld food mixer and two battery operated toys, coverage was restricted for both digital portable television use and mobile phones. The interference has potential to affect these radio services with and without modification of the standards. Degradation before modification is worse and 10 dB of additional signal level would be required to fully compensate for the additional interference.

However, the duty cycle of the interference was found to be small. The non-simultaneous usage of each of the devices would typically result in around 22% of time that some interference would be present. Therefore radio service operators would be unlikely to modify their networks to compensate for this effect. The additional volume of the house affected by the change in standards peaks at 73% for DVB-T services, and 67% mobile network coverage (assuming simultaneous use of all four devices).

The costs of modifying the appliances to achieve the extra 10 dB of shielding is not expected to be significant. We believe that good design practice should achieve this at minimal cost.

3.10.3 Economic analysis

The study in Appendix 5 showed that degradation of services is likely to occur in the future if there is no change to CISPR14 to extend the frequency range. In addition, further court cases may ensue. Significant restrictions on availability of use within the home would be likely to occur. However, the overall impact is limited by the small duty cycle of interference. Since the interference will not occur often then mobile operators and television broadcasters are unlikely to make efforts to improve coverage to compensate.

Therefore any economic benefits of the factual assumptions will arise through preventing the loss of utility experienced by householders that may be unable to obtain indoor portable television coverage or use their mobile phones.

The source of interference is slightly different from other indoor sources investigated in this report, in that the householder will be able to identify the source of interference, and control the times at which both interference source and victim systems are used within the householder's premises. For flats, terraced houses and semi-detached houses the householder will have no control over interfering devices used by neighbours. However, the study in Appendix 5 showed that there is limited

breakthrough from one room to another, which implies that little (non-discretionary) interference could be expected from a next-door neighbour.

3.10.4 Conclusions

Further economic analysis was not undertaken in this case because there are actions that can be undertaken by the victims of the interference to alleviate the impact of the interference at little or no cost. However, the nature of the interference can be considered inconvenient and to limit the source of interference does increase the quality of the spectrum to users.

However, there is also little or no cost to implementation of the interference limiting measures by the manufacturers of equipment.

In this case, the benefits are slight, but the costs are also slight (given the low cost of the research project and the low implementation costs by manufacturers). To ensure that these relatively small issues are dealt with effectively can be considered good management practice even though they are less influential in determination of EMC policy.

3.11 Summary of the economic Impact

The potential economic impact of nine major EMC issues that were subject to Agency funded research projects has been investigated in this section and are summarised in the Table 3.8.

EMC Issue	Potential economic impact		
	Attribution of net benefits to the Agency based on 68%	**Attribution of net benefits to the Agency based on 41%**	**Impact on spectrum value**
Proactive research projects			
Faster clock processors	£7.7 million	£4.6 million	0.32%
SMPS and SELCs	The research project is on-going		
Lighting	£3.5 million	£2.1 million	2.9%
xDSL and Power Line Communication Technologies	It is likely that remedial actions can be undertaken with or without the research.		
Railway environment	£0.058 million	£0.035 million	0.05%
Electric vehicles	The research found that the EMC standards were adequate.		
Total benefits	*£11.2 million*	*£6.7 million*	
Reactive research projects			
Dithered Clock Oscillators	The research is not likely to result in a change to EMC standards in the near term.		
Industrial microwave ovens	£3.2 million		£3.2 million
Household appliances and electric tools	In general, the owner of the property has discretion over use of both EMI source and victim system		

Table 3.8 Summary of the economic impact of Agency funded EMC projects

The total calculated economic benefits of the Agency funded EMC research projects is £11.2 million, which exceeds the £2.0 million spent by the Agency on all the proactive projects undertaken in the three years 2000/01, 2001/02 and 2002/03.

The sensitivity of assuming a reduced level of attribution of economic benefits to the Agency was also calculated. It was found that even under this scenario the economic benefits arising from the research projects (£6.7 million) comfortably exceeds the initial funding.

4. IMPACT OF PROPOSED CHANGES TO THE EMC DIRECTIVE

4.1 Introduction

The EMC Directive 89/336/EEC is a part of the European legislation that like other EC directives, is intended to promote a common approach to products and markets across the EEA[52]. The EMC Directive (EMC-D) became legally binding in all member states in 1996, replacing national legislative measures in which individual countries adopted their own standards and legislation to manage EMC issues. The main impact of the EMC-D was to devolve the technical standards from the legislation that enacted them. This means that so long as EMC standards are considered harmonised (as published in the Official Journal of the European Communities) then any equipment falling within their remit and conforming to their technical requirements, has 'a presumption of conformity' with the EMC-D. This allowed standards to be developed and applied at the international level with consequent market benefits to product manufacturers by providing better certainty of compliance and a broader market base.

In 1998, the EMC-D was included within Phase III of the Simpler Legislation for the Internal Market (SLIM) process. This review resulted in a number of proposed amendments[53] which are currently in the final stages of adoption within a new EMC Directive. A transition period of 2 years will also be applicable to the new EMC-D, to allow those affected by the directive to adjust to the new regulatory regime. A comprehensive description of the current EMC Directive and the proposed new EMC Directive is provided in Appendix 6[54].

The EMC-D serves a very important function in the protection of services from electromagnetic interference. It is the means by which standards are enforced within the European electronics industry. Without the EMC Directive and no effective implementation of standards, national regulatory authorities would have to wait for EMC problems to arise, detect any undue interference, arbitrate between manufacturers of interfering equipment and victims of interference, and enforce corrective action.

[52] The European Economic Area comprises the 15 EU nations and Norway, Iceland and Lichtenstein

[53] Commission proposal COM(2002) 759 for a revision of Directive 89/336/EEC introduced on 24/12/2002

[54] Appendix 6 – Review of the EMC Directive (89/336/EEC), produced in support of this project by Quotient Associates Ltd, York EMC Services Ltd and Dr Chris Doyle.

From an economic perspective this is not desirable because:

- Costs are incurred in routine monitoring and detection of interference. Either the operators of victim systems would incur cost or the government in protecting their ability to offer services;
- Service degradation and costs may arise from Interference prior to detection;
- Costs may continue to be incurred due to delays before remedial actions are undertaken;
- Long term costs may be incurred due to inability to apply measures retrospectively (for products already sold);
- Costs may be associated with legal action and arbitration;
- Costs of remedial action – remedial costs are higher later in the product lifecycle and particularly damaging after products enter the market.

However, a more likely outcome in the event of there being no EMC Directive is that each nation would implement its own legislation to apply national EMC standards or other international standards that are available. Whilst this might result in protection of services from undue interference, it results in a fragmented market because victim systems are different in scale and characteristics in each country and compromises between interferers and victims systems would also be likely to differ in each country.

The result for manufacturers, and operators and end users of victim systems is that there would be a smaller market for harmonised products and a lack of certainty resulting in higher design margins, more effort to monitor and test, and more funds set aside for lobbying and legal action. This potential for market inefficiency was the driving force for the EC's new approach directives.

Why is it important economically

The EMC-D is the legislation which enacts and applies a set of harmonised standards to products offered for sale in the European Community. However, its success in dealing with the costs outlined above depends upon there being adequate standards for each product type and effective procedures for ensuring compliance with the standards.

Adequate standards are the result of:

- Effort expended by international standards bodies to produce harmonised standards;

- Participation by both sides (suppliers of potentially interfering equipment and operators of victim radio systems) in the standards development process to ensure an equitable compromise;
- Good information on technical matters so that the nature of interference and the potential for service degradation can be understood;
- Good information on the potential economic impact so that an appropriate balance can be found that takes account of:
    - Safety of life considerations;
    - Potential economic loss sustained by each party;
    - Fairplay (ability of minority groups to access radio services);
    - Maximising technical performance for all affected by the interference.

Without good information, the standards development community are not able to produce appropriate standards and the full benefits of the EMC Directive would not be realised, and there would be subsequent economic loss. The provision of impartial technical information has been a role of the Agency in its EMC research funding, and has been assessed in the preceding sections of this report.

However, the Agency also has a role in participating in discussions on the legislative aspects, and to understand the importance of this function, we have reviewed in this section the economic implications of the EMC Directive and quantified the costs and benefits to the UK of the proposed new EMC-D.

4.2 Economic impact of the proposed amendments

4.2.1 Summary of the proposed amendments

There are eight major areas of change proposed in the new EMC Directive. These are summarised below:

1. More coherent scope and product definition – products coming under the directive are now subject to a more systematic classification of ‘equipment’, ‘apparatus’, ‘components or sub-assembly’ and ‘fixed installations’. It is believed that this provides more clarity on what is subject to the directive and the consequent obligations. In the current publicly available draft wording of the new EMC-D, ‘ready-made signal-carrying connecting devices’ are explicitly included within the directive. However, this has been removed from the latest internal draft and we do not expect it to form part of the final legislation;

2. Exclusion of benign or low disturbing equipment – products having a very low emission characteristics are explicitly excluded from the directive;

3. Regime for fixed installations – this exempts fixed installations from conformity assessment with the EMC-D (note that the installation must still meet the protection requirements);

4. Apparatus must meet protection requirements without the use of additional devices – This requires that apparatus should not be reliant on additional devices to achieve compliance unless such devices are always sold with the apparatus or that the apparatus is defined for 'professional use';

5. Information requirements for apparatus – This extends the product labelling requirements and operating instructions to include batch number, serial number, manufacturer's name and address, precautions for assembly and restrictions on use;

6. Clarification on the use of harmonised standards

7. Voluntary resort to notified bodies – Currently manufacturers are obliged to obtain a certificate from a Competent Body when following the Technical Construction File route to compliance. Under voluntary resort this will no longer be required;

8. Notified body report – under the new EMC-D a manufacturer may at his option obtain a *report* from a notified body to include in his technical information; this is currently mandatory when a manufacturer uses a Technical Construction File (TCF) to demonstrate conformity;

In support of the process to develop appropriate amendments, the EC commissioned a report by Risk & Policy Analysts Limited (RPA) to assess the costs and benefits of the proposed changes[55]. The RPA Study concluded that overall, there was a net social utility loss associated with the proposed changes ranging from €1.3 billion to €3.5 billion, with €2.4 billion being considered a typical figure. However, since the higher value is less than 0.1% of the total production and value of work covered by the EMC Directive and the changes tend to formalise current practice, its recommendation was that the proposed amendments be adopted, with some clarification on interpretation.

Since the RPA Study was undertaken there has been further development of the new EMC Directive. In particular, the RPA Study assumed that ready-made signal carrying connecting devices would be included, whereas it now appears likely that they will not

[55] Cost Benefit Analysis on the Draft Amendment of the EC Directive on Electromagnetic Compatibility, Risk & Policy Analysts Limited prepared for the European Commission Directorate-General Enterprise, January 2002.

be included. Our analysis of economic impact of the proposed amendments in this report uses the RPA Study results for much of the data and structure, but performs the economic analysis in the context of the UK only and excludes ready-made signal carrying connecting devices.

4.2.2 Parties affected by the directive

The structure of the manufacture and supply of electronic products is shown in Figure 4.1.

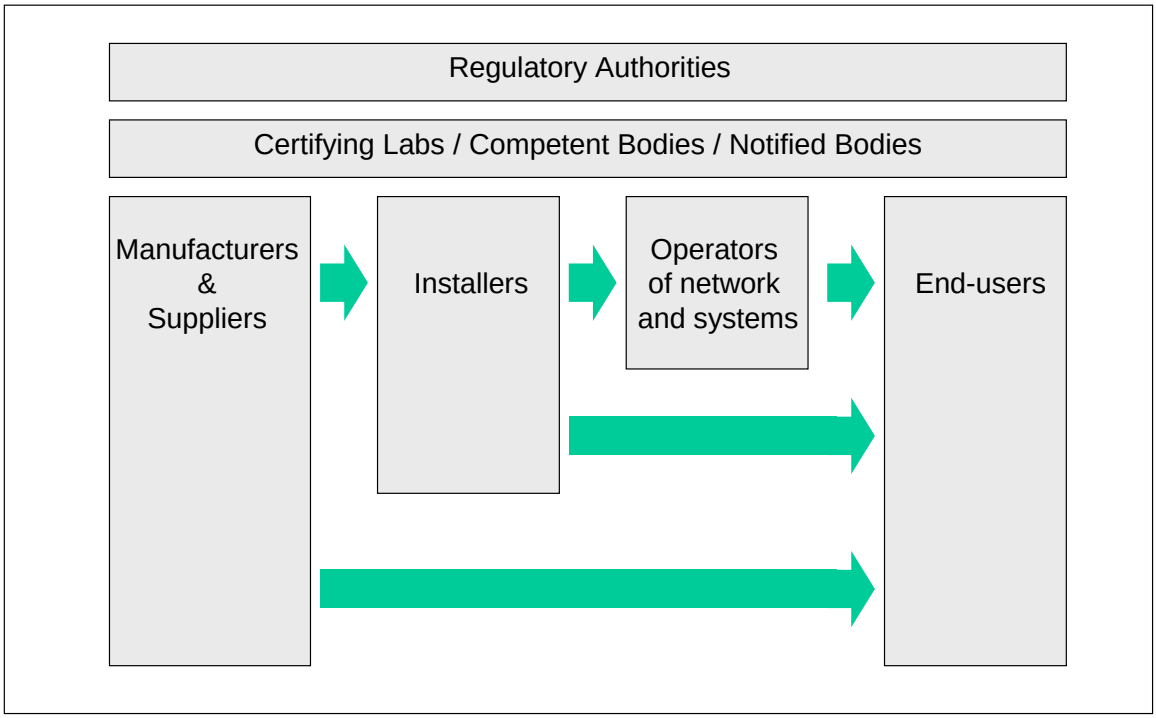

Figure 4.1 Major parties affected by the proposed amendments to the EMC Directive

The manufacturers and suppliers carry most of the burden of EMC compliance. They must design products to remain within the specified emission limits, test the products and maintain appropriate documentation. However, installers of equipment also have a responsibility to ensure that installations do not cause EMC problems. The operators of networks and end users of equipment (both professional and private) are the major beneficiaries of an interference free environment.

In the UK, Trading Standards is the regulatory authority responsible for overseeing EMC regulation although where cases of undue interference do arise as a complaint, Ofcom are also involved. In either case enforcement may lead to using the judicial system.

The current EMC Directive mandates, in some cases, the preparation of a Technical Construction File which must be reviewed by accredited Competent Bodies. These same organisations usually also offer the same services on a voluntary basis or independent testing and design support. Certifying laboratories, Competent Bodies and Notified Bodies are collectively termed Notified Bodies in this section.

4.2.3 Economic analysis in the context of the UK

The approach to analysis of economic impact of the proposed amendments is based on the modelling work undertaken in the EC study work undertaken by RPA. The model which was used in the RPA Study is publicly available, therefore our approach was to recalculate the costs and benefits using amended inputs and assumptions so that the results for the UK could be isolated and the impact of ready-made signal carrying connecting devices excluded. The economic costs and benefits that were identified in the RPA Study are assessed for each type of organisation affected by the proposed amendments to the EMC Directive. Therefore these were attributed to the UK by the same proportion to which UK organisations of that type contribute to the EEA total.

The method of estimating the UK proportional contribution varied depending upon the organisation type. The approach taken in the EC study was based on questionnaire responses by a large population of manufacturers and suppliers, user groups, competent bodies, public authorities and installers. The UK is well represented within the responses and therefore we have no reason to assume that the results are biased to or from the UK. For manufacturers and suppliers, the RPA Study identified that the UK contributes around 14% of total EEA output. For the remaining organisation types we used Gross Domestic Product (GDP) as the basis for attributing costs and benefits to the UK. The UK GDP represents 15.7% of the total GDP of the EEA nations[56].

In order to calculate the overall economic impact of the proposed amendments to the UK we made three further changes to the methodology used within the RPA Study:

- The actual costs calculated as part of the methodology are discounted over a period of eight years in the RPA study. We have applied 10 years to be more consistent with other calculations performed within this report;
- For the discount rate we have used the UK Treasury recommended rate of 3.5%, rather than the 3.25% used in the RPA Study;
- The RPA Study incorporates a net efficiency formula which provides weighting factors to be applied independently for costs and benefits. The impact of these weightings is to bias the results towards benefits as opposed to costs, and in

[56] Source: CIA world factbook available at http://www.cia.gov/cia/publications/factbook

doing so reflect the political values of the EC. For the purposes of this report, we have removed these weighting factors to avoid bias.

From the analysis, it was found that there is likely to be a net cost to the UK of £76 million resulting from the proposed amendments. The amounts vary according to participants in the industry, with manufacturers and suppliers bearing the brunt of the costs.

The net costs and benefits to each group of participants is shown in Figure 4.2.

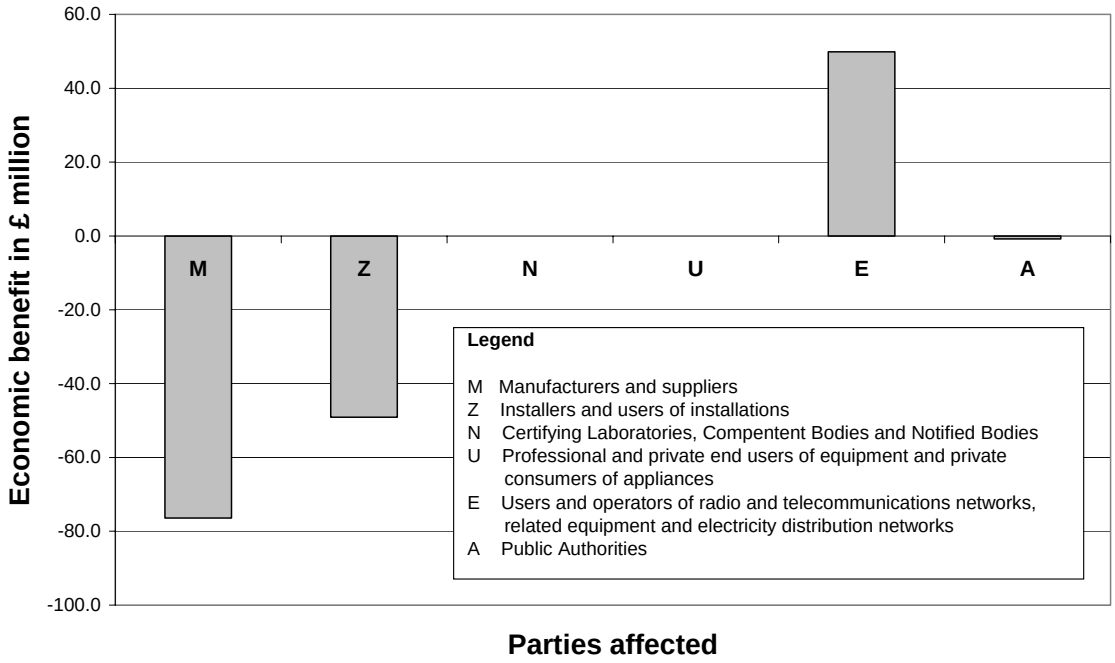

Figure 4.2 Chart showing the economic impact of the proposed amendments to the EMC Directive by affected party

The impact of the proposed amendments on each of the parties affected is summarised as follows.

Manufacturers and suppliers

Manufacturers are suppliers are likely to bear the brunt of most of the changes to the EMC Directive. These comprise £131 million in costs, offset in part by £55 million in benefits. The cost component is due to the increase in the product labelling obligations. The benefits accrue from changes to the regime for fixed installations where the manufacturers will have reduced compliance costs for equipment intended only for use in fixed installations.

Installers and users of installations

Installers and users of installations face increased risk of interference due to the absence of compliance by manufacturers of equipment for fixed installations. This is expected to result in costs of £49 million arising from the need to arrange independent investigation of interference following complaints.

Certifying laboratories, Certified Bodies and Notified Bodies

On the basis of the survey responses obtained within the RPA Study, this group would experience no net change as a result of the new EMC Directive. Some of this group reported to the RPA Study that they expected a decrease in their work, but contrary to this, manufacturers foresaw no reduction in their use of Notified Bodies. Overall we expect a reduction in work for Notified Bodies as there will be no commercial imperative to use the TCF type approach in the absence of standards. Some mitigating factors might be that: the technical information requirements placed on manufacturers (similar to the old TCF) may initially be unfamiliar to manufacturers; and secondly, presumption of conformity by meeting a standard will require the standard to have been followed to the letter, which in effect could mean accredited testing.

Professional and private end users of equipment and consumers of appliances

The RPA Study concluded that this group would not experience any quantifiable costs or benefits as a result of the proposed amendments.

Users and operators of radio and telecommunications networks

This group is expected to experience benefits of £50 million as a result of the proposed amendments. These benefits are due to interference reduction arising from:

- Installers having to provide evidence of conformity (64%);
- Apparatus having to achieve compliance without use of additional devices (34%)[57];
- More clarity in labelling resulting in less use of equipment in unsuitable environments or incorrect assembly of apparatus (4%).

Like the more general user group, there is potential for some of the manufacturers' costs to be passed on to users of networks. However, in the RPA Study it was felt that competition and lack of price premium in these markets would prevent this transfer from occurring.

[57] It was reported to the RPA Study that where additional devices are necessary for compliance, some consumers do not purchase the additional devices or install them correctly.

Public authorities

Overall, Public Authorities are expected to face costs due to the proposed amendments. The costs of £0.84 million are predominantly due to a perceived increase in the need to review technical information under the regime of voluntary resort to notified bodies. These costs are offset in part by benefits of £0.033 million arising from easier identification of non-compliant products resulting from clarity in product labelling.

4.3 Conclusions on economic impact of the proposed amendments

The calculations show that there is likely to be a net cost to the UK of £76 million as a result of the proposed new EMC Directive. Like the conclusions of the RPA Study, this can be considered to be very small (< 0.1%) when compared to the overall size of the UK markets incorporating the products affected.

The RPA Study found that since the proposed amendments tended to formalise current practice then they should go ahead despite the net costs. This conclusion is equally valid for the UK.

However, there are elements of the analysis that affect individual parties more than others, and it can be expected that the UK may have a higher contribution to some of these groups than others. For example, the UK supplies a higher proportion of IT equipment than many other European countries. This means that the UK could be affected by some amendments more than other European countries. This does not appear to be the case, however, without continued scrutiny of future amendments there is no way of knowing whether the UK is being disadvantaged.

The RPA Study identified some responses from UK manufacturers that envisaged a high impact of the proposed amendments because they were perceived to have misinterpreted the spirit of the levels of compliance required to harmonised standards. There is an inference that may be drawn from the provisos on standards that measurements should be performed as described in the standards (e.g. emission measurements using CISPR 16 receivers). In our view, this is likely to be an attempt to ensure that testing is consistent throughout Europe, and outside Europe where products are manufactured for European markets. It may imply the use of accredited laboratories and therefore increased testing costs. However, given the uncertainty on this issue, there is a role for the government to ensure that UK manufacturers do not misinterpret the EMC Directive and incur unnecessary compliance costs.

5. CONCLUSIONS

5.1 Summary of findings

5.1.1 Analysis of the economic impact of Agency EMC research funding

Proactive research funding

The Agency funded projects cover a diverse range of technologies and tasks at various stages of the standards process. The projects that show the most promise of economic returns are those that look at the impact of future changes in technology. However, not all projects can be expected to result in net economic benefits to the UK since:

- Not all of the projects result in identification of undue interference levels;
- Not all projects result in a change to the standards;
- Not all of the projects logically result in economic benefits where it can be shown that the interference could be mitigated against in a timely manner without the research;
- Not all quantifiable benefits exceed the initial research spending.

However, these findings are the result of knowing the results of the research. For an individual research project this cannot be known *ex-ante*. In cases where the outcomes of individual projects are uncertain, it is appropriate to select projects that yield the highest expected benefits. For the policy to be worthwhile, the overall benefits should exceed the total spent in funding the research policy.

This report considered the performance of the Agency's research policy in the three years from 2000 to 2003. It is likely that all the research will convey some economic benefit on the basis that all information removes some uncertainty and allows more appropriate decisions to be made. However, the analysis in this report concentrates on those projects likely to generate economic benefits of a scale to justify the research spending.

Of the 27 projects undertaken in the period, only 3 projects generated readily quantifiable economic benefits totalling £11.2 million calculated over 10 to 20 years (depending upon the project considered) and discounted at the current Treasury rate of 3.5%. This exceeds the total research spending in the three year period of £2 million and indicates that in the 3 year period considered, the EMC research policy was worthwhile from an economic perspective.

However, to inform future EMC research policy we need to consider how this translates into future research activity. The work in Appendix 1 illustrates the wide range of

interference issues and the rate at which technology likely to advance. Technical innovation shows little sign of abating, therefore it is reasonable to assume that EMC issues will continue to arise at a similar rate into the future.

Although two of the analysed projects (concerning energy efficient lighting and the railway environment) resulted in modest economic impact (because the affected populations of users were small), the third involved a large impact (a benefit in the form of cost savings to mobile network operators) that was offset in part by increased spending required by equipment manufacturers. This illustrates that:

- Very high economic impacts are possible as a result of interference compared to the costs of funding the research projects;

- Finding an equitable balance between the potential costs to manufacturers of interfering equipment and to operators and users of victim systems is important.

The role performed by the Agency's research has been to provide impartial guidance and detailed, quantitative inputs to the standards development process. This has provided two major benefits to those involved in standards development: firstly to gain an awareness of potentially damaging EMC issues where the users of radio services are not well represented within the standards committees; and secondly, to promote a better informed equitable compromise between manufacturers of interfering equipment and the users of victim systems. It should be noted that this compromise is not necessarily optimal from the perspective of national economies.

However, the Agency has little direct influence on standards development other than that provided by adopting formal roles in standards committees, and therefore cannot enforce a solution that, whilst being the most economically advantageous for national economies, goes against the commercial interests of participating industrial organisations. Despite this lack of alignment between commercial and national interests, a well-informed equitable compromise can level the economic impact on each of the affected consumer groups and maximise access to diverse products and service.

Although our study found that the Agency's EMC research policy did indeed provide economic benefit to the UK outweighing the costs of research, we cannot conclude from this that the policy is optimal. Many EMC issues are undertaken in stages since the scale of the problem is not known at the outset. Hence the initial stage is often a scoping study to determine the scale of the problem and understand the broad range of remedial actions that could be undertaken. If elements of economic impact analysis similar to that performed in this report, were included in such studies then this would provide an early understanding of the scale and nature of the economic impact.

The benefits of this are that:

- Future funding by the Agency can be better prioritised and justified;
- An appreciation of the importance of the EMC issues would be gained by all in the industry – equipment manufacturers, operators and users of victim systems, and standards development agencies;
- Both manufacturers of potentially interfering equipment and operators of victim systems would be motivated to:
    - Research the EMC issue themselves (operators of victim systems in order to protect future business and manufacturers to maximise opportunity and remove uncertainty in a timely manner);
    - Lobby standards organisations for effective inclusion in the standards.

A clearer idea of the returns and higher participation by industry in the standards process should result in more appropriate standards.

Given the potential scale of the impact demonstrated by the research projects into emissions greater than 1 GHz, the research funding can be viewed as an insurance premium, which helps guard against extreme interference effects that could potentially devastate the operation of an entire radio service. Although in theory, operators of victim systems should be motivated to undertake research to protect their own industry sector, the broad remit of such research is probably more efficiently undertaken by a single body able to look across all sectors and make results publicly available in a way that is not biased towards any industry sector.

Reactive research funding

In addition to the proactive funding already discussed, the Agency has a role in reactive research where solutions are sought for a known interference issue. To understand this aspect, we have evaluated the economic impact of one such project, the mitigation of interference on mobile phone networks due to industrial microwave ovens.

In this project, the funding was discretionary in that the mobile operators were already being compensated for the service degradation by a reduction in administrative licensing fees, and therefore the research need not have been undertaken. However, it need not form part of a funding policy provided that the projects can be commissioned on a timely basis as interference issues arise.

The Agency performed an important arbitration function because of its ability to view the requirements of each party impartially. This arbitration function is an important role as the economic benefits of £3.2 million illustrate. However it should be noted that to perform the function correctly requires that the Agency has sufficient expertise to:

- Recognise opportunities for arbitration;
- Structure and manage the research work effectively
- Assimilate the results and identify a way forward for all parties to implement the solution

5.1.2 Impact on spectrum value

Spectrum value can be considered in two ways:

- Value to the UK (both public and private values);
- Value to operators of services using the spectrum (largely private).

The former has been calculated as part of our analysis and is generally considered the sum of the producer surplus and consumer surplus. The amount that could be paid in fees for spectrum either as part of an auction or in administrative fees is generally affected by the producer surplus (or the value attached to the spectrum by the operators).

The analysis shows that the economic benefits of research to operators generally occurs in two forms:

- Savings in costs (where changes to the standards enable operators to avoid additional investment that would otherwise be required to maintain the same performance);
- Avoided revenue reduction (where changes to the standards reduce interference that would otherwise result in fewer subscribers able to use the service or reduced availability of the service).

The value attached to the spectrum is governed by the profit that an operator expects to make and the returns on investment expected by the shareholders. In general the narrower the margins in an industry the lower the value attached to the spectrum. Since the economic impact is an absolute reduction in profits rather than a proportional reduction in scale of business, the economic impact of interference is magnified. At the extreme, there is potential for severe interference to render the business unviable.

The victim systems investigated in this report (FM sound broadcasting and mobile telephony) exhibit healthy operating profits, therefore the research projects had a

modest impact on spectrum value in percentage terms. For example, without the anticipated changes to the standards, we estimate that the value of FM broadcasting spectrum would be reduced by 2.9% and the GSM1800 spectrum by 0.32%.

5.1.3 Economic impact of amendments to the EMC Directive

The EMC Directive is the means by which the harmonised standards become implemented within the products that have potential to cause harmful interference. Implementing these measures is a significant proportion of the selling price of products; compliance with the EMC Directive is estimated to account for between 1 and 5% of the prices paid for products. In the UK this amounts to between £550 Million and £2.75 billion annually[58]. This is a substantial sum and it is important to get the legislation right if the benefits of interference limiting standards are to be realised.

The form of the EMC Directive directly influences these costs and the proposed amendments to the directive are estimated to result in an increase in net costs to the UK of around £76 million. Like the conclusions of the RPA Study on this issue, these are not considered significant compared to the value of products affected by the EMC Directive. However, the manufacturers and suppliers of equipment share the burden of most of the costs of compliance and indeed the costs of these proposed changes and it is a significant proportion of their compliance costs.

A number of issues lie within the amendments that are particularly important from a UK perspective. The EC study on the issue identified a number of issues where UK firms may perhaps misinterpret the intent of the directive or provisions within the directive may have a disproportionate impact on the UK industry. In such cases there is a clear case for involvement in the overall process by UK government representatives, to:

- Ensure that UK industry correctly interprets the intent of the provisions;
- Lobby for clarity at European level;
- Argue against provisions that might unfairly discriminate against UK companies.

This requires expertise in EMC and its associated industries to reside in the UK either as a government department or industry organisation.

[58] The RPA Study estimated the total value of UK manufacturers products and service affected by the EMC Directive to be £55 billion annually.

5.2 Recommendations

Our study has shown that there is an overall net benefit from the Agency funded EMC research projects, which was determined from economic analysis of selected projects. This leads to the following recommendations:

- That Ofcom continues to fund EMC research projects;
- That the EMC research policy be adjusted to include:
  - Assessment of technical impact on potential victim systems at a quantitative system level (so that the implications on commercial deployment can be clearly identified);
  - Economic impact assessment of EMC issues as part of the preliminary aspect of projects examining new and emerging interference sources;
- That sufficient expertise is retained by Ofcom to:
  - Manage and coordinate EMC research funding (to avoid duplication and highlight issues not being fully addressed within standards bodies);
  - Monitor and promote EMC issues of particular concern to the UK within international standards organisations;
  - Continue to monitor and challenge amendments to the EMC Directive as part of the coordinated UK response.

Ofcom is in a situation where the efficiency of spectrum management is being reconsidered at a fundamental level. Therefore it is appropriate that the economic benefits of its activities are scrutinised. As Ofcom undertakes a review of it's future EMC policy, then this study is supportive of continued activity in EMC.

6. GLOSSARY

Abbreviation	Meaning
ADSL	Asymmetric Digital Subscriber Line
BBC	British Broadcasting Association
CAA	Civil Aviation Authority
CIA	Central Intelligence Agency
CISPR	International Special Committee on Radio Interference
CPU	Central Processing Unit
CRCA	Commercial Radio Companies Association
DAB	Digital Audio Broadcasting
DCO	Dithered Clock Oscillator
DCF	Discounted Cash Flow
DfT	Department for Transport
DSL	Digital Subscriber Line
DVB-T	Digital Video Broadcasting - Terrestrial
EC	European Community
EEA	European Economic Area
EIRP	Effective Isotropic Radiated Power
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMC-D	Electromagnetic Compatibility Directive
EMI	Electromagnetic Interference
EN	European Norm
FCC	Federal Communications Commission
FM	Frequency Modulation
GHz	Gigahertz
GPS	Global Positioning System
GDP	Gross Domestic Product
GSM900	Global System for Mobile communications at 900 MHz
GSM1800	Global System for Mobile communications at 1800 MHz

Abbreviation	Meaning
HDSL	High speed Digital Subscriber Line
IMT-2000	International Mobile Telecommunications – 2000
ISM	Industrial Scientific and Medical
ITU-R	International Telecommunications Union – Radio
LRIC	Long Run Incremental Costing
LW	Long Wave
NDB	Non Directional Beacon
NPV	Net Present Value
Ofcom	Office of Communications
PBR	Private Business Radio
PC	Personal Computer
RA	Radiocommunications Agency
RAB	Radio Advertising Bureau
RAJAR	Radio Joint Audience Research
RF	Radio Frequency
SDSL	Symmetric Digital Subscriber Line
SELC	Switched Electronic Load Controller
SLIM	Simpler Legislation for the Internal Market
SMPS	Switched Mode Power Supply
TETRA	Terrestrial Trunked Radio
TCF	Technical Construction File
TRL	Transport Research Laboratory
UWB	Ultra Wide Band
VDSL	Very high speed Digital Subscriber Line
xDSL	The set of Digital Subscriber Line technologies