Demand for use of the 2.4GHz ISM Band
Final Report

Spectrum Management Advisory Group

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1 INTRODUCTION

This report documents the findings of work undertaken by Ægis Systems Ltd on behalf of the SMAG, between May and July 2000.

The objectives of the work were:

- to estimate demand for use of the band currently and over the next two to five years
- to forecast bottle-necks for the use of new wireless technology
- to advise on spectrum management strategies for handling demand

1.1 Background

The 2400 – 2483.5 MHz frequency band, hereafter referred to as "the 2.4 GHz band", is being used for an increasingly diverse range of applications. These include: Electronic News Gathering / Outside Broadcast; radio frequency identification devices; lighting; microwave ovens; public telecommunications; short range radio devices and low power audio, video and data links (including RLAN, Bluetooth, HomeRF).
This diverse, and increasingly intensive, use of the band brings with it the potential for congestion and consequent possible degradation in service quality. As noted above the objective of this study is to identify and scope the type of problems that may be faced by 2.4 GHz users in the future, and to offer some direction as to how these potential problems might be avoided or overcome.

Historically, the 2.4 GHz band has been licence exempt for private users, although it has been regulated with regard to power levels that may be used. It is therefore an inherently anarchic environment, with unpredictable levels of interference leading to potentially erratic levels of service quality. Arguably, such an environment may seem inappropriate for safety critical and public services where an agreed quality of service must be guaranteed.

However, the band has a number of attractions. Firstly, its relatively low frequency makes it appropriate for mobile / nomadic communications. Secondly, its global availability offers a rare opportunity for manufacturers to take advantage of the economies of scale that come with operations in a world wide market[1].

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1 Until recently only a small part of the band was available in Japan, France and Spain. However Japan made the whole band available in October 1999. In July 2000 France made the whole

1.2 Study method

The work documented in this report was carried out during early summer 2000. Much of the richness of the report content arises from the quality of information provided by the extensive range of companies who generously agreed to participate in the study. The authors would like to express their gratitude to all those who took part. Every effort has been made to report the views of participants accurately. Responsibility for any errors in interpretation / understanding rest with the authors. The list of participants is provided as Annex B.

In addition to extensive industry consultation a variety of secondary inputs were also drawn upon. These included:

- European Radiocommunication Office: Detailed Spectrum Investigation Report
- CEPT Spectrum Engineering Working Group, Project Team 24: RFID systems operating in the 2400 - 2483.5 MHz band
- Aegis Systems Ltd: Compatibility between radiocommunication and ISM systems in the 2.4 GHz band

Market projections are an important part of this report. However, this information tends also to be commercially confidential. Recognising this, a 'broad consensus' figure has been used for applications where companies have provided commercially sensitive information. In some areas companies have been unable, or unwilling, to provide any but global figures. In this instance it has been assumed that the UK accounts for around 20% of European sales, or around 5 to 10% of global sales. This reflects the size of the UK population, combined with its position as an 'early adopter' of new technologies. These figures are intended to offer a very approximate guide as to the magnitude of users that may be expected for any given application.

The report comprises five major chapters as follows:

Chapter 2: Documents those applications currently using, or expected to use, the band.

Chapter 3: Scopes the likely intensity of current and future use, and examines the drivers for, and constraints on, market development

band available from 1st January 2001. Spain has yet to make a decision on opening up the band.

Chapter 4: Considers the problems that arise from current, and projected future, use and regulation of the 2.4 GHz band, together with the potential impact of changes in other bands

Chapter 5: Addresses the type of policy instruments that might be introduced to increase the efficiency and effectiveness of use of the band

Chapter 6: Closes the report with a set of recommendations, and identifies areas requiring more detailed examination

A series of annexes are attached to the report. These address:

Annex A: Acronyms

Annex B: List of participants in the study

Annex C: Power limits for licence-exempt systems

Annex D: Major technical standards

Annex E: Health limits

2 USE OF THE 2.4 GHZ BAND

To provide a starting point for the study, the following sections examine each of the major users of the 2.4 GHz band, summarising the nature of each application, describing technical characteristics relating to spectrum use and standards, and providing high level market forecasts for potential future use.

Users of the band have been grouped in to 6 main groups as shown below. It is interesting to note from the outset, that three of these user groups are charged for their use of the spectrum, whilst the remainder enjoy access without licence fees.

User type		Licence fee paid
Military		
Electronic News Gathering and Outside Broadcast		
Public provision of Fixed Wireless Access		
Wireless Networking:	Radio LANs	✘
	Bluetooth	✘
	SoHo and Home networking	✘
Other short range devices:	RF Identification Devices	✘
	Video applications	✘
ISM applications:	Microwave ovens	✘
	Sulphur plasma lighting	✘

Each user group will now be considered in detail.

2.1 Military

2.1.1 The application

Military use of the overall ISM band is for aircraft / missile telemetry. From time to time however, arrangements are also made for *ad hoc* use for other applications, such as point to point links to support operations undertaken by allied military groups, for example US Air Bases. In such cases applicants are encouraged to operate within the constraints applied to licence exempt operations.

The military use of the ISM band arises from the fact that the military allocation at 2310 - 2450 MHz overlaps with the ISM band. Military interests in the band are therefore restricted to the bottom half (2400 - 2450 MHz) of the ISM band.

It may be noted that the military pays a six figure sum of money each year for the use of the 2310 - 2450 MHz band. As such it largely has pre-eminence in the band and other users of the bottom half of the ISM band are required to take account of military operations either on a proactive basis (e.g. some ENG / OB channels are not made available in certain parts of the country) or on a reactive basis (e.g. for licence exempt devices continuing to operate until interference occurs and an instruction to cease transmission results). Historically, consultation with the MoD has enabled additional services to be introduced to the band (e.g. Automatic Vehicle Identification, AVI, for trains in the band 2446 - 2454 MHz, the bottom 4 MHz of which falls within the military band).

2.1.2 Technical characteristics

Aircraft and missile telemetry tend to use 20 MHz channels (10 - 13 dBW EIRP omni-directional AM modulation of multiple channels). These telemetry channels usually only extend up to 2410 MHz so do not encroach significantly on the ISM band. This application uses the radio channels on a part time basis (i.e. when trials are being undertaken) but at known (and fixed) areas around the country.

2.1.3 Predicted demand

The ISM band is not heavily used by the military, nor is any increase in use foreseen.

2.2 Electronic News Gathering & Outside Broadcast TV Links

2.2.1 The application

Electronic News Gathering and Outside Broadcast TV links are used across the UK to provide services ancillary to broadcasting. Most links tend to be used for comparatively short periods of time (hours), though some OB events may last for weeks.

Electronic News Gathering (ENG) is, almost by definition unpredictable in terms both of its timing and its location. It requires that links be established quickly, allowing very little time for frequency co-ordination and licensing. ENG requires video links to carry data from small, hand-held, filmless cameras, to the news room, or to portable video tape recorders. ENG tends to use vans having extensible antenna poles which communicate with 2 foot steerable dish antennas at the top of masts (at Wrotham, Barbican, Millbank, Crystal Palace in the London area for example). The links are therefore temporary fixed point-to-point, may not be line-of-sight, but will always be to a high mast-head receiver.

Outside Broadcast (OB) is normally associated with sporting events, outdoor concerts, ceremonial events etc which tend to be predictable and are planned well in advance. Video links are required to support the use of cordless cameras and may also be needed to provide a temporary link between the OB van and the studio. Generally, these links will be to a receiver which is close to the ground, though occasionally helicopters, or other repeaters at some distance from the ground, may be used.

Typical OB applications include:

- Golf tournament. Camera to Buggy (repeater) – very short distance
- Formula 1 racing. Omni camera to poleman (10 GHz). Poleman to fixed point (2.5 GHz)
- Races followed by a motorbike or helicopter.

For OB and, to a lesser extent ENG, it can be seen that mobility is a key requirement.

2.2.2 Technical characteristics

Within the UK, there exist fifteen channels of nominal 20 MHz bandwidth allocated for use by temporary video links in the 2390 – 2690 MHz band. Nine of these channels are used for ENG in London.

Additional channels have been allocated as follows:

- 3500 – 3600 MHz: 4 channels
- 5472 – 5815 MHz: 10 channels
- 7110 – 7424 MHz: 12 channels
- 8460 – 8500 MHz 2 channels

A further 15 channels are available above 10 GHz. All channels below 10 GHz are 20 MHz wide, giving the UK a greater allocation of spectrum to ENG/OB than any other European country. It is interesting to note that whilst ENG in the London area uses the 2.4 GHz channels, in Birmingham the 7 GHz channels are used; the difference between London and Birmingham is for historical / political reasons.

The ENG/OB channels may be used in a variety of ways, as follows:

- Cordless camera: up to 500 metres range, power output 6 dBW (4 watts), normally enjoys clear line of sight to the receiving equipment
- Portable links: up to 2 km range, power output 16 dBW (40 watts), line of sight may be obstructed
- Mobile links: up to 10 km range, power output up to 26 dBW (400 watts), often obstructed and susceptible to multipath
- Point to point: up to 80 km range, power output 40 dBW (10,000 watts), clear line of sight for OB, but potentially obstructed for ENG

ENG/OB links can be deployed in most parts of the UK, and may on occasion be deployed via helicopter, thereby creating the potential to cause interference over a wide geographic area.

It may be noted that of the 43 CEPT countries, 20 permit use of ENG/OB equipment around 2.4 GHz.

2.2.3 Predicted demand

The forthcoming proliferation of digital TV channels, allied to an ever-growing emphasis upon sport and news as programme content, is likely to fuel demand for ENG/OB links. Although some of the demand may be offset by increased use of satellite news gathering, this is likely only to reduce demand for point to point links, rather than the mobile and portable links which most specifically require use of the 2.4 GHz band. Furthermore, on occasion the unavailability of transponder capacity (whether due to financial constraints on hiring transponder capacity, and/or technical reasons such as difficulties in sighting the satellite) requires that terrestrial links be used even when satellite provision might be preferable.

Pressure on the 2.4 GHz band from ENG/OB applications will be further exacerbated by the fact that the total bandwidth available to satisfy user demand is likely to be reduced. Most specifically, the decision at WRC 2000 to allocate 2520 – 2670 MHz as future expansion spectrum for third generation mobile services is likely to intensify pressure on the 2390 – 2520 MHz band.

Efficiency of spectrum use

The demand for ENG related bandwidth will be influenced by the number of links required, but also by the efficiency with which the available spectrum is used. With this in mind, it is interesting to note that the lifetime of the current equipment (both mastheads and vans) is close to expiry and that a decision must shortly be made therefore as to the next generation of equipment for at least two major broadcasters. Three possible options exist;

- firstly efforts could be made to extend still further the life of the current equipment;
- secondly digital technology might be introduced;
- thirdly the 2.4GHz band might be abandoned.

The first option seems unlikely as the existing equipment is already very old. With regard to the second option, it would seem that, overall, the only real obstacle to ENG going digital is that of cost. As might be expected when the cost of the spectrum is relatively low and there is no apparent congestion, at present there exists no real incentive to invest additional money in new technology. For much OB use, however, extreme mobility of wireless cameras is often important, and digitalisation may not be possible for some time due to constraints of power, weight and size.

The third option has not been explicitly considered, though it would appear that the broadcast community would not be surprised if a move to a higher frequency were to be compelled by the regulator as rumours to this effect have been circulating for some years. It should be noted that for all involved, and end to this uncertainty would be beneficial.

2.3 Fixed Wireless Access (FWA)

2.3.1 The application

The term “Fixed Wireless Access” refers to radio based systems, using a mesh or point-to-multipoint architecture, providing either narrow or broadband services to a community of subscribers. Such systems are also known variously as Radio Fixed Access, Fixed Terrestrial Wireless Access or Wireless in the Local Loop. In this context, FWA should be understood to refer to systems used to provide public telephony and / or data services.

At present there are two licensed FWA operators using or planning to use the 2.4 GHz band in the UK, namely Atlantic Telecommunications Ltd and Kingston Communications Ltd. Kingston is licensed to provide services in the East Yorkshire area and Atlantic is licensed to operate in most of the rest of the UK. Atlantic first approached the RA in 1993 requesting spectrum at 2.4 GHz for a narrow band FWA service using off-the-shelf spread spectrum equipment. A licence was awarded in 1998, initially covering the Strathclyde area and subsequently extended to cover the Eastern half of Scotland. Further licences covering most of the UK mainland were awarded in 1999 following a public consultation exercise.

Atlantic uses a frequency hopping spread spectrum (FHSS) technology based system, delivering up to four standard telephone lines or basic rate ISDN to each subscriber on the network. The company has enjoyed considerable success in Scotland and is now in the process of extending its service south, starting in the Manchester area. The company also intends to add a wide band data capability, offering data rates of up to 4 Mbit/s using the same 2.4 GHz spectrum.

It may be noted that the UK's decision to licence FWA in the ISM band is unusual, with the majority of countries choosing not to allocate the band; Ireland is an exception however, having recently issued a national licence covering the 2400 – 2460 MHz band.

The Radiocommunications Agency licenses operators under controlled conditions:

- equipment is required to demonstrate the ability to operate effectively in the 2.4 GHz radio environment by laboratory based compatibility trials
- licences are issued on a region-by-region basis with a requirement that radio spectrum is monitored to ensure that there is a realistic opportunity for a high quality public service to be provided before a licence is issued
- network performance is monitored to ensure quality of service is maintained

2.3.2 Technical characteristics

FWA systems operating around 2.4 GHz are subject to CEPT Recommendation 70-03, Decision ERC/DEC(96)17 and ETSI standard ETS 300 328 (wide-band data system specification).

2.3.3 Predicted demand

Market forecasts for the roll-out of FWA services within the UK. One suggestion sees deployment rising over the next three years to about 100,000 lines within saturation occurring at that point. This scenario sees deployment being concentrated on suburban districts of major cities with density being relative to the population density in a particular area. An alternative view anticipates an installed base of around 20,000 lines per major city, with additional lines being provided in non-urban areas. Under this scenario, and assuming that licences are granted for the 25 largest British cities (excluding London where FWA is probably not appropriate), a market in excess of 500,000 might be foreseen.

2.4 Wireless Networking

The 2.4 GHz band is proving increasingly attractive to industrial groups who are developing and promoting wireless network applications and products. There exist a number of applications that may broadly be categorised as wireless networking:

- Radio Local Area Networks (RLANs)
- Bluetooth
- Home networking

Each will now be considered.

2.4.1 Radio Local Area Networks

2.4.1.1 The application

Radio Local Area Networks (RLANs), also known as Wireless Local Area Networks (WLANs) or Cordless Local Area Networks (CLANs), provide a cordless solution to office connectivity. RLANs are used in two distinct ways; as an indoor substitute for or complement to conventional wired LANs, and as an outdoor system for point to point data transfer (LAN bridges).

Indoor applications

The widest spread use of RLANs to date is for internal networking of PCs and peripherals. Here the functionality provided is essentially similar to that offered by a conventional wired network, but, crucially, allows users to behave in a nomadic fashion within the office environment, moving freely around the coverage area but being static at the point of interaction with the LAN itself. This permits a more flexible working style, and also allows greater planning flexibility in terms of the office layout and use of space.

Thus far, the approach has proved particularly attractive to companies having a ‘hot desking’ approach, for example where a large sales force is concerned, or for areas such as conference facilities and meeting rooms where users may be present for a fairly brief period of time, but will require a wide range of Information Communication Technology (ICT) facilities whilst in the area.

It is interesting to note however, that although RLAN manufacturers are enthusiastic to promote the advantages of wireless connectivity, there remains a general view that RLANs are probably at their most valuable when used as a supplement to, rather than a complete substitute for, cable. The bandwidth offered by CAT5 cabling for example, combined with its immunity to interference, are characteristics that radio cannot currently meet.

Another common application of RLAN technology is in retail and warehousing environments, where they are used to link electronic point of sale (EPOS) terminals and stock control equipment such as remote bar-code readers. In this application the technology may be used in conjunction with radio frequency identification (RFID) devices, also operating in the 2.4 GHz band.

Outdoor use

In outdoor applications, RLANs may be seen as an alternative to the costly hire of a leased line, installation of a licensed point to point microwave link or the even more capital-intensive installation of fibre or cable. Against these options, RLANs offer comparatively low capital cost, with little (if any) recurring cost.

The link length achievable through the current generation of RLANs is variable dependent upon the required data throughput. For example, a link of 1.5km can be expected to sustain a throughput of around 5.6 Mbit/s using DSSS technology, however a longer link, say 6 – 7 km, would realistically sustain only 1 Mbit/s.

The majority of both current and anticipated outdoor RLANs are anticipated to use discrete point-to-point links. However, there exist a wide range of applications where point-to-multipoint systems may be expected to be installed, for example local authorities operating on multiple sites; university and school campuses, and increasingly 'out of town' company campuses.

Types of user

Whether indoor or outdoor, RLANs may be anticipated to work according to one of two operational scenarios, the first involving a self –provision by a closed user group, the second involving public provision by a single, or indeed by multiple, providers.

Private user group: Today RLANs tend to be operated by a specific user group, (such as a company, university or hospital) for the exclusive use of members of their group. Here the operator has a comparatively high level of control over the use of potentially interfering systems, and, if necessary, is able to determine and to some extent control, the level of service available to different services in different areas.

Multiple user groups; Although the regulatory status of the publicly provided RLAN facility is unclear, the operational paradigm offers a persuasive business case. A number of networks are already operating in this mode, providing data only links to a small groups of clients. In the future a more diverse range service offerings might be envisaged. For example, users could be clients paying on an ad hoc basis, as in the case of RLAN provision at airports or in hotels; or clients subscribing for an on-going service, as in the case of use of RLANs by Internet Service Providers or the provision of EPOS facilities within shopping malls.

Some of these systems are currently covered under the Telecommunications Act by the Telecommunications Services Class Licence (TSL). The TSL permits any person to provide third parties with a wide range of fixed telecommunication services, provided that the Applicable Systems comprise apparatus situated in and linking up to no more than 20 separate sets of premises, where a single set of premises must be within a single contiguous boundary under a common management regime.

However, provision of mobile services and provision of more general public services is not permitted under the TSL. The Cordless Class licence enables localised mobile services to be provided on a similar basis to fixed communications under the TSL, but currently restricts this to DECT and CT2 technologies. The pros and cons of regulatory change in this area are discussed in Chapter 5.

2.4.1.2 *Technical characteristics*

IEEE 802.11 and IEEE 802.11b are the key international standards influencing RLAN development[2]. These define the specifications for Frequency Hopping, operating at maximum of 3Mpbs and Direct Sequence Spread Spectrum, offering 11Mps products. IEEE 802.11 does not necessarily ensure interoperability however. Many RLAN manufacturers have therefore signed up to the WiFi trademark, sponsored by WECA, the Wireless Ethernet Compatibility Alliance. This compatibility programme is designed to ensure that interoperability is achieved.

IEEE 802.11 defines operation of RLAN systems at frequencies between 2400 and 2483.5 MHz. FHSS RLAN systems utilise 79 hopping channels between 2402 and 2480 MHz with channel bandwidth equal to 1MHz. 11 channels for use in Europe. DSSS RLAN systems used in Europe may utilise 9 (IEEE 802.11) or 11 (IEEE 802.11b) frequency channels with channel occupying 22MHz of the spectrum. The values of all DSSS RLANs channel centre frequencies are illustrated in Annex D.

2 In Europe the equivalent standard is ETS 300 328

Note, the development of technical standards is ongoing. Recently, FCC has issued a notice of proposed rule making in which it notifies the desire to allow frequency hopping systems to operate with 3MHz and 5MHz channel bandwidths. This would enable FHSS systems to achieve data rates up to 11 Mbps (similar to IEEE 802.11b data rates for DSSS systems).

RLAN (both DSSS and FHSS) maximum transmit power is equal to 100mW.

Depending on how the RLANs are used it is possible to achieve the following ranges:

- Indoor RLANs - maximum range of up to 200 metres
- Outdoor RLANs - maximum range of up to 10 km (point-to-point links)

2.4.1.3 Predicted demand

Although R-LAN products were available as long ago as the mid-1990s, it is only during the first half of 2000 that the market has begun to see dramatic growth. This can be attributed to three key drivers:

Increasing speed: The early FHSS systems were comparatively costly when first introduced and supported a maximum effective speed of typically 2 Mbit/s. Whilst this was acceptable for users for whom mobility was an overwhelming priority, for other users the performance was seen as being uncompetitive with wired systems (then offering a minimum 10 Mbps with potentially up to 100 Mbit/s). As a consequence the 2 Mbit/s systems were attractive primarily in situations where fixed RLANs were not a practical or cost-effective alternative and where transmission speed was not a prime requirement. FHSS RLANs were, for example, popular in retail environments, where regular changes to store layout mitigated against hard wired systems.

However, the introduction of Direct Sequence Spread Spectrum (DSSS) has extended the maximum data rate to 11 Mbit/s which in practice provides an effective throughput of over 5 Mbps. Although this is still significantly slower than current leading cabled networks, operating at 100 Mbps, the 10 Mbps RLAN cards are sufficient to offer an effective networking option to all but the most bandwidth dependent users. The cost of the systems has also become very much more competitive, with a card now retailing at around $175 and expected to fall.

Introduction of the IEEE 802.11. This standard, widely accepted around the world, has led to a significant increase in user confidence; this has been boosted by the introduction of the WiFi brand, allowing immediate recognition of interoperable products.

User sophistication: The past five years have seen a dramatic increase in the level of 'radio awareness' among the user community, brought about largely through the prevalence of the use of mobile and cordless phones. This has ensured that users already have some degree of consciousness of the potential benefits of wireless connectivity. At the same time they are also aware of some of the difficulties which use of radio may bring.

Estimates for market growth

There has been considerable activity in the market during the past year or so, with a variety of strategic alliances being formed within the industry (for example between PC and network manufacturers) and with other companies adopting the buy out route, for example the acquisition of Aironet, by Cisco, the world's leading supplier of internet transport and routing systems. These alliances are highly significant as they seem set to ensure that the next generation of laptops will include RLAN functionality as standard, giving the market a substantial boost as it will create a whole generation of RLAN ready PCs. Corporate, and indeed domestic, users will then have a comparatively simple, low cost step to implementation of an RLAN.

A number of participants to the study provided approximate market forecasts. In each instance the figures provided were both commercially confidential and known to be very approximate. In broad terms the UK market might be expected to develop as follows:

Year	Annual Unit Sales
2000	39,000
2001	97,500
2002	243,000
2003	609,00
2004	1,500,000
2005	3,800,000

Source: Amalgamated responses from study participants

At present the market is dominated by internal installations, averaging around 500 users per installation. Current external installations are dominated by point to point systems, with the occasional campus style installation. Whether this market structure continues into the future will depend at least in part upon future management of the 2.4GHz band.

2.4.2 Bluetooth

2.4.2.1 The application

“Bluetooth” is a global wireless connectivity standard that has been developed by a consortium of IT and telecommunications companies comprising 3Com, Ericsson, IBM, Intel, Lucent, Microsoft, Motorola, Nokia and Toshiba. It is intended to replace proprietary cable links which currently connect IT and telecommunication devices to one another and replace them with a single universal short range radio link. Bluetooth differs from RLANs in that it is intended to provide very short range connectivity (typically 10 metres or less), i.e. it is a substitute for individual cables linking mobile phones, PCs, modems, printers etc rather than for entire networks. Unlike existing infra-red links, Bluetooth does not require a clear line of sight path between the two devices and will, for example, allow an e-mail to be sent from a laptop PC via a mobile phone which might be in the user’s pocket or briefcase. As it can convey voice as well as data, Bluetooth can also be used to provide a wireless link between a mobile phone and a hands free headset; indeed the range of applications that can be addressed by Bluetooth are extensive, particularly if the 100mW option is included.

2.4.2.2 Technical characteristics

Bluetooth uses FHSS technology to ensure robust performance in a noisy radio environment, supporting both voice and data, up to a gross data rate of 1 Mbit/s. Bluetooth is designed to be compliant with international standards, including ETS 300 328 which permits operations up to 100 mW, but in general will operate at a lower power level of 1 mW EIRP, reflecting the shorter range requirement of most users. The Bluetooth standard itself is available to all members of the Bluetooth Special Interest Group (SIG), membership of which is open. Future enhancements to Bluetooth, most notably an increase in the data transmission rate with a consequent increase in power, are being considered by SIG members.

2.4.2.3 Predicted demand

Amongst the companies involved, there exists a strong consensus that the market for Bluetooth applications will enjoy extremely rapid growth. The broad order of magnitude is suggested in the following table.

Year	Total installed units
2000	96,000
2001	1,750,000
2002	5,500,000
2003	13,100,000
2004	20,000,000

Source: Amalgamated responses from; study participants, ERO DSI report, Cahners In-Stat

It may be noted that the Bluetooth Special Interest Group has arrived at significantly higher forecast figures.

In closing, it is interesting to note that whilst Bluetooth applications tend to be seen as having very broad markets, some products are under test that may employ Bluetooth to address highly niche problems. Take for example the work of a British company specialising in automated metrology. Here a radio controlled touch probe is under development that is likely to use FHSS at 2.4GHz, possibly adhering to Bluetooth. Powers of up to 100mW are expected, on the control side only, with a duty cycle of under 1%. The 2.4GHz band is especially appealing for this application as the available bandwidth enables status information to be transmitted from the battery powered probe in very short packets, thus conserving battery power. Sales of this niche product are likely to be numbered in hundreds only.

2.4.3 Home & SoHo Networking

2.4.3.1 The application

The concept of "home networking" extends the benefits of RLANs to users in a domestic or small office environment.

UK

Within the UK wireless networks aimed at domestic and Small office / Home office (SoHo) applications are now being developed. Direct Sequence Spread Spectrum (DSSS) has been chosen in preference to Frequency Hopping (FHSS), as DSSS provides a higher gross data rate (11 Mbit/s as opposed to 3 Mbit/s). For the same reason, one developer has chosen not to adopt the HomeRF standard (see below). One developer plans to combine the 2.4 GHz DSSS technology with DECT (at 1.8 GHz), enabling 2.4 GHz use for data and 1.8 GHz for voice. Early systems will use DECT for both voice and data but will be limited to around 250 kbit/s and so will quickly be superseded by the faster 2.4 GHz variant.

USA

Within the USA the drive towards home networking is being led by the HomeRF consortium, an industry grouping comprising most of the major players in the IT and telecommunications industries, including many Bluetooth consortium members. The HomeRF vision sees a wide range of electronic home equipment being wireless networked within the home and made accessible remotely via public telecommunication or data networks. Although initially aimed at interconnection for PCs, Televisions, and other conventional applications, the HomeRF vision extends well beyond the PC peripherals. One example cited by the consortium concerns the delivery of Internet data to mobile display terminals, which could be used to display recipe information in the kitchen or DIY information in the garage.

2.4.3.2 Technical characteristics

Home networking is largely directed towards PC-centric applications driven by the availability of increasing processing power coming to the market and the need to encourage consumers to use (and pay for) this additional capability.

One company participating in the study has developed a home networking system based on IEEE 802.11. This operates at the full 100 mW level, however apart from an occasional polling signal they only transmit when data is being sent. It was considered unlikely that they would be used for continuous transmission applications such as connection of hi-fi components or video links. A potential problem concerning interference between Bluetooth and Home Networking devices where both were present in the same machine had been noted, but it was believed the industry was addressing this issue.

In common with Bluetooth, an open, non-proprietary standard for home networking has been developed for home networking. The HomeRF open standard is titled SWAP (shared wireless access protocol, not to be confused with WAP, the internet protocol used over mobile phones). A number of similar proprietary protocols are becoming commercially available from manufacturers such as Diamond and Alatron; all currently use FHSS technology.

The HomeRF standard has passed through a number of iterations:

- initially for voice and data
- amended to Version 1.1 to reflect a 1 Mbps data only product that is available now

- expected to be amended further (to Version 1.3) to incorporate voice again
- depending on the result of the FCC NPRM, may emerge as Version 2 having a 10 Mbps capability

SWAP will also support voice, and is compatible with the DECT Generic Access Profile (GAP) for digital cordless phones. As an open, royalty-free standard, SWAP may well succeed in displacing existing cable based connections, particularly if supplied as a standard component of new PC systems.

2.4.3.3 Predicted demand

Figures regarding the anticipated demand for products aimed at the small office / home office (SoHo) workers vary significantly from source to source. Indeed, the variation is such that it is not meaningful to provide a set of tabulated figures. However, in so far as a broad consensus can be determined, it would appear to suggest an early phase of rather sluggish growth, with sales being constrained by the initially high cost of the products. Sales might be expected to be numbered in thousands, rather than tens of thousands. In the longer term however, this situation is expected to change, with significant demand in the residential sector expected as prices fall and awareness of the benefits increase. One source suggested that around 10% of all UK households may have home networking products by 2004, indicating sales of around 2.5 million during the next 3 to 4 years. Conversely, Dataquest have suggested that up to 35% of all homes in the USA could be wired by the end of this year. Assuming a similar, though delayed, level of growth, sales in the UK might reach almost 9 million.

HomeRF products at 10 Mbps are expected to be marketed during the late autumn 2000 / spring 2001. Non-HomeRF prototypes of products which combine 2.4GHz DSSS technology with DECT (at 1.8GHz) are anticipated during 2001, with commercial launch a year later. The market for these combined service products is expected to plateau around 2005 / 2006.

2.5 Other Short Range Devices

A diverse range of SRDs are deployed in the 2.4 GHz band and low power analogue audio and video links may also be used in the band. This section examines the most significant applications.

2.5.1 Radio Frequency Identification Devices (RFIDs)

2.5.1.1 The application

RFIDs, are already widely used around the globe for an incredibly diverse range of applications, from tagging cows and monitoring milk yields, through to monitoring railway rolling stock, timing marathons, retailing petrol, seeking lost golf balls, and charging on toll roads. With tags tending to be small and cheap, profitability in the RFID market is closely linked to volume of sales. Developments have therefore tended to focus upon frequencies where significant markets have common allocations.

In the UK RFIDs are regulated under the category of "equipment for the detection of movement or alert" although it is possible for RFIDs to operate in line with the regulations applying to other types of SRD.

2.5.1.2 Technical characteristics

The major areas of RFID developmental interest are the 2.4 GHz band and the 5.6 GHz band. In Europe, RFIDs should conform to CEPT/ERC Recommendation 70-03, with the technical characteristics being described in a number of ETSI standards (see Annex C).

RFID tags may be broadly divided into two types;

- Passive (batteryless RFID tags)
- Active (RFID tags with batteries)

Both passive and active RFID system consists of a reader and a tag. The reader transmits data to the tag using amplitude shift keying (ASK). The tag transmits data (or signal) to the reader by receiving an unmodulated RF carrier from the reader, modulating the signal with phase shift keying (PSK) and then reflecting this signal back to the reader. RFID systems are sometimes referred to as “modulation backscatter systems”.

RFIDs may utilise different RF physical layers, but typical occupied bandwidth is between 7 and 10 MHz. For example, ETS 300 328 defines frequency hopping system with a 20 hopping channels. The minimum RFID channel bandwidth is equal to 350 kHz for the data rate of 100 kbps. This means that the total occupied bandwidth of the RFID system is 7 MHz.

Passive RFIDs

RFID tags without batteries absorb RF field and receive interrogating data from reader. The absorbed RF field is used to derive DC voltage supply to the tags. If the RF field to the tags falls below the predefined threshold (required to induce minimum operational DC voltage), the passive RFID tag will cease to operate. Passive RFID devices have a maximum one metre range for data rates up to 100kbps. If the data rate is increased to above 100kbps, the range decreases.

Active RFIDs

High power (4W EIRP) indoor active RFID tags have an operating range of up to 10 metres at the maximum data rates of 1 Mbps. Low power (500 mW EIRP) RFID tags can achieve same maximum operating range of 10 meters but at the maximum data rates of 100kbps.

The active RFIDs have some operational limits:

- The power received at the tag from the reader must be above the tag threshold. The tag threshold varies (with the separation distance between reader and the tag) between 0.3 mW (for 10cm separation distance) to 300 mW (for 10 metres separation distance). This threshold is different from that for passive RFID tags.
- The path from the reader transmitter to the tag and the return path reflected from the tag to the reader receiver must have a sufficient margin. A typical level for link budget margin is 6 dB.

In the UK, RFIDs are regulated under the category of "equipment for the detection of movement or alert" ("EFDOMOA"). The current UK power limit for "EFDOMOA" is 100 mW EIRP in the band 2445 - 2455 MHz sub-band, with an exception of 500 mW EIRP for tagging and identification applications in this sub-band. If implemented in the rest of the ISM band, the more general SRD limit of 10 mW EIRP would apply. If the system is operated within the frequency hopping / direct sequence requirements of ETS 300 328 then an EIRP of 100 mW is allowed across the whole of the band.

Under Section 15 regulations in the US applications in the range 2435 - 2465 MHz (twice the bandwidth of the UK sub-band) are limited to a field strength of 500 mV/m (at 3 metres) which is equivalent to an average power of 75 mW and a peak power of 7.5 Watts. In the rest of the ISM band the limit is a field strength of 50 mV/m (0.75 mW average, 75 mW peak). However if the system adheres to the frequency hopping and/or direct sequence requirements of Part 15 in relation to the whole ISM band then an EIRP level of 4 Watts may be deployed (1 Watt transmitter + antenna gain of 6 dBi).

It can be seen therefore that there is a disparity between the US and UK regulations not only in terms of power but also in terms of width of the sub-band.

Representations have been made within Europe regarding the application of a higher power limit than those currently in place (there is a variation across Europe). It is understood that the original suggestion was for a 4 Watt EIRP limit across the whole of the ISM band on the basis of the US regulations for frequency hopping / direct sequence systems in this band. Work undertaken by CEPT Project Team 24 has examined the potential for interference between the various types of system using the ISM band and, subject to further work to be carried out with respect to RFIDs v. Bluetooth, concluded that:

- Co-frequency sharing between the proposed high power RFIDs (4 Watts) and connection-oriented services (ENG/OB and Fixed Services) is not possible unless the RFIDs are confined to a sub-band and required to use directional antennas. The sub-band would then be avoided by ENG/OB and Fixed Services

- Co-frequency sharing between the proposed high power RFIDs (4 Watts) and packet-oriented services (RLANs and possibly Bluetooth) would still be possible in the sub-band but with a potential reduction in capacity.

On the basis of this sub-band approach SE24 have suggested that the higher power level could be considered in the band 2446 - 2454 MHz as ENG/OB is known to avoid this part of the band (the main area for ISM interference) and higher power devices (e.g. AVI operating at 500 mW) already exist in this sub-band.

From the analysis undertaken by SE24 it appears that even constraining RFIDs to a sub-band still has the potential to cause some problems. In most cases these will be loss of throughput and/or range capability. One aspect that does need to be tied down is that of the RFIDs' duty cycle as this has a direct impact on the probability of causing interference. The SE24 analysis considers duty cycles of 10% and 100%, with the former causing less interference than the latter as might be expected. Regulation directed towards RFID operations in the band should define a maximum duty cycle for the devices.

2.5.1.3 Predicted demand

Given the diverse range of uses to which RFIDs are put, it is quite difficult to arrive at a general figure for demand. Furthermore, the market forecasts that have been undertaken vary very dramatically, with some forecasting sales of tags world wide to reach 1 billion by 2002, whilst others see the market reaching only 100 million in the same year. Only one of the study participants felt able to discuss figures for market growth, and this was primarily to highlight the variation in demand forecasts. To understand how such variation can occur it is informative to look at just one case in the UK.

Electronic tolls

The current UK market for toll collection RF devices is around 150,000 to 200,000. This modest market may well continue to experience gentle growth for years to come, remaining a valuable, but fairly small, commercial sector. However, it could conversely be dramatically increased by two socio-political issues:

- Firstly the introduction of road-tolls to high use areas (for example the M25 or London – both of which have been suggested recently) would create an immediate market for, say, 5 million toll devices.
- Secondly, the introduction of vehicle based e-commerce (for example at petrol stations, "drive-thru" food outlets etc), would create a more gradual, but much larger market, that could be measured in the tens of millions.

It can be seen therefore that the market for these types of devices could range from a few hundred thousand, to tens of millions, depending upon changes in policy and consumer behaviour. It should however be noted that from an interference point of view any potential problem is likely to be due to the read devices transmitting at a relatively high power, rather than to the tags themselves reflecting far lower levels of power. The number of readers will be far less than the numbers quoted above.

2.5.2 Video applications

2.5.2.1 The application

Closed Circuit Television (CCTV) is an increasingly familiar element of the urban and suburban environment. The overwhelming majority of local councils have introduced CCTV in an effort to deter crime from the streets of their towns and cities. Systems can be as large as 200 cameras[3], though most systems are smaller, with an average British town centre being covered by 20 to 50 cameras and a car park requiring 10. Conventionally, a fibre optic link is installed between the command and control room, and a series of cameras installed at strategic locations around the town, such as

3 Inter-linked London traffic CCTV systems actually result in a system of 250,000 cameras, this is however quite exceptional.

car parks, high streets, subways etc. Recently however, radio based CCTV has begun to gain popularity.

Initially conceived as a means by which to cover specific, temporary events, such as summer festivals, major road works etc, the cameras are increasingly being deployed in a semi-permanent fashion. This allows a council, or other user, to move cameras in response to changing patterns of crime or other risks, without incurring the cost of laying new fibre optic links. Whilst a conventional camera is comparatively cheap, installation of an outlying unit is not, potentially incurring installation costs (primarily road / pavement works) of £20,000, with an annual on-going line rental cost of £2,000 to £5,000. The radio based camera is more capital intensive, costing around £10,000, but avoids the installation and recurring costs.

Current radio based CCTV cameras achieve a 1km range from camera to base when using omni-directional antennas, with up to 4km being achieved using directional antennas. However, on occasion, the radio camera may be installed on one side of a major road, with a receiver being installed on the other side of the road, tapping directly into an existing fibre link.

Radio based cameras do have their disadvantages however:

- The need for line of sight between camera and base station (which may be the control room, but could be a repeater) limits the areas in which they can operate
- The capital cost of the camera itself is greater than that for a conventional camera, thus where the fibre infrastructure already exists a radio camera could prove expensive
- Radio cameras cannot be sequenced together for time-lapse photography due to the limited number of channels available
- Interference from other systems may result in the loss of signal

As a consequence, it is envisaged that radio based CCTV will only ever be a compliment to, rather than a replacement for, conventional, fibre based CCTV.

It may also be noted that home use of CCTV is also increasing within the UK, with a variety of products now available.

2.5.2.2 *Technical characteristics*

Radio links associated with CCTV have primarily been based around the 1394 MHz frequency assigned for this purpose. Implementation tends to be based on a 500 mW FM carrier using a channel bandwidth of 10 MHz. Data channels are provided in addition.

Straightforward whip or dipole antennas are used for the shorter ranges, up to 1 km, for example, under line of sight conditions. Use of a directional antenna, for example a Yagi having a gain of 10 dBi can increase the range to 2 km or more.

It is understood that, even though only one channel is available, interference does not occur very often as the transmitters in a system do not all transmit simultaneously. However in those instances where interference does occur, and when it cannot be avoided by relocating equipment, use of the 2.4 GHz band can be the solution.

Both analogue and digital equipment is available for CCTV use in the 2.4 GHz band. The analogue equipment is constrained to an EIRP of 10 mW whereas the digital equipment can operate at an EIRP level of up to 100 mW. It is claimed that, while these power levels are lower (particularly in the analogue case) than in the case of the 1394 MHz carrier, satisfactory ranges can be obtained.

2.5.2.3 Predicted demand

It is estimated that around 50 to 100 radio cameras will have been sold by the end of 2000. However, it seems likely that sales will increase fairly rapidly.

The installed base of CCTV is already substantial, with growth set to continue into the foreseeable future; CCTV is widely recognised as causing crime to relocate, rather than to stop, thus networks must continue to expand. It has been suggested that in the medium term, it would be reasonable to expect around 25 – 50% of all CCTV devices to be mobile, that is to say radio based. The Home Office has allocated a budget of £153 million for grants towards the purchase and installation of CCTV devices between 1999 and 2002. Working on the assumption that an ‘average’ camera costs around £20,000 to purchase and install (which is probably a little high as some cameras will be co-located thereby reducing the installation cost), it can be assumed that around 7,000 to 8,000 cameras will be installed during next few years. This in turn suggests an installed base of perhaps 1,000 to 2,000 radio CCTV devices by 2003. Although this is a dramatic increase on current use, it seems that CCTV will probably remain a comparatively low level user of the band.

2.6 Industrial, Scientific and Medical (ISM) applications

ISM equipment continues to be a key occupant of the 2.4 GHz frequency band. Although not strictly an industrial, scientific or medical device, the domestic microwave oven falls into this category in regulatory terms and is by far the most prominent non-communications application in the band. Industrial uses include food processing, lighting and rubber vulcanisation, while medical uses include hypothermia for the localised treatment of certain cancers. It should be noted that as non-communication devices, microwave ovens and other ISM devices do not come under the control of the Radiocommunications Agency.

2.6.1 Microwave Ovens

2.6.1.1 The application

There are many millions of microwave ovens in use throughout the UK and the market is still growing. Ovens may be used in the domestic environment, or for specific industrial applications, such as drying or cleansing, but most commonly in catering establishments.

Monitoring carried out by the RA has shown that cumulative RF leakage from microwave ovens can be a significant source of interference in urban areas at certain times of the day. The effect is unlikely to be catastrophic for indoor systems such as RLANs, but can affect the performance of outdoor systems. For this reason, the FWA services operated by Atlantic are configured to avoid transmission on frequencies around the centre of the band. Similarly, ENG/OB operators also avoid the central 10MHz of the band.

2.6.1.2 Technical characteristics

All microwave ovens deploy magnetrons, which produce typically 700 to 1000 watts RF power nominally centred on 2.45 GHz.
Use of microwave ovens is controlled for safety reasons by way of a power density limit defined by the National Radiological Protection Board. Within the UK, industry seeks to keep the near field limit to below 10 W/m^2, although a level of 50 W/m^2 is permissible.

The Radio Regulations require administrations to "take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal" within the bands designated for such use. To comply with the EU Directive on Electromagnetic Compatibility (89.336/EEC), ISM equipment must meet the emission limits defined in EN 55011. However this is under review with regard to frequencies above 1 GHz. At present therefore there are no EMC limits at the fundamental frequency of microwave ovens.

2.6.1.3 Predicted demand

The market for microwave ovens has shown steady growth for some years. Whilst the market for domestic ovens might initially be thought to be saturated once each of the 24.8 million households in the UK has a microwave, the US experience indicates that this is not the case. In the States the sales have continued to expand responding to demand for ovens in rooms other than the kitchen, the continuing growth in single person households and the growth in consumption of convenience foods.

2.6.2 Sulphur Plasma Lighting

2.6.2.1 The application

This is a relatively recent development in which microwave energy is focussed onto a small quartz sphere that is filled with gaseous sulphur and argon. The energised sulphur provides a highly efficient source of light, which has the further advantage of being close in spectrum terms to natural daylight. The microwave source is a 2.45 GHz magnetron, but power levels can be significantly higher than conventional microwave oven magnetrons.

2.6.2.2 Technical characteristics

It is unclear just how serious an interference source these systems may be. RA tests suggest emissions from each installation could be as high as 500 mW. The use of sulphur lighting for outdoor floodlighting applications could be particularly problematic, as there is potentially a clear line of sight path to local outdoor receiver installations. In the USA, concerns about potential interference from Sulphur Lighting installations have been raised with the FCC by representatives of the RLAN community.

2.6.2.3 Predicted demand

The demand for sulphur lighting is extremely difficult to gauge. Anecdotal evidence suggests that such lighting may be used at the forthcoming Olympics, suggesting a healthy market. However, as noted above, it has been claimed that the sole manufacturer, Fusion Lighting Inc., has discontinued production.

2.7 Miscellaneous applications

2.7.1 Cordless telephones

Within the USA in particular, there exists a growing market for long range cordless telephones, based on spread spectrum technology in the 2.4 GHz (and in some cases 900 MHz) band. Use of these would not be permissible in the UK unless they were ETS 300 328 or R&TTE compliant.

There exists a strong consensus that the quality of service, availability and increasingly competitive price of DECT phones will result in little, if any, demand for phones operating at 2.4 GHz. A market forecast has not therefore been provided. It may, nevertheless, be noted that occasional "rogue" phones may be imported and operated, and a degree of enforcement action may be required in this area.

3 CONGESTION AND QUALITY

Having examined the diverse range of applications that use the 2.4 GHz ISM band, and with a very rough indication of market growth to hand, it is now possible to consider the potential for congestion, together with any associated degradation in quality of service.

3.1 Underlying assumptions

This study has not attempted to undertake a detailed simulation of inter- or intra-system interference arising between the many users of the band. Such work would have been beyond the remit of the project. However, the study has drawn upon the technical work that preceded the current study, and has extended this to provide a first order estimation of the potential for interference arising during realistic operational scenarios.

The modelling work considered each of the major users of the band, examining the potential for each to interfere with all other users, and with users within its own class of service (e.g. RLAN to RLAN). In each instance the required assumptions were made using the following guidelines:

- Power level; base on known equipment performance
- Duty cycle: base on known equipment performance, combined with realistic assumptions as to equipment use
- Other operational characteristics: base on advice of interviewees or equipment specifications
- Density of devices: where density was required as an input parameter the advice of interviewees, or figures from the earlier Aegis study were used. This is explored in detail in the next section.
- Acceptable interference threshold: defined as an upper limit of interference at which the victim system performance is degraded to the level at which the maximum bit error rate (BER) is 10^{-5} (IEEE threshold for good BER performance).

The modelling sought to identify three types of case:

High concern: where, given realistic operational assumptions, the victim system could experience substantial interference, leading to a clearly noticeable (or in some cases catastrophic) degradation in the quality of service, that is to say the interference limit is exceeded by a significant amount

Moderate concern: where a clearly noticeable degradation in quality of service might be experienced either in very restricted geographical locations, or on rare occasions, or only under extreme operating conditions

Low concern: where a noticeable degradation in quality of service is unlikely to be experienced in the foreseeable future, given the modelling assumptions used.

3.2 Density assumptions

As noted above, a series of assumptions have been made in order to undertake high level modelling of the potential for congestion to cause serious problems to users of the band. One of the most complex assumptions is that regarding the density of devices, which is itself largely dependent upon the earlier market forecasts. This section outlines the working assumptions made for each of the major application areas. Each of these sections considers densities for around 2004 / 2005.

3.2.1 ENG/OB

It has been assumed that a single system is operating at any one moment in time. Whilst realistic for normal day to day broadcasting, this will result in conclusions that are potentially optimistic with regard to, for example, major state or national sporting events where multiple ENG/OB systems are operating.

3.2.2 Radio Fixed Access

Based on current deployments of RFA systems in this frequency band, cells are assumed to have a radius of 1 to 1.25 km. Taking account of the need to provide overlap (for uniform coverage), this corresponds to a base station density of the order of **1 per km^2**.

3.2.3 Radio LANs

On the basis of the earlier market figures it has been assumed that:

- there will be an installed base of 6 million RLAN devices in the UK by the year 2005.
- 20% of these will be installed in the London area (M25).
- while hotspots will increase the calculated density of devices, the migration of RLANs to the 5 GHz band that is likely to occur around this time will conversely reduce the density. These factors have been taken to be self cancelling i.e. any increase in density due to hotspots is decreased by the same amount due to 5 GHz migration.

- a device activity of 10 %, acknowledging that this is a pessimistic value (some sources suggest that a figure of 1% might be more appropriate).

The density of simultaneously active RLAN devices based on the assumptions above is therefore **40 per km^2**.

The split between indoor and outdoor devices is not known. However it will be seen that outdoor densities of 1 per km^2 cause a problem. In relation to the above figure, it is not unreasonable to expect that an outdoor density of simultaneously active RLAN devices of 1 per km^2 will arise.

3.2.4 Bluetooth

On the basis of the earlier market figures it has been assumed that:

- there will be an installed base of 20 million Bluetooth devices in the UK by the year 2004.
- 20% of these will be in the London area (M25)
- device activity will be 10%

The density of simultaneously active Bluetooth devices based on the assumptions above is therefore **140 per km^2** but it can be expected to be higher in hotspots.

3.2.5 Home networking

Drawing once again upon the earlier market forecasts, it has been assumed that:

- around 30% of all UK homes have some form of home networking
- device activity will be around 7.5% (following the pattern of use of domestic telephones)

This results in an anticipated density of around **17 km^2**

Since the market forecasts for home networking vary significantly from one source to another, the previous study extended the penetration to a value twice as large as the above i.e. **34 km^2**.

Having developed density figures for the key applications, the study went on to determine the consequential likelihood of congestion arising between the various applications. The results are detailed in the next section.

3.3 Determining congestion

The outcome of the modelling activity is summarised in the Table 3.1. As discussed above three levels of concern are indicated, as follows:

- High concern - cells shaded in red (or pale grey)
- Moderate concern - cells shaded in blue (or dark grey)
- Low concern - no shading applied to cells

3.3.1 High Concern

Looking at all the different types of application using the band and the resulting sharing scenarios it is possible to identify those systems that overall have the greatest potential to cause interference and to suffer from it. The three types of system falling into this category are:

- Radio Fixed Access
- Outdoor RLANs[4]
- ENG/OB

It is no coincidence that all of these are outdoor systems. The most serious potential problems involve these systems interfering with one another. The simultaneous operation of any two types of these systems or any two systems of the same type may potentially cause serious levels of mutual interference. It can be seen from Table 3.1 that even with relatively low densities of RFA and outdoor RLAN systems, the mutual interference may exceed the interference limits[5] by a considerable margin and/or with unacceptable probability.

The modelling indicates that a single ENG/OBTV transmission may cause serious levels of interference to RFA and outdoor RLAN systems operating in the same area. This finding is reinforced by the empirical evidence of a recent case where an ENG/OB TV transmission seriously degraded operation of RFA network for a limited amount of time.

The modelling also indicates that the co-channel operation of two ENG/OBTV services in the same area may also cause congestion. However, this is not considered to be a matter of concern as the situation is unlikely to arise in practice, since ENG/OBTV transmissions are managed by the JFMG.

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[4] It may be noted that the outdoor RLAN antennas are assumed to be omni-directional, which is of course the worst case scenario, but is also the choice for applications such as internet service provision.

[5] Exceeding the interference limit will in some cases (such as interference into Bluetooth, HomeRF devices and RLANs) reduce the operating range and/or throughput of the system and will not necessarily result in catastrophic failure.

In summary, at the density levels predicted, it seems likely that ENG/OB, outdoor RLANs and RFA will not be able to co-exist.

3.3.2 Moderate concern

The blue (dark) shading in table 3.1 illustrates those cases that give rise to moderate level of concern, that is to say where congestion is only anticipated under certain conditions. Such conditions can include a variety of issues such as unusually high system penetration levels, higher than expected duty cycle, high power levels etc. For example, at the predicted densities indoor RLANs should not cause significant interference to co-located RFA networks. However, if the density were to increase to beyond the predicted 40 simultaneously active indoor RLAN devices per km^2, co-existence between indoor RLAN systems and RFA networks could become a congestion issue. Whilst this level of density is not expected to be widespread within the UK, in certain hot-spots, such as the City of London and other areas of intense office development, this level of installation could well be exceeded.

It is interesting to note that it can be assumed that there will be mixed penetration of RLANs. For the purposes of simulation, it has been assumed that the split between FHSS and DSSS devices will be 68% and 32%[6]. It appears that users are opting for the faster DSSS systems so this split may no longer be valid. The previous study looking at the interference between systems considered the possibility of the ratio being reversed. This did not have a significant effect on the results.

3.3.3 Low / no immediate concern

A number of scenarios do not give rise to any immediate congestion concerns under the modelling assumptions used.

Take for example the case of Bluetooth. Here, the interference from Bluetooth devices has been analysed assuming maximum penetration 140 Bluetooth devices per km^2. Assuming a duty cycle of 10% and a power level of 1 mW, this level of penetration is almost exactly in line with the projected market forecast for 2004, suggesting that Bluetooth should not present a problem. However, if higher power devices are permitted, if the duty cycle is greater, or if the Bluetooth SIG market forecasts are taken into account, a potential interference problem may well arise. Similarly, if “hot spot” areas experience high densities, the congestion analysis would need to be revisited.

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6 “World Wireless LAN Markets”, report no. 5781-74,Frost & Sullivan, 1999

It is important to understand that this is not to say that these applications can be ignored; should the market develop in an unforeseen fashion the ‘low concern’ applications could become ‘moderate concern’ applications. This situation therefore requires monitoring.

3.3.4 Other issues

3.3.4.1 Hotspots

Although the above discussion is primarily directed towards those systems (outdoor) that are considered to be the most susceptible and most polluting with respect the interference environment, this does not mean that other systems using the band are completely trouble free. In general there are bound to be occasional difficulties between Bluetooth, HomeRF and RLAN devices operating very close to one another even though they apply robust modulation techniques. In many situations the problem will be manifest as a reduction in operating range and/or data throughput. This may prove not to be a major problem in practice, depending upon the level of user expectation and the severity of degradation experienced. The IEEE have formed a coexistence group in order to establish the nature and severity of the problem and to determine how the situation can best be managed.

In some places the density of users can be expected to be very high. Such locations are likely to be public areas, for example airport lounges. In these "hotspots" there is a strong likelihood of congestion if the different applications that are being proposed come into being. For example this would arise if highly concentrated wide area networking is implemented at 100 mW (whether by RLAN or by Bluetooth) in an area where low power Bluetooth devices (1 mW) are being used on a more localised scale. The congestion would be most severe if DSSS RLANs were to be deployed for the public access system. Many of the wide area networking applications that have been proposed relate to public services rather than any private use, and would effectively compete with services delivered via licensed 2G and 3G mobile networks.

In order to allow for the successful operation of the low power devices under hotspot conditions one solution would be to constrain the power level of these public services to 1 mW. Private applications could be allowed to use 100 mW on the basis that it is very unlikely that such applications would occur in high concentration in public places. Private applications using 100 mW might reasonably be expected to take place mostly in homes and offices. Constraining public services to 1 mW would still allow for close proximity transactions (e.g. interaction with vending machines).

3.3.4.2 Proposed change to FHSS operations

In terms of interference between the various devices, the current FCC Notice of Proposed Rule Making (NPRM) could change the environment. A request has been made to change the hopping characteristics of FHSS systems such that the throughput can be increased from 2 Mbps to 10 Mbps. The proposed change increases the channel bandwidth from 1 MHz to 3 or 5 MHz (while maintaining the same number of hop channels thereby giving rise to channel overlap) and at the same time reduces the maximum power level from 1 Watt to 316 or 200 mW.

It is possible to interpret the consequences of the proposed changes to the rules in a different way when one considers the situation where devices are operating at power levels less than the maximum allowed. If, for example, a device using 10 mW supports 2 Mbps over a maximum distance, D, what would be the consequences to the interference environment of supporting the higher bit rate of 10 Mbps over the same distance. As before there will be a higher probability of data loss (collisions) due to the wider channel bandwidths being used. However in this instance there will not be any compensating benefit in terms of closer coexistence. In order to support the higher data rate over the same distance the power level would have to be increased pro rata to 50 mW (still within the maximum level proposed to be allowed). This gives rise to the same interfering power density but depending on the characteristics of the victim receiver this means that the coexistence distance will be the same or greater than that required for the 2 Mbps link.

Where the interference threshold is exceeded (i.e. devices are close to one another) and data is lost the situation will be made worse as there will be a higher probability of data loss (collisions) due to the wider channel bandwidths being proposed. Otherwise the situation will be better as the lower power levels mean that there can be closer coexistence (i.e. devices can be closer to one another before the received interference level causes data loss).

3.4 Summary

This chapter has illustrated that there exist a variety of actual or potential congestion problems within the band, some of which demand immediate attention, others which can be considered in the longer term. It has shown that, at present, the key concerns relate to outdoor systems. However, it has also demonstrated that the global allocation of the band means that regulatory changes in other parts of the world may have ramifications on the situation in the UK. In order to develop a set of viable policy options that might address these problems, it is first necessary to have an understanding of a number of key issues that affect the band. These are addressed in the next chapter.

4 ISSUES AFFECTING THE BAND

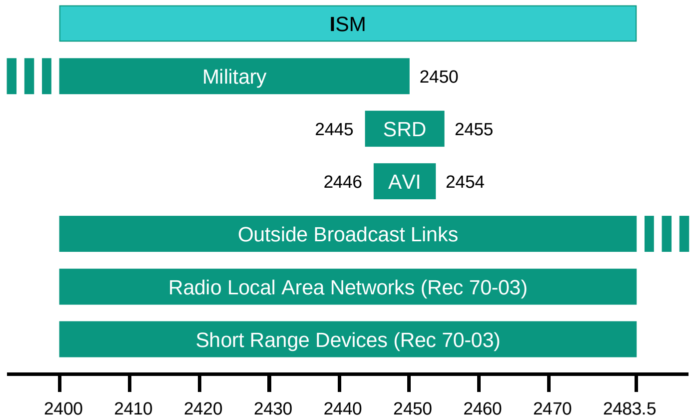
The extent to which future use of the 2.4 GHz ISM band will contribute to the overall wealth of the UK will be influenced by a number of factors, the potential congestion detailed in the previous chapter being just one. Other significant issues will include:

- The way in which the band is regulated and managed
- The extent to which the band exhibits the characteristics that make it valuable as a commercial resource
- Changes in society
- Health risks associated with use of radio

Each of these issues must be borne in mind when developing and assessing potential policy options regarding future use and management. These are now considered.

4.1 Regulation and management

The policy towards management of the 2.4 GHz frequency band in the UK has evolved over many years. Until the 1990's, the band was used by ISM equipment (principally microwave ovens and other heating devices) together with a limited range of low power devices. The band was not particularly intensively used and attracted little attention. During the 1990s however, the situation began to change. Today matters are very different, with a diverse range of applications, as illustrated in Chapter 2, vying for use of the band within the framework illustrated below.



Notes: AVI - Automatic Vehicle Identification for railways. 500mW in 2446 - 2454 MHz.
Radio Local Area Networks - also used for Radio Fixed Access and planned to be used by Bluetooth.
SRDs - Short Range Devices. 10mW in 2400 - 2483.5 MHz; 500 mW in 2445 - 2455 MHz for movement detection (tagging).
2445 - 2455 MHz also used for short range indoor data links (no analogue speech).

Figure 4.1 Current use of the 2.4GHz band

The popularity of the band is at least in part due to its licence exempt status. However there exists a widespread misunderstanding as to what this means in practice. The ISM band is often referred to by potential users as being an unlicensed band or a 'non-regulated' band, neither of which is technically correct. In reality the band is 'licence exempt' for a specified class of applications, that is to say there exist a pre-defined set of applications which are exempt from the conditions applying under Section 1 of the Wireless Telegraphy Act (WT Act) 1949. These applications are detailed in Schedule 6 of the Statutory Instrument "The Wireless Telegraphy (Exemption) Regulations 1999" (SI 1999 No. 930). All other applications are subject to the conditions of the WT Act and so must be licensed.

Furthermore, irrespective of whether the application is licence exempt or not, any user operating in the band must conform to the requirements of the new R&TTE Directive. This mandates that manufacturers self-declare that equipment is conformant with the appropriate standard(s), for example ETS 300 328 for R-LAN and similar applications, and ETS 300 440 for short range indoor data links or otherwise demonstrate that it avoids harmful interference in accordance with Article 2 of the Directive. The R&TTE Directive also encompasses the older EMC certification process, to which radio transmitters were previously subject. Equipment now has a single, simplified process of conformance.

The exemption operating in the band is applicable only to defined application groups, and to defined uses. Exemption does not, for example, include provision of a public telecommunication service or third party service. Such provision requires both a WT Act licence, and, a Telecommunications Act (T

Act) licence. As will be seen in a later chapter, the distinction between private and public networks is becoming a key issue with regard to how the band may be used in the future. It may also have ramifications for the use of other parts of the spectrum.

In short, although licence exempt applications are not required to pay a licence fee, leading to the view that the spectrum is ‘free’ (if the cost of self-certification is excluded) both licensed and licence-exempt users are required to adhere to the regulations that affect the band.

The following table indicates how the licence regime varies between applications using the band:

User type		**Required licences**
Military		WT Act
Electronic News Gathering and Outside Broadcast		WT Act
Public provision of Fixed Wireless Access		WT Act / T Act
Wireless Networking:	Radio LANs	Exempt
	Bluetooth	Exempt
	SoHo and Home networking	Exempt
Other short range devices:	RF Identification Devices	Exempt
	Video applications	Exempt
ISM applications:	Microwave ovens	Not applicable
	Sulphur plasma lighting	Not applicable

Note: ISM applications are required to adhere to safety standards

It is interesting to note that the existing Radio Fixed Access providers are licensed on a ‘no protection’ basis, that is to say although a fee is payable to the Radiocommunications Agency, the Agency is under no obligation to investigate, or resolve, interference experienced by the provider. In practice however, some support has been given where interference has occurred from a source which is clearly in breach of the overall regulations governing operations in the band. This support may however be seen simply as the RA fulfilling its wider obligations, with the RFA provider benefiting co-incidentally.

In summary, it can be seen that the UK regulatory approach has been, and remains, one of a ‘light touch’ requiring applications to be licensed only where strictly necessary for overall use of the band. This approach is in keeping with an ongoing government policy of deregulation and minimised administration. However, the recent and intense interest in the ISM band calls into question the extent to which all current applications can continue to co-exist under the prevailing regulatory regime. Chapter five considers some of the changes that might be made to regulatory policy in order to achieve the longer term viability of the band.

4.2 Market factors

For use of the band to contribute fully to the UK economy it is important that policy be sensitive to the needs of the market. This section considers some of the key characteristics that have, and that are likely to, influence market growth within the band and of which policy makers should be aware.

Globalisation

The availability of spectrum which is both licence exempt and harmonised on a global basis, presents a significant commercial opportunity. It allows manufacturers to address a world-wide consumer population, thereby permitting substantial economies of scale, and offering considerable potential for profit. Combined, these two factors have led to the substantial investment in the research and development required to arrive at innovative and marketable products such as the various personal area network devices and RFIDs discussed earlier.

Open standards

The common understanding that exists within industry regarding the need for global sales, has helped to ensure that many companies have worked together and with standards organisations, to achieve viable, open standards. As noted earlier, the ratification of IEEE 802.11b is seen as having played a major role in the growth of the R-LAN market. The development by industry of the open Bluetooth standard has introduced the potential for a wide range of innovative uses of mobile communications in both the corporate and domestic environments. Furthermore, the emphasis upon product compatibility, shown in the marketplace with a simple badge, should encourage quick take-up by end users.

Quality of service

One of the key concerns regarding growth in the market for 2.4GHz based products is the impact of congestion on quality of service. The key areas of concern in this regard have been detailed in Chapter 3. However, it is perhaps worth revisiting this area briefly to consider the impact of congestion from a market point of view.

For R-LANs, Bluetooth devices and home networking systems, the consensus view is that congestion will lead to a gradual degradation in the quality of service achieved, probably manifest as an erosion in the available working range and/or throughput of each device type. In general these devices tend to have a comfortable interference margin as they always operate at their full rated transmit power level.

For receiver devices operating close to their threshold level, which could include RFA base stations in some instances, the impact of congestion is likely to be very much more dramatic, potentially leading to a loss of service. In this regard, the increasing deployment of direct sequence spread spectrum may be seen as a particular worry as this has the effect of raising the noise floor across much or all of the band, depending on the number of RF channels in use. With FHSS, quality only degrades when there is a significant probability of a co-channel “collision” and should therefore only arise in practice when twenty or more systems are operating in close proximity. With DSSS using current coding techniques however, it is unlikely that two co-channel systems will be operable at the same location, since there is insufficient coding gain to provide scope for code division multiple access. A proliferation of outdoor DSSS systems could therefore lead to significant levels of mutual interference as well as interference to other systems; in practice such systems are likely to become “self-limiting” in terms of the coverage range or link length that can be achieved.

Whether it is appropriate for a public service to operate in a licence exempt band and on a licence exempt basis does to some extent depend on the quality of service issue.

It is not appropriate for a full public telecommunications service to be offered on an uncontrolled basis in the band as the public service obligations (e.g. access to emergency services) might be disrupted by interference[7].

It could be considered appropriate, from a quality of service point of view, to offer Internet access in the band as Internet access does not generally entail a guaranteed service. However, attempts to deliver a full PTO service using IP technology should be subject to the same regulatory requirements as existing FWA services. In practice, it is considered unlikely on the basis of the previous study that two such PTO services could co-exist within the band in the same geographic area.

Whether providing public Internet access at all is appropriate overall would also have to take account of the commercial impact on other licensed services which may have incurred significant licensing costs to access spectrum.

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7 It can be noted that the introduction of the FWA system to the band is being done on a controlled basis such that the service obligations are met.

4.3 Societal issues

Changes in society and in user expectations have already played a key role in determining use of the 2.4 GHz band.

Changes in the structure of society have provided a boost to sales of a variety of 2.4 GHz devices:

- the increasing prevalence of single person households, for example, has generated significant growth in the demand for microwave ovens,
- the growing trend towards home working has generated demand for SoHo network devices. In the SoHo sector ease of connectivity and a reluctance to install widespread cabling has given radio based systems an important marketing edge relative to conventional network products.
- the UK government's push towards a fully internet enabled society has opened the potential for massive sales of radio based networks to schools, community centres, libraries and other public access points.

User expectations have also changed during the past few years. Today, products that were once seen as technologically advanced business tools, such as GSM phones, have become almost ubiquitous, often experiencing a product lifecycle that mirrors a fashion item rather than a functional product. This shift in the perception of the end user, particularly with regard to the anticipated lifecycle of a product, is likely to prove influential in determining the speed at which Bluetooth products, for example, are introduced to, and replaced within, the market.

Within the corporate market, there exists an ever growing expectation that devices will enable mobility, or at least nomadicism[8], and that bandwidth will not be a limiting factor in product performance. This expectation is clearly fuelling a major growth in sales of all forms of radio based products, though it is also interesting to note, that radio based systems are often used to provide a complement to, rather than a complete replacement for, cable based systems. Growing user familiarity with the potential of radio is also enabling highly innovative uses of basic technology; take for example the use of RFIDs for monitoring milk yields.

The purchase criteria applied by users will of course influence the preferred radio technology. A crude division may be foreseen between purchasing behaviour in the private sector and in the public sector. Resource rich, and

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8 That is to say a mixture of fixed and mobile when a device is moved from place to place. In general the device will function at each place (fixed) and may or may not function in between (while mobile).

productivity sensitive companies are likely to opt for the highest performance system available on the market at the time of purchase, potentially irrespective of the company's current need. This maximising behaviour would tend to suggest that corporate buyers may lean towards installation of the faster DSSS products. In the public sector however, particularly in schools where speed is generally secondary to the overall system cost and the number of nodes sustainable on the network, the greater expansion capabilities of the FHSS systems may prove more important than the faster performance of the DSSS products.

Government also influences use of the radio spectrum in a variety of ways, not simply through the direct avenue of spectrum regulation. It may be noted, for example, that the funding approach to public sector organisations as a whole could be seen as tending to encourage use of radio devices. A number of interviewees, from both public and private sector organisations, highlighted the role of funding as a, probably, unintended driver towards R-LAN use in particular. Where funding is available for capital expenditure and where year on year operational funding is uncertain, radio offers a means by which to move costs from one budget to another. Whereas a leased line implies low initial cost, but with substantial recurring cost, radio offers little, if any, on-going costs, but at the price of much more substantial initial investment.

With a wide variety of IT implementation projects now underway, or shortly to start, connecting schools, libraries, museums, community centres etc, the number of installations likely to be completed is very substantial indeed.

4.4 Health

For some time now the concern of the general public about the perceived health risks attributable to radio transmissions has been increasing. Although both national and international recommended limits on radio emissions with respect to health have been in place for some time it is clear that these are not enough to satisfy the concerns of the general public.

Up until recently there have been two main guidelines that can be considered applicable to the UK; those of the National Radiological Protection Board (NRPB) and those of the International Commission on Non-Ionising Radiation Protection (ICNIRP). The limits on exposure to RF energy are similar in both the sets of guidelines although under the ICNIRP guidelines the levels relating to the public are about five times less than those recommended for workers. The ICNIRP guidelines have recently (12 July 1999) been incorporated in a European Council Recommendation

(1999/519/EC) which has been agreed in principle by all countries in the European Union - see Annex E for details.

Most concern has been expressed about the possible health risk arising from the pervasive use of mobile phones. Because of this the Government established an Independent Expert Group on Mobile Phones (IEGMP), chaired by Sir William Stewart, to examine the possible effects of mobile phones, base stations and transmitters on health. The overall conclusion of the IEGMP report is that the balance of evidence does not suggest that mobile phone technologies put the health of the general population of the UK at risk. A comprehensive set of recommendations have been made including the proposal that ICNIRP guidelines for public exposure be adopted for use in the UK rather than the NRPB guidelines, and the proposal that Specific Absorption Rate (SAR) values for mobile phones, based on an international standard for the assessment of SAR values, should be available to consumers.

To put this into context with respect to the devices currently operating and foreseen to operate in the 2400 - 2483.5 MHz ISM band it is necessary to relate the operation of these devices to the operation of mobile phone systems, given that all mobile phones on the UK market are claimed to meet the NRPB and ICNIRP guidelines.

The maximum permitted powers of GSM mobile phones are 2 Watts (900 MHz) and 1 Watt (1800 MHz). However the use of adaptive power control, discontinuous transmission and the multiple access method used means that the average power is likely to be 0.25 Watts (900 MHz) and 0.125 Watts (1800 MHz) and with power control is significantly less.

The licence exempt devices operating in the band operate with peak powers in the range 1 to 0.5 Watt. As with mobile phones the average powers will be far less than this and are therefore very unlikely to present a hazard even when operated next to the body.

It should however be noted that some medical devices about the body (i.e. personal pacemakers and defibrillators) can be prone to disruption by radio emissions having low frequency signals of a similar rate to the heart beat. These signals can be demodulated by the body and provide misleading information to the medical device. This may well be an issue for systems operating in the 2.4 GHz band if these systems operate next to the body and have low frequency components in their transmissions.

A possible concern does arise when comparing the power level of 4 Watt RFIDs (if they are allowed to operate in the band) with the power levels of mobile phones. However RFIDs are likely to have a very low duty cycle (and hence low average power) and are unlikely to operate close to the human body.

5 POLICY OPTIONS

Having examined the major applications using the band, together with some of the key issues influencing future use, this chapter moves on to consider the policy options that exist with regard to future use and management of the band. These policy options may be grouped into two very broad categories; those which seek to address potential problems whilst containing them within the ISM band, and those whose solution will have ramifications for other parts of the spectrum.

It is perhaps useful to preface this chapter by observing that, irrespective of the option, or options, finally selected, there exist a number of actions that are of some urgency, driven by issues such as market growth, pressure from potential users, brief windows of commercial opportunity, product substitutability and the equipment replacement plans of key organisations that may be affected by policy decisions. These decisions are highlighted at appropriate points in this chapter, and summarised in the next chapter.

5.1 Solutions through containment

5.1.1 Status quo

At present the 2.4GHz ISM band functions in a fairly efficient and effective fashion. Few of the organisations involved in this study had experienced interference problems; those who had, had experienced occasional incidents which caused little overall concern. The band offers sufficient capacity to accommodate a moderate density of all those systems whose use of the band is clearly permitted.

However the available evidence suggests that the current level of use is likely to change dramatically over the next five years, and although the precise population of most systems is difficult to determine, even the more conservative estimates suggest that congestion will begin to occur. This need not necessarily be considered a problem from a regulatory point of view. For many users the impact of congestion will become evident over a period of time, allowing the possibility of upgrading an existing system to a higher performance, higher frequency, alternative. To some extent therefore the issue of congestion might be expected to be self-correcting. Furthermore, as the band is mainly licence exempt it is arguably a situation of *caveat emptor*; indeed participants in this study stressed that users tend to understand, in broad terms, that use of the band does not come with any quality of service guarantees. At present, users are able to accept the occasional problems that are encountered.

A case may therefore be made for leaving the band as it stands, with all current users present, with new entrants welcomed to the band and with no change to the current licensing regime. However, as the following sections illustrate, there already exist the early signs of a number of potential problems that it would be unwise to ignore. Adhering to the status quo seems unlikely therefore to achieve the desired goal of maximising the efficient and effective use of the spectrum.

The following sections develop policy options which require an increasing level of change to current situation. It should be recognised that these options are not mutually exclusive, nor need all the points in each option be adopted.

5.1.2 Close the band to new users

This option seeks to minimise the future interference problems experienced in the band, whilst ensuring that the investment and market interests of the incumbents are protected.

Under this policy option the band would be closed, at least for a defined period of time, to new users seeking to operate in one of the 'high concern' application areas (ENG/OB, FWA, outdoor RLANs,). Controlling use of the band by new ENG/OB and FWA services would, in theory, be comparatively straight forward as both applications require WT Act licenses, which may be legitimately withheld when spectrum is unavailable. The situation with regard to outdoor RLAN / RWAN is however very much more complex as the following discussion illustrates.

5.1.2.1 Licence exempt provision of public data services by radio

The provision of data services, by means of radio, to a small user community, is a complex, and contentious, regulatory matter. At present the regulatory situation in this area is considered by some potential users of the band to be unclear and/or legally indefensible. The strength of feeling is particularly strong amongst the entrepreneurial companies involved in Internet Service Provision (ISP). For example, the perception that the ISM band is unlicensed and therefore 'free' has led at least one ISP to investigate the legality of charges being levied on any user operating in the band.

A 'grey' market for quasi-public provision of internet services (data only) using outdoor RWANs already exists, with a number of British cities being served by systems aimed at a niche, high-end, business market, requiring a data-only service. The providers hold neither a WT Act, nor a T Act licence, but do use equipment that is compliant with the R&TTE Directive. All equipment is owned by the provider rather than the user.

The legality of this situation remains unclear, primarily due to the lack of clarity as to what constitutes a 'public' service. If such a service is deemed simply to require the passage of third party data, then the ISPs may be operating illegitimately. However, if a different definition is used, namely that a public service must include voice traffic and must interface to the PSTN, the ISPs may be operating legitimately.

5.1.2.2 Desirability

The current definition of 'public' is clearly important from a short term enforcement point of view, as it determines whether existing operators are within, or in contravention of, the regulations. However, from a policy stance, the more significant question is whether or not it is desirable from a national point of view to permit ISPs, and other operators, to provide by wireless means, a data only, public service, in a licence exempt band? In other words should specific steps be taken to permit the operation of ISPs in the band?

A case can be created either to support, or oppose, permitting the operation of ISPs.

In favour, permission may:

- help to maximise competition within the sector
- support wider government policy seeking the 'information society'
- satisfy hot spots of local demand
- encourage innovative uses of the spectrum and entrepreneurial companies
- provide choice and diversity to one or more niche market(s)

Against the proposal, permission may:

- damage the overall licensing regime, by permitting a system with a non-determined quality of service to provide a public service, thereby potentially undermining the reputation of radio based services in the public mind
- undermine specific licensing activities / licence holders; for example the recent UK 3G license winners, when paying a combined licence fee of over £22 billion, will not have anticipated that a potentially competing service would be permitted to use the spectrum without charge.

Similarly, it seems likely that future FWA licences will attract significant fees, whether through auction or beauty contest, and so once again, these licence holders are unlikely to take a sympathetic view towards competing services operating without charge.

- by undermining the concept of spectrum pricing, permitting ISPs to provide public services may ultimately result in a loss of revenue to the Treasury – though an argument could also be made that the newly provided services will encourage productivity in subscriber companies, thereby generating income for the Treasury.
- ISP strategy is to target the central business district of key cities and towns, together with other areas supporting a high concentration of potential users (out of town science parks etc). This ‘cherry picking’ approach may also be harmful to the business case of the 3G / FWA licensees.
- The fixed service being offered requires the use of radio for speed of roll-out, rather than the unique radio functionality of mobility; the service could therefore be provided by other means.
- The possibility of offering Voice over IP enables ISPs to potentially offer full PSTN service in the future thereby competing directly with licensed FWA operators.

The decision as to whether to permit public data communications by radio within the 2.4GHz band can be argued in either direction. However, what is clear, is that firstly, the decision is urgent, and secondly that the result must be very clearly communicated and explained to all those likely to be affected. Urgency is required to ensure that, if permitted, the ISPs are able to roll-out their service within the overall timeframe of the general unbundling of the local loop. Delay is likely to result in the market opportunity being lost to alternative providers, such the cable companies.

Clear communication will be required irrespective of the decision reached as many parties have much to lose. In the case of a decision against the ISPs, subsequent policing, which must to some extent be based upon consent, will require that the basis for the decision be made transparent.

5.1.2.3 Summary

Closure of the band to new entrants in the high risk application areas will help to constrain future interference problems. However, it will also have detrimental consequences for the three applications involved, not least of which may be the stifling of innovation in spectrum use.

For the ENG/OB community, refusal to grant future operational licenses would have an impact, for example, on overseas broadcasters wishing to report upon UK events. However, such users may be satisfied by Satellite News Gathering facilities and/or be able to use equipment in the other frequency bands already available to ENG/OB.

For FWA the decision would leave an effective regional monopoly for each of the two operators, though of course competitors would be free to provide services at other frequencies. The policy would need to address how a 'level playing field' might best be maintained between operators at different frequencies with regard to the licence conditions and fees payable. Constraints upon future FWA licences might encourage longer term migration to a higher frequency should either operator wish to achieve fully national coverage.

For outdoor RLANs, as discussed above, a decision as to whether or not to permit public provision of data services within the band has the potential to revolutionise use of the band, but also to create substantial problems and inequalities between the numerous companies who offer, or who will offer, fixed and / or mobile telecommunication services.

5.1.3 Impose tighter constraints

The importance of the licence exempt status, and global harmonisation of the ISM band has been stressed on a number of occasions. However, without any detriment to these two characteristics, it remains quite feasible that certain aspects of use of the band be made more 'polite'. That is to say, there exist regulatory steps that can be taken in an effort to ensure that all users operate in a fashion which both achieves each application's ultimate objective, whilst taking account of the needs of other users in the band. These areas may be loosely divided into two; mitigation techniques and regulatory constraints.

5.1.3.1 Mitigation techniques

5.1.3.1.1 Directional antennas

One of the key interference sources within the band is likely to be the outdoor RLAN, using an omni-directional antenna. This problem could be mitigated by mandating the use of directional antennas (greater than 20 dBi, for example) whilst at the same time maintaining the current EIRP limit. It would not be expected that this requirement be applied to portable PCs operating in the garden for example. It is directed towards fixed installations on the tops of buildings.

5.1.3.1.2 "Polite" operations

As more and more systems share the same spectrum it is increasingly important that such systems employ adaptive features in order to avoid interference. These so called polite systems actively take account of other users of the same spectrum before transmitting. A good example of this can be seen in the arrangements that have been made to allow HIPERLANs to operate in the 5 GHz band. A number of space and terrestrial services already operate in the band and during the discussions held to enable the entry of HIPERLANs to the band it was established that HIPERLANs would have to implement interference mitigation techniques in order to allow for coexistence with the existing services. These techniques are Dynamic Frequency Selection (DFS) and Transmitter Power Control (TPC). DFS is designed not only to avoid interference to and from nearby terrestrial services but also to provide a uniform spread of the loading of HIPERLANs across the band and therefore minimise interference into satellite channels. It is a condition of HIPERLANs using the band that both DFS and TPC are employed.

This sort of approach is very helpful in allowing for more efficient use of the spectrum overall. However the question arises as to whether this sort of approach should or could be applied with respect to the multitude of applications in the ISM band.

In the case of HIPERLANs their technical specification was being developed by ETSI at the same time as the spectrum engineering / frequency management decisions were being taken by CEPT as to how and under what conditions HIPERLANs should be permitted to operate in the 5 GHz band. Under these circumstances it was relatively easy to ensure a mutually acceptable set of conditions that puts into place a "polite" technology and increases the use of the spectrum.

While it is difficult to see the same procedure applying to all the different systems operating in the ISM band, the key question is whether the pressure to incorporate transmit power control and dynamic frequency selection should come from the regulator or whether the manufacturers should be relied upon to incorporate these features for their own and others' benefit. In our opinion there are two factors that often put off the implementation of mitigation techniques. In the first instance there is a cost involved, and secondly there is a tendency for such measures to be avoided if there is no direct benefit in the near term. It can however be noted that the environment of the ISM band means that some mitigation techniques have already been put into place at the instigation of the manufacturers (e.g. the carrier sense / collision avoidance protocol used in 802.11).

Notwithstanding this it is felt that it would be useful if the regulator were to offer guidance on the implementation of mitigation techniques in the band. At this stage it is not clear what the techniques should be and whether they could be made mandatory.

Of course, bearing in mind the global market, it is possible that such UK encouragement to adopt such measures will have little or no impact unless other regulators can be persuaded to follow suit. However the gesture could be made.

5.1.3.1.3 Power limits

Within a given radio environment it is generally important that there is a consistency of power level (i.e. homogeneity) in order to level out the mutual interference between systems. The level should be set as low as possible whilst satisfying the basic link requirements and should also take account of the density of systems. In the event that interference avoidance measures are taken by systems this requirement for power homogeneity can be reduced and/or densities of sharing systems can be increased.

To achieve maximum spectral and economic efficiency, the regulatory regime needs to reflect both the inextricable link between device density and power limits, and the uncertainty that surrounds the future density of devices. This might be achieved by introducing a phased set of regulations. For example, consideration could be given to allowing a 100 mW power limit for the years 2000 - 2005, 10 mW for the years 2005 - 2010 and 1 mW beyond 2010, where these limits would apply to new devices, not existing ones. A period of 5 years should be sufficient for manufacturers to be able to take advantage of the availability of the spectrum at a particular power level. In the event that it becomes clear that the device density has reached a plateau it would be possible to then freeze the power limit at the value applying at that time. Needless to say, as the power level is reduced the overall capability of the devices becomes restricted in terms of range / throughput. Applications requiring a particular range / throughput would therefore have to relocate to another frequency band if one of the power reductions prevented the system from functioning.

This type of approach may also help to address the concerns of the 3G / FWA licence community regarding the possible threat posed by public provision of services using licence exempt applications. Permitting devices such as Bluetooth to operate in public places, whilst in this instance simultaneously restricting maximum power limits for use in such places, could achieve a balance between flexibility and regulation. Whilst the licensees might welcome an immediate power restriction to, say, 1mW, effectively reducing Bluetooth to a proximity device when used in a public space, a phased approach as detailed could prove more spectrally and economically efficient. The dates associated with power reduction might perhaps be set to reflect key points in the 3G product lifecycle. The licensing issues associated with public provision of services is addressed later in this chapter.

5.1.3.1.4 Digital technology

The broadcast community currently use analogue techniques. It is recommended that these should be abandoned in favour of digital techniques, not only providing an increased tolerance of interference but also making better use of the spectrum by the use of narrower channel bandwidths.

A move to digital technology within the 2.4 GHz band would offer not only a bandwidth advantage (8 MHz v. 20 MHz say) but also less susceptibility to interference (C/N+I required = 6 dB compared with 20 dB for analogue) and potentially multipath resistance depending on the modulation chosen. A possible digital channel plan in the remaining spectrum would be 11 x 8 MHz OFDM channels using two polarisations and interleaved / staggered channels. It can be seen therefore that digital technology could appear very attractive to the broadcast community if it is to continue operating in the band. However, it should also be noted that one of the major broadcasters has investigated the availability of digital technology and has concluded that at present suitable equipment is not yet on the market. Even where technology is available however, the prevailing condition of uncertainty regarding future access to the 2.4 GHz band is causing difficulty in trying to make major capital investment decisions.

5.1.3.1.5 Higher power limits

Although initially somewhat counter-intuitive, in order to achieve the goal of maximised spectrum use, it may prove appropriate to permit the existing RFA operators a higher EIRP. Greater power, combined with directional antennas, would reduce the impact of interference from other sources and thereby help achieve an improved quality of service offering.

RFA systems would be expected to be exempt from the future power reductions proposed earlier.

5.1.3.1.6 Limiting outdoor use

As Chapter 3 indicated, the principal difficulties within the band arise from outdoor systems. For some systems, such ENG/OB where mobility is critical, outdoor use at a comparatively low frequency such as 2.4GHz is a fundamental requirement. For others however, such as RLAN, outdoor use is a commercially desirable facility. The functionality offered by these systems could often be achieved by using an alternative higher frequency, or by using an alternative delivery platform, such as cable.

From a regulatory point of view, it might be seen as desirable to curtail the outdoor use of RLANs. However, the practicality of this is highly dubious as it will be extremely difficult to define “indoor” and “outdoor”. Furthermore, such a limit could serve to stifle the market. Anecdotal evidence from the USA, where such a constraint has been imposed on the lower part of the 5GHz, indicates that manufacturers will avoid any band where litigation might follow from illicit use of an outdoor system. Other issues related to outdoor use of RLANs were discussed earlier in this chapter.

5.1.3.2 Licensing & enforcement

5.1.3.2.1 Licensing

When making any recommendation regarding licensing in this band it is essential to remember that licensing and regulatory requirements must be kept to a necessary minimum if the market is meet its full potential. On the other hand however, it is important that the integrity of the overall regulation and licensing of the spectrum be maintained, and that policy be kept consistent between licensed and partially licence exempt bands. With this in mind, it is interesting to note that a variety of the innovative devices that have been developed for business and domestic use within the band have the capability to be used on either a public or private basis. As with the ISP issue discussed above, there exists some lack of clarity with regard to the regulatory position of these devices. Once again, this lack of clarity has the potential to lead to technical (congestion) problems and to undermine the benefit of the band to the UK economy.

At present, devices such as Bluetooth, though essentially conceived as privately operated systems have the potential to be operated via a public network. The Bluetooth device operated within a closed group, such as a single company office environment, needs no regulation above that already in place. However, should such devices operate via a third party provided PSTN access point (take for example provision of Bluetooth access at an air port departure lounge), a strong case can be made that the provider of the access point should be subject to the provisions of the WT and T Acts. If however, the third party provides access to the internet only not via the PSTN, it is unclear as to the extent to which licensing might be required, or would be appropriate.

Nevertheless, in common with the ISP example discussed above, it is clear that such provision would be detrimental to the business case of the 3G &

FWA licensees. However, unlike the ISP example, the Bluetooth access does require the mobility that is the unique functionality of radio.

This area requires more detailed examination to determine how best to proceed. An initial way forward could lie with an examination of the application of the Telecommunication Services Licence (TSL) and the Cordless Class Licence, as detailed under the 1984 Telecommunications Act. Combined, these class licenses permit an operator to provide mobile (DECT) services over a 200m radius area, connected to the PSTN, without the necessity to apply for a licence, or to pay a fee. Expansion of the CCL to address some of the 2.4GHz applications might therefore provide a rapid mechanism by which to clarify the existing situation.

Once again, clarity in terms of the regulatory position will be an important factor in ensuring that the market has the certainty required to allow the necessary product investment and development.

5.1.3.2.2 Enforcement

It appears that government departments are directly or indirectly responsible for the funding of many RLAN installations around the country. It would be useful if the funding of these installations were to be tied to the use of recognised installers.

It is recognised that the control of "cowboy" installers is difficult as by their very nature they are unlikely to take notice of any code of practice. However it is felt that the proposal above would at least provide some control on the interference environment.

5.1.3.3 Summary

Encouraging polite use of the spectrum, and providing a very clear and if possible simple, set of regulatory rules with regard to public service provision, is likely to pay dividends regarding the long term use of the band.

5.2 Frequency migration solutions

5.2.1 Refarming

The options thus far have concentrated on the activities that are possible assuming that all current users retain their right to operate in the band, notwithstanding the earlier observation that for some applications the impact in congestion will lead to a self-correcting migration of some users to higher frequencies.

However, it is of course possible to take the utilitarian view that the interests of the majority of users are best served by requiring one or more existing user groups to migrate to an alternative, usually higher, frequency. This section considers each application area, looking at the viability of refarming, together with the destination bands to which applications might be encouraged, or compelled, to move.

5.2.1.1 Military

It will be recalled that military use of the band, primarily for occasional airborne telemetry, is confined to the lower half (2400 – 2450 MHz) of the band. The military have access to the adjacent spectrum (2310 – 2400 MHz), including exclusive primary status bandwidth from 2380 to 2400MHz.

It has been indicated that, whilst not policy, the military might countenance vacating the ISM part of the band in the longer term as the spectrum is so relatively lightly used. The military currently foresee such a move as being most likely as a response to spectrum pricing developments, however refarming might also be considered as a policy option.

Should the military vacate the band as a licensed, paying user, it would nevertheless remain interested in using the ISM band in the same way as any other licence exempt user. Given the very diverse requirements of military operations and the current developments both within the military and civil establishments, this is unsurprising. It is not unreasonable to assume that many of the applications currently being used or planned for use in the ISM band will be used by the military at some point in the future. It is more than likely that such uses would fit in with licence exempt use, not only because the operating characteristics will be similar but also because deployment is expected to be light and constrained to barracks and training areas.

Removing military use of the band on a licensed basis would help to make use of the ISM band more consistent from a regulatory point of view. However, it will have limited impact on the overall occupancy of the ISM band as there exist only a few instances where the military have curtailed civilian use of the band (e.g. some areas where ENG/OB is not allowed to operate on some channels).

5.2.1.2 ENG/OB

Refarming ENG/OB does appear to be a viable option.

For ENG/OB several alternative bands are already available (e.g. 3.5, 5 and 7 GHz), whilst other bands might, with a little imagination, also be seen as potential destinations. The possibility of sharing with the military might for example be considered. Although the military make much more intense use of the band below the ISM band (i.e. 2310 - 2400 MHz) than of the 2400 -

2450 MHz, it may nevertheless be worth exploring the possibility of sharing the lower band.

Moving up a little in frequency, it may be recalled that the DSI Phase III proposed 2.7 – 3.4 GHz as a possibility for ENG / OB. This would however require ENG/OB to share with radar (already a problem on the 2.68 GHz channel near airports). Such a scenario would probably not be appropriate for ENG (high masts) but could be useful for low profile short OB links.

The 3.5 – 3.6 GHz band is already reserved for OB. At present analogue mobile cameras are used; the band might perhaps be used more intensively in the longer term through the introduction of digital equipment, once this has been reduced to a sufficiently compact size to permit practical use. ENG would not be eligible to use this band under the present JFMG approach to band management, but a change to this policy could be considered.

Both 5GHz and 7GHz offer potential alternatives for the application, with both already being used by broadcasters. The BBC for example already has dual band equipment operating at both 2.4 GHz and 7 GHz. The 12 GHz band, currently used for 2-way steadycam (PITACAM), may also be available, dependent upon whether there is considered to be a UK requirement for DBS.

One option may be to restrict the 2.4 GHz band to the lower power “mobile camera” applications, with high power point to point links migrated to higher frequency bands.

It can be seen therefore that there exist a number of potential options for refarming ENG/OB services. However, it should be noted that any move is likely to result in the broadcasters incurring significant capital costs. Given that much of the ENG/OB equipment of both the BBC and ITN is likely to reach the end of its useful life within the near future a fairly rapid decision concerning the future of the application in the band is required.

5.2.1.3 Radio fixed access

In the case of RFA, consideration could be given to moving the current incumbents to the 3.5 GHz band although an enforced, as opposed to voluntary, move might cause significant legal problems. Alternatively a move to 10 GHz might be considered.

5.2.1.4 Wireless networking

The availability of non-contiguous bandwidth in the 5150 – 5875 MHz region for use by RLANs provides a clear potential destination for RLANs. However, the band has its drawbacks;

- at present a variety of power limits apply across the different sections of the band, ranging from 200mW (indoor only) to 1W (indoor and outdoor).
- different parts of the band are allocated in different countries; only a small part of the band has been harmonised on a global basis, this being the area shared with MSS.
- the situation with regard to licensed vs. licence exempt operations in the band has yet to be determined.

Thus it can be seen that there exist some difficulties for manufacturers wishing to develop products for a global RLAN market. However, the band clearly does offer significant potential and its use is already being considered by some interviewees as a longer term home for professional wireless networks. Users of higher performance systems are expected to begin migrating to this band around the middle of the decade. This should relieve pressure on the 2.4 GHz band, which in the longer term is foreseen as catering predominantly for the residential rather than business sector.

Another area already under consideration by industry is use of the licence exempt ISM band at 5725 - 5875 MHz (25mW power constraint). The Bluetooth community is currently considering use of this band.

5.2.1.5 Other short range devices

Assuming that the operation of higher power RFIDs (4W) is constrained to the centre of the band (2445 – 2455 MHz), neither RFIDs nor CCTV operations are considered problematical in terms of interference exported, although the latter may themselves be prone to interference. Refarming is not therefore essential but use of a dedicated frequency band such as 31 GHz is recommended where performance or reliability is critical.

5.2.1.6 ISM applications

Refarming ISM applications such as microwave ovens is not appropriate. An extensive installed base of appliances already exists, and no clear overall advantage would be gained.

5.2.1.7 IMT 2000 spectrum

The initial allocation of spectrum to third generation mobile services based on the IMT-2000 family of standards includes provision for licence-exempt services. In Europe a minimum of 10 MHz has been earmarked for such use by CEPT ERC. Licence exempt IMT-2000 may provide an attractive alternative to Bluetooth and other 2.4 GHz in some applications, since many 3G terminals are likely to provide access to the licence exempt spectrum. However, the current lack of a global IMT-2000 allocation means 2.4 GHz is likely to remain the dominant wireless connectivity band, particularly where devices are incorporated into PCs and other IT equipment intended for a global market.

5.2.1.8 Millimetric Spectrum

In the longer term scope for millimetre wave bands (esp. 60 GHz), though ironically 2.4 GHz outdoor links are probably gaining at the expense of the 58 GHz band currently (this is an argument for ensuring that the two are treated equitably, which would imply abolishing the current licence fee at 58 GHz.

5.2.2 Introducing new licence exempt bands

The final policy option that might be considered is the introduction of further licence exempt bands.

The popularity of the 2.4 GHz band is in part built upon its licence exempt status, which has encouraged companies to invest heavily in developing applications which can operate without the need for complex licensing processes. This tends to indicate that the availability of licence-exempt spectrum encourages innovation and dynamism within the private telecommunications sector.

To maximise its commercial potential, such a band would need to be global, or Europe-wide at the very least. Two possible candidates that might merit further investigation would include:

- IMT-2000 expansion spectrum. As noted above, the current IMT-2000 allocation includes a licence exempt portion, currently 10 MHz within in Europe but not available globally. The expansion spectrum recently agreed at WRC-2000 provide scope for substantially more, some of which could eventually be global, depending upon the availability of spectrum in individual countries. Migration from analogue to digital technology for applications such as TV broadcasting and MMDS, which currently occupy a large part of this expansion spectrum in some countries, could facilitate this move.
- The upper half of TV broadcast bands IV and V also present possibilities as services migrate to digital (part of this has already been identified as expansion spectrum for IMT-2000. This band may have scope for global allocation.

Another candidate would be the ISM band in the 5 GHz band at 5725 - 5875 MHz. The current situation regarding this band can be summarised as follows:

- 5725 - 5825 MHz is already used in the US for Unlicensed National Information Infrastructure (UNII) devices operating at EIRP levels up to 4 Watts.

- The CEPT Recommendation relating to the use of Short Range Devices identifies the whole band 5725 - 5875 MHz for use by non-specific SRDs using up to 25 mW EIRP and 5795 - 5815 MHz for use by Road Transport and Traffic Telematics (RTTT) using up to 4 or 8 Watts EIRP.

- The UK has not signed up to the non-specific SRD part of the recommendation for the 5725 - 5875 MHz band. This ISM band is therefore not available for general licence-exempt use in the UK. The middle part of the band (i.e. 5795 - 5815 MHz) is available for RTTT applications operating at EIRP levels of 2 Watts or below, noting that a system operator may require a WT Act and/or T Act licence while the end users (vehicle units) will be licence-exempt.

- The primary allocation in the UK is to Government Radiolocation. This should not be a serious impediment to sharing with other services providing "polite technology" is deployed, as was the case when establishing the sharing conditions between HIPERLANs and Government Radiolocation in the bands between 5250 MHz and 5725 MHz.

It may be observed that should other spectrum become available that might appear suitable for candidacy as a licence exempt band, pressure to auction the band in preference to creating a ‘fee free’ areas, may mitigate against further license exempt allocations in the future, especially where the spectrum is suitable for wide area mobile applications.

5.3 Band Partitioning

There may be a case for restricting some services that are less prone to interference to the central part of the band, i.e. the part most affected by ISM emissions. The adoption of digital technology for OBTV systems, and the reduced bandwidth requirement that will result, may provide such an opportunity. Since OBTV systems have significantly higher power margins than other equipment in the band, these would appear to be a strong candidate for such a move. This option would provide the further benefit of reducing the probability of interference from OBTV systems to FWA, since the FWA operators tend to avoid this part of the band

5.4 Developing policy

The preceding sections have detailed a variety of policy options that could be adopted within the UK. As noted at the outset, many of these are not mutually exclusive, but can, to some extent, be brought together to maximise the efficiency with which the spectrum is used.

Three types of systems that have been identified as causing the most concern in terms of potential interference between each other. The easiest solution, in theory rather than practice, would be to relocate two of the systems somewhere else in the spectrum and allow one system to continue operating in the ISM band. The implications for each of the three systems would be as follows:

RFA - It has always been the case that RFA systems operating in the ISM band are vulnerable to interference. This has been accepted on the basis that existing systems have been relatively localised and have not covered areas where there has been intensive activity by the other systems sharing the band. With the expanding coverage of RFA systems it is likely that interference will be experienced on a more frequent basis. If demand for RFA services expands significantly it may be appropriate, in consultation with the operators, to consider relocating these systems to a more benign part of the spectrum. Ideally this should be an exclusive assignment to enable fuller control over the grade of service delivered.

Outdoor RLANs - It is difficult to distinguish between indoor and outdoor devices for the purposes of the practical enforcement of any regulation that might be put in place. One therefore has to consider RLAN applications as a whole and any consideration of removing RLANs from the band would involve removing them in toto. Given the global market for RLANs operating in this band, and the fact that these devices are already reasonably widespread in terms of deployed numbers and with significant growth forecast, it is difficult to see them being excluded from the band completely. However, it is clear that the availability of the 5 GHz band for RLANs allows for an escape route. RLAN providers have already identified this transition for 2 to 3 years time.

In the event that RLANs continue to operate in the band it is important that some guidance is given to those deploying outdoor links. A code of practice should be provided requiring a minimum antenna gain (in terms of half power horizontal beamwidth) and pointing out the interference risk by indicating that links in this band should not be seen as a substitute for licensed point-to-point links where performance is important.

ENG / OB - A number a factors suggest that ENG/OB being moved out of the band is a possibility. Those factors are that most existing equipment is coming to end of its life, other bands are already available and, except in some circumstances, Satellite News Gathering (SNG) is an acceptable alternative to ENG.

Application	For refarming	Against refarming
ENG/OB	• Broadcasters are about to replace much of their existing equipment • Other bands are available for, and are already being used by, the broadcasters	• Higher frequencies are not quite as good from a propagation point of view; more "black spots" will exist where it is difficult, or impossible, to establish links • ENG/OB is a legitimate, licensed user of the band • Considerable capital has been invested in equipment suitable only for use in the band. • Some former alternative bands have been re-allocated to other services (e.g expansion spectrum for IMT-2000)
RFA	• Operation in a co-ordinated or exclusive band would bring protection and hence avoid potential degradation to long term quality of service • Not dependent upon core 2.4GHz band characteristics • Could offer wider coverage as fewer areas would be interference limited	• RFA is a legitimate, licensed user of the band • Considerable capital has been invested in equipment suitable only for use in the band. • One of the two operators is a relatively newly established enterprise
Outdoor RLANs	• [if public] unfair competition with licensed services • Natural path to 5GHz already established	• Licence exemption a key factor in business case • Practical problems associated with defining / preventing "outdoor" use might require all RLANs to be refarmed in order to ensure that outdoor RLANs cease to operate

Note: the legitimacy of public service provision through the licence exempt outdoor RLANs has yet to be determined. It is recommended that such services should not be permitted, as these would be anti-competitive with regard to licensed operators, who may have paid significant sums to acquire spectrum.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Operation in the 2.4 GHz ISM band is attractive for a number of reasons:

- it is, effectively, a global allocation
- there is a limited amount of regulation ("light" constraints)
- access to this part of the spectrum is generally free
- it is ideally suited to high density fixed and mobile applications[9]

Arguably, this is a beneficial combination of factors that leads to the investment and R&D commitment needed to generate the innovative applications that are springing up in the band.

The fact that for license exempt operations there is no protection from interference, and that there is the possibility that a device causing interference might be forced to cease operations, does not appear to dampen the enthusiasm for using the band. This is probably due to the short term attraction of commercial opportunity which is as yet uninfluenced by the problems of interference (a longer term issue).

It is not considered that it would benefit the UK as a whole if a regulatory regime that was detrimental to the above combination of factors were to be introduced. However there are problems associated with this band that need to be addressed.

1. The current vision of many people using and seeking to use the 2.4 GHz ISM band is at odds with the current licensing regime. For example it is foreseen that Bluetooth devices will enable the public to exchange data (financial or otherwise) with different types of vending or cash machine in public places. These machines may be connected to the public telephone network or the Internet. Similarly, Internet service providers wish to provide public services through RLANs either direct to customers' premises or in public spaces. In both cases the proponents of these systems would like to offer/provide such services on a license exempt basis. It follows that there would be no financial charge (relating to spectrum use) to the Internet service provider associated with this service.

9 Transmission is less constrained to line-of-sight than in higher bands and spectrum can be re-used more intensively than in lower bands.

This situation would then be contrary to the provision of service in other bands (e.g. those allocated to 3G mobile or, BFWA) where significant fees have been, or are expected to be, paid for use of the relevant spectrum.

2. The main potential for congestion relates to the three types of systems that operate outdoors, namely, outdoor RLANs, ENG/OB and RFA. In the longer term it is not considered practical for all three types of system to coexist in the band. The implications of moving one or more of these services out of the band have been discussed earlier in the report. Ideally two of the systems should be moved out of the band in order to provide a satisfactory interference environment for the remaining outdoor system. If this is not possible for policy reasons, it will be necessary to put further controls in place on some or all of these services (e.g. enforced antenna directionality for outdoor RLANs) in order to reduce the probability of interference in the future. This will to some extent curtail the flexibility of use which currently makes the ISM band attractive.

3. In addition to the congestion problems associated with outdoor systems there is also the potential for congestion in hotspots when devices of 100 mW are used. These hotspots are generally expected to be public areas and the 100 mW applications are expected to be largely public wide area services. Co-existence of a high density of these relatively high power public wide area services with low power (1 mW) devices will be difficult.

4. For some existing and potential users of the band the uncertainty surrounding its use may be constraining development. In the case of ENG/OB, while use of the band is continuing to full advantage for the time being, investment decisions are being held off. There is also considerable pressure from Internet Service Providers to use the band. This potential development is being held up because the legality of their business proposal is unclear.

These issues need to be resolved by way of a number of decisions being taken and a subsequent clear and unambiguous statement on who may or may not use the band.

5. For most of the other users it is not foreseen that congestion will be a significant problem. However this is predicated on the market forecasts and assumptions used in the analysis, and on the expectation that the manufacturers themselves will devise ways to ensure that the licence-exempt RLANs, Bluetooth and home networking devices can operate in close proximity to one another. It is not considered appropriate for the regulator to define this sort of detail.

6.2 Recommendations

This report has highlighted a number of issues affecting the future efficiency and effectiveness of the band and has provided a set of policy options which will help address these issues. This section makes a series of recommendations as to the steps that SMAG might take to ensure the effective use of the band.

6.2.1 Urgent actions

6.2.1.1 Outdoor operations

The foremost question facing the SMAG is the current use of the band by 3 types of outdoor system. Recognising the quality of service problems likely to result from the continued, simultaneous use of the band by these outdoor applications, the study recommends that this situation be addressed boldly - by initiating the refarming to other bands of two of these three services, at least for new equipment installations.

ENG/OB has a historic claim to the band as it requires the non-line of sight capability that is a fundamental characteristic of frequencies below 3 GHz. RFA networks involve a substantial capital investment in equipment that can not be readily modified to operate in other frequency bands. Refarming costs are likely to have a significant adverse bearing on the competitive position of RFA networks, where equipment might otherwise be deployed over a period of ten years or more. The anticipated migration to digital technology over the next few years and the resultant reduction in the bandwidth requirement may provide an opportunity however, either for migration or for restricting these systems to the portion of the band which is most affected by ISM emissions. This would also reduce the risk of interference to FWA systems, which generally avoid using this part of the band.

Outdoor RLANs offer an innovative and (for users) economically attractive use of the band, though in some cases (notably where services are being provided to third parties) their legitimacy can be questioned. There are therefore well-founded arguments both for and against a decision to refarm any of these applications and any decision is likely to prove both difficult and contentious. Nevertheless, it is clear from the study that such a decision must be made if the quality of all three services is not to suffer in the longer term. A specific recommendation in this regard has not been made in this report, since there are a number of potentially conflicting economic, political and regulatory issues, outside the scope of this study, that must be taken into account. It is recommended that a policy review should commence as a matter of urgency with a view to reaching a decision on the future of these three outdoor services within the band.

6.2.1.2 Internet Service Provider (ISP) licensing

If outdoor RLANs are to be allowed to continue operating in the band there exists an immediate question as to the legitimacy of ISPs using the band for the provision of public data services. As detailed in the report this area has already been subject to significant debate, but at present remains unclear. This deters the ISPs from rolling out their services (if allowed) and hampers the Agency in its enforcement role (if not allowed). This study has not sought to address the merits of permission or non-permission, but has outlined some of the factors that might usefully be taken into account.

In order to inform the decision that has to be made it is recommended that an assessment should be made of the economic impact on 2G and 3G mobile networks and on RFA networks in the event that ISPs are permitted to operate in the band. This is particularly important given the increasing improvements to Voice over IP technology, which presents the prospect of a fully featured PSTN service being delivered using an all-IP platform.

6.2.1.3 Hot spot congestion

Apart from the congestion problems associated with outdoor devices, congestion in hotspots is also likely to occur when the use of 100 mW devices for public wide area networking is considered. If this is to be avoided it is recommended that public services should be constrained to 1 mW. This would allow for close proximity public services but would not allow for public wide area access as proposed by ISPs and others as discussed above.

6.2.2 Related actions

Depending on the decision made regarding the occupancy of the band by outdoor systems, it is recommended that the following areas be addressed:

- If the decision on outdoor systems (see § 6.2.1.1 above) allows for RLAN / RFA coexistence, and in the event it is not possible to mandate against the use of RLANs outdoors, it is recommended that outdoor RLANs are mandated, or at least strongly encouraged to use directional antennas.
- A quick decision regarding the ENG/OB situation is required. If refarming is required as a result of the outdoor decision then the most appropriate spectrum needs to be identified. It is recommended that a transition period of 2 years should be allowed. In the event that ENG/OB remain in the band then it is recommended that digital

techniques be mandated and that consideration be given to restricting the deployment of the higher powered temporary point to point links in the band (these could be relocated to higher frequency bands).

- If the RFA systems are refarmed to other bands it is recommended that compensation be made by way of reduced license fees over a suitable period of time.

6.2.3 Other actions

In the light of the study findings, it is also recommended that the SMAG give thought to the following actions:

- the military vacating the ISM part of their band. This would reduce uncertainty surrounding the interference level in the band.
- the encouragement of polite technology
- the release of further licence-exempt bands. In particular the reasons for the current unavailability of the 5 GHz ISM band need to be investigated.

6.2.4 Summary

This study has shown that use of the 2.4GHz band offers significant potential benefits for the UK. However, it has also identified a number of issues that need to be addressed, in a number of cases as a matter of urgency, if use of the band is to reach its full potential. The study has made a number of recommendations as to how possible obstacles in the path of full band usage may be overcome, and has identified one area in particular where additional investigation would be of value.

7 ANNEX A: ACRONYMS

3G:	Third generation mobile communications
AVI:	Automatic Vehicle Identification
BFWA:	Broadband Fixed Wireless Access
CCL:	Cordless Class License
CCTV:	Closed Circuit Television
CEPT:	Conférence Européen des Postes et Télécommunications
CLAN:	Cordless Local Area Network
CT2:	Cordless Telephony 2
DECT:	Digitally Enhanced Cordless Telephone
DFS:	Dynamic Frequency Selection
DSSS:	Direct Sequence Spread Spectrum
EMC:	Electro-Magnetic Compatibility
ENG:	Electronic News Gathering
EPOS:	Electronic Point of Sale
ETSI:	European Telecommunications Standards Institute
FCC:	Federal Communications Commission
FHSS:	Frequency Hopping Spread Spectrum
FWA:	Fixed Wireless Access
HIPERLAN:	High Performance Local Area Network
ICNIRP:	International Commission on Non-Ionising Radiation Protection
ICT:	Information Communication Technology
IEEE:	Institute of Electrical and Electronic Engineers (USA)
IEGMP:	Independent Expert Group on Mobile Phones
ISDN:	Integrated Services Digital Network
ISM:	Industrial, Scientific and Medical
ISP:	Internet Service Provider

JFMG:	Joint Frequency Management Group
NRPB:	National Radiological Protection Board
OB:	Outside Broadcast
PSTN:	Public Service Telephone Network
RFA:	Radio Fixed Access
RFID:	Radio Frequency Identification Device
RLAN:	Radio Local Area Network
RWAN:	Radio Wide Area Network
SAR:	Specific Absorption Rate
SMAG:	Spectrum Management Advisory Group
SRD:	Short Range Device
SWAP:	Shared Wireless Access Protocol
TPC:	Transmitter Power Control
TSL:	Telecommunication Services License
WAP:	Wireless Access Protocol
WECA:	Wireless Ethernet Compatibility Alliance
WLAN:	Wireless Local Area Network

8 ANNEX B: ACKNOWLEDGEMENTS

Organisation	Representative	Position
3COM	Angelo Lamme	
AIM Inc	Steve Halliday	Vice President, Technology
Altohiway Ltd	Richard Sharpe	Managing Director
AMDEA	John Humphries	
Amtech Inc	Bob Frank	
Associated British Ports	John Sessions	
Atlantic Telecom	Gordon Slay Susy Atkinson	Director Corporate Affairs
BBC	Andrew Latham Robin Mortby Nick Buckley	Operations Manager, BBC News Resources Location Manager, BBC News Resources Outside Broadcast
British Education Communications Technology Agency	Theo Wright	
Breezecom Europe Ltd	Hugh Garrod Dionne Ross	UK National Sales Manger Business Development
BT Cellnet	Alan Chisholm	Mobility Systems Design; BT Group Technology
	Alan Freeman	Spectrum & Health Strategy
	Bruno Nigeon	Manager; Cordless Technology & Mobility
	Steve Buttery	Technical Assessment, Future Technology
	Mark Fourier	Bluetooth
Cadence Design Systems Ltd	Michael Barkway	Business Manager; Bluetooth Semiconductors
Council for Museums, Libraries and Archives	Chris Batt	
Ericsson Ltd	John McPherson	Technical Executive, Business Development
Ericsson Mobile Communications AB	Lars-Goran Thorslund	Consumer Products
Internet Service Providers Association	Tim Snape	Managing Director, Abbotsbury Software Ltd Council Member, ISPA
Intel Inc	Ben Manny	Chair, HomeRF
Intermec	Chris Rhodes	Business Development Manager
ITN	Keith Cass Dave Randles	Head of Information Technology and Communications
JFMG	Paul Gill	
Low Power Radio Association	John Hallett	Microwave Solutions Ltd, member LPRA
Lucent Technologies	Bryan Hall	WaveLAN Business Development Manager UK & Ireland
Marconi Communications Ltd	Richard Bell	Manager, Access Marketing

	Jeff Wheat	Office of Chief Technology Officer
Medical Devices Agency	Andy Smith	Critical Devices
	Peter Solesbury	Implants
Ministry of Defence	Ian Worthington Roy Snowdon	
Motorola	Tim Cull	Manager, Telecommunications Policy
Nokia UK Ltd	James Page	
One to One	Robert Davies	Senior Systems Engineer
Petards International Ltd	Mike Williams	Managing Director
Proxim Ltd	Lynn Chroust Dr Kevin Negus	Director of Product Marketing VP Business Development, Proxim Inc.
Radiocommunications Agency	Annette Henley	Radio LANs
	Mike Low	Military issues
Renishaw plc	John Liptrot	
Southampton Container Terminal	Bill Galman	
TagMaster AB	Steffan Gunnarsson	Manager
TCL Communications Ltd	Richard Searle	Director
Toshiba Research Europe Ltd	Mike Fitton	
Wireless Airware Ltd	Jim Kernahan	Director

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The following organisations were invited to participate but declined or did not respond: BREMA, CISCO, Nortel, Telxon

9 ANNEX C: POWER LIMITS

(Source: RA Short Range Devices Information Sheet)

Application	Frequency range	Radiated level	Channel b/w	Music or speech permitted	Standard
TT&C: General	Full*	10 mW eirp	< 20MHz	No	I-ETS 300 440
TT&C: Industrial / Commercial	Full*	100 mW eirp	-	No	I-ETS 300 440
R-LAN	Full*	100 mW eirp (DSSS allowed to –20 dBW/1 MHz within eirp) (FHSS allowed to –10 dBW/100 kHz within eirp)	-	No	ETS 300 328 (Previously MPT 1349)
Short range indoor data links	2445 – 2455 MHz	100 mW eirp	-	Yes	I-ETS 300 440
Equipment for the detection of movement or alert	2445 – 2455 MHz	100 mW eirp (up to 500 mW for tagging & ID)	-	No	I-ETS 300 440
Video applications	Full*	10mW eirp	20MHz	Yes	I-ETS 300 440

* The full frequency range is from 2400 MHz to 2483.5 MHz.

Special notes:

2445 – 2455: Automatic Rail Vehicle Identification Systems – EN 300 761

2400 – 2483.5: Visual image transmission equipment allocation – UK only. To be used for general purpose CCTV, including low power video senders. May also be used for airborne video applications.

The use of speech and music is not allowed in the band, unless specifically permitted.

10 ANNEX D: TECHNICAL STANDARDS

Standards	Technology	Channel Bandwidth (MHz)/Max Output power(W)	Aggregate bit rates/modulation
IEEE 802.11[1]	FHSS	1/0.1	2Mbps max/4 level/GFSK
	DSSS	22/0.1	2Mbps max/DQPSK
IEEE 802.11b[1]	FHSS	1/0.1	3Mbps max/8FSK
	DSSS	22/0.1	11Mbps max/CCK
ETS 300 328	FHSS	0.1 min/0.1 (draft 0.5)	250kbps min/not specified
(Draft EN 300 328)	DSSS	10 min/0.1 (draft 0.5)	250kbps min/not specified
Draft EN 300 440[2]	Various	1/0.5 (eirp)	N/A
EN 300 761[3]	N/A	1.5 / 0.5	N/A
FCC Part 15[4]	FHSS	1(maximum 20 dB bandwidth)/1	N/A
	DSSS	0.5 (minimum 6 dB bandwidth)/1	N/A

[1] RLAN and HomeRF only

[2] Short Range Devices (Movement and Alert)

[3] Automatic Vehicle Identification for Railways (AVI) at 2446-2454 MHz

[4] Radio frequency devices

10.1 IEE 802.11

IEEE 802.11 defines two RF physical layers, namely FHSS and DSSS. Generally, FHSS is considered better at supporting a dense population in a small area, because it has more independent RF channels, whilst DSSS provides greater operating range and coverage area (because it can operate with a lower carrier to noise ratio) and enables greater data throughput.

FHSS RLANs

IEEE 802.11 defines the following characteristics for FHSS RLAN systems:

No. of RF channels:	79
No. of hop sequences:	78 (3 sets of 26)
RF Channel bandwidth:	1 MHz (20 dB)
Minimum freq sep between consecutive hops:	6 MHz
Maximum data rate:	2 Mbit/s (over the air)

Table 10.2 Principal characteristics of IEEE 802.11 RLANs

Channel centre frequencies are 2402.0 – 2480.0 MHz inclusive, at 1.0 MHz intervals. Hopping sequences from the same set collide three times on average, five times worst case over a hopping cycle, including co- and adjacent channel collisions. All hopping sequences are derived from a common base sequence, by incrementing the frequency of each hop by *k*, where k = 1, 2, 3,…78.

The 78 available hop sequences are sub-divided into three groups of 26. Within each group, the 26 sequences are orthogonal to one another (i.e. there will be no co-channel or adjacent channel frequency collisions), allowing systems to be co-located with minimal interference. In practice, however, this orthogonality is compromised since independent systems are not synchronised. This places a practical upper limit on the number of FHSS systems which may be co-located (e.g. within a single building) of 15, although some suppliers suggest that up to 22 systems can be co-located without any appreciable degradation of performance. Co-located FHSS systems need not be synchronised unless they are deployed for real time applications such as voice.

The 1 MHz individual RF channel bandwidth limits the over the air data rate of FHSS systems to 2 Mbit/s (with GFSK modulation).

DSSS RLANs

Although there are a number of proprietary DSSS systems on the market, there is an increasing trend towards compliance with the IEEE 802.11.

The principal characteristics of the 802.11 DSSS physical layer are:

- Spreading sequence: 11 bit Barker code
- Coding gain: 10.4 dB
- Maximum Data Rate: 2 Mbit/s

- RF Bandwidth 22 MHz

IEEE 802.11 defines operation within 2400 to 2483.5 MHz frequency range (2473-2495.0 in Japan). There are 12 DSSS carrier frequencies for use throughout the world. These are:

CHNL_ID	FCC Channel Frequencies	ETSI Channel Frequencies	Japan Frequency
1	2412 MHz	N/A	N/A
2	2417 MHz	N/A	N/A
3	2422 MHz	2422 MHz	N/A
4	2427 MHz	2427 MHz	N/A
5	2432 MHz	2432 MHz	N/A
6	2437 MHz	2437 MHz	N/A
7	2442 MHz	2442 MHz	N/A
8	2447 MHz	2447 MHz	N/A
9	2452 MHz	2452 MHz	N/A
10	2457 MHz	2457 MHz	N/A
11	2462 MHz	2462 MHz	N/A
12	N/A	N/A	2484 MHz

10.2 IEEE 802.11b

IEEE 802.11b standard is development from IEEE 802.11 standard. Using different modulation scheme higher maximum data rates are achieved for both FHSS and DSSS systems. FHSS system can now achieve data rates up to 3 Mbit/s by utilising 8FSK, whilst DSSS systems can now achieve up to 11 Mbit/s by using CCK. Additional ETSI and FCC channel frequencies of 2467 and 2472 MHz are added, which makes the total number of utilised FCC channel frequencies equal to 13 whilst we have now 11 ETSI channel frequencies.

10.3 ETS 300 328

The European standard, ETS 300 328, requires FHSS systems to hop between at least 20 non-overlapping radio channels within the 2.4 GHz band, with a dwell time on each channel of not more than 400 msec. Each radio channel must be occupied at least once within a period equal to the product of the channel dwell time and the number of channels, implying a uniform probability of transmission. The maximum bandwidth of a single hopping channel is 1 MHz. EIRP limits for ETS 300 328 compliant FHSS systems are:

- Total EIRP: -10 dBW
- Peak EIRP: -10 dBW / 100 kHz

FHSS is a form of CDMA, whereby a large number of transmissions can occupy a given frequency band by deployment of different spreading codes. The coding gain of an FHSS system is effectively the number of hopping channels divided by the individual channel bandwidth, i.e. 78 (= 18.9 dB) for a typical 78 channel system.

ETS 300 328 defines all spread spectrum modulation schemes which do not conform to the above requirements for FHSS as DSSS. No limits are defined for the bandwidth of the spread spectrum signal, so long as the transmitted power envelope lies within the 2400 – 2483.5 MHz band. Limits for the peak EIRP spectral density are – 20 dBW / MHz. The maximum RF bandwidth currently used by commercially available 2.4 GHz DSSS systems is c. 30 MHz and the coding gain is typically 10 - 11 dB. Note that this coding gain is not sufficient to deliver effective CDMA, hence co-located DSSS systems generally must operate on different carrier frequencies.

There is currently work in ETSI which would result in increase in peak EIRP levels for both FHSS and DSSS systems to –3 dBW. The latest work has produced a draft EN 300 328 specification.

10.4 Draft EN 300 440

EN 300 440 covers the minimum characteristics considered necessary for Short Range Devices (SRDs) in order to make the best use of the available frequencies. In the 2.4 GHz band, this standard covers SRDs operating between 2400 and 2483.5 MHz. The maximum EIRP specified by this standard in this frequency band is –3 dBW. This standard does not specify any particular RF physical layer to be used.

10.5 EN 300 761

The present document applies to 2.45 GHz Short Range Devices (SRDs) for use in Railway AVI which fulfil the Union Internationale des Chemins de fer (UIC) specifications (annex E) and are interoperable with the current UIC system except for the interrogator (Track Units (TU)) bandwidth. The Interrogator bandwidth is limited to 8 MHz shared within five channels operating on radio frequencies between 2446 MHz and 2454 MHz. Each channel bandwidth is 1.5 MHz. Maximum EIRP defined by this standard is –

3 dBW. Finally, this standard covers the minimum characteristics considered necessary in order to make the best use of the available frequencies.

10.6 FCC Part 15

This part covers minimum operational standards for radio frequency devices operating between 2400.0 and 2483.5 MHz. Both FHSS and DSSS RF physical layers are defined by this standard. FHSS systems will use at least 75 hopping channels with the maximum 20dB bandwidth of the hopping channel being 1 MHz. For DSSS, the minimum 6 dB bandwidth shall be at least 500kHz. The maximum peak output power shall not exceed 0 dBW for both FHSS and DSSS systems.

11 ANNEX E: HEALTH LIMITS

With respect to the frequency range of concern to this study limits are put in place in order to prevent whole-body heat stress and excessive localised heating of tissues. The limit is initially expressed in terms of a Specific energy Absorption Rate (SAR) averaged over the whole body or over parts of the body. This is defined as the rate at which energy is absorbed per unit mass of body tissue and is expressed in Watts per kilogram (W/kg). While whole body SAR is a widely accepted measure for relating adverse thermal effects to RF exposure it is also necessary to have local SAR values in order to limit excessive energy deposition in small parts of the body (e.g. exposure of parts of the body in the near field of an antenna).

	Whole body average SAR (W/kg)	Localised SAR (head and trunk) (W/kg)	Localised SAR (limbs) (W/kg)
10 MHz - 10 GHz	0.08	2	4

EC Recommended basic restrictions

Notes:

- All SAR values are to be averaged over any six-minute period.
- Localised SAR averaging mass is any 10 g of contiguous tissue having nearly homogeneous electrical properties.
- For pulsed exposures in the frequency range 0.3 to 10 GHz and for localised exposure of the head, in order to limit and avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the Specific energy Absorption (SA) should not exceed 2 mJ/kg averaged of 10 g of tissue.

	E-field strength (V/m)	H-field strength (A/m)	B-field (µT)	Equivalent plane wave power density (W/m²)
2 - 300 GHz	61	0.16	0.20	10

EC Recommended reference levels (unperturbed rms values)

Notes:

- For frequencies between 100 kHz and 10 GHz all values are to be averaged over any six-minute period.

- For frequencies between 10 MHz and 300 GHz peak reference values for the E, H and B fields are obtained by multiplying the corresponding rms values by 32
- For pulsed signals at frequencies exceeding 10 MHz the plane wave power density as averaged over the pulse width should not exceed 1000 times the reference level.
- For frequencies between about 0.3 GHz and several GHz and for localised exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, the specific absorption from pulses must be limited. In this frequency range, the threshold SA of 4 - 16 mJ/kg for producing this effect corresponds, for 30 µs pulses, to peak SAR values of 130 - 520 W/kg in the brain.

The relationship between the reference levels and the basic restrictions is indirect, but the levels chosen have been developed on the basis a review of all published scientific literature. Only established effects have been taken into account so it is possible that the limits will change as the results of further work emerges.

It is important to note that:

- exceeding the reference level does not necessarily mean that the basic restriction will be exceeded
- in certain situations where the exposure is highly localised, such as with hand-held telephones and the human head, the use of reference levels is not appropriate. In such cases respect of the localised basic restriction should be assessed directly.