The Spectrum and Its Uses

- A simple guide to the radio spectrum -

September 2006

Executive Summary

The radio spectrum is a scarce resource. The advent of digital services, which use spectrum more efficiently than analogue services, will make spectrum available for new, innovative services. But spectrum scarcity will not disappear.

Broadband wireless access, mobile TV and local TV programme services are just some of the newly-developing services which will need spectrum in the years immediately ahead. High Definition TV and new developments in digital radio broadcasting may be offered to the public before long.

Radio waves do not respect international borders, buildings or each other. We are a long way away from a world where different types of services would compete for your attention while using the same frequencies. International harmonisation sets out rules for each spectrum band. Bilateral international co-ordination and national spectrum planning ensure that different services do not interfere with each other (so that, for instance, you do not pick up walkie-talkie conversations on your mobile phone).

Recent years have seen a distinct move by the Government towards the use of market forces (e.g. through the auctioning of spectrum) in place of the Government deciding which companies should be given licences to provide services. Even so, those responsible for spectrum planning face difficult decisions. How, in particular, should they decide what is the right balance between making spectrum available for companies providing commercial services, and ensuring universal availability of public services such as free-to-air broadcasting?

This document explains the technical terms associated with the spectrum; it sets out how spectrum planning takes place in the UK; it discusses the "Digital Dividend" as we move away from delivering some services in analogue form, and it describes the different services that might take advantage of that dividend.

Introduction

New developments in broadcast and mobile communication technologies have increased the demand for radio frequency spectrum, a finite natural resource. Pressure is growing on the regulators and current users to accommodate more and more services. Mobile TV, wireless broadband and enhanced mobile phone services, additional television channels and High Definition Television (HDTV) are all lining up to be launched.

Experts generally agree that if all existing analogue services were provided in a digital format, their spectrum need would be one quarter of their current take-up. In other words, three quarters of the currently occupied spectrum could become available to be used for other services. But it is a bit more complicated than that. Different technologies work better in particular parts of the spectrum. Certain frequency bands will remain occupied by current users while others will be cleared for new uses. Historic developments, technical and economic considerations as well as European harmonisation of spectrum use play a part of the equation.

What is spectrum?

The electromagnetic spectrum incorporates the range of all electromagnetic radiation, and extends from electric power at the long-wavelength end to gamma radiation at the short-wavelength end. In between, we find radio waves, infra-red, visible light, ultra violet and X-rays used in medical diagnostics. In principle, the spectrum is claimed to be the size of the universe itself but its different parts are limited to certain ranges of electromagnetic waves.

Electromagnetic waves are defined by their special characteristics, such as frequency, wavelength and amplitude. The frequency refers to the number of waves generated in a set period of time and is measured in hertz (Hz). 1 Hz means one wave per second, 1 kHz (kilohertz) means one thousand waves per second, 1 MHz (megahertz) means one million waves per second, 1GHz (gigahertz) means one billion waves per second and so on.

Wavelength is the distance between two waves. There is a fixed mathematical interrelation between the frequency and the wavelength. The higher frequencies have shorter wavelengths and the lower frequencies have longer wavelengths. The wavelength also indicates the ability of the wave to travel in space. A lower frequency wave can reach longer distances than a higher frequency wave. Radio waves are usually specified by frequency rather than wavelength.

The radio frequency spectrum (which is simply referred to as spectrum) is only a comparatively small part of the electromagnetic spectrum, covering the range from 3 Hz to 300 GHz. It includes a range of a certain type of electromagnetic waves, called the radio waves, generated by transmitters and received by antennas or aerials.

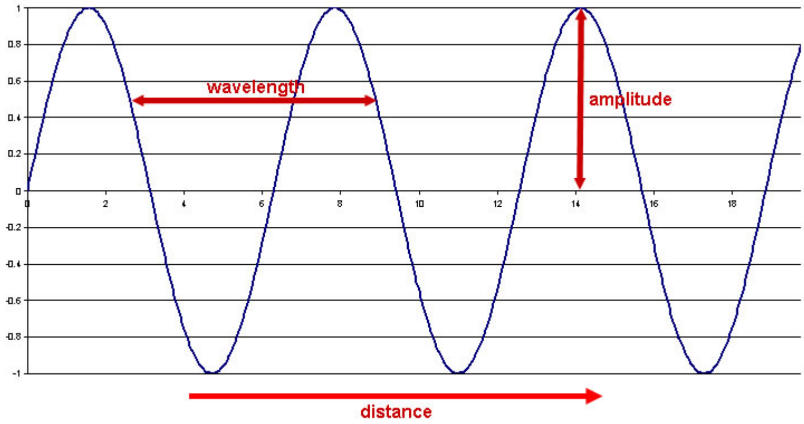

Figure 1. Electromagnetic wave

How radio spectrum works

The radio spectrum is the home of communication technologies such as mobile phones, radio and television broadcasting, two-way radios, broadband services, radar, fixed links, satellite communications, etc. due to its excellent ability to carry codified information (signals). It is relatively cheap to build the infrastructure which can also provide mobility and portability.

Depending on the frequency range, the radio spectrum is divided into frequency bands and sub-bands, as illustrated in Figure 2. Appendix A lists all the radio frequency bands and their general uses.

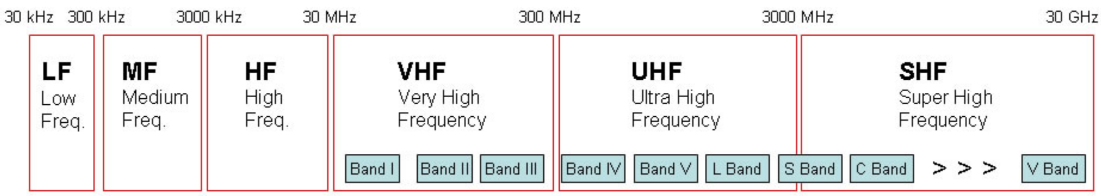

Figure 2: Frequency bands and sub-bands

In theory, different communication technologies could exist in any part of the radio spectrum, but the more information a signal is to carry, the more bandwidth it needs. In simple terms, bandwidth is the range of frequencies that a signal occupies in spectrum. For example, an FM radio station might broadcast on the 92.9 MHz frequency, but requires 0.3 MHz (equivalent of 300 kHz) bandwidth – the spectrum between the frequencies 92.8 and 93.0 MHz inclusive. Other stations cannot broadcast on these frequencies within the same area without causing or receiving interference.

For planning purposes, the spectrum bands are divided into channels. The bandwidth of spectrum channels can vary band by band. VHF Band II, the home of FM radio, for instance, is sliced up in 100 kHz-wide channels. An FM station requires 300 kHz bandwidth, therefore each FM radio station takes up three spectrum channels. In the case of television broadcasting, the agreed bandwidth of a channel is 8 MHz in UHF Band IV/V. The bandwidth requirement of an analogue TV programme channel happens to be the same as the bandwidth of one spectrum TV channel, i.e. 8 MHz.

Lower frequencies have less bandwidth capacity than higher frequencies. It means that signals that carry a lot of information (such as television, broadband or mobile phones) are better placed in the higher frequency bands while simple radio (audio) signals can be carried by the low frequency waves. Since low frequencies travel long distances but have less bandwidth capacity, placing one television channel (which uses a lot of bandwidth) in the UK in the lower frequency bands would mean that most of the Long Wave and Medium Wave radio services from Northern Europe to Sub-Saharan Africa would be squeezed out.

Once a radio signal has been transmitted, it has certain propagation characteristics associated with its frequency. Propagation describes the behaviour of a radio wave in spectrum. In different bands, waves have distinct abilities to hop, spread and penetrate. Certain waves can go through or bounce off walls or curve around corners better than others. Your mobile phone will probably work inside a building because its signal goes through windows, but you will generally need a rooftop aerial for your TV set to achieve good reception. Figure 3 describes the propagation characteristics of the radio frequency bands.

Frequency Band	**Propagation mode (the way radio waves spread in spectrum)**	**Coverage**
Very Low Frequency	On the ground	Long distances, e.g. for submarine communications and time code signals.
Low Frequency	On the ground and in the sky at night	Country wide. Some reduction of coverage at night due to reflections from the ionosphere.
Medium Frequency	On the ground and in the sky at night	Regions of a country. At night time, coverage is significantly reduced by signals reflected from the ionosphere.
High Frequency	Hopping between the ground and the sky	Long distance coverage to continents. A range of High Frequencies are needed to provide continuous coverage during the day and night and at different times of the year.
Very High Frequency	In line-of-sight, but for short periods, the wave enters the troposphere (the lowermost part of the Earth's atmosphere)	High power broadcasting stations provide coverage up to around 50 to 70 km radius. For short periods of time signals can propagate for long distances in the troposphere (the lowermost portion of the Earth's atmosphere) and cause interference between services on the same frequency.
Ultra High Frequency	In line-of-sight, and tropospheric for short periods	Similar range to VHF but requires many more filler stations to overcome obstructions to the signal arising from the attenuation of terrain features.
Super High Frequency	Between focussed points and in line-of-sight	Need a clear line-of-sight path as signals blocked by buildings or other objects. Ideally suited for satellite communications and fixed links where highly focused antennas (dishes) can be used or for short range coverage, e.g. inside buildings.
Extremely High Frequency	Between very focussed points and in line-of-sight	Short paths and no possibility for penetrating building walls.

Figure 3: Propagation characteristics of radio frequency bands

In order to understand how radio spectrum works, one more buzzword has to be remembered: modulation. Modulation is the actual process of encoding information in a radio signal by varying the characteristics (the amplitude, the frequency or the phase) of the radio wave. Simple examples of the resulting waves are illustrated in Figure 4.

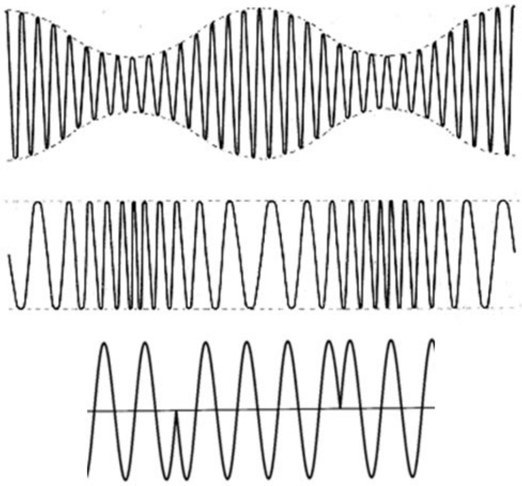

Figure 4: Types of radio wave modulation

Amplitude modulation (AM) has been used to generate carrier waves for AM radio stations which cover large areas. Radio 4 on long wave (LW), for instance, is carried by an amplitude modulated signal. Frequency modulation (FM) is used for FM broadcasting which provides better sound quality to AM radio but the signal does not travel as far as an AM signal.

Phase modulation (PM) and amplitude modulation is used to encode digital information (consisting of 0s and 1s) into radio signals. There are very complex advanced variants of these modulation techniques which allow for large amounts of digital data to be encoded or compressed into a signal.

International harmonisation

Radio waves do not respect international borders. Signals can cross boundaries easily. International harmonisation – to reduce the scope for unwelcome interference between one country and another – takes place at three levels:

- the International Telecommunications Union on a worldwide basis;
- the Conference of Postal and Telecommunications Administration (which brings together 46 countries) in Europe; and
- a bilateral country-by-country basis (for example, to ensure that transmitters in the South of England do not cause interference in France and ensure that French transmissions do not interfere with services in the South of England).

International harmonisation of spectrum bands for particular uses helps create valuable economies of scale. The scope to use mobile phones across the European Union, because of such harmonisation, improves the market for consumers. And harmonisation provides the prospect of a mass market, and lower prices, for receiving equipment.

A major international planning conference (often referred to as RRC-06) in the spring of 2006 agreed a harmonised plan (GE06) for digital terrestrial broadcasting in Bands III, IV and V for Europe, Africa and many other countries. Almost all of the spectrum requirements of each country were met.

Thus, so far as the UK was concerned, the frequency plans produced by the conference endorsed the UK's "digital switch-over plan" which is discussed later in this document. It also approved the use of some spectrum traditionally assigned to TV broadcasting for non-broadcast applications such as wireless broadband services.

Spectrum management in the UK

The radio spectrum is a scarce resource. Often compared to a piece of land, there are a limited number of services and uses that can be accommodated in any given part of the spectrum, even in the digital world. Just as farmers partition their land to achieve the best harvest in both volume and variety of produce, spectrum needs to be divided among potential users and different uses to ensure benefits to society.

If a user disrespects the partitioning in spectrum, the subsequent interference can make services provided by another user completely useless. Television viewers would not appreciate screens going bank while trying to watch their favourite series as a result of their neighbour having a mobile phone conversation.

National Governments carry out the more detailed planning of the spectrum. They decide how to partition the spectrum, whether on a national, regional or very local basis, and for how many years a licence should last. In the UK this work is now carried out by the Office of Communications (OFCOM).

In the past, the Government simply assigned spectrum to services, including radio and television, emergency and defence services. As more and more commercial services emerged (commercial radio, mobile telephony, private radio networks etc.), the Government had to look for a spectrum allocation mechanism to cater for competition for spectrum. Consequently, a selection system often referred to as "beauty contest" was followed to judge applicants against a set of criteria. The spectrum licence was awarded to the contender whom the Government judged most closely met the criteria.

In the 1990s, new legislation enabled the Government to introduce higher charges for spectrum which caused many existing tenants to hand back their licences. Where blocks of spectrum have been made available for new commercial services, auctions rather than "beauty contests" have become the norm to determine who wins. Most famously, in 2000, the winning bidders collectively paid £22 billion for 3G (Third Generation) mobile telecoms licences as a result of an auction.

Spectrum management is moving to a more liberalised world where the market can decide how spectrum is used and for what services. Critics of the planned approach argue that "technology neutrality" in spectrum allocation is a better guarantee for efficiency. "Technology neutrality" may one day become technically feasible. Today, however, the scope for any transmission to cause interference to other users reduces its potential. Some degree of planning is inevitable to ensure efficient use by different technologies and that social benefits are delivered by the use of this public resource.

Despite the move to liberalisation, government policy still plays a part in spectrum management decisions. National regulators need to take account of the technical options for deploying new technologies; the differing constraints on the design of appropriate transmitting or receiving equipment; the implications for the consumer (for instance, would it be reasonable to expect all users to have to purchase new equipment to receive a better service?); and government objectives in relation to public services that use the spectrum.

Difficult judgements are required to determine the right balance between public and private uses of spectrum. Commercial or private networks can potentially offer lucrative sums of money for spectrum that can be spent on other public causes by the Government, but there are also a number of public services that deliver benefits to the wider society with their use of the spectrum.

The Government has, for example, decided that digital terrestrial television, free at the point of delivery, must play a key role in driving the switch-over to full digital television broadcasting. Therefore, the digital terrestrial service has been launched in parallel with analogue television broadcasting to take the process forward. Many consumers invested in new set-top boxes and upgraded their aerial to receive Freeview.

Technology developments constantly increase the scope for more efficient use of the spectrum by improving encoding and error correction systems. Digital television channels, for instance, could be converted to a higher level of compression almost every few years. Although these solutions can potentially enable increased efficiency of spectrum use, the introduction of a new standard could also make existing receivers incompatible and therefore redundant.

Subscription networks could facilitate the change of receiving equipment more easily. If, for example, mobile service providers decided to switch technology, they could give incentives to consumers to change their phones to new ones that operate to the new standard. Similarly, when BSkyB launched its digital satellite broadcasting service on 1 October 1998, they managed to switch off their analogue signal within 3 years, on 27 September 2001, after facilitating rapid equipment change.

In the case of open access (public) networks, changing consumers' equipment can cause many problems. Free-to-air (including public service) broadcasters, for example, do not have the scope to ask users to change their set-top boxes every now and then. Most TV viewers expect their receivers to remain operational for many years. This is why even though plans for digital switchover for terrestrial broadcasting were first announced in September 1999, the process will take until 2012 to be completed.

Subscription networks could also choose to acquire spectrum according to what they judge commercially lucrative. They can opt for licences that fit their business plan and might choose not to cover certain areas of the country. A commercial television service provider might opt for delivery platforms that are commercially suitable. Public service broadcasters in the UK, in contrast, are mandated by the Government to maintain free-to-air terrestrial broadcasting and PSBs on Freeview are obliged to cover at least 98.5% of the UK population.

The Government also makes spectrum available for unlicensed use. WiFi, the broadband wireless access technology, walkie-talkies, remote controls or other wireless equipment in the household, cordless microphones at pop concerts and theatres operate in unlicensed spectrum. It means that you don't have to apply for a licence to plug in your wireless headphones at home or your Bluetooth enabled mobile phone headset while you are on the move. These devices emit a low-power signal that covers a very small area and therefore are not likely to cause interference with other similar devices.

However, unlicensed use of spectrum does not mean that someone can set up any service in that spectrum space. It is allocated to specific equipment and specific use.

Many users – especially wireless broadband communities – advocate the increase of unlicensed spectrum to accommodate future demand.

For some years to come, spectrum management is likely to combine and balance three allocation mechanisms: a competitive market based approach; assignment for public purposes; and allocation for unlicensed use.

Analogue to digital – making more room in spectrum

Advanced farming technologies open up the potential for a better harvest on the same size plot or for the cultivation of previously unused land. Similarly, new technologies and constantly improving compression techniques make room for a better 'harvest' with more communications services reaching more consumers.

It is difficult to describe the "size" of the spectrum that is becoming available in the UK. Different parts of the spectrum accommodate different technologies in different ways. Generally, spectrum scarcity of the analogue-only world is diminishing but not completely disappearing for the time being.

Some industry forecasters predict the creation of the "spectrum commons" where ubiquitous communication systems operate using cognitive or "smart" receivers which are able to distinguish and decode the different signals they receive using their propagation properties as identification tags. Spectrum scarcity would completely disappear and spectrum licensing would become redundant in this “utopian dream”. At the moment, however, spectrum use is still heavily regulated to avoid chaos in the airwaves.

The terms “digital spectrum” and “analogue spectrum” often come up in debates and conversations but these words are somewhat misleading. There is just one kind of spectrum that can be used to provide both analogue and digital services. When people talk about “digital spectrum”, what they really mean is spectrum used by digital technologies.

How many digital services can be fitted in the spectrum? This question is difficult to answer. It is like asking a farmer how many plants he can fit on his land. It depends if he wants to plant beetroot, raspberries or plum trees.

In analogue broadcasting, picture and sound information are carried by fluctuating radio signals and a receiver converts these fluctuations back into sound and picture. In digital broadcasting, information is transformed into digits (1s and 0s) and is carried by a radio signal to a receiver that can reproduce the original information by decoding this numerical chain. Digital compression technologies and coding systems make it possible to squeeze much more information into a radio signal than in the case of analogue technology.

A digital television multiplex – a machine which encodes, combines and transmits several TV programme channels in a single broadcast signal – takes up 8MHz bandwidth just like an analogue television channel. The difference is that, using digital compression technology, this one signal can carry the picture and sound information of not just one, but several television programme channels. That means that more television services can be provided using the same amount of spectrum as compared to analogue broadcasting.

This, however, does not mean that demand for spectrum is diminishing. There are many service providers who are eager to launch new services in the spectrum that is becoming available. Some of these new technologies, like broadband wireless access services or High Definition Television (HDTV) could prove to be quite intensive users of spectrum. While digitalisation definitely provides the foundation for more efficient use of spectrum, the room that is to be freed by analogue switch-off could potentially become very crowded indeed.

Spectrum availability

Spectrum that can be used in new and innovative ways is regularly becoming available as new technologies make more efficient use of the spectrum and obsolete technologies free up spectrum space.

Change is taking place in various frequency bands, although in some cases, analogue and digital technologies will co-exist for quite some time.

The **Low Frequency (LF), Medium Frequency (MF) and High Frequency (HF)** broadcasting bands (below 30 MHz) are still used in much the same way as they always have been since the birth of radio broadcasting over 80 years ago for Long Wave (LW), Medium Wave (MW) and Short Wave (SW) analogue broadcasting. BBC Radio 4 is still being broadcast on LW and BBC World Service programmes are distributed on SW in the HF band. But, also in the HF band, a growing number of transmissions are being established in digital (DRM) format, primarily for international broadcasting. In the MF band, a limited range of frequencies are available for local analogue Medium Wave (MW) radio services.

A part of the **Very High Frequency (VHF)** band is used intensively for FM sound broadcasting in most countries and planning of new analogue services is still being carried out. There are a limited number of frequencies available for regional, local and community stations. Currently the re-allocation of this spectrum for digital services is difficult to envisage. In the longer term, digital services such as DRM+ Digital Radio could use this band, but the technology has not yet been fully tested.

The ongoing debate about spectrum availability in the UK is focussing on a "sweetspot" where most modern communication technologies such as DAB Digital Radio, digital television, 3G mobile phones and WiFi wireless Internet access services operate. The sweetspot, in fact, is the upper part of the Very High Frequency (VHF) band and the whole of the **Ultra High Frequency (UHF)** band, incorporating frequencies from around 200 MHz to 3 GHz as illustrated in Figure 5.

The top end of the VHF band (known as Band III) is used for DAB Digital Radio Broadcasting. A total of seven frequency blocks are currently used here for two national and 46 local and regional DAB multiplexes. Four additional frequency blocks have been recently advertised for licensing.

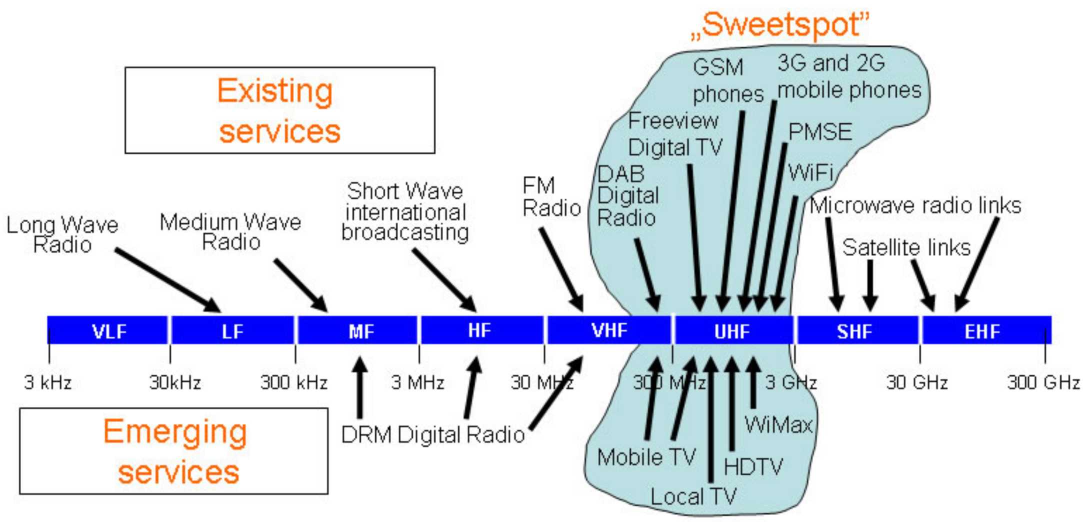

Figure 5: The "sweetspot" in the radio spectrum

The UHF band includes four named sub-bands: Band IV, Band V, L-band and S-band as shown in Figure 6. These sub-bands also differ from each other in certain characteristics and uses are not necessarily inter-changeable between them.

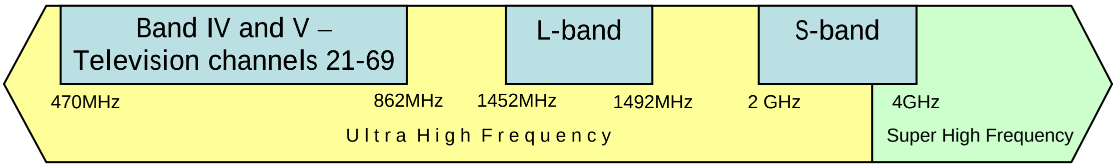

Figure 6: Sub-bands in the Ultra High Frequency Band

UHF Band IV/V is divided into 49 channels. 46 of them are currently used for both analogue and digital television broadcasting. After digital switch-over, the six existing television multiplexes will occupy 32 channels. The "digital dividend", the spectrum to be afforded by analogue switch-off will be equivalent to 14 spectrum television channels, each containing 8 MHz bandwidth. The total spectrum becoming available during the digital switch-over process from 2008 through to 2012 will be 14 x 8 MHz = 112 MHz. Figure 7 shows what will become available in Band IV/V after digital switch-over.

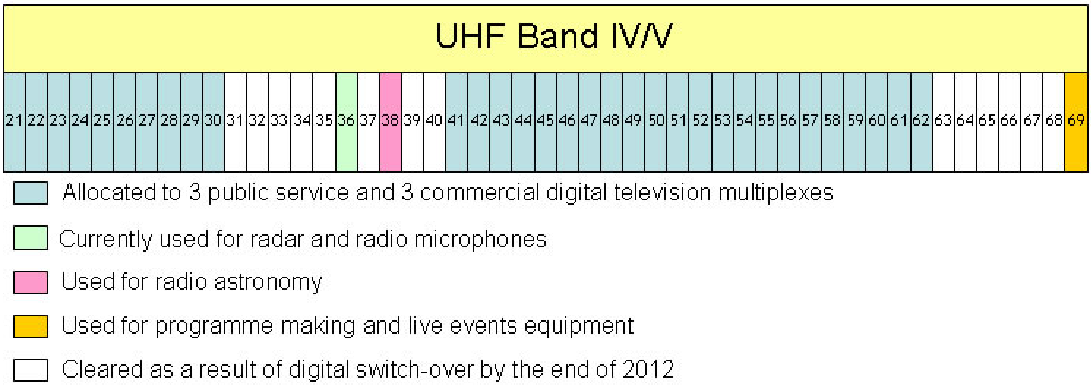

Figure 7: Spectrum availability in UHF Band IV/V

Public attention heavily focuses on the "digital dividend" as it can host a number of new and innovative services such as High Definition Television, mobile TV or broadband wireless access services. OFCOM is currently undertaking research to define the possible uses of the "digital dividend" and is examining options to make some of the released spectrum available for other uses on a rolling basis region by region from 2008, the start of the switch-over process.

Some other parts of the spectrum will become available sooner. The L-band, expected to be awarded in 2007, is an interesting possibility for multimedia services such as mobile TV or wireless internet access as there would be scope for harmonisation of this band at pan-European level.

UHF Channel 36 (currently used for radar and radio microphones) is being considered to be released for other uses. Potential contenders for this spectrum could be mobile TV, broadband wireless access and terrestrial digital broadcast services.

OFCOM has also published a consultation on awarding licences for frequencies at 10 GHz, 28 GHz and 32 GHz in 2007. These frequencies could possibly be used for wireless programme making equipment or for high-speed data connections for mobile and fixed broadband networks.

A list of spectrum bands that are becoming available in the UK over the next few years can be found in Appendix B.

New and emerging technologies explained

There are many services that could use newly available spectrum. Before considering deployment options, it might be useful to describe the technologies that underpin them.

Digital terrestrial television (DTT): DTT services are broadcast by multiplexes that encode picture and sound of several TV programme channels and some interactive information services in one signal. The signal is then decoded by either an Integrated Digital Television (IDTV) set or a set-top box (e.g. Freeview) connected to the TV set. The technology is called Digital Video Broadcasting Terrestrial (DVB-T).

There are three public service and three commercial multiplexes serving the UK. Just like an analogue television channel, a multiplex requires 8 MHz-wide spectrum channels. However, using just one 8 MHz-wide channel, several Standard Definition Television (SDTV) programme channels can be provided to the public on each of the six multiplexes. This is what you see on your screen today, for instance, through your Freeview box.

The precise number of TV channels in a multiplex depends on the transmission mode employed, the range of services to be accommodated and the desired level of picture quality. Some DTT multiplexes have 10 video channels in them, but the pictures look less than ideal, especially on big screens. Some multiplexes host only four SDTV channels and the pictures look great.

High Definition Television (HDTV), which has not yet been introduced on Freeview, offers an enhanced viewing experience with sharper picture quality and improved sound. It is ideal for over 30-inch big screens. Importantly, HDTV is much more demanding of spectrum – it could take up nearly three times the data transmission capacity requirement of SDTV.

HDTV services are already available in many countries, including Japan, South Korea, France and USA. Most HDTV channels are carried on satellite platforms at the moment and some of them are provided as a premium service. Free-to-air broadcasters are seeking to launch their HDTV services on terrestrial platforms such as Freeview.

Local television: There is growing interest among companies in providing local TV services, either across a conurbation or in very localised areas.

Local TV services could have two technical options for delivery on digital terrestrial broadcasting platforms.

First, they might acquire space on a regional multiplex transmitter. National DTT networks use a number of regional transmitter sites to achieve UK-wide coverage and some spare capacity might be available on some of these. However, so far these multiplexes have tended to operate at full capacity and the scope for regional "add ons" to serve local TV interests may not be great.

The second option is to take advantage of "interleaved spectrum" which might be available in the area they wish to cover. "Interleaved spectrum" is the by-product of national networks that use several 8 MHz-wide channels in the UHF Band IV/V to cover the UK. Some of these channels might be not used in certain areas and could be allocated to low-power local TV multiplexes. One interleaved channel could provide two programme channels. The signal would be sufficiently rugged in the local area and would be automatically picked up by Freeview boxes.

Mobile telephony: Mobile phones, the most successful communications development of our times, occupy various parts of the spectrum. Thus, "2G" (Second Generation) phones – the standard mobile phone – operate just under the 1GHz and around the 1.75 GHz band. The increasingly popular "3G" (Third Generation) phones operate around the 2GHz band. In addition, mobile expansion bands have been allocated in other parts of the spectrum to allow the delivery of additional services by mobile.

Mobile TV: A potentially important innovative service, mobile TV would enable users to watch TV wherever they want. Already there are several different standards which will be vying for market success. For instance:

Mobile TV on DAB-IP (like BT Movio) has already been tried in the UK for Windows Mobile-based Smartphones. These phones are enabled with Digital Audio Broadcasting Internet Protocol (DAB-IP) technology, using "3G" mobiles as platform.

"3G" mobiles themselves might provide a platform for mobile TV services, though transmission capacity problems could be formidable. The mobile operator Hutchinson 3G UK Ltd. has already made TV services available on mobile phones.

Digital Video Broadcasting Handheld (DVB-H) is a more robust means of getting TV content to the user. It might provide up to 20 programme channels in an 8 MHz spectrum channel.

Qualcomm MediaFLO is an American standard for mobile TV that is being tested by BSkyB in the UK. It works similarly to DVB-H.

Digital Multimedia Broadcasting Terrestrial (DMB-T), delivered on the DAB Digital Radio platform, can also provide mobile TV.

It might sound a bit confusing that digital radio platforms can deliver television or video services. But the nature of the digital signal is that it can carry practically any information on any platform if the receiver is designed to process that information.

WiMax (Worldwide Interoperability for Microwave Access): Regarded as a revolutionary technology for internet wireless access, WiMax, in theory, could provide the service up to 30 miles from the base station. The technology has several standards. The latest one is designed for a theoretical connection speed of up to 75 megabits per second. WiMax can utilise a wide range of spectrum bands from 2 to 66 GHz and can take up channels of varying bandwidth from 1.25 MHz to 20 MHz.

Currently there is no standard for WiMax below 1GHz but it is likely that one will be developed soon as this is seen to be attractive for providing services to rural locations.

DAB Digital Radio: Launched by the BBC in 1995, DAB Digital Radio is now a rapidly growing service in the UK. Several technical standards exist for this technology, but in Europe, the Eureka 147 T-DAB system has prevailed. For listeners, it means that a digital radio set purchased in the UK can also be used in any other country where digital radio is provided in the Eureka 147 format.

These services are broadcast by T-DAB terrestrial multiplexes – transmitters that combine a number of radio stations in one signal. There are two national (BBC and Digital One) and a number of local multiplexes in the UK.

Each multiplex occupies 1.7 MHz of bandwidth and the use of single frequency network (SFN) configurations means that only one frequency block is necessary to provide UK-wide coverage of the BBC's national radio services. The number of radio stations that a multiplex can carry depends on the sound quality expected of each station. As a general rule, around nine radio stations at a joint stereo bit rate of 128 kilobit per second can be accommodated on a single multiplex. DAB can also carry video channels for small handheld screens.

Digital Radio Mondiale (DRM) is the digital technology for Short Wave (SW) international radio broadcasting in the High Frequency band, but trials have also taken place for the Medium Frequency band. SW signals can reach large distances but reception is usually poor.

DRM offers a dramatic enhancement in sound quality, and mitigates the effects of audible interference from other stations. It is also designed to make receiver operation more user-friendly. DRM promises to re-invigorate the use of the Low, Medium and High Frequency Bands. New digital radio receivers are under development to combine both DAB and DRM reception, so one radio set would be capable to pick up local digital radio signals as well as signals coming from Italy, Mexico or even China.

Another version of this technology, called DRM+ is under development for VHF Band II which has traditionally been used by FM radio.

PMSE: The abbreviation stands for Programme Making and Special Events equipment that are used at concerts, theatres, and filming, recording and live broadcasts. These include cordless microphones, cameras and other cordless devices.

These devices can operate in various spectrum bands and can be interleaved between existing other services due to their low radiated power, thus making efficient use of the spectrum. Their signal reaches just a few meters, with very little chance to interfere with other similar devices. However, they still need their well defined spectrum space so that other technologies do not interfere with them.

Further into the future, ***Software Defined Radio (SDR) and Cognitive Radio (CR)*** might be very attractive both to users and spectrum planners. These are not radio sets, but technologies that would combine several services that use radio waves. SDR users would simply request a service through the device which would then negotiate with the network to identify the most appropriate frequency for that service.

Cognitive radio would have the additional ability to recognise and distinguish signals, making spectrum practically abundant. Again, this technology is still in infancy.

Competition or co-habitation?

Just as certain types of plants are best grown on particular types of soil, not all technologies are suited to all frequency ranges. Certain services may be more suitable for particular frequency bands. This may be because

- different services have different needs. Broadcasting, for instance, is a one-way communication: the transmitter sends a signal to the receiver. Mobile phones or WiFi devices have to “talk back” to the base station to upload as well as download information, so they need frequencies to enable this two-way communication to take place.

- the propagation is different in each frequency band. Higher frequencies can provide more rugged signals for mobile communication devices than lower frequencies. Mobile phones usually work on trains or inside buildings due to the construction of dense base station networks which are needed to provide the link from the low power mobile phone to the base station. Try to use an FM radio on a train; it probably won’t work very well because the metal structure of the carriage blocks the FM signal.

- different constraints exist on transmitter and receiver equipment design. Bigger antennas are needed to receive the signal on lower frequencies while higher frequency signals can be detected by smaller antennas. Think of your FM kitchen radio or your HiFi set at home which needs a fairly long antenna (some times the rooftop aerial has to be plugged into the HiFi) to get good reception. Early GSM mobile phones also needed extendable antennas. Your 2G or 3G mobile phone, on the other hand, operates with a very small antenna; you can’t even see it as it is hidden inside the phone.

- moving a service from one band to another might require users to re-tune or to change the receiving device. This could undermine the sustainability of the service given the vast quantities of TV and radio receivers in people’s homes.

- different international co-ordination puts constraints on different bands. (As discussed earlier in this paper.)

These considerations influence the way in which different technologies are deployed. Nevertheless, some technologies have more possible outlets than others. Figure 8 indicates the different bands that could, in theory, be used to deliver a range of services.

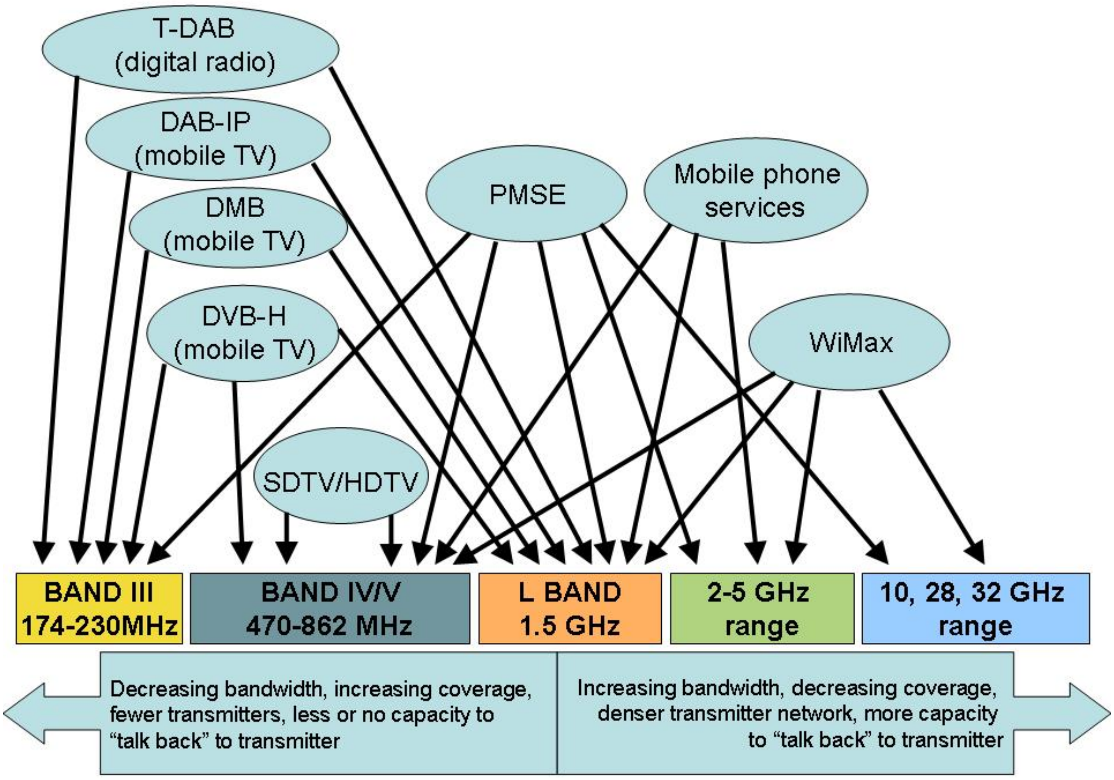

Figure 8: Alternative frequency bands for digital technologies

Mobile TV technologies can be deployed in several bands. DAB-based services have been optimised for Band III or the L-band, while DVB-H is designed to operate in Band III, IV and V or even the L-band. Companies wishing to provide such services will have to examine their options carefully regarding both the technologies and the bands. Acquisition of spectrum in more heavily used bands, like Band IV/V could prove too costly to make it an affordable service.

DAB-based mobile TV services can co-exist with radio services on national, regional and local T-DAB multiplexes. They operate in Band III at present, and some capacity might be available for mobile TV on the existing multiplexes. Further spectrum in Band III will be awarded by Ofcom in the near future which could be sufficient for a third national DAB multiplex. It could be used for both radio and mobile TV services.

Some DVB-H mobile TV services could be accommodated in Band IV/V. For example, Channel 36 (currently used for radar and radio microphones) could be assigned to mobile TV as well as a few other channels which will be available as part of the "digital dividend" after digital switch-over. Channel 36, however, might be problematic to co-ordinate with neighbouring countries as they might also seek to introduce new high-power assignments in that channel, limiting its use within the UK. Television broadcasters might also be strong contenders for these channels as SDTV and HDTV services have no other deployment options outside Band IV/V.

Local TV providers could put further demand on Band IV/V as they can operate in the spectrum interleaved regionally between the channels used by national DVB-T television multiplexes. But interleaved spectrum could also be used to enable Programme Making and Special Events (PMSE) equipment and WiMax broadband wireless access services to operate in Band IV/V.

WiMax providers might seek to secure channels in Band IV/V for broadband wireless access services. Here, however, there has to be a trade-off between how many users can be supported in a cell, the available data transfer rate and the number of network providers. Although the use of Band IV/V could make the coverage area (the cell size) bigger, due to these constraints, channels in this band might only be required as a way of delivering WiMax services to remote rural communities where the number of users per cell could be relatively small. Indeed, the proponents of WiMax systems seem to be favouring higher frequencies such as the 2.5 and 3.5 GHz or the 10, 28 and 32 GHz bands (the latter bands only support short range indoor reception).

Mobile phone services could also use Band IV/V and some service providers are interested in this band, particularly for providing coverage in rural areas. However, there are compatibility issues concerning sharing with broadcasting services and these would need to be studied. There is also a 190 MHz expansion band at 2.5 GHz which is harmonised throughout Europe for mobile phone services.

The L-band (also known as the 1.5 GHz band) can support a number of different approaches. Propagation in this band could provide better conditions for mobile users. Radio signals in L-band go through windows and can benefit from reflections, particularly in built up areas, so they can reach receivers “on the move” (on trains, buses etc.). But the networks would require more transmitters therefore infrastructure could involve higher costs.

Current European frequency plans harmonise the use of the L-band for DAB technology which supports both radio and mobile TV services. In the UK, T-DAB is presently placed in Band III, but several countries including France, Germany and the Czech Republic operate T-DAB in the 1.5 GHz band, although this has not yet proved to be a great success.

Regulators, however, seem to be open to the idea to change international harmonisation rules in the future and allow technologies such as DVB-H, DMB-T (mobile TV) and WiMax to use this band. Further technical research might be necessary to establish the feasibility of these services in the L-band.

Competition for spectrum seems to be inevitable as market players try to capture opportunities to launch new services. Alternative deployment solutions for various technologies might ease the demand for spectrum in certain frequency bands. Band IV/V could offer more spectrum after digital switch-over than any other band but the demand for additional SDTV and HDTV services could be high. The level of consumer demand and viable business models would have to be established for new services such as mobile TV and broadband wireless access before their need for spectrum can be assessed with confidence. Some degree of planning could mitigate these uncertainties and encourage the development and co-existence of innovative services.

For information, the capacity achievable for some technologies in Band IV/V is set out in Appendix C.

Conclusion

Deploying technologies in spectrum is a complex decision that takes many different factors into account. Technology design, efficient use of bandwidth, availability of spectrum for alternative deployment options, the cost of acquiring spectrum, end user demand, availability of receiver equipment, investment in infrastructure and many other technical and market conditions have to be examined to make appropriate judgement.

The scope for new services to be made available in many parts of the spectrum is exciting. But that adds to the challenges facing those responsible for national spectrum planning.

How should national regulators balance the advantages and disadvantages of:

(i) requiring that certain services are provided in those parts of the spectrum which, in technical terms, would be the most appropriate;

(ii) allowing the market, rather than the planners, to determine our future uses of the spectrum; and

(iii) meeting Government objectives to provide public services to consumers in a way which allows them to be received universally on the existing base of consumer equipment?

If regulators preferred market forces to determine how spectrum should be used, how should they take account of the social value of certain services – broadcasting is a classic example – whose value to society cannot be set entirely in financial terms?

Spectrum scenarios can be developed for the time after analogue broadcasting ends which would provide scope for, say, 60 mobile TV services to co-exist with extra capacity for the Programme Making and Special Events community as well as for the introduction of High Definition TV services by broadcasters. But the implementation of such scenarios requires a level of Governmental planning that advocates of market forces would regret.

And planning of that kind involves a risk in itself. How can spectrum planning at a national level take account of innovation – indeed, of services that, today, do not exist? We live in a world still driven by Moore's Law (in the 1970s Gordon Moore forecast that the processing power of computers would double every two years). iPods and WiFi, growing in use so quickly today, were virtually unknown six years ago. How quickly will WiMax become standard? What new services will take over the world by the time that analogue broadcasting ends in six years' time?

Critics of the national planning of spectrum argue that "technology neutrality", supported by the introduction of spectrum trading so that companies could buy and sell spectrum in an open market, provides a more satisfactory way forward. Pure "technology neutrality" may one day be technically feasible. Today, however, technical constraints and interference concerns reduce its potential – indeed, it makes it impossible for spectrum channels to be used differently overnight. Not least, because in the case of universally receivable public services any move to new standards needs to be done in a co-ordinated way – as with digital television switchover – to ensure continued access to those services. Until "technology neutrality" is a reality, the national planners will have to face their dilemmas.

APPENDIX A
The Radio Spectrum

Band name	Frequency	Wavelength	Uses
Extremely low frequency	3–30 Hz	100,000 km – 10,000 km	Communication with submarines
Super low frequency	30–300 Hz	10,000 km – 1000 km	Communication with submarines
Ultra low frequency	300–3000 Hz	1000 km – 100 km	Communication within mines
Very low frequency	3–30 kHz	100 km – 10 km	Submarine communication, avalanche beacons, wireless heart rate monitors
Low frequency	30–300 kHz	10 km – 1 km	Navigation, time signals, AM long wave broadcasting
Medium frequency	300–3000 kHz	1 km – 100 m	AM medium-wave broadcasting
High frequency	3–30 MHz	100 m – 10 m	Shortwave broadcasting and amateur radio
Very high frequency	30–300 MHz	10 m – 1 m	FM and television broadcasting
Ultra High Frequency	300–3000 MHz	1 m – 100 mm	television broadcasts, mobile phones, wireless local area networks (WLAN), ground-to-air and air-to-air communications
Super High Frequency	3–30 GHz	100 mm – 10 mm	microwave devices, mobile phones (W-CDMA), WLAN, most modern radars
Extremely High Frequency	30–300 GHz	10 mm – 1 mm	Radio astronomy, high-speed microwave radio relay
	> 300 GHz	< 1 mm	Night vision

For more information on frequency bands, see Wikipedia article on Radio frequency at http://en.wikipedia.org/wiki/Radio_spectrum

APPENDIX B
Available spectrum

Band	Amount available	Potential uses	Status
56-68 MHz	8 MHz	Radio Restricted Services Land mobile PMSE*	Consultation closed in July 2006
412-415 MHz paired with 422-424 MHz	4MHz	CDMA** TETRA*** PMSE*	Provisional application date set
470-862 MHz ("digital dividend")	112MHz	SDTV/HDTV**** Mobile TV Broadband Wireless Access PMSE*	In preparation (consultancy work)
872-876 MHz paired with 917-921 MHz	8MHz	Public mobile radio (e.g. walkie-talkies) Fixed Wireless Access Mobile data or voice services PMSE*	Consultation closed in June 2006
1452-1492 MHz (L-band)	40MHz	Digital radio Mobile TV Broadband Wireless Access PMSE*	Consultation closed in June 2006
1785-1805 MHz (Ireland and Northern Ireland)	20 MHz	PMSE* Mobile technologies Fixed links Broadband Wireless Access	Consultation closed in March 2006
2010-2025 MHz	15MHz	Cellular mobile Broadband Wireless Access PMSE* Mobile multimedia ENG/OB*****	In preparation (consultancy work)
2290-2302 MHz	12MHz		
2500-2690 MHz	190MHz		
10GHz	12 licences to be offered.	PMSE* Broadband Wireless Access Satellite links	Consultation closes in September 2006
28GHz			
32GHz			
40GHz			

Source: OFCOM/BBC Spectrum Planning
*Programme Making and Special Events equipment (radio microphones, radio cameras, etc.)
**Terrestrial Trunked Radio (TETRA) is an open digital standard for professional mobile radio communications used by police, emergency and security services.
***CDMA is a form of multiplexing used by services such as mobile telephony or global positioning systems
****Standard Definition and High Definition Television
*****Electronic Newsgathering and Outside Broadcast equipment (subject to a rolling 3 month notice period from January 2007 onwards).

APPENDIX C
Possible technologies in UHF Band IV/V

Technology	Number of services or capacity in an 8MHz-wide Band IV/V channel	Reception mode	Average transmitter power	Diameter of area covered	Possible number of users in the coverage area
Standard analogue television	1 TV programme channel	Fixed	300 kW	100 km	Average 1 million (11 million for London)
Digital SDTV	One multiplex can accommodate at least 4 TV programme channels or a number of services (TV, radio and interactive). The exact quantity depends on the transmission mode employed and the range of services	Fixed reception but also portable reception within a reduced coverage area	70 kW	100 km	Average 1 million (11 million for London)
Digital HDTV	1-2 TV programme channels at present, but possibly 3 channels by 2012 due to anticipated improvement in compression technology	Fixed	70 kW	100 km	Average 1 million (11 million for London)
Mobile TV	20 TV programme channels for small screens	Mobile	8 kW	~5/10 km outdoors/indoors Coverage can be much larger for single frequency network of transmitters (SFN)	Thousands
WiMax (Concept only)	System not yet specified for frequencies below 1 GHz but 1 to 10Mb/s data transfer capacity achieved in current trials	Nomadic/ Portable/ Full Mobility	Not tested but perhaps ~1 kW	Similar to mobile TV (5-10 km) for mobile reception. Longer distances for fixed reception.	The more users connect to the service, the slower the connection gets
PMSE	10 Radio Microphones 10 Talkback Systems 1 Digital Radio Camera	Fixed/Mobile	Various: 10 mW 100 mW 1 Watt	30 to 200 meters. These distances can be significantly reduced where building attenuation applies e.g. between studios	Large numbers of devices can be used in an interleaved TV channel due to the low power.

Source: BBC Spectrum Planning