

A simple guide to

Radio spectrum

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BBC

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 as these new services are developed. Furthermore, radio waves do not respect international borders, buildings or each other. International harmonisation is needed for each spectrum band.

Recent years have seen a distinct move by the Government towards the use of market forces, for example through the auctioning of spectrum. 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?

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 television, 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 needs 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 in 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.

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, 1 GHz (gigahertz) means one billion waves per second and so on.

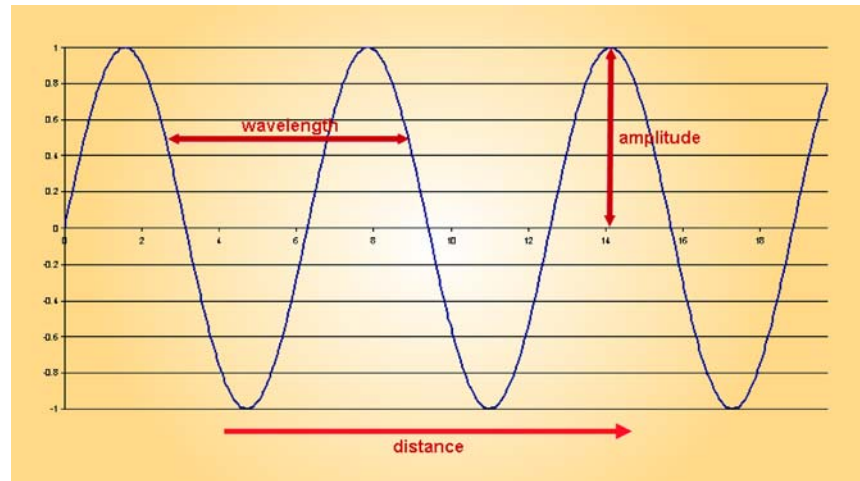


Figure 1
The electromagnetic wave

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 *radio waves*, generated by transmitters and received by antennas or aerials.

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 *Fig. 2*. *Appendix A* lists all the radio frequency bands and their general uses.

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 the spectrum. For example, an FM radio station might broadcast on a frequency of 92.9 MHz but requires a bandwidth of 0.3 MHz (300 kHz) – the spectrum between 92.8 and 93.0 MHz inclusive. Other stations cannot broadcast on these frequencies within the same area without causing or receiving interference.

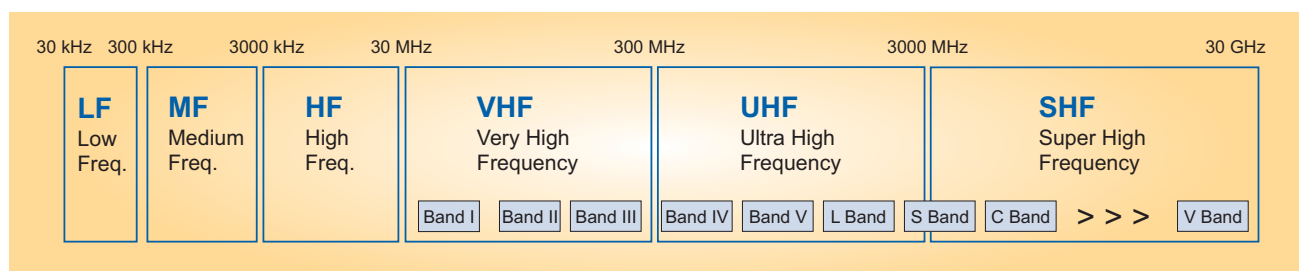


Figure 2
Frequency bands and sub-bands

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 in many parts of the world is 8 MHz in UHF Band IV/V. The bandwidth requirement of an analogue television programme channel is the same as the bandwidth of one spectrum television channel, i.e. 8 MHz.

Lower frequencies have less bandwidth capacity than higher frequencies. This 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 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. *Table 1* describes the propagation characteristics of the radio frequency bands.

Table 1
Propagation characteristics of radio frequency bands

Frequency Band	Propagation mode (the way radio waves spread in spectrum)	Coverage
Very Low Frequency	Over the ground	Long distances, e.g. for submarine communications and time code signals.
Low Frequency	Over the ground and in the sky at night	Country-wide. Some reduction of coverage at night due to reflections from the ionosphere.
Medium Frequency	Over 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	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 and cause interference between services on the same frequency.
Ultra High Frequency	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 attenuation caused by terrain features.
Super High Frequency	Between focussed points with a line-of-sight	Needs a clear line-of-sight path as signals are 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 with a line-of-sight	Short paths and with no possibility for penetrating building walls.

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 *Fig. 3*.

Amplitude modulation (AM) is used to generate carrier waves for AM radio stations which cover large areas. Radio services on long and medium waves (LF/MF), are 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.

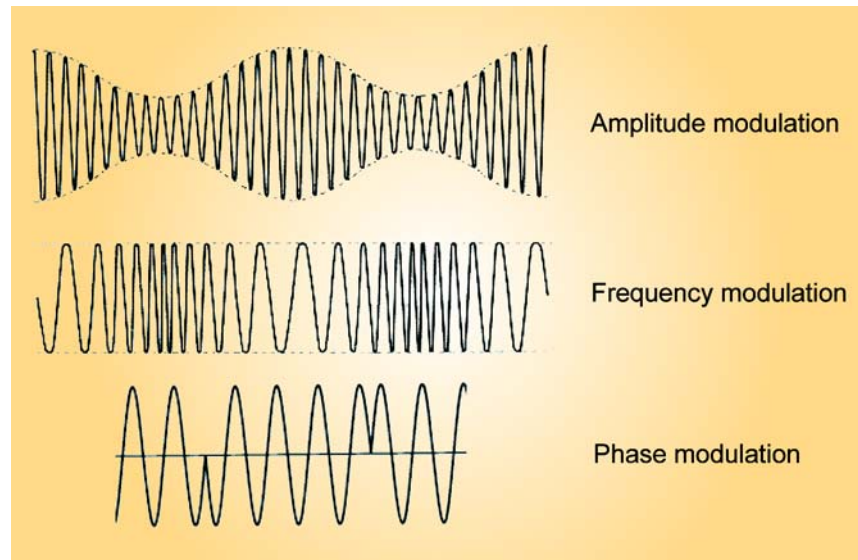


Figure 3
Types of radio wave modulation

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 Telecommunication Union on a worldwide basis;
- the Conference of Postal and Telecommunications Administration (CEPT which brings together 47 countries) in Europe and, to some extent, the European Commission;
- a bilateral country-by-country basis

International harmonisation of spectrum bands for particular uses helps create valuable economies of scale. Harmonisation provides the prospect of a mass market with lower prices for the receiving equipment.

A major international planning conference (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.

As far as the UK was concerned, the frequency plans produced by the conference endorsed the UK's "digital switchover plan" which is discussed later in this article. It also approved the use of some spectrum traditionally assigned to TELEVISION broadcasting for potential use by other non-broadcasting 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 blank 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 UK Government 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 a “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 some 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 to be 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.

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.

Abbreviations

CEPT	<i>Conférence Européenne des Postes et Télécommunications</i> (European Conference of Postal and Telecommunications Administrations)	DVB	Digital Video Broadcasting http://www.dvb.org/
CR	Cognitive Radio	DVB-H	DVB - Handheld
DAB	Digital Audio Broadcasting (Eureka-147) http://www.worlddab.org/	DVB-T	DVB - Terrestrial
DMB	Digital Multimedia Broadcasting http://www.t-dmb.org/	ITU	International Telecommunication Union http://www.itu.int
DMB-T	DMB - Terrestrial	PMSE	Programme-Making and Special Events
DRM	Digital Radio Mondiale http://www.drm.org/	SDR	Software Defined Radio
		SFN	Single-Frequency Network
		T-DAB	Terrestrial - DAB

The UK Government has, for example, decided that digital terrestrial television, free at the point of delivery, must play a key role in driving the switchover 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 the new services known as *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 two or three years. Most television 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 these broadcasters 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 the 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 after analogue switch-off. Different parts of the spectrum accommodate different technologies in different ways. Generally, the 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 the 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 television programme channels in a single broadcast signal – takes up 8 MHz 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 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, for example, 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 interna-

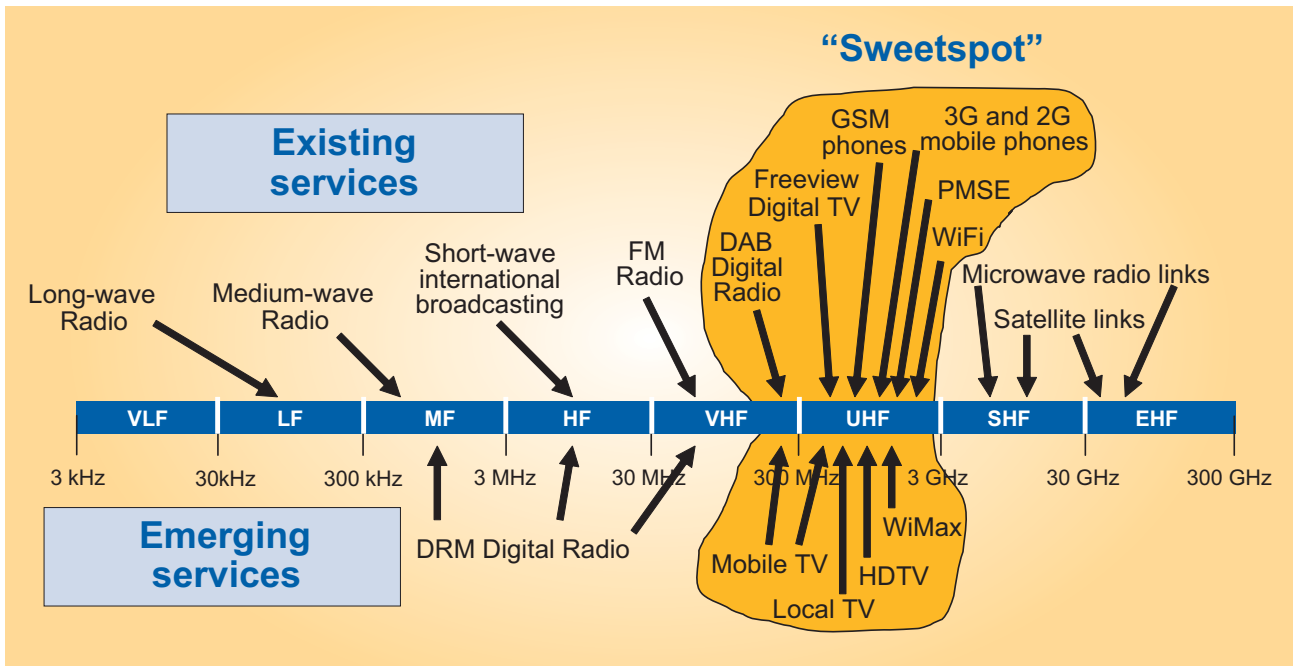


Figure 4
The “sweetspot” in the radio spectrum

tional 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-Plus 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 *Fig. 4*.

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 will shortly be advertised for licensing.

The UHF band includes four named sub-bands: Band IV, Band V, L-band and S-band as shown in *Fig. 5*. These sub-bands also differ from each other in certain characteristics, and uses are not necessarily inter-changeable between them.

UHF Band IV/V is divided into 49 channels. 46 of them are currently used for both analogue and digital television broadcasting in the UK. After digital switchover, 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 switchover

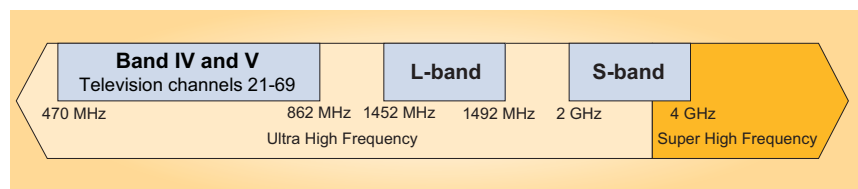


Figure 5
Sub-bands in the Ultra High Frequency Band

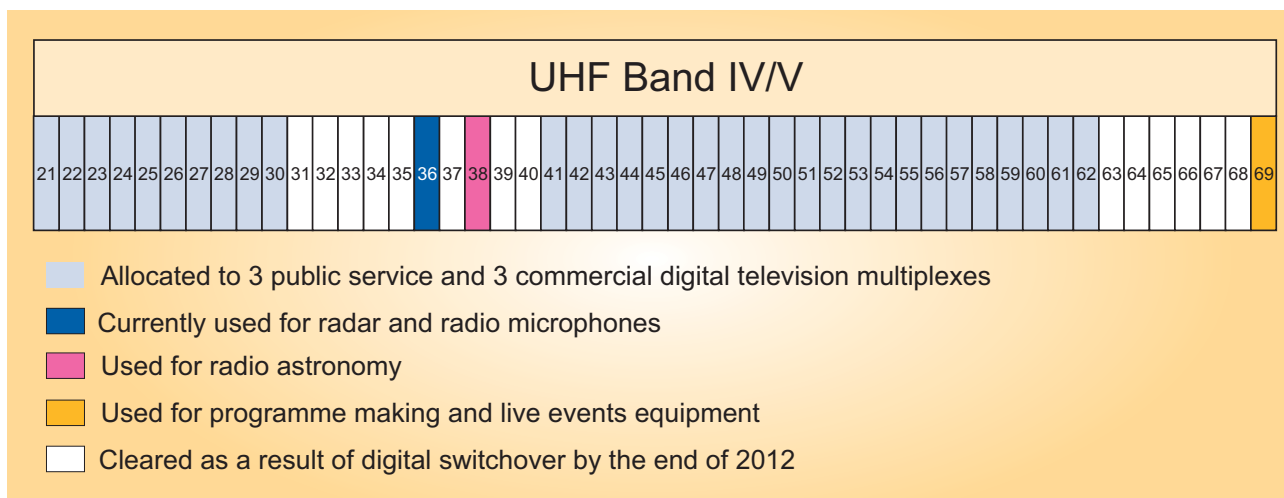


Figure 6
Spectrum availability in UHF Band IV/V

process from 2008 through to 2012 will be $14 \times 8 \text{ MHz} = 112 \text{ MHz}$. Fig. 6 shows what will become available in Band IV/V after digital switchover.

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 television 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 switchover 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 television or wireless internet access, as there would be scope for harmonisation of this band at a 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 television, 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.

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 recognize 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 to get good reception (sometimes a rooftop aerial has to be plugged into the HiFi). Early GSM mobile phones also needed extendable antennas. Your 2G or 3G mobile phone, on the other hand, operates with a very small antenna; in those cases 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 television 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. *Fig. 7* indicates the different bands that could, in theory, be used to deliver a range of services.

Mobile television technologies can be deployed in several bands. DAB-based services have been optimized for Band III or the L-band, while DVB-H is designed to operate in Bands 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 television 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 television 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 television services.

Some DVB-H mobile television services could be accommodated in Band IV/V. For example, in the UK, Channel 36 (currently used for radar and radio microphones) could be assigned to mobile television as well as a few other channels which will be available as part of the "digital dividend" after digital switchover. 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 television 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 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.

PMSE¹ is an important application for broadcasters who require good communications facilities at concerts, theatres, film and recording sets and for live broadcasts. PMSE equipment includes 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.

1. Also known as SAB/SAP (services ancillary to broadcasting and programme making) in Europe

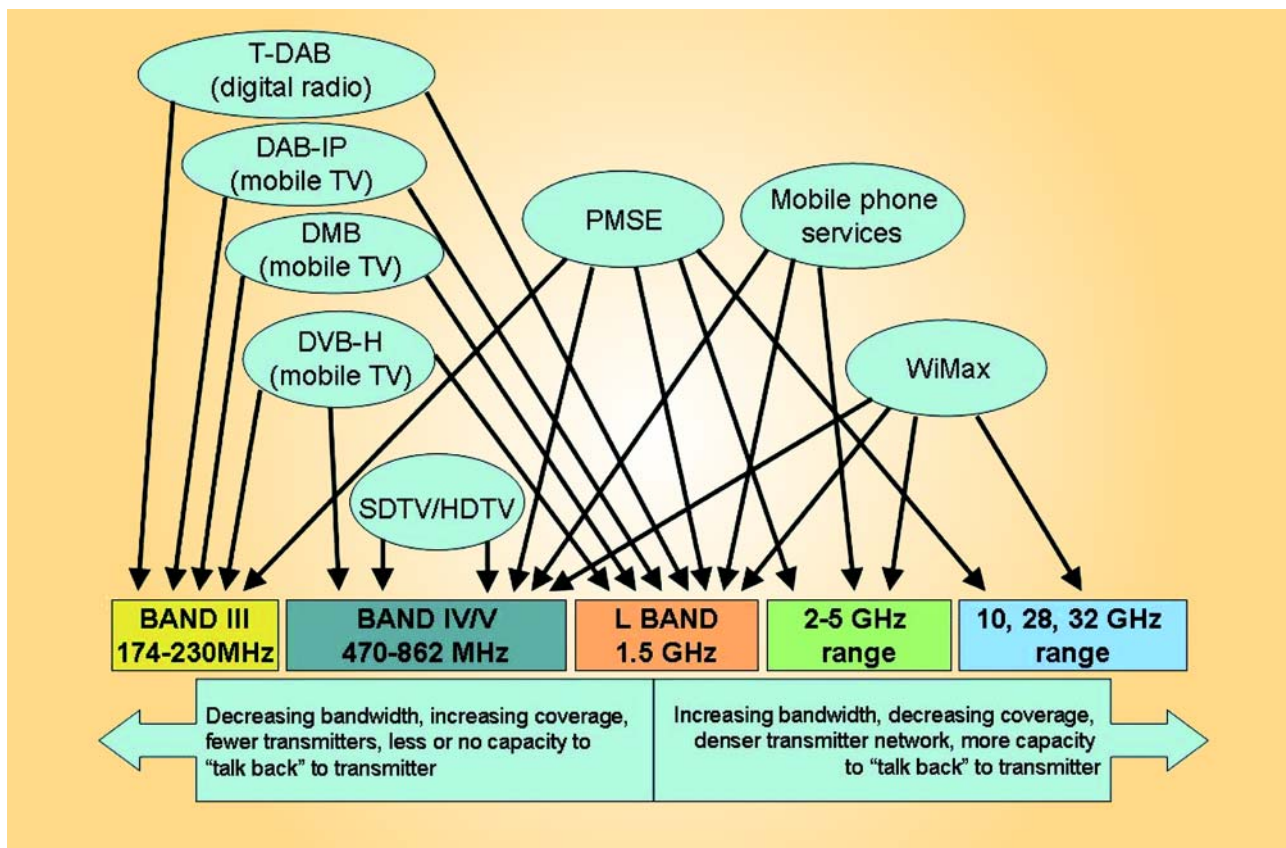


Figure 7
Alternative frequency bands for digital technologies

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, the 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). Band IV/V, however, could improve in-building penetration of wireless access services as building penetration losses are lower at the lower frequencies.

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 and inside buildings. 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 and wireless access 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 and therefore the 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 television 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 of changing the international harmonisation rules in the future and allowing technologies such as DVB-H, DMB-T (mobile television) 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 switchover 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 television 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 B*.

Conclusions

Deploying technologies in the radio 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 an 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:

- 1) requiring that certain services are provided in those parts of the spectrum which, in technical terms, would be the most appropriate;
- 2) allowing the market, rather than the planners, to determine our future uses of the spectrum; and
- 3) 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 television services to co-exist with extra capacity for the Programme Making and Special Events community as well as for the introduction of High Definition television 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 do not exist today? 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



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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: Possible technologies in UHF Band IV/V ²

Technology	Number of services or capacity in an 8MHz-wide Band IV/V channel	Reception mode	Average transmitter power	Diameter of area covered	Typical number of users in the coverage area
Standard analogue television	One television programme channel	Fixed	300 kW	100 km	Average 1 million (11 million for London)
Digital SDTV	One multiplex can accommodate at least four television programme channels or a number of services (television, 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	One to two television programme channels at present, but possibly three channels by 2012 due to anticipated improvement in compression technology	Fixed	70 kW	100 km	Average 1 million (11 million for London)
Mobile television	20 TELEVISION 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

2. Mobile phone technologies might also use this band but we do not have detailed information about these technologies (*Source: BBC Distribution*)