Annex A: UHF Technical Compatibility Issues

Prepared for Ofcom by Ægis as part of the 'Preparatory study for UHF spectrum award'

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ÆGIS spectrum engineering

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The work forming the basis of this annex has been driven by the underlying objective of the study to seek to develop a service and technology neutral award process. This study therefore considers compatibility issues between alternative technologies at a high-level rather than the detailed technology-specific analysis that would be undertaken in a detailed interference analysis between (for example) two or more specific technologies.

In the study we have identified a wide range of potential uses of the digital dividend spectrum and, within each use, a range of potential technologies that could be deployed. The nature of technical compatibility assessments means that specific technologies need to be considered, and for this reason we have had to make assumptions about the technology deployed and technical characteristics of the services/systems that could be deployed in the digital dividend spectrum. In view of the variability of alternative technologies etc our assessments of interference (co-channel, adjacent channel etc) should be regarded as being indicative, as we have sought to draw high-level conclusions which would be applicable in a technology neutral environment.

1 RADIO PLANNING AND INTERFERENCE ISSUES

1.1 The wanted signal

Even in the absence of any interference, a radio signal must overcome the thermal and other noise generated in the environment, and in receiver equipment. The power necessary to overcome this natural noise defines the 'noise-limited' field-strength limit for a service.

To give 'acceptable' picture quality, an analogue television signal requires that the wanted signal is in the order of 30-40dB stronger than the noise power. This is referred to as the carrier-to-noise (or C/N) ratio for the system. Digital (DVB-T) systems offer greater flexibility, in that the C/N requirement may be traded for additional channel capacity; thus, a heavily-coded QPSK signal has a required C/N ratio of only ~4dB, but can only carry some 6 Mbit/s, while the use of 64-QAM modulation with little coding demands a C/N ratio of around 21dB, but will carry over 30 Mbit/s.

The noise power can readily be calculated, knowing the characteristics of typical receiving equipment, and the necessary field strength for a given service determined. If the service were to be provided over a cable connection between transmitter and receiver, this would be the end of the problem.

Unfortunately, off-air reception involves allowing for the statistical variability of the propagation medium. Not only will the field strength vary from location to location, but also from time to time, at the same location.

For the relatively short paths associated with a wanted signal, it is the location variability that is most important. For many planning purposes, it has been found appropriate to model this by assuming a log-normal statistical spread of field strength, with a standard deviation of 5.5 dB. This is illustrated in Figure 1.1.

FIGURE 12

Ratio (dB) of the field strength for a given percentage of the receiving locations to the field strength for 50% of the receiving locations

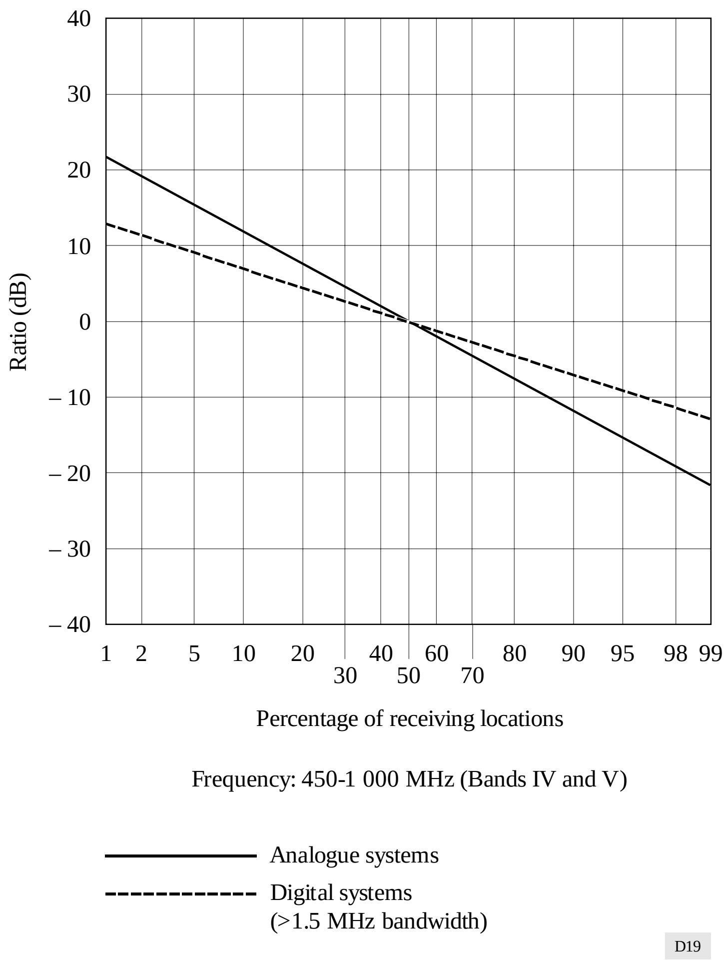

Figure 1.1: Location variability of field strength (source: ITU-R Recommendation P.370-7)

The implication of this variability is that, if a service is to be provided to, say, 98% of locations, it is necessary to allow a median field strength some 11dB higher than would otherwise be the case.

To generalise this correction, the field strength E which will be exceeded for q% of locations is given by:

$$E(q) = E\ (median)\ \ Qi(q / 100)\ \sigma_L(f)\ \ dB(\mu V/m)$$

where:

Qi (x) : inverse complementary cumulative normal distribution as a function of probability

σ_L: standard deviation of the Gaussian distribution of the local means in the pixel area.

A further increase in field strength will be required if a service is to be provided to terminals with antennas located indoors. An allowance in the range 8-15dB is often made for building penetration loss, but measured values show a very wide spread.

A further determinant of the required field strength will be the type of aerial assumed for the receiver/mobile terminal. For the case of domestic television reception in the UK, this is assumed to be mounted at around 10m above ground level, free from immediate clutter, and to have a gain of around 12-14dBi. A portable device, on the other hand, might have an embedded aerial with a gain of around -5dBi, and be used in a cluttered environment at a height of around 1.5m. The combination of the low gain and reduced height might imply that an increase in the reference field strength at 10m of up to around 30dB might be required.

These differences in the receive/mobile terminal characteristics have an implication for the design of the transmitter network, and hence system costs. Given the inverse square law of free space propagation, it is likely to be very inefficient to try to obtain the uniform high field strengths required by indoor, portable devices from the same network that supports fixed reception using rooftop aerials.

1.2 Interference mechanisms

1.2.1 Co-channel interference

This is, conceptually, the most straightforward form of interference. There is clearly the potential for two radio systems sharing a common frequency[1] to cause mutual interference.

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[1] The terms ‘frequency’ and ‘channel’ are often used interchangeably in discussing RF transmission and interference. For the avoidance of confusion with a television programme channel, the term ‘UHF Channel’ will be used when the associated (8 MHz) frequency resource is intended.

All radio systems have a susceptibility to such interference, expressed as the 'Carrier-to-Interference' (C/I) ratio, which can be readily determined under fixed conditions. The situation is similar to determining the C/N requirement, with the difference that interfering signals may cause more (or less) degradation than thermal noise. This difference is often small however, and an analogue television signal requires that the wanted signal is in the order of 30-40dB stronger than any interfering signal on the same UHF channel. This is referred to as the 'protection Ratio' for the system. As for the C/N requirement discussed above, Digital (DVB-T) systems offer greater flexibility, in that susceptibility to interference can be traded for additional channel capacity.

1.2.1.1 *Location variability*

Just as the wanted signal is subject to location variability, so is the interfering signal, and the joint statistics of this variability need to be accounted for. For example, it is possible that the wanted signal may be faded at a location where the interfering signal is enhanced. It is therefore necessary in planning to make allowance for this effect

If two (log-normally distributed) signals are present at a receiver, having standard deviations of σ_1 and σ_2, the location variability of the aggregate signal is given by:

$$\mu \times \sqrt{(\sigma^2_1 + \sigma^2_2 - (\rho.2.\sigma_1.\sigma_2))}$$

where μ represents the 'distribution factor' – the value of the log-normal cumulative distribution function (CDF) – at the required area coverage factor. For a log-normal distribution, and an area coverage of 99% this factor has a value of 2.33.

In the expression above, ρ represents the correlation between the two signals: if these are assumed to be entirely uncorrelated, and if the standard deviations of the two are the same, the expression reduces to:

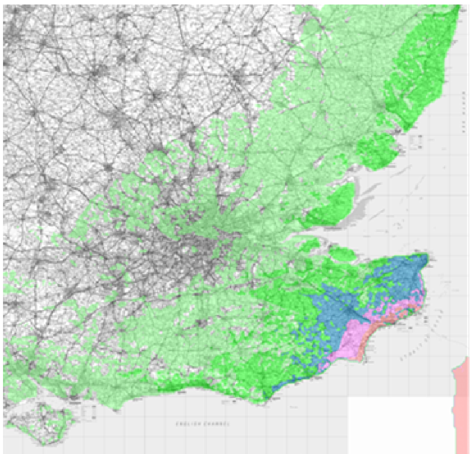
$$\mu\ (\sqrt{2}\ .\ \sigma\ )$$

If a value for σ of 5.5 dB is assumed this gives a required location variation correction of ~18 dB for 99%, and ~4dB for 70% protected area coverage.

1.2.1.2 *Temporal variability*

Interference paths are often much longer than those associated with the wanted signal. For cases such as a DVB-T domestic receive aerial, or a cellular base station antenna, the wanted signal levels may be relatively low, allowing interference paths in the order of 100km or more to be significant. Over such path lengths, the impact of signal enhancements due to tropospheric ducting becomes very significant. Though such enhancements will occur only for short periods of time, it is necessary to dimension the system to allow for them, particularly in view of the 'cliff-edge' failure associated with digital systems.

The significance of this effect is illustrated in Figure 1.2 below, which illustrates incoming levels of interference to the UK from the likely network of continental TV transmitters on UHF channel 32. The interference contours are at 10dB intervals[2].



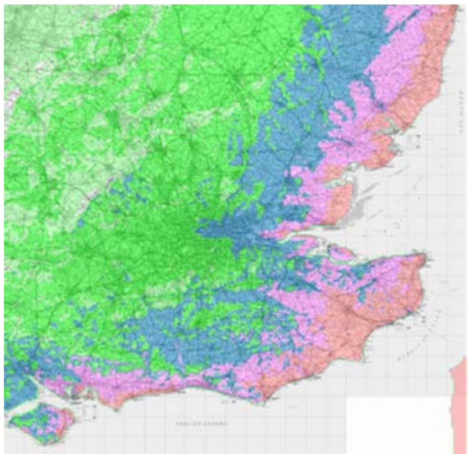


Figure 1.2a: Interference (50% time) **Figure 1.2b: Interference (1% time)**
(Source: Aegis)

The implication of this variability is that very careful consideration needs to be given to the specification for network availabilities, as protection to small %-times carries a considerable burden.

1.2.1.3 Modelling

In this study, co-channel interference effects have been modelled using a bespoke software tool developed by Aegis Systems. This model used the propagation model of ITU-R P.1546, and input data taken from the RRC process and from the UK DTT planning process.

This model accounts for propagation over terrain representative of that around each UK transmitter[3], and also allows for actual transmitter and receiver aerial radiation patterns and polarisation. It should be emphasised that this software was developed solely to provide input to other areas of this study, and that the

[2] Red: ≥ 50 dBμV/m, Mauve ≥ 40 dBμV/m, Blue: ≥ 30 dBμV/m, Dark Green: ≥ 20 dBμV/m, Light Green: ≥ 10 dBμV/m

[3] The 'effective height' parameter is used at each azimuth from a transmitter

modelling is therefore at a high level. In particular, the geographical resolution of the output is low, to minimise the necessary computer run-time.

A sample of the output from this model is shown in Figure 1.3 below, showing the interference generated by the Crystal Palace (London) transmitter to a grid of test points distributed across the UK. Test points at which the interference limit is exceeded are coloured red, with the locations of main transmitters indicated as blue circles.

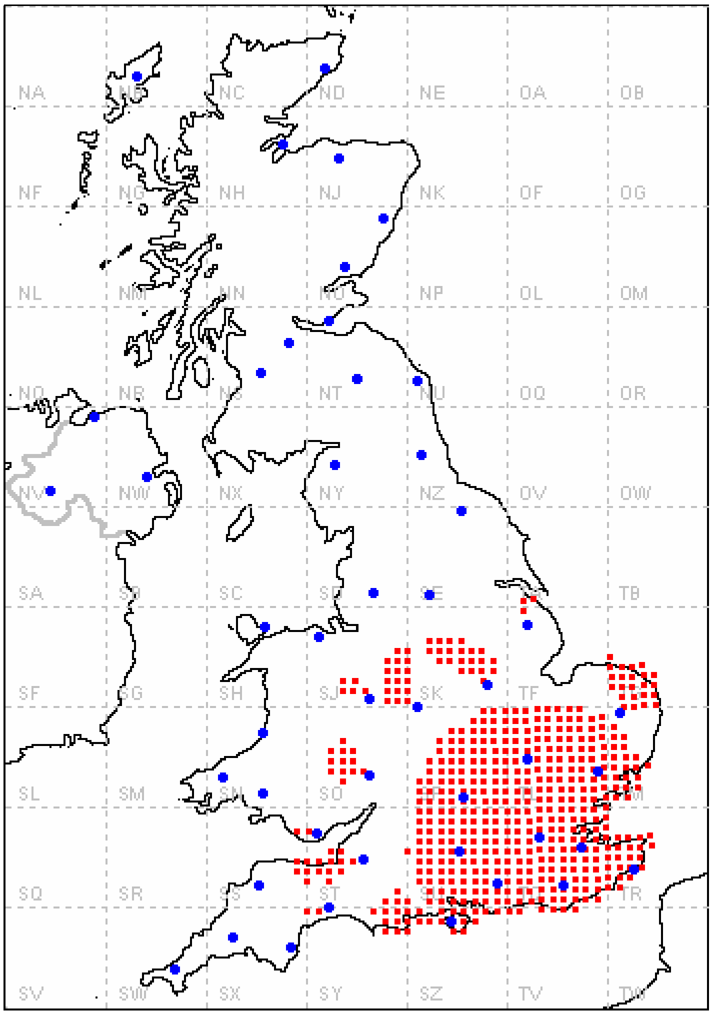


Figure 1.3: Co-channel interference model, Crystal Palace outgoing (Source: Aegis)

It is assumed, in this case, that the victim service is also DTT, and that, as a consequence, antennas at each test receive point will be aligned to their nearest DTT transmitter station.

This has the effect of rendering some grid points relatively near to the Crystal Palace area insensitive to interference as they are pointing away from the interfering transmitter. On the other hand, more distant test points, where receive aerials are ‘looking’ past their ‘own’ transmitter in the direction of Crystal Palace, suffer higher interference levels.

1.2.2 Adjacent channel interference

It is fairly straightforward to predict, from first principles, the sensitivity of any receiver to co-channel interference. The protection ratio is unlikely to show a wide variation, as the value is largely determined by the system characteristics (modulation type, bandwidth).This is not the case for adjacent channel interference, which is crucially determined by the particular implementation of front-end and IF filtering in specific receivers, and by the transmitter output filters.

The response of receivers to adjacent channel (and beyond) signals is often, but not always, specified in standards. It is important to understand this parameter, as it will determine the ability of radio services located in the same area to operate on closely spaced frequencies.

This would be relevant, for instance, where a DVB-H, or other mobile broadcast service requiring high field strength levels, was implemented in spectrum adjacent to an existing DVB-T service. In such a situation, it will be possible for the DVB-H service to ‘punch holes’ in the DVB-T coverage.

The DVB-T receiver performance target set for UK planning given in the so-called ‘D-Book’ available to members of the Digital Television Group[4] (DTG) [D-book] is that receivers should have a protection ratio in the adjacent channel of -28dB, and in further adjacent channels of -42dB (for 64-QAM, r=2/3). This target is compared, in Figure 1.4 with measurements [BBC2] made by the BBC.

[4] The industry association for digital television in the UK. See www.dtg.org.uk.

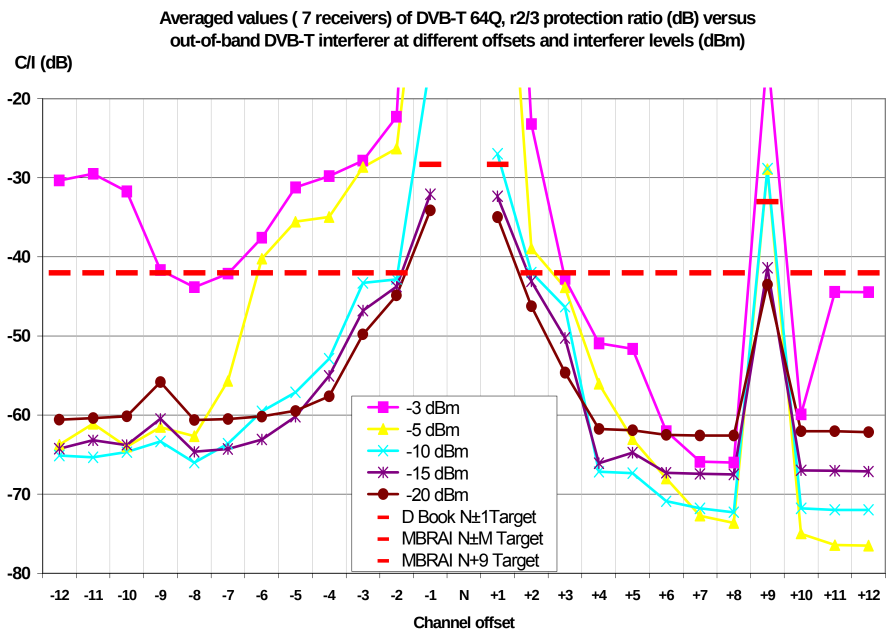


Figure 1.4: Adjacent channel performance of DTT receiver (Source BBC)

In Figure 1.4, it can be seen that, for interfering signals of moderate power (≤-15dBm) the performance target is met, with the important exception where the interfering signal falls nine UHF channels above the wanted signal (n+9). This is discussed under 'Image Channel' below.

This average receiver performance allows an assessment to be made regarding the statistical likelihood of the type of 'hole-punching' problem referred to above.

1.2.2.1 Hole punching

Hole-punching occurs when a receiver suffers interference from a local transmitter operating on a channel adjacent to the wanted signal.

A DVB-T signal will require a protection ratio in the order of 10-20dB, for co-channel interfering signals. The precise figure will depend on the modulation level, code rate and propagation channel characteristics. This means that the power of the interfering signal should be 10-100 times less than that of the wanted signal.

For a signal on the adjacent UHF channel (i.e. with a centre frequency 8 MHz away from the wanted signal), the protection ratio reduces to around -28 to -42dB as seen above. This implies that the interference power may be some 1000 times more than that of the wanted signal.

This apparent tolerance to adjacent channel interference has made possible the relatively simple introduction of DTT in the UK, by allowing DTT transmissions to be added on frequencies adjacent to the existing analogue signals from each site.

Where both wanted and adjacent-channel signals originate from the same site, their powers will clearly fall off ‘in step’ as distance from the site is increased. If the ratio of powers (including the effect of aerial radiation patterns) at the site is correctly chosen there will be no risk of interference.

A different situation will obtain where wanted and adjacent transmissions are made from different sites. The possibility then exists that the wanted signal is relatively weak, perhaps at the edge of coverage of a distant transmitter, while the adjacent signal may be from a very local transmitter. In this case, there is a real possibility that the >-28dB protection ratio will be exceeded.

1.2.3 Image channel relationships

Most radio receivers make use of the ‘super-heterodyne’ principle, in which the received frequency (which may be selectable by the user) is converted to a second, fixed, intermediate frequency (IF), by mixing it with a locally-generated signal at the required frequency difference.

As an example, if the receive frequency is 600 MHz, and the IF frequency is 39.5 MHz, the conversion can be effected by mixing the incoming signal with a local oscillator (LO) signal of 639.5 MHz. Unfortunately, in this arrangement, not only is the wanted signal at 600 MHz (LO-IF) converted to the IF, but also any signal at 679 MHz (LO+IF). This spurious response must be rejected by additional filtering, but this can, practically, only be partially effective.

This spurious response is referred to as the image channel, and is evident at n+9 in Figure 1.4 above. The practical consequence is that it may be necessary to assume that the ‘hole-punching’ interference mechanism described above may not be limited to near-adjacent channels.

In the particularly sensitive case of interference to the DTT 6-MUX plan, new services in the cleared spectrum may have image channel implications for DTT services on UHF channels 22-26, 28,30-31 and 54-59.

The *n+9* limitation is not a new effect – the same relationship was a significant constraint in the development of the original analogue TV plan.

1.2.4 Non-linear effects

Where interfering (or wanted) signal levels are very high, the amplifiers in the sensitive ‘front-end’ circuits of a receiver may no longer operate in a linear fashion. If this happens, spurious signals, or ‘intermodulation products’ may be generated.

One effect of this will be to decrease the effective selectivity of a receiver, as can be seen in Figure 1.4 for the higher interfering power levels.

A second effect is that if high level interfering signals are present at channels n+2 and n+4 (where the wanted signal is on channel n), mixing can occur in the receiver to create a spurious signal on the wanted channel. This will result in desensitisation of the receiver, the effect being illustrated in Figure 1.5.

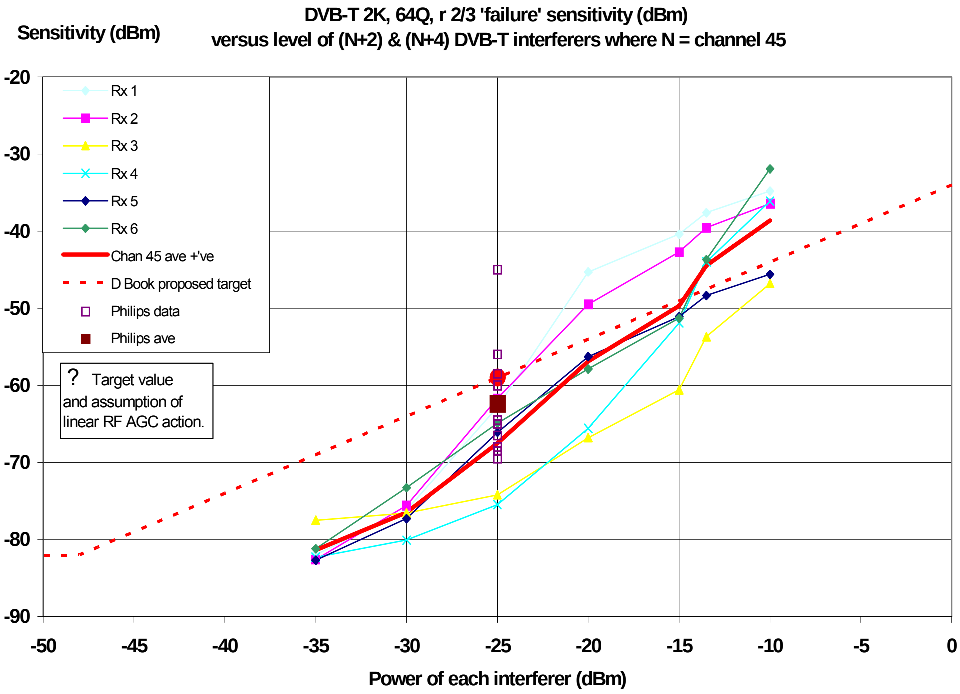


Figure 1.5: DTT receiver performance with interferers on channels n+2 and N+4 (Source BBC)

The relevance of this effect in determining UHF spectrum rights is that if, for example, UHF channels 32 and 34 in the cleared spectrum were brought into use by a network seeking to provide very high field strengths (e.g. for a mobile multimedia service to handheld devices) this might result in a degradation of the service area of the PSB multiplex from Crystal Palace on UHF channel 30.

Initial modelling suggests that the impact of these effects will not be great: in main station service areas, as protection will be afforded to the DTT receivers by polarisation discrimination. In relay station service areas, wanted field strengths are, typically, sufficiently high to mitigate interference problems.

A further manifestation of non-linear effects occurs when a large number of radio microphones are used at a single venue. The large number of signal sources will tend to generate spurious ‘mixing products’ in the receivers, causing interference.

This effect is partly responsible for the large frequency resources consumed by radio microphones.

1.2.5 Receiving antenna discrimination

For some services, planning is greatly assisted by the use (or assumed use) of directional receiving aerials. These can allow significant rejection of interference arriving from directions other than the wanted signal.

By virtue of this directionality, such aerials will also have ‘gain’, allowing the use of a lower wanted signal than would otherwise be possible. While allowing economy in transmitter power, or the number of sites needed in a network, this also has the effect of reducing the systems tolerance of incoming interference. Thus, receivers such as cellular base stations and domestic DTT installations are sensitive to long-range interference from the direction of the wanted signal (usually a 120° cell sector in the cellular case).

On the other hand, receivers such as mobile TV handsets have very low gain antennas, implying an inability to discriminate against interfering signals. The same low gain, however, implies that the wanted field strength must be rather high, giving protection against interfering signals.

Just as fixed antennas can offer useful directionality, so they can discriminate between the polarisation of signals. All main station TV transmitters in the UK (and the rest of Europe) are horizontally polarised; this allows co-channel relay stations using vertical polarisation to be located closer to a main station than would otherwise be possible.

It should be noted that polarisation and directivity are not simply additive – the full polarisation discrimination is only obtained when the signal is arriving through the main response of the antenna. Thus, if an aerial offers a maximum discrimination of 15dB to signals arriving off-axis, and a polarisation discrimination of 15dB, it is unlikely that a total discrimination of 30dB would be achieved.

2 DTT

In evaluating interference issues, DTT networks present the most straightforward case amongst the systems discussed in this report. As the service has been established for some time the technical characteristics and vulnerabilities are well understood. In addition, the type of network involved (service planned on the basis of reception using fixed, rooftop antennas) constrains the range of interference scenarios that must be considered.

2.1 Wanted signal assumptions

The UK post-DSO switchover plan makes the following assumptions.

Parameter	**Value**		**Notes**
Mode	2k		
Modulation type[1]	64-QAM	16-QAM	
Code rate	2/3	¾	
Guard interval	1/32	1/32	
TS bitrate	24.1 Mbit/s	18.1 Mbit/s	
Minimum theoretical C/N[2]	16.5 / 17.1 dB	12.5 / 13.0 dB	*Gaussian /Ricean channel*
Minimum practical C/N[3]	22.8 dB	18.7 dB	
Practical RX input[3]	33.5 dBµV	30.9 dBµV	
Minimum Field Strength[4]	**46.8 dBµV/m**	**42.7 dBµV/m**	*500 MHz*
Location availability	70% (marginal), 90% (standard)		*'Marginal' coverage assumed in public documents*
Time availability	99%		
Median FS at 10m for target location availability **(dBµV/m)**	**52.7 dBµV/m** (70%) 56.9 dBµV/m (90%)	**48.6 dBµV/m** (70%) 49.8 dBµV/m (90%)	*Assumes SD of 5.5dB* *Calculated[4] for 650 MHz*

Table 2.1: Assumed DTT characteristics

[1] 64-QAM assumed, but 16-QAM specified as additional UK option

[2] *From D-book, table 9-9, after ETS 300 744. All limits refer to BER=2x10^{-4} post-Viterbi*

[3] *From JPP/MB/1*

[4] *Base FS at 500 MHz, assuming net gain of aerial & feeder is 7dBd.For other frequencies, minimum FS given by base_fs+20log(f/500)*

For the purposes of the modelling carried out in this study, the median field strengths given above for the ‘marginal’ (70%) coverage at 650 MHz will be rounded, and assumed to apply to the entire UHF band. The assumed figures are thus **53dBμV/m** for 64-QAM and **49dBμV/m** for 16-QAM. It is very likely that all of the muxes will move to 64QAM at switchover and so the modelling has focussed on this mode.

In determining the degree of coupling from DTT transmissions into services using adjacent (or other) UHF channels, it is necessary to characterise the transmitter in terms of the radiated spectrum.

Symmetrical spectrum masks for non-critical and sensitive cases

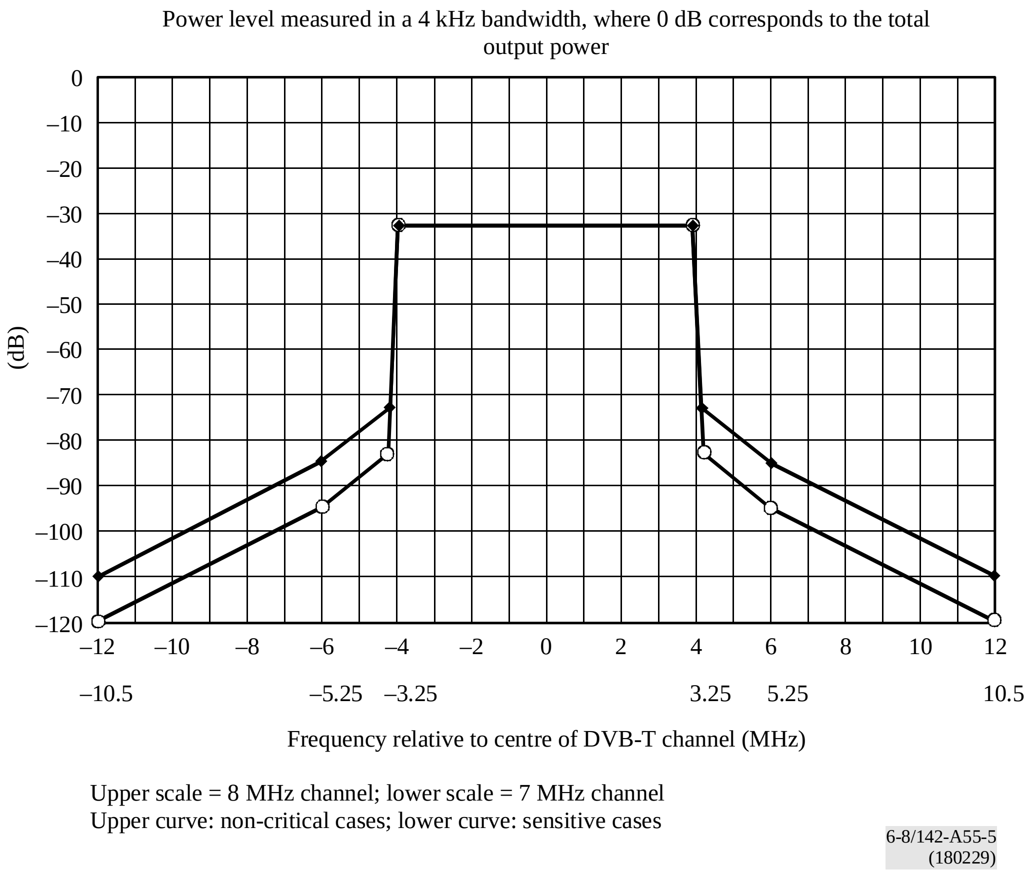


Figure 2.1: Transmitted spectrum masks for DVB-T (*source ITU*)

In this study the masks quoted in chapter 3 of the report of the first session of the RRC [RRC] are assumed, and are reproduced in Figure 2.1 above. The mask for ‘sensitive cases’ is intended for use in situations where it is necessary to minimise the power in adjacent channels to ensure inter-system compatibility. Such a mask is typically specified for channels at a band edge (e.g. channel 21). It should be noted that a more stringent mask has recently been specified by ETSI, for use in such critical cases. This has not been modelled within the present study.

2.2 Interfering signal assumptions

2.2.1 Co-channel DVB-T/DVB-H interference

For co-channel interference between DVB-T services, Reference [D-Book] gives C/I values of 17dB for 64-QAM (2/3 code rate) and 13dB for 16-QAN(3/4 code rate), for a Ricean channel.

With an allowance for joint fading, and a 70% target location variability, these values give a co-channel interference limit of **33dBμV/m.** Interference between DTT services may occur either where a relatively close victim receiver has an aerial pointing away from the interferer (and hence providing up to 16dB discrimination) or where a more distant victim is ‘looking through’ its wanted transmitter to the interferer.

Calculations using the curves of P.1546 [P] at 50% and 1% time, show that the limiting case will generally be that involving the closer receiver, and that a separation between transmitter and victim of ~80 km is required for a typical interferer of 10kW power. If the wanted service area has a (typical) radius of 50km, this implies a transmitter separation distance of **130km**, or, alternatively, a spacing of 30km between co-channel main stations.

It should be borne in mind that geography, and the careful design of transmit aerial patterns, may allow closer separation distances.

2.2.2 Adjacent channel DVB-T/DVB-H interference

Reference [JPP] gives a protection ratio of -25dB for adjacent channel (*n+1* or *n-1*) interference. This compares with a value of -30dB given in Table 1 of Reference [BT], and with values of -27 and -29 given in Table 9-12 of Reference [D-book] for 64-QAM and 16-QAM respectively.

Measurements made on 64-QAM receivers by the BBC [BBC2] show a spread of performance with protection rations between -26 and -38dB for *n-1*, with some receivers showing slightly worse performance at *n+1*. The JPP value of **-25dB** will be adopted for this study (for both 16- and 64-QAM).

2.2.3 Non-adjacent channel interference

For channels removed by more than 8 MHz from the wanted channel, Reference [D-book] gives a protection ratio of **-42 dB**. This value is, generally, supported by the BBC measurements, except where the interfering signal exceeds -10dBm at the victim receiver, and will be used in this study.

2.2.4 Image channel

The image channel response of a UK DVB-T receiver causes the protection ratio for interference on channel n+9 to be degraded. The D-book specifies a target performance of -31dB (64-QAM) or +35dB (16-QAM). The BBC measurements suggest that this figure is, generally, met. A single, average value of **-33dB** will be used in this study.

2.2.5 Response to other interfering signals

A DVB-T receiver will exhibit a different response to interference from other types of signal (e.g. analogue TV or a single (CW) frequency). As most of the potential interferers in this study will be digital systems with broadband emission characteristics, the response in respect of DVB-T interference will be considered typical.

2.2.6 Summary of receiver interference response

The interference response described above is summarised in Figure 2.2 below.

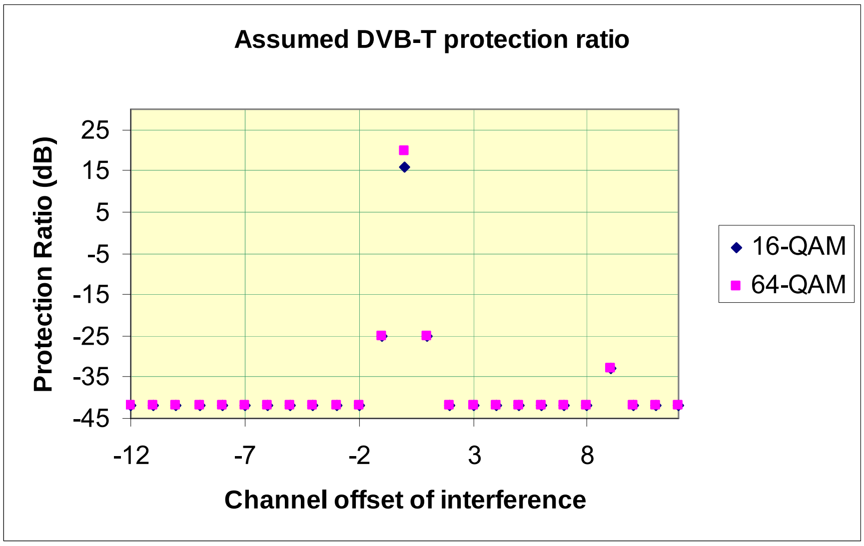


Figure 2.2: Assumed DVB-T receiver response

It may be helpful to put these values in context. If a DTT receiver is located at the edge of the coverage area, with a field strength from the wanted (64-QAM) service of 53dBμV/m, it will be able to tolerate an adjacent channel signal at a field strength of up to 53+25 = 78 dBμV/m. This is the field strength that would be expected from a 1kW transmitter at around 28km (assuming a line of sight path). This separation distance assumes that the two transmitters (wanted and unwanted) are of the same polarisation, and are both aligned with the receiver aerial. If either polarisation discrimination or (full) aerial discrimination are available, the distance will be reduced to around 4.5km.

2.3 Planning of DTT networks

The 6-MUX DTT network is planned on the basis of (on average) 5.33 UHF channels per MFN. This contrasts with the 11 channels per MFN required by the four original analogue networks, reflecting the much better performance of DTT with regard to co-and adjacent channel re-use.

Studies [e.g. BBC1] have suggested that a 4-channel MFN would allow some 84% coverage from 128 sites, but with little opportunity for further expansion of coverage. A 6 channel MFN from the same sites would give around 89% coverage, and would allow for further expansion. These estimates assume that clear channels are available – incoming and outgoing interference constraints will necessitate a larger ‘pool’ of channels.

The cleared spectrum will include 8 UHF channels in the middle part of the spectrum and 6 in the upper part. It might be proposed that DTT would best be accommodated in the upper spectrum, as these frequencies cannot readily be used for mobile TV.

This would appear to offer a sufficient frequency resource for an MFN with good coverage. Unfortunately, the agreements made at RRC complicate this, as there are restrictions on the power that may be radiated on the upper channels (68 & 69) near France (to protect military uses), and, in addition, not all main stations have a high power assignment in this spectrum. In particular, areas such as London, the West Midlands, West Yorkshire, the Solent, Cardiff, Belfast and Glasgow would have no allocation.

Such deficiencies may be ‘repaired’ by making use of allocations from the lower block of release channels, but this leads to a more complex pattern of spectrum release, and will exacerbate the potential interference problems due to the use of adjacent spectrum by dissimilar services.

An alternative approach might make some use of the SFN technique. At one extreme, this would use a single UHF channel to provide national coverage.

However, studies indicate that, even with a long guard interval (and hence low data rate) coverage may be limited to some 60% of population.

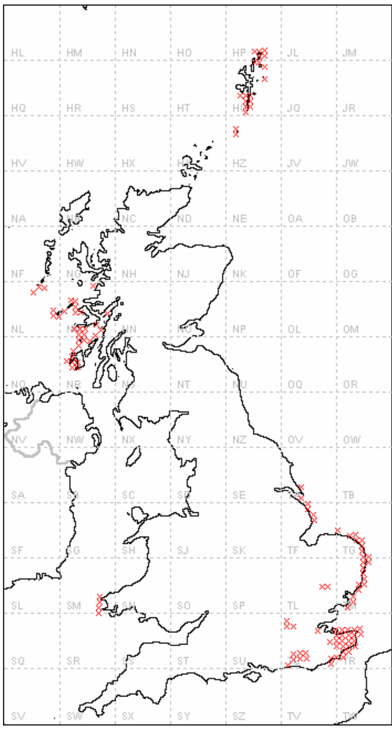
If the SFN is used on a regional basis, this figure increases to more than 80%, when four channels are available. It is apparent, therefore, that there is, in practice, no useful spectral gain with respect to the MFN approach. Local SFNs may, however, provide a very valuable flexibility for improving local coverage deficiencies, and this approach is used in some areas in the post DSO plan for the retained spectrum.

2.3.1 Constraints on use of specific channels

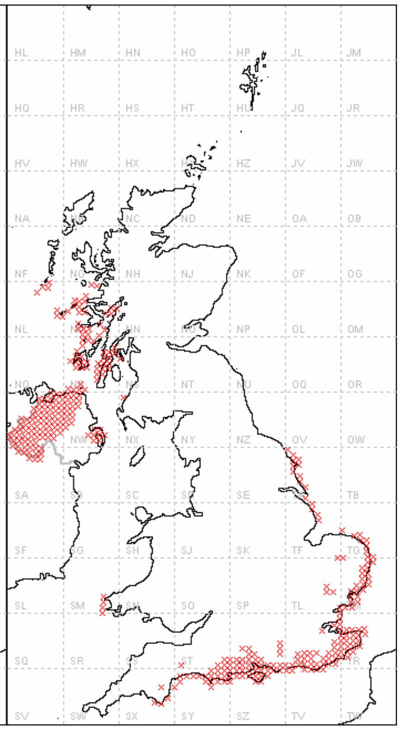
In a clear band, with no existing users, there would be few reasons to prefer the use of one UHF channel over another; The propagation losses are lower at channel 21 than at channel 68, and some UK DTT receivers are unable to tune to channel 69, but these are minor considerations.

In practice, however, the constraints imposed by other existing or potential users of the band are very significant. While no other UK use of the cleared spectrum need be considered, it will be necessary to protect UK services operating in the retained spectrum, and continental and Irish services operating anywhere in the UHF bands. In addition, allowance must be made for the levels of incoming interference from the continent and Ireland. Predictions, based on inputs[5] to the RRC-06 process, have been made of the interference environment for each of the release channels, and these are illustrated in the figures below.

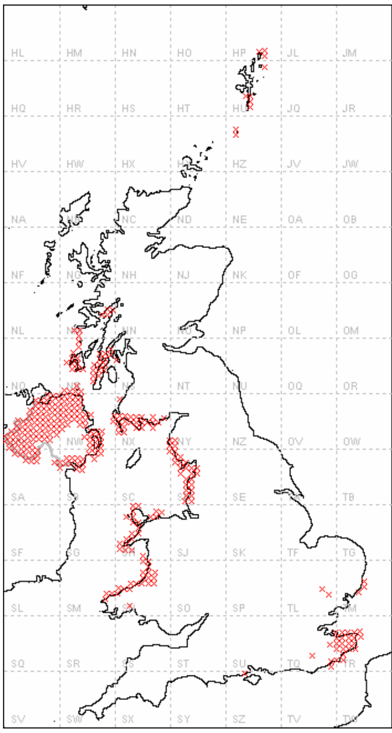
[5] It should be noted that these maps were prepared before the final RRC agreement was concluded, and there may be differences of detail with respect to the eventual outcome.



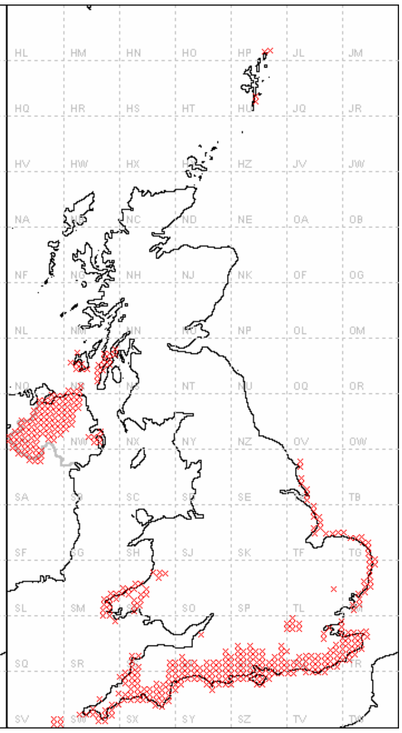
Channel 31



Channel 32



Channel 33



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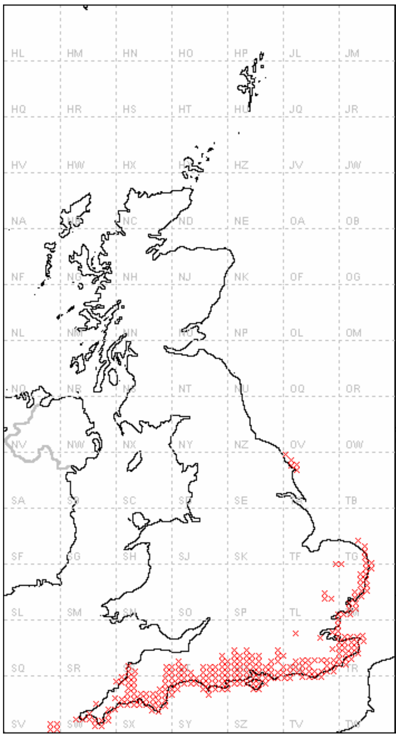

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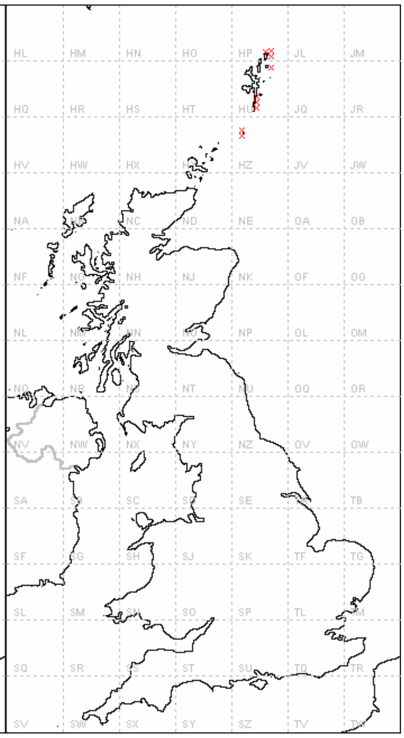
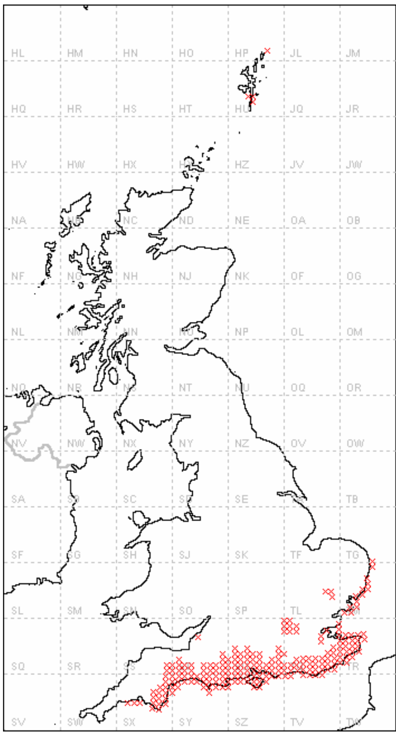


Channel 36



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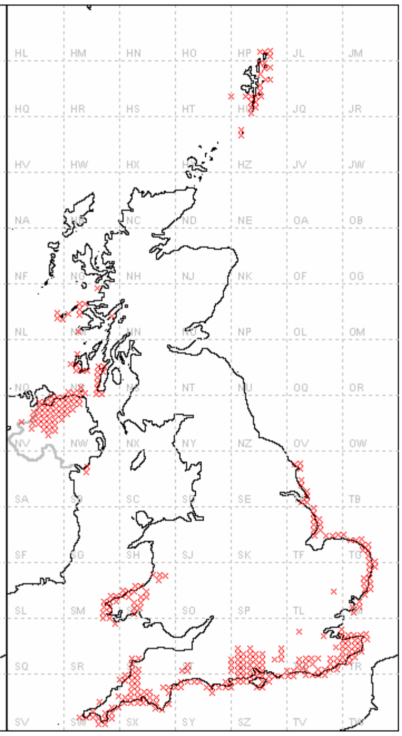

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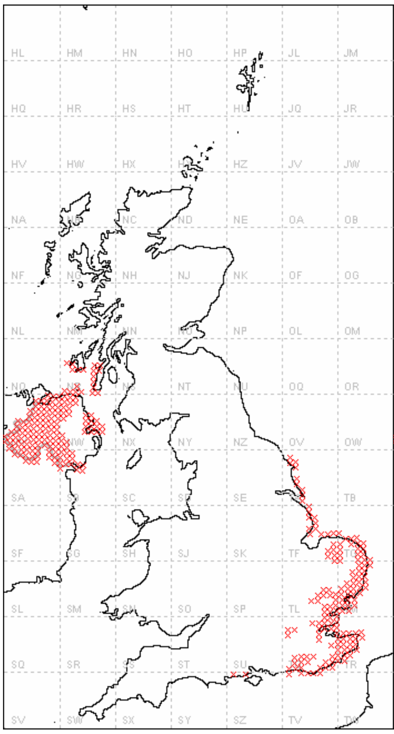
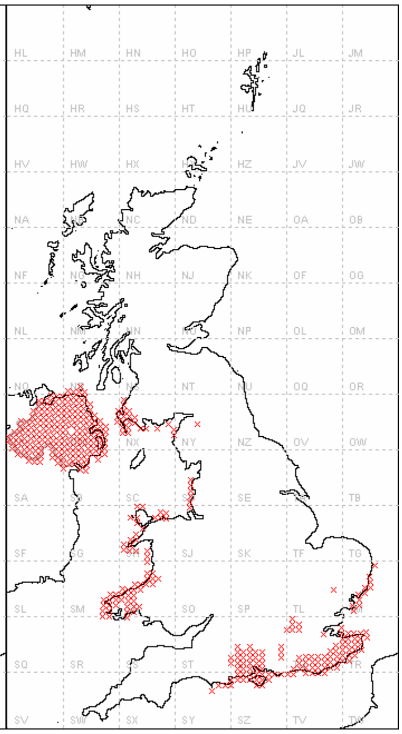
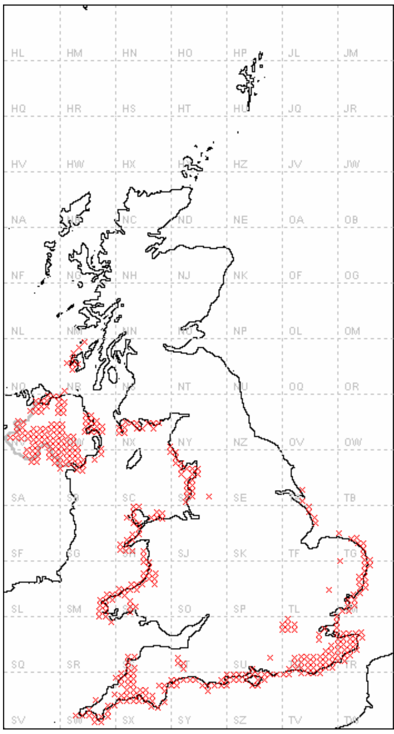


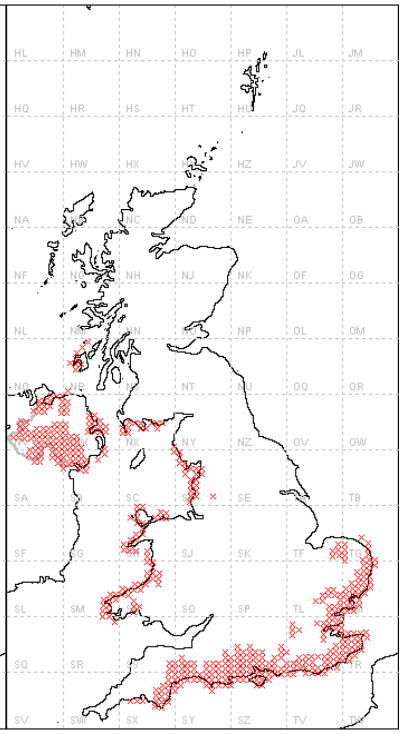
Channel 40



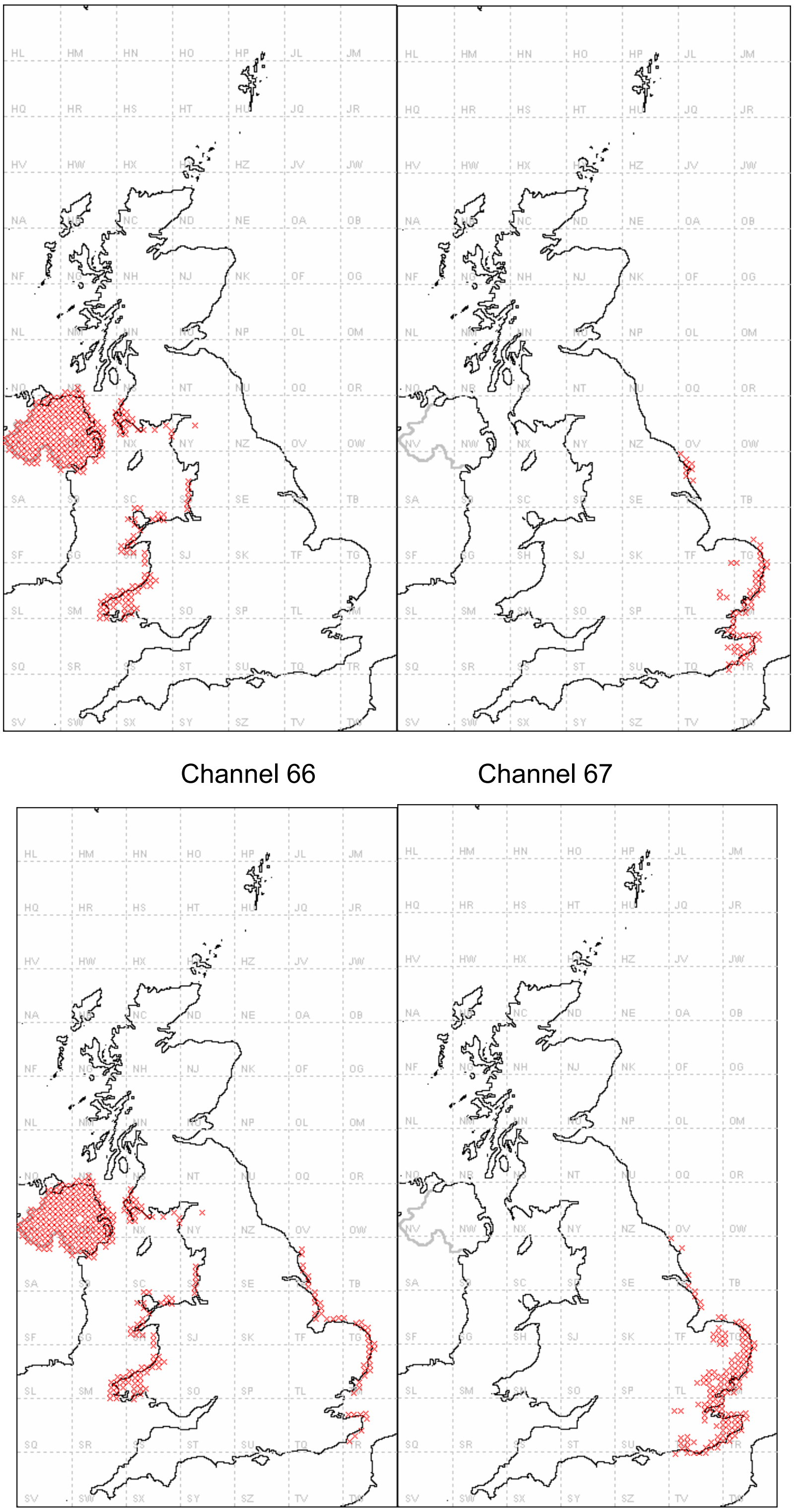
Channel 63



Channel 64



Channel 65



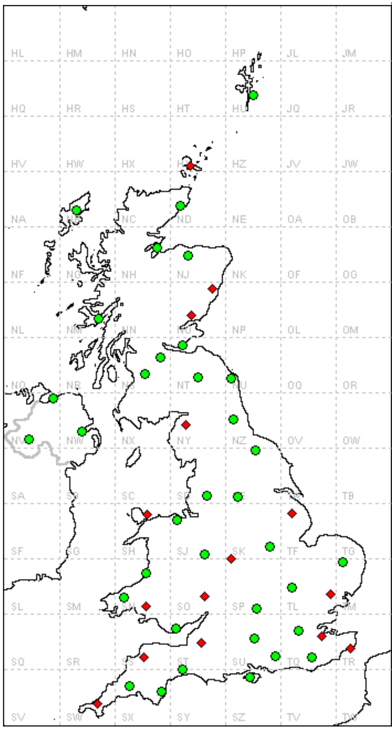
Channel 66 Channel 67

Channel 68 Channel 69

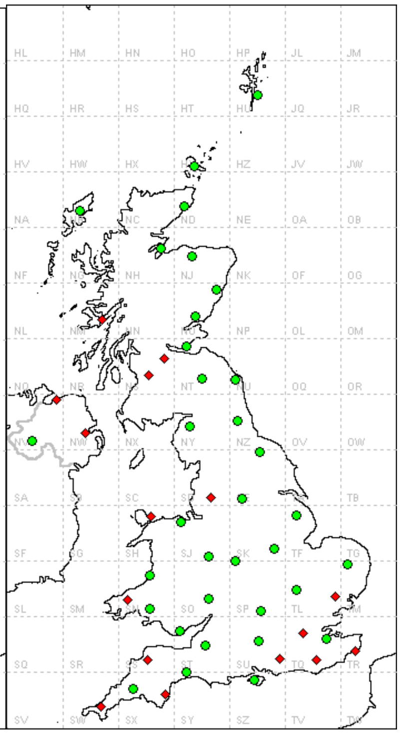
Figure 2.3: Constraints on DTT due to incoming interference

In each of the plots, the red-shaded areas indicate aggregate incoming interference at levels above 33 dBμV/m (at 1% time), taking DTT receive aerial discrimination into account. It should be noted that the plots were prepared before the conclusion of RRC-06, and the detailed structure of the incoming interference will have changed. The overall pattern will, however, be similar, though there will now be less interference along the East coast on channels 68 and 69. It must be emphasised that the presence of red shading in a given area does not indicate that incoming signals from the continent or Ireland *will* cause interference to DTT reception – the actual impact will depend on the relative level of the wanted and unwanted signals.

The constraints due to outgoing interference are illustrated in Figure 2.4, which indicates which DTT main transmitter sites (shown as red diamonds) would breach international agreements[6] if used at their nominal power[7] on each channel.



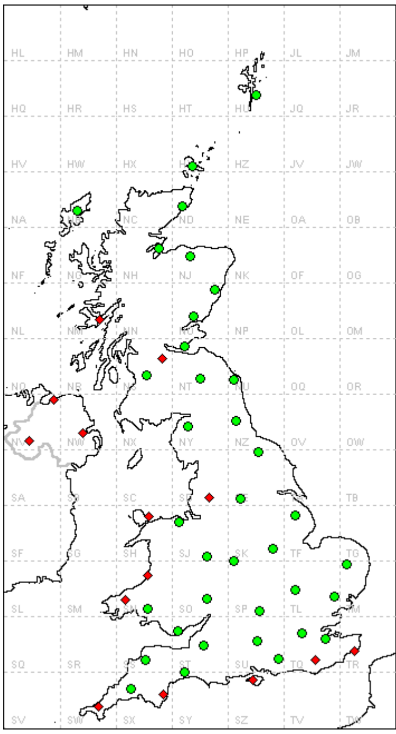
Channel 31



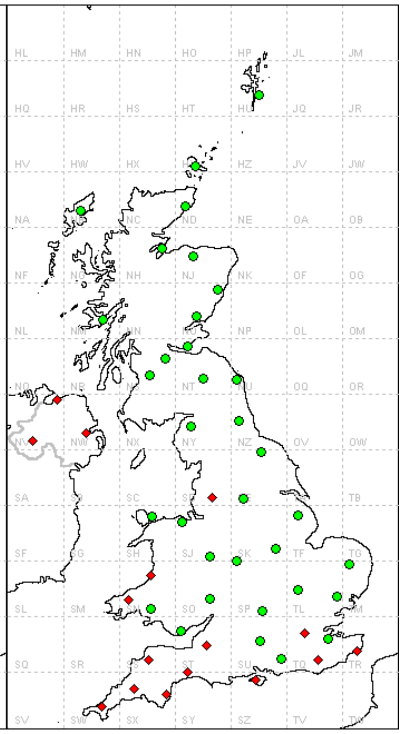
Channel 32

[6] These plots were prepared before the conclusion of the RRC, and the detail of the restrictions will have changed.

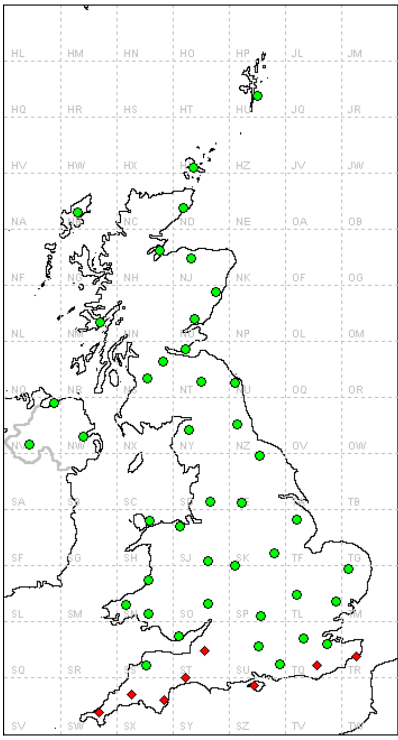
[7] i.e. that power for which international agreement has been obtained for use on the assigned RRC channels at that site



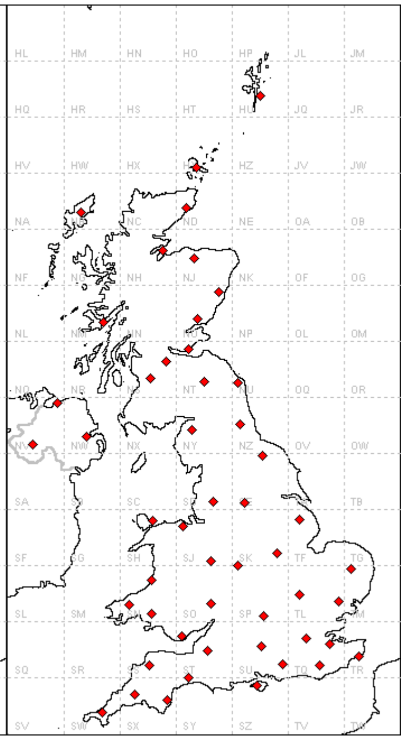
Channel 33



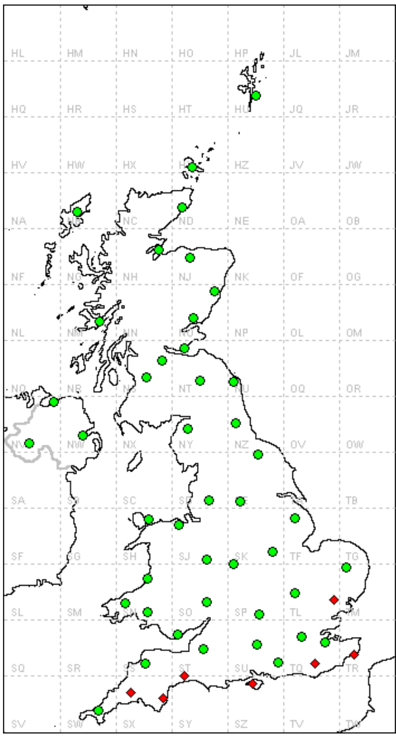
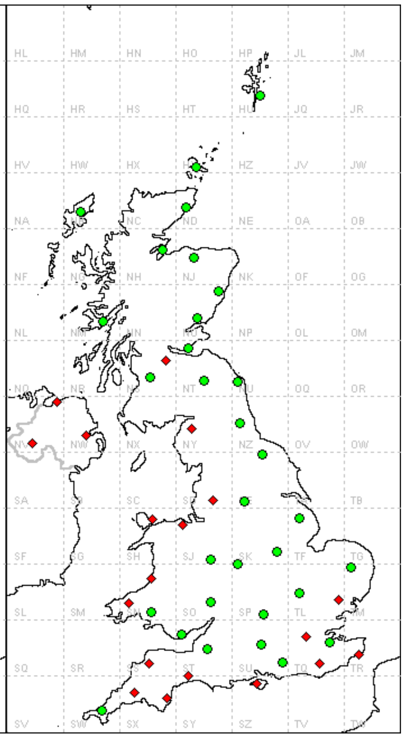
Channel 34



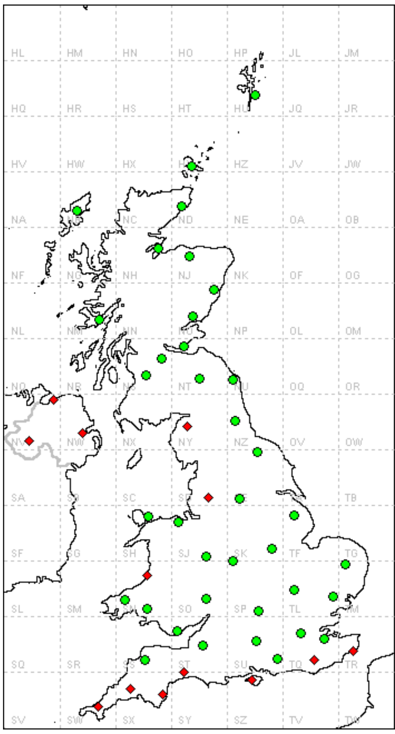
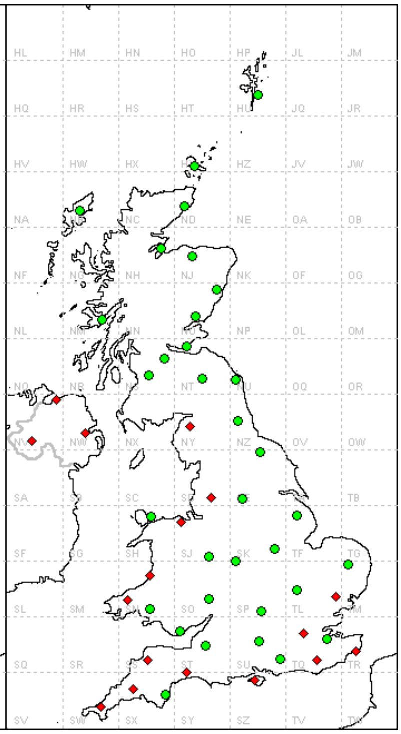
Channel 35



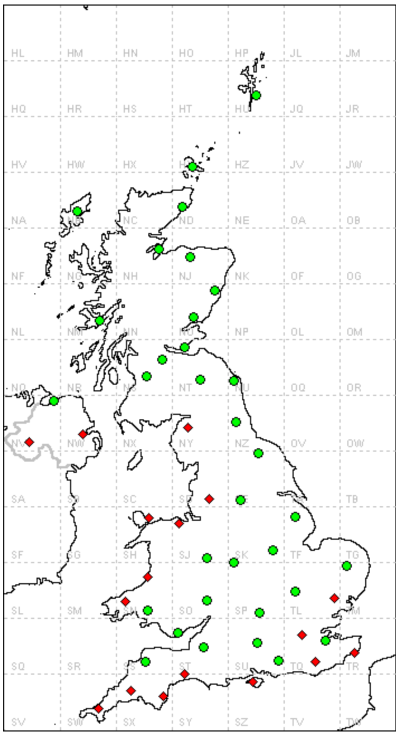
Channel 36

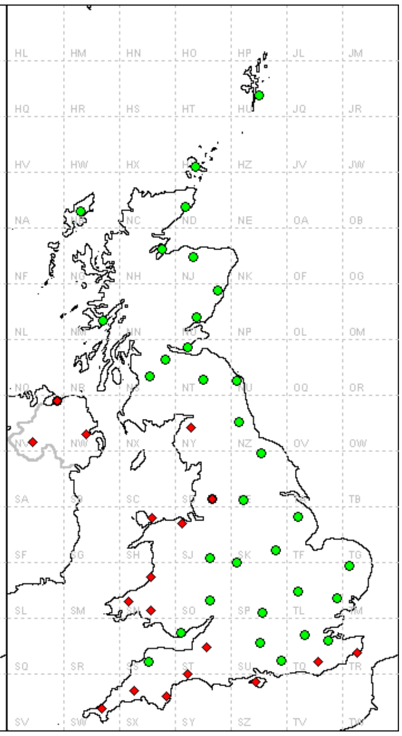
 

Channel 37 Channel 39

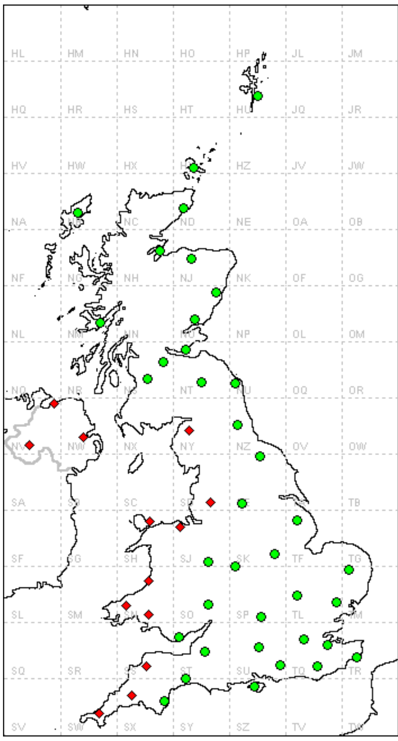
 

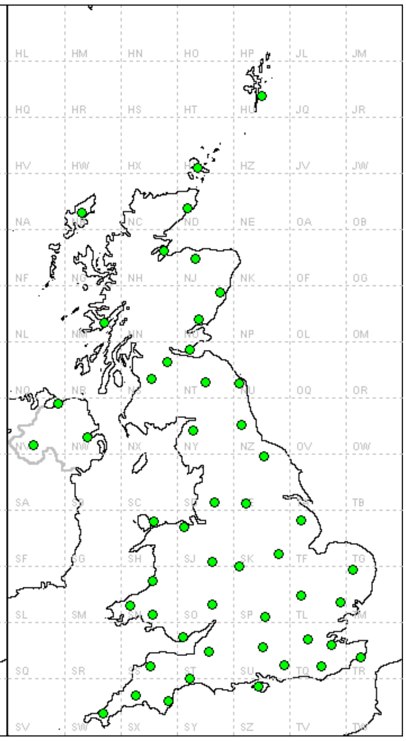
Channel 40 Channel 63



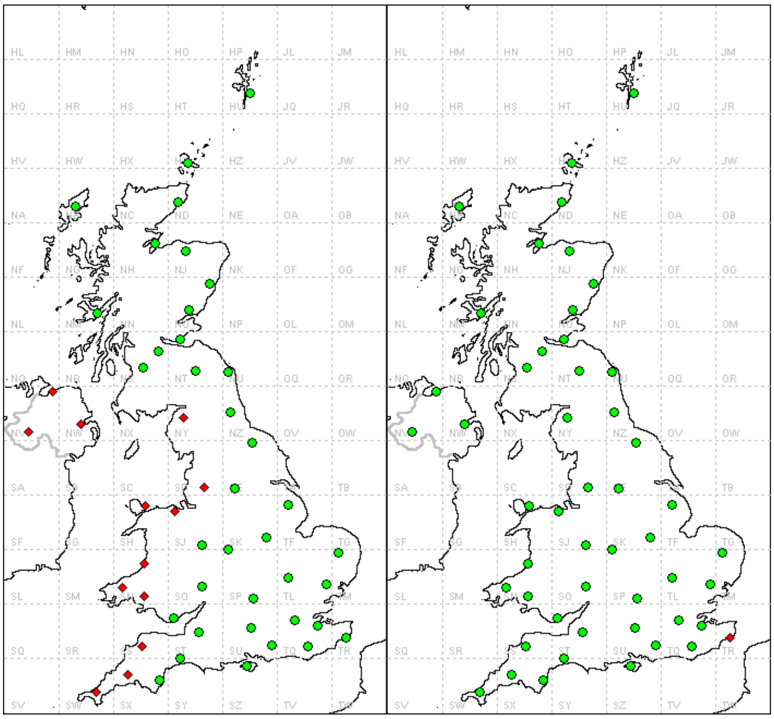


Channel 64 Channel 65





Channel 66 Channel 67(see text)



Channel 68 (see text) Channel 69 (see text)

Figure 2.4: Constraints on DTT due to outgoing interference

NB: It should be noted that the plots of Figure 2.4 reflect technical compatibility with other DTT assignments – the results for channels 67-69 appear optimistic, as they do not take other bi-lateral agreements into account. In practice, the use of these channels is restricted by agreement to protect aeronautical use on the continent.

The overall constraints, due to incoming and outgoing interference limits can be very severe, and it will generally be impossible to operate a main station on a given channel in the southern half of the UK or in Northern Ireland unless specific clearance has been obtained for that transmitter and channel at the RRC. It is important to appreciate, however, that the RRC process is only the staring point for the planning of these bands, and that such clearance can be sought, at any time, through bi-lateral or multilateral negotiation. A successful outcome to such a process could never be assumed however, and it would be necessary for any potential bidder to assume that only existing UK spectrum rights obtained.

In this light, it is useful to examine the distribution of channel allocations at main stations in the two portions of cleared spectrum. The notional multiplexes 7 and 8, which were the basis of the UK plan submitted to the RRC, were formed from assignments interleaved throughout the available spectrum, so as to maximise the potential coverage.

If only one of the two portions of cleared spectrum were to be available for DTT use, this would, as noted above, leave a significant number of gaps in coverage that it might be very hard to make good. The situation is illustrated in Figure 2.5 below.

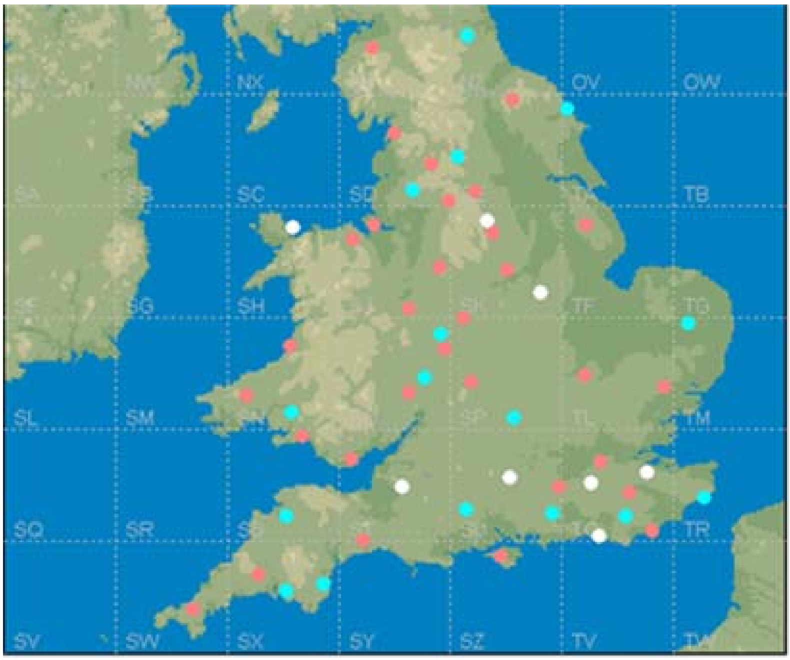


Figure 2.5: Showing distribution of release channels at larger UK sites

In this figure, sites having release channel allocations in both bands are shown in white, while those having a pair of release channels in the lower or upper bands are shown in red or blue respectively. This pattern implies that it may be difficult for an incumbent operator in either band to achieve uniform coverage.

Particularly significant sites (>0.7m population) that will have no assignment in the upper band include (with approximate coverage areas and populations):

- Crystal Palace (London, 10.3m)
- Sutton Coldfield (Birmingham & West Midlands, 4.7m)
- Emley Moor (West Yorkshire, 3.1m)
- Rowridge (Solent, 2.3m)
- Black Hill (Central Scotland, 1.8m)
- Belmont (Lincolnshire, 1.8m)
- Bilsdale (North Yorkshire, 1.3m)
- Sudbury (Essex, 1.3m)

- Divis (Belfast, 1.0m)
- Wenvoe (Cardiff, 0.8m)

The problem is eased if the choice is limited to the lower release band. However, there is a chain of main stations in South East England with no assignment in the mid band (Midhurst, Heathfield and Dover). Major sites outside the south east (>0.7m population) with no channels in mid-band:

- Winter Hill (6.0m)
- Pontop Pike (1.7m)
- Tacolneston (0.8m)
- Oxford (0.8m)

The most flexible approach will be to allow a potential operator to acquire the rights to use channels spread across the two release bands. It is, however, likely to be impossible to guarantee in advance of the release that an operator seeking to assemble a multi frequency DTT network will acquire the necessary spectrum rights at all main stations.

A number of approaches would be open to address such a shortfall. In some cases it may be possible to enter negotiations with UK neighbours, under the plan maintenance procedures agreed at the RRC, to obtain agreement for the use of specific assignments[8]. Such a process may be lengthy, with no assurance of success. Furthermore, agreement may be contingent on the use of a very specific transmit antenna pattern, with nulls in specific directions to limit outgoing interference. Such a pattern would be unlikely to correspond with an existing DTT antenna at the site, requiring the installation of a new antenna (if mast space is available at reasonable cost).

An alternative might be to repair the loss of a specific main station with a number of lower power filler sites, operating on a frequency that will not exceed the outgoing interference constraints. As an example, suppose that a potential DTT operator has acquired channels in the upper cleared spectrum, but wishes to provide coverage within Greater London. One approach might be to make use of a number of filler sites operating co-channel as an SFN. One possible frequency for this would be channel 65, assigned at the Bluebell Hill (Kent) and Midhurst (West Sussex) sites. The outgoing interference to the continent will be dominated by these sites. It should, therefore, be possible to add a number of medium-

---

[8] An 'Assignment' refers to the use of a specific frequency at a given power at a specific transmitter site.

power sites to provide coverage in the London area using the same channel without dramatically increasing the levels of exported interference.

In the modelling presented here, it is assumed that the existing broadcast sites at Tolworth (West London), Shooters Hill (East London), Alexandra Palace (North London) and Crystal Palace (South London) are used. The power at each site is set to 3kW. No attempt has been made to optimise the transmitter network, as the purpose is illustrative.

Such a network might operate as an SFN involving the existing Bluebell Hill and Midhurst assignments, or independently, relying on aerial discrimination and topography to provide the necessary isolation.

In these scenarios, the use of 8k with a 1/8Tu guard interval has been assumed. The coverage obtained if the four London sites form part of a wider SFN is illustrated in Figure 2.6a.

It can be seen that reasonable coverage is obtained in most of the greater London area, though a further site is probably required in the north-west. The other unserved, or interfered-with areas will generally be served from other sites (Hannington, Guildford, Reigate).

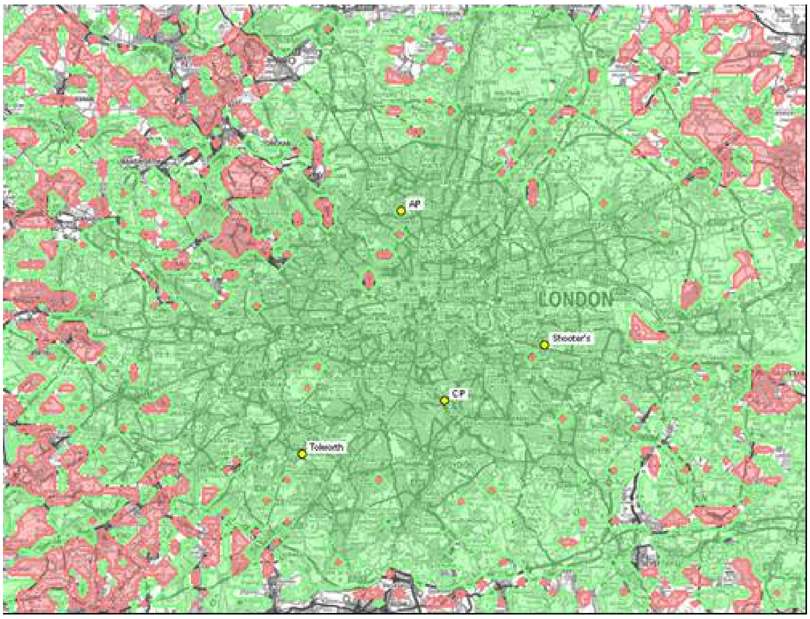


Figure 2.6a: London coverage (SFN with Bluebell Hill & Midhurst)

The alternative is to operate the four London sites as an independent SFN, which might be necessary for editorial[9] reasons, or owing to a release of spectrum on a

[9] To allow different programme services to be provided in the London and Kent areas

regional basis. In this case significantly higher levels of co-channel interference will arise, giving the coverage pattern shown in Figure 2.6b

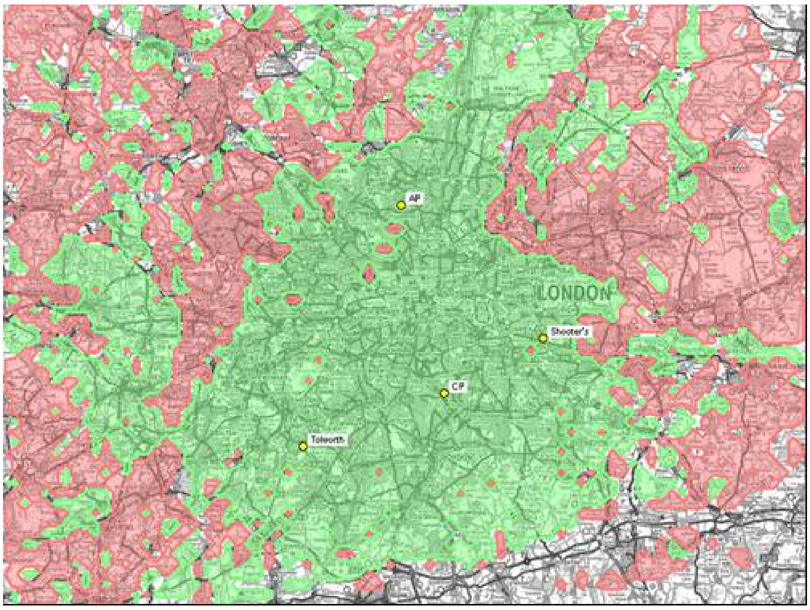


Figure 2.6b: London coverage (independent London SFN)

It is clear that in such a scenario a larger number of (possibly lower-powered) sites will be needed.

In either of the scenarios above, it will be necessary for the majority of viewers to erect new aerials, as existing installations will be of the wrong group and, generally, orientated to the wrong transmitter.

2.3.1.1 Unavailability to DTT of specific mid-band channels

For reasons discussed in Section 3.3.2 below, there is a preference on the part of potential mobile TV operators for the use of channels in the middle cleared spectrum.

If these channels were to be used for such services their use would thereby be denied to potential DTT operators. The impact of the loss of a particular channel is indicated in the maps below, which illustrate the high power assignments currently available under the RRC.

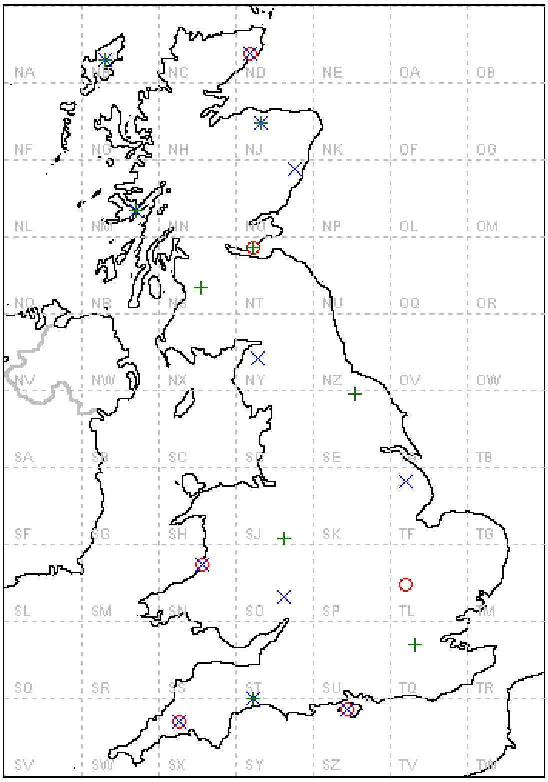


Figure 2.7a: RRC assignments to Channels 31 (o), 32 (X) and 33 (+)

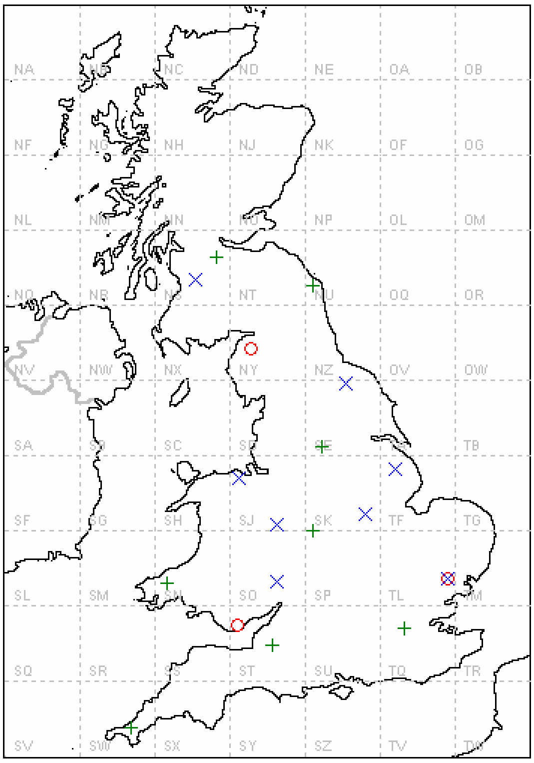


Figure 2.7b: RRC assignments to Channels 34 (o), 35 (X) and 37 (+)

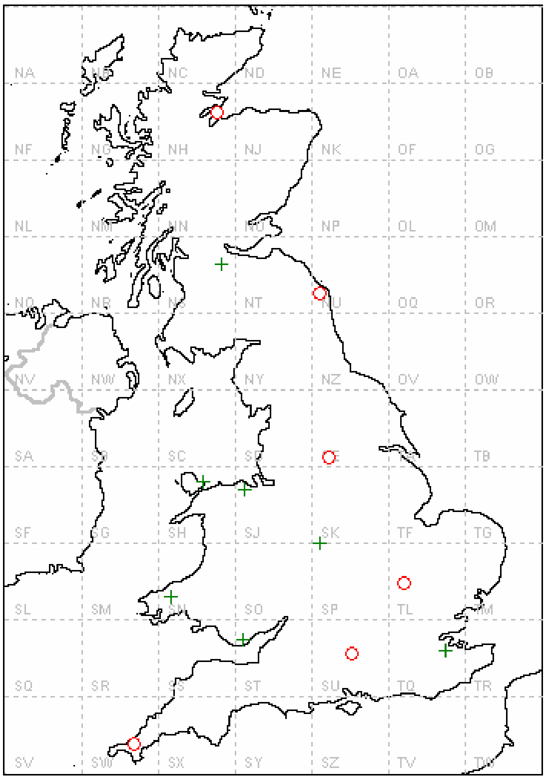


Figure 2.7c: RRC assignments to Channels 39 (o) and 40 (+)

From the maps of Figure 2.7a-c, it can be seen that some of these channels are likely to represent particularly valuable resources for potential DTT operators: channels 33 and 37 in London, channels 31 and 32 in central Southern England and channels 34 and 35 in Essex are likely to be particularly difficult to replace.

2.4 Interference issues

2.4.1 Protection of other DTT services

Assuming the same sites are used for the provision of DTT services in both the retained and released spectrum, there will be no particular constraints on channel allocation. DTT services currently operate from the same site on adjacent channels – a flexibility that was not available to analogue TV planners, but made possible by the -25dB protection ratio noted above.

2.4.2 Co-channel interference to other services

A limit for interference to the **base statio**n receiver of a **cellular / BWA** service of 13.6 dBμV/m is derived below. As interference from a DTT main station will be cross-polarised, an additional protection of some 16dB can be assumed, giving a criterion of 29.6 dBμV/m. Applying this to the case of a 10kW DTT transmitter, with a 300m effective height gives a required separation distance (by ITU-R P.1546) of **180 km** for protection at 99%-time, falling to 110km for 50%-time. These figures assume that the DTT transmitter is on a bearing that falls within the main response of the cellular BS antenna.

For the associated **cellular / BWA mobile terminal** receiver, the separation reduces to **70km,** assuming that no polarisation discrimination is exhibited by the terminal antenna.

2.4.3 Adjacent -channel interference to other services

Adjacent channel interference should not be a problem with respect to other DTT of local services, as these are likely to be co-sited, or, in the case of local TV, to use transmitter sites closer to the target. In both cases, this will ensure that the assumed adjacent channel protection ratio of -25 dB will not be exceeded.

Adjacent channel interference may occur to mobile TV receivers, in the vicinity of a DTT transmitter, though the effect will be limited by the high fields strength of the mobile TV service. A value of 1km is derived in section 3, below, but it must be appreciated that such separation distances will be very variable, depending on the details of local clutter and geography.

3 MOBILE TV

In evaluating interference issues, mobile TV presents the complication that a number of technical solutions are possible.

The T-DMB standard has been developed from DAB, retaining the physical layer but adding appropriate coding and MAC provision to allow the delivery of multimedia services. The primarily targeted frequencies are at Band III and L-band (in the existing DAB allocations), but there is no reason for the standard not to be used at UHF. The channel bandwidth is 1.7 MHz, as for DAB, so it would probably be necessary for an operator to combine four multiplexes in an 8 MHz channel.

DVB-H is an evolution of the DVB-T standard; a DVB-H compliant receiver should be backwards compatible with DVB-T. The significant changes are (i) the introduction of ‘time-slicing’ to conserve limited receiver battery power, (ii) the use of a more robust coding system and (iii) the introduction of a new physical layer mode (4k) offering a better trade off between possible terminal speed and the SFN size.

MediaFLO is a proprietary offering from Qualcomm, and, unlike the other two standards, has been developed, and optimised, for mobile multimedia. It uses a particularly efficient coding scheme, and claims superior performance to the other standards. While IPR concerns have deterred many European operators, BSkyB is shortly to undertake limited trials of the system in the UK.

There has been a great deal of argument, claim and counter-claim regarding the comparative efficiency, both technical and economic, of the systems. For the current purpose, it is sufficient to note that these differences are unlikely to have a significant bearing on spectrum packaging and compatibility issues (with the possible exception of the T-DMB channelisation).

3.1 Wanted signal assumptions

A variety of estimates of required service field strengths for mobile TV have been made.

- It has been suggested by a transmission operator that a median field strength of around 92 dBμV/m will be needed to assure a sufficiently robust coverage.
- In the RRC process, the receiver characteristics assumed for networks intended for mobile and portable (outdoor) reception, require a median field strength of 78 dBμV/m. The equivalent value for a network providing indoor coverage is 88 dBμV/m. This assumes a portable receiver gain of

0dBd, which seems optimistic. This corresponds to a C/N of 17-18dB, which should support 16-QAM or QPSK modes in a portable channel.

- In the ETSI report on guidelines for DVB-H implementation [ETSI] it is stated (tables 11.11 & 11.13) that in an urban environment, to provide a C/N of 14dB, which should just allow a 16-QAM, 1/2 service to a handheld, would require field strengths of 88 dBμV/m (outdoor) or 104 dBμV/m Limited indoor use).

A **required median field strength value of 90 dBμV/m at 10m height** has therefore been adopted for this study. With an assumed C/N requirement of 15dB, this will imply a maximum interfering median FS in the region of 75 dBμV/m. No receive aerial directionality can be assumed. It can be assumed that DVB-H (or similar) services will use **vertically-polarised** transmitters. The use of low gain portable receivers may mean that little or no polarisation discrimination is available with respect to incoming interference from horizontally-polarised DTT transmitters. However, in assessing outgoing interference from the UK, polarisation discrimination would be available in many continental service areas, for rooftop DTT reception.

The location variability of both wanted and interfering signals will be higher than for the DTT case; a value of 8 dB is tentatively assumed. As such, the correction for joint fading and enhancement of signals (at 95% coverage) will be 18.6dB. The assumed **interference limit (50% locations) therefore becomes 56 dBμV/m at 10m.**

The levels of outgoing interference from a mobile TV network will depend on the transmission infrastructure adopted. The necessary topology of transmitter networks is currently the subject of considerable debate, informed by theoretical studies and by the experience of the field trials conducted in the last couple of years.

While some initial models assumed the use of a fairly small number of high power transmitters, it seems that there may be an emerging consensus that rather dense networks will be required to provide reliable service in an adverse radio channel (particularly to indoor users).

In the recent Helsinki trial, an 8 km radius is served using 3 transmitters of 2-3kW and a number of low power repeaters. In Oxford, some 9 transmitters of ~500W are being used to serve a 6km radius.

3.2 Interfering signal assumptions

Mobile TV receivers will have technical characteristics that are significantly different from fixed DTT receivers – in particular, the antenna gain will be some 15dB lower. Furthermore, the transmission network supporting them will be far more dense than for DTT, and will provide a median field strength some 30dB higher. This, together with the low terminal receive antenna gain will ensure a degree of immunity to interference from DTT transmissions.

The MBRAI specification for DVB-H (originally '*mobile DVB-T*', hence the annotation in the figures below) receiver performance state that receivers shall operate correctly for wanted signal levels of up to -28dBm, in the absence of any interfering signals.

3.2.1 Adjacent channel interference

Performance pattern S2 specifies the behaviour of the receiver in the presence of a single DVB-T transmission on another channel, while the L3 test specifies linearity in the presence of DVB-T signals on channels N+2 and N+4.

The S2 requirement is illustrated in Figure 3.1, below:

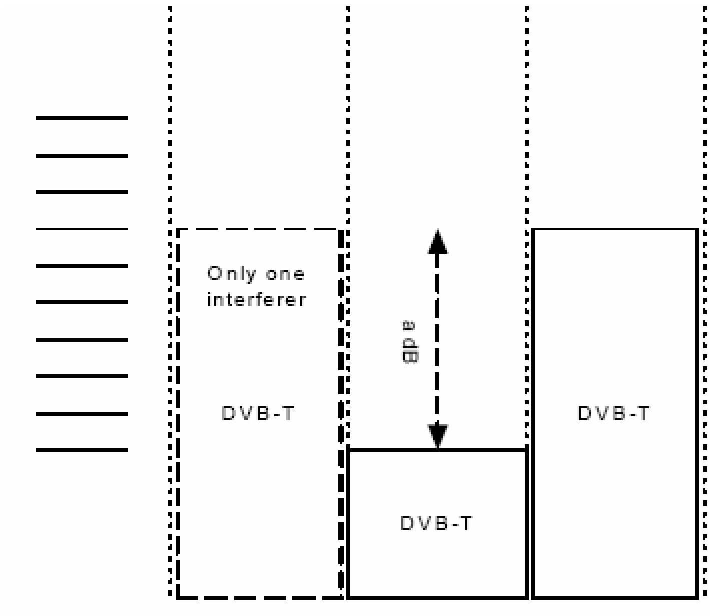


Figure 3.1: S2 test for selectivity *(source EICTA/TAC/MBRAI-02-16)*

Mode	a [N±1]	a [N±m (m≠1) except Image]	a [Image]
2k/8k 64QAM CR=2/3 GI=All	27 dB	40 dB	31 dB
2k/8k 64QAM CR=3/4 GI=All	27 dB	40 dB	29 dB
2k/8k 16QAM CR=1/2 GI=All	29 dB	40 dB	39 dB
2k/8k 16QAM CR=2/3 GI=All	29 dB	40 dB	36 dB
2k/8k 16QAM CR=3/4 GI=All	29 dB	40 dB	35 dB

Table 3.1: Immunity to pattern S2 *(source EICTA/TAC/MBRAI-02-16)*

For the purposes of modelling in this study, a value of **27dB** (N±1) **40dB** (N±m) and 29dB (image) will be assumed. In practice, it appears that most DVB-H receivers will be fabricated using a direct conversion (or zero-IF) architecture, so the image channel parameter is not relevant.

3.2.2 Non-linear effects

The L3 requirement is illustrated in Figure 3.2, below:

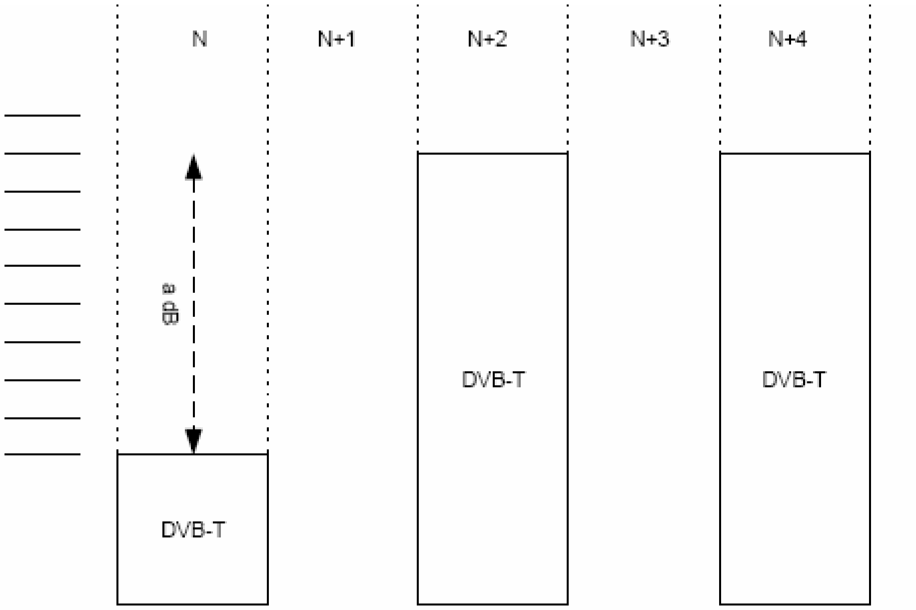


Figure 3.2: L3 test for linearity *(source EICTA/TAC/MBRAI-02-16)*

Mode	a [N+2 and N+4]
2k/8k 16QAM CR=1/2 GI=All	40 dB
2k/8k 16QAM CR=2/3 GI=All	40 dB

Table 3.2 : Immunity to pattern L3 *(source EICTA/TAC/MBRAI-02-16)*

There is limited data available on the actual performance of existing DVB-H receivers, but chip manufacturers stress the compliance of their various devices.

The ETSI DVB-H implementation guidelines [ETSI] specify (in section 10.3.3) that "*the receiver should provide reference BER for […] -100.2 + C/N dBm*". For 16-QAM with CR=1/2, the required C/N is 12.1 dB (from Table 10.2). The overall minimum input power is, therefore, -88.1 dBm.

An adjacent DVB-T signal can therefore be tolerated up to a power of :

-88.1 dBm +27dB = -61.1 dBm

An input power of -61.1 dBm corresponds to a field strength of around 81dBμV/m at a frequency of 650 MHz and assuming an antenna gain of -10dBi. For free-space propagation, this field would be given at some 20km from a 1kW transmitter.

This is an extreme case, assuming the minimum possible DVB-H field strength, and a very optimistic propagation path for the interferer. In practice, the DVB-H field strength will need (in open areas) to be in the region of 80-90dBμV/m at 10m above ground. This implies that a DVB-T field strength of around 117 dBμV/m would be necessary to cause adjacent channel interference, corresponding to some 300m from the 1kW DVB-T transmitter, or **1 km** from a 10kW main station. Although the two services use different polarisations, it could not be expected that the mobile handset antenna would offer any useful discrimination.

3.3 Planning considerations for mobile TV

3.3.1 Network implications

The very high field strengths noted in section 2.2.1 imply that a dense transmitter network will be necessary for the provision of mobile TV services. While the adherents of particular standards debate the differences between the systems, it seems to be the case that any such network will have a density closer to that of GSM 900 Macrocells than that of broadcast TV.

For the purposes of assessing the compatibility of mobile TV services this has the important consequence that there will be a very large population of transmitters that are not co-located with DTT sites. There is therefore, a very significant risk of 'hole punching' to the DTT network – the mobile TV network is more robust, owing to the very much greater wanted field strength. This is discussed below.

3.3.2 Restrictions on use of specific channels

It is generally agreed by proponents of mobile TV standards that it will be necessary to use frequencies below 750 MHz for any mobile TV service. This restriction is determined by the need to ensure compatibility with the GSM 900 terminals that it is assumed will be integrated in the same terminals.

This implies that only the middle release channels (31-40) may be used for such services.

It appears that this restriction is based on the assumption that receivers will need to be able to tune to any channel in the remainder of the band. It seems likely that, if such flexibility were sacrificed, it might be possible to use narrow-bandwidth, high-Q filters to select DVB-H channels above 750 MHz. Such an arrangement would, however, imply increased handset costs, and an inability to allow roaming (unless harmonised allocations are agreed).

3.4 Interference to and from other services

3.4.1 Co-channel outgoing interference

For the modelling within this study, mobile TV networks are assumed to make use of a dense network of sites, represented by transmitters with an omni-directional ERP of 500W, and an effective height above terrain of 20m.

To determine accurately the outgoing interference potential of such a network, and hence the necessary separation distances would be a complex exercise, requiring detailed knowledge of the deployment and geography involved. Furthermore, the degree to which the interference from different sites will be correlated in terms of time-variability is unknown[10].

For the purposes of determining representative separation distances it will (simplistically) be assumed that interference is caused by the aggregate interference from 10 such transmitters, represented by a single source of **5kW** at **20m** effective height, located 5km within the target service area.

Using the curves of Recommendation P.1546[11] [P], gives the following distances for 50% and 1% time. The 1% values will be assumed in the modelling associated with this project.

[10] This topic is currently the subject of a research study being carried out under Ofcom's Spectrum Efficiency Scheme.

[11] 600 MHz land curves, with no further correction

Victim	Interference threshold (at 10m)	Condition	Separation Distance (50%)	Separation Distance (1%)
DTT / Local TV	33 dBμV/m	Co-pol,on axis (0dB)	40 km	62 km
	49 dBμV/m	X-pol, or off-axis (-16dB)	17 km	**18 km**
Mobile TV	56 dBμV/m[1]		12 km	**12 km**
BWA / Cellular	13.6 dBμV/m[1]	BS receiver (co-pol, on axis)	120 km	**220 km**
	29.6 dBμV/m[1]	BS receiver (X-pol)	45 km	80 km
	43.7 dBμV/m[2]	MS receiver	23 km	**24 km**
PMSE	48 dBμV/m[3]	Outdoor	19 km	**19 km**
	58 dBμV/m[3]	Indoor	12 km	12 km

[1] From 4.8 dBμVm^{-1}.MHz^{-1} - see Section 2, above)

[2] From 24.9 dBμVm^{-1}.MHz^{-1} - see section 2, above, with 10dB height loss)

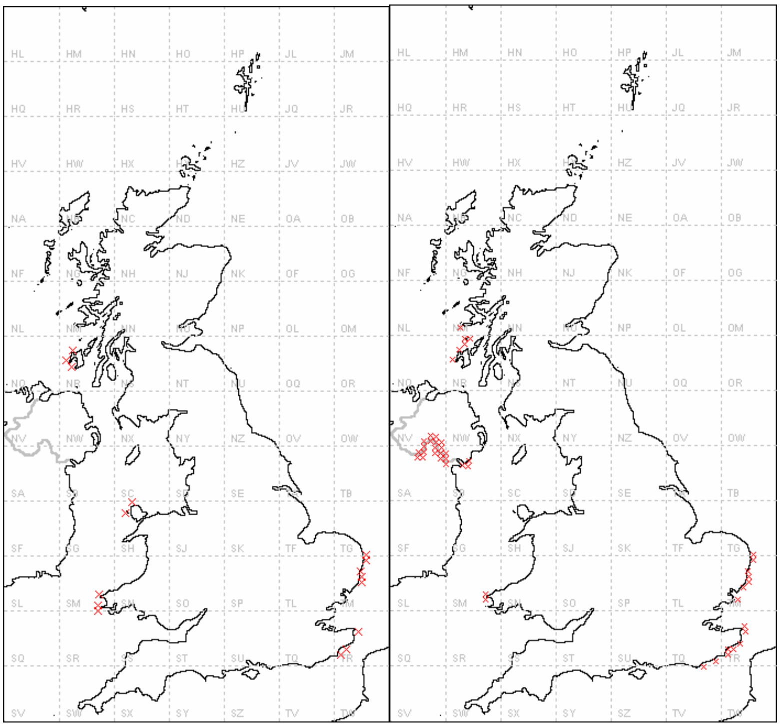
[3] From Section 6, below

Table 3.3: Co-channel separation distances assumed from Mobile TV reference network

The values in bold will be assumed to represent realistic distances in modelling elsewhere in this study.

Outgoing interference constraints to Ireland and the continent have also been modelled, as for the DTT case, but assuming the aggregate interfering sources described above. Owing to the relatively low power and lower mast height, the restrictions are far less onerous than for DTT. Figure 3.3 illustrates, for two example channels, the areas in which restrictions would apply to the deployment of transmitters for mobile multimedia services[12].

[12] These restrictions are also broadly representative of those that would apply to cellular & BWA networks.



Channel 31 Channel 64

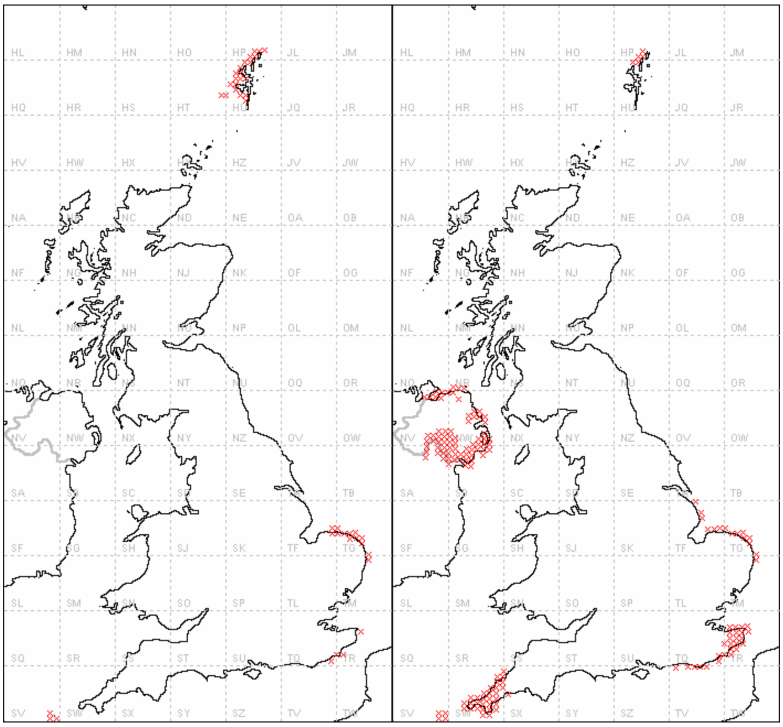
Figure 3.3: Outgoing interference restrictions for mobile multimedia networks

3.4.2 Incoming Co-channel interference from DTT

Given the likely near-ubiquitous coverage of any Mobile TV service, there seems little likelihood that a co-channel sharing situation would arise, with respect to any other UK service.

For the 56dBμV/m interference limit derived above, a separation distance of **35km** would be required to protect a mobile TV handset from a typical 10kW main DTT transmitter, with a 300m effective height. If polarisation discrimination (i.e. DTT is HP, Mobile TV is VP) could be taken into account, this would reduce to around 17 km; unfortunately, the antenna in a handheld TV receiver, though nominally vertically polarised, will exhibit virtually no polarisation discrimination in practice.

Given the very high levels of the wanted signal, the impact of continental and Irish interference, from DTT services operating under the RRC-06 plan, is minimal. The areas in which there is some possibility of interference are illustrated for two example channels in Figure 3.4.



Channel 31 Channel 64

Figure 3.4: Incoming interference restrictions for mobile multimedia networks

These plots show areas in which interference may exceed a value of 56dBµV/m for 1% time.

3.4.3 Adjacent channel interference to DTT

The possibility exists for interference to receivers located near the edge of DTT coverage from adjacent channel mobile TV transmitters located nearby. The accurate determination of the risk will require careful study of the joint field strength distribution in space of the two signals.

This section illustrates the problem with some practical examples.

This ‘hole punching’ problem need not be limited to the adjacent channel; this will, however, be likely to constitute the worst case. If DVB-H or similar services are to be implemented in cleared spectrum, adjacent channel interference can, clearly, exist only to DTT services operating on the three retained UHF channels adjacent to this spectrum. Table 3.4 lists the DTT transmitters for which RRC assignments on these channels have been sought (it must be borne in mind that a very large number of lower powered sites will also operate on these channels following switchover).

channel 30
CRYSTAL PALACE
BELMONT
CALDBECK
HASLINGDEN
DOVER TOWN
RAMSGATE
ALDEBURGH
HASTINGS
EASTBOURNE

channel 41
EMLEY MOOR
BLACK HILL
WENVOE
SUDBURY
THE WREKIN
HANNINGTON
REDRUTH
CHATTON
TUNBRIDGE WELLS
HEMEL HEMPSTEAD
ARFON
LONDONDERRY
WEYMOUTH
CAMBRET HILL
NEWHAVEN
BELCOO

channel 62
WINTER HILL
PONTOP PIKE
WALTHAM
TACOLNESTON
OXFORD
MIDHURST
BLUEBELL HILL
HUNTSHAW CROSS
SELKIRK
BRIERLEY HILL
MALVERN
CAMLOUGH
SALISBURY
POOLE
LIMAVADY
GIRVAN

Table 3.4: DTT assignments potentially vulnerable to 'hole-punching'

The sites shown in bold are main stations, and operate with horizontal polarisation (HP). These services should, therefore, be some 16dB less vulnerable to interference from vertically polarised (VP) DVB-H sites.

Some simple calculations give some idea of the likelihood of interference. The median DTT field strength limit assumed in this study is 53 dBµV/m. The assumed protection ratio for adjacent channel DVB-H to DVB-T interference is -25dB, which implies an interfering field strength of 78 dBµV/m. If the victim service is from an HP site, this value will increase to 94 dBµV/m.

The former figure corresponds to the free space field strength at 20 km from a 500W (ERP) transmitter; the latter figure to a distance of 3 km. These values would seem to represent upper limits for such interference.

A hypothetical scenario has been constructed, in which mobile TV coverage is provided in the town of Hemel Hempstead from a number of 100W ERP transmitters operating on channel 40. The DTT service for this area is provided by a high power relay site (1kW) some 2km from the south-east edge of the town.

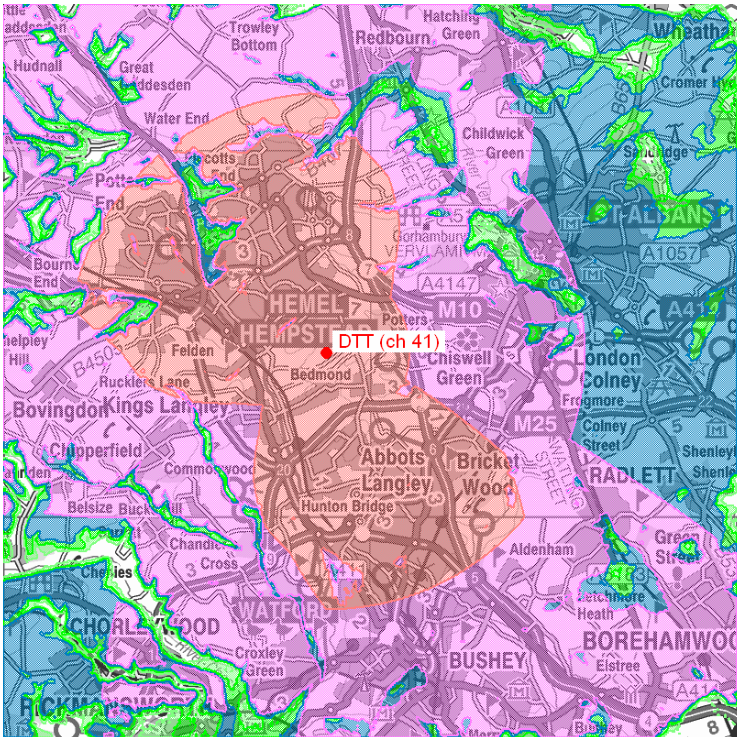


Figure 3.5: DTT coverage of Hemel Hempstead (Channel 41, VP, 1 kW)

In the figure above, the shading represents field strength, with red-shaded areas exceeding 90dBμV/m, and contours at 10dB intervals. The service is line of sight to most of the town, with a few diffraction limited 'holes'.

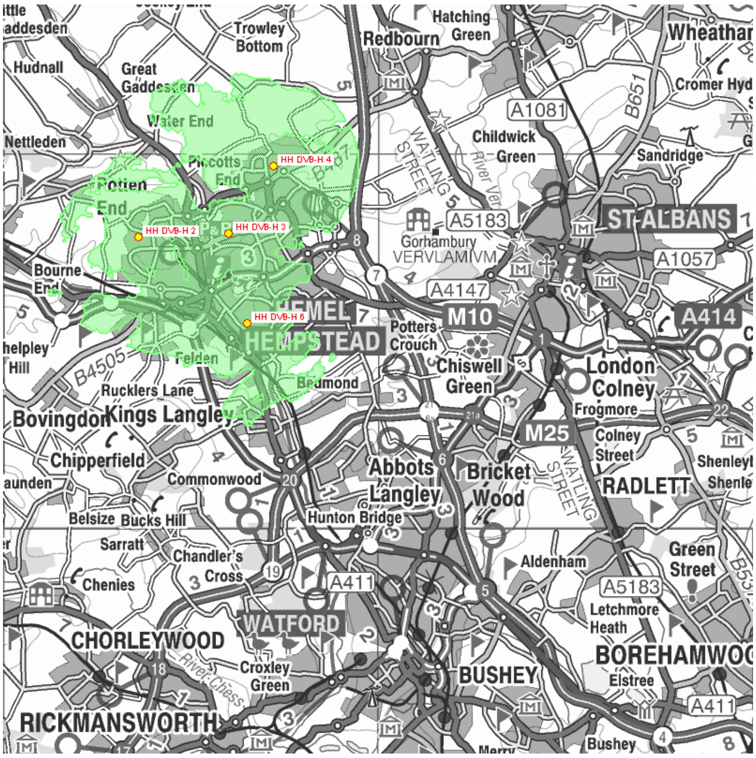


Figure 3.6: Assumed mobile TV network

Interference to the DTT services from the adjacent channel network has been modelled using an assumed protection ratio of -25dB. The result is shown in Figure 3.7, below.

Figure 3.7: DTT coverage (1 kW), showing interference

It can be seen that interference is very limited, being restricted to the immediate vicinity around one DVB-H site. Given the very high DTT field strength levels in the town, this result is not surprising.

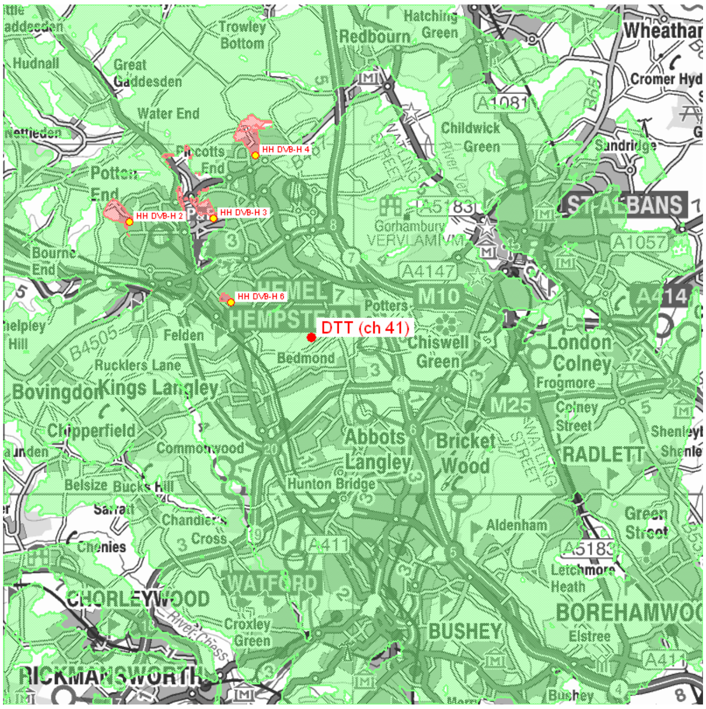


Figure 3.8: DTT coverage (10W), showing interference

The same prediction was made for the situation in which the DTT transmitter power is reduced by 20dB, to 10W. Even at this significant reduction, interference is slight.

Relay stations often operate with relatively high field strengths within their service areas, with the coverage limit being determined by sharp increases in diffraction (e.g. the Welsh valleys) or by incoming interference. Fringe area reception is more often associated with main transmitter sites, and these, as noted, will have a further 16dB of protection due to polarisation discrimination.

While these results may look optimistic, serious caveats apply. Firstly, the protection associated with receive aerial directivity may be less than assumed, and this will certainly be the case for portable reception.

Furthermore, the plots shown above are made on the basis between the median field strengths of the two services, and do not take the joint statistical distribution into account. This can be approximated by applying a correction based on the assumption that both wanted and unwanted signals exhibit a log-normal variability, and are uncorrelated. In this case, the joint distribution will also be log-normal, with a standard deviation given by:

$$\sigma_{total} = \sqrt{\sigma_w{}^2 + \sigma_u{}^2}$$

If the standard distribution of both distributions is taken as 5.5 dB (a value often used in planning), the following ‘exclusion’ distances are obtained for a DTT receiver with an aerial directed towards a 500 W mobile TV transmitter operating on an adjacent channel.

In all cases the distances are calculated assuming free space propagation, and a more realistic Okumura-Hata type method. Values have been predicted for both the edge of coverage and for a point 10dB above the DTT reception threshold.

Median wanted FS	Required location protection	Receiver ACI protection ratio	DTT polarisation	'Exclusion' distance (free space)	1546 (20m)
53 dBµV/m	70%	-25dB	HP	5.9 km	900m
53 dBµV/m	70%	-28dB	HP	4.2 km	800m
53 dBµV/m	70%	-25dB	VP	37.0 km	2.4 km
53 dBµV/m	70%	-28dB	VP	26.2 km	2.0 km
53 dBµV/m	95%	-25dB	HP	16.0 km	1.5 km
53 dBµV/m	95%	-28dB	HP	13.0 km	1.3 km
63 dBµV/m	70%	-25dB	HP	1.3 km	**600m**
63 dBµV/m	70%	-28dB	HP	1.9 km	400m

Table 3.5: Illustrative exclusion distances for adjacent-channel 'hole-punching' by a 500W transmitter

It should be borne in mind that these distances relate to the case of a DVB-H transmitter falling in the main beam of a domestic DTT receive aerial. These distances will fall off rapidly for the off-axis case. The wide spread of values is important to note – it is impossible to make precise judgments without detailed knowledge of local geometry for each case. For the purposes of modelling within the present project, the '10dB above threshold' value, with polarisation discrimination will be used (i.e. **600m**).

In conclusion, it appears that 'hole-punching' is only likely to be a significant problem near the edge of coverage of DTT services, for a limited range of aerial alignments. It should be straightforward to predict areas in which there is risk of such interference.

Should interference be found to present a problem in specific cases, it should be straightforward to install a low-power DTT transmitter at the DVB-H site. The only additional cost will be that of the DTT transmitter and a combiner unit; this is likely to be insignificant in comparison to the cost of site rental.

It will be necessary to provide a suitable feed, which may be off-air (paying attention to the adjacent channel isolation) or from an existing satellite distribution[13]. If the off-air option is possible, small DVB-T rebroadcast transmitters are already coming onto the market, such as the Harris 'SPOT' series.

If an off-air feed is to be used in such cases, it may be necessary to identify a new frequency to be used at the site. The new generation of digital repeaters introduce significant delay to the rebroadcast signal, preventing operation in an SFN. This will not be the case for an analogue repeater, but such devices require very careful alignment to achieve suitable antenna isolation.

The availability of new frequencies on which to operate such fillers may be limited, but the power required will generally be low, and the service directional. In general, it should not be necessary for viewers to re-orient aerials, as (by definition) the existing installation must have sufficient response in the direction of the offending transmitter site.

3.4.4 Adjacent channel interference to Cellular / BWA services

Adjacent channel interference may also occur between Mobile TV and cellular / BWA services. For the assumed 500W ERP, 20m effective height transmitters, and the cellular/ BWA characteristics of Section 4, below, such interference may occur at distances of up to **3.2 km and 3.0 km** for interference to **base and mobile** receivers respectively. It is important to understand that these are representative values only. Actual distances will be greatly affected by specific terrain and clutter; furthermore, the calculations are based on parameters assumed for a service that does not exist, and for which no standards have been agreed.

[13] But note that no suitable feed is expected to exist. Even if correct programme content was available by satellite, it would be necessary to re-multiplex, correct timing and to insert suitable Service Information (SI), so the option would be expensive.

4 CELLULAR / BROADBAND WIRELESS

The key feature of these services is that they would be bi-directional, with transmit-enabled user terminal able to roam freely. In other parts of the spectrum where such services operate, it is usual for guard bands to be provided to ensure compatibility between such roaming terminals and other services.

A second problem in considering these services is that no standards exist for such applications in this spectrum. The two main candidate systems are IEEE 802.16, or Wi-MAX, and UMTS (both currently only specified to operate in bands above 2 GHz).

It should also be noted that the 3G standards body, the 3GPP, are in the early stages of the definition of plans for Long Term Evolution (LTE) of 3G standards. One of the characteristics of LTE proposals is likely to be a more flexible use of spectrum, with system bandwidth adaptable to available spectrum resources. In the context of this study, this will tend to make such mobile technologies look more similar to those proposed under the Wi-MAX umbrella.

4.1 UMTS 500

A hypothetical version of UMTS, operating in the lower portion of the UHF band, is often referred to as 'UMTS 500'

The UMTS forum [UMTS] notes that: "*The mobile allocation in this band could in particular benefit developing countries, rural areas and larger areas of low population density along with its potential for long-range coverage. In addition this band has the potential for a global mobile allocation*"

"*With an allocation of 2x30 MHz and based on existing 5 MHz channelling, it could be possible to have three UMTS/IMT-2000 operators each having 2x10 MHz. This would provide a viable business case for operators and balanced competition. Also with 2x30 MHz, the band can be considered wide enough to be interesting from vendors' point of view. This spectrum amount could also facilitate greenfield operators in some emerging markets, like Africa. Based on the above, the UMTS Forum is recommending 2x30 MHz as a viable minimum band needed*."

The UMTS Form report is illustrated with a case study relating to coverage provision in the sparsely-populated rural area of the Massif Central. The Report concludes: "*covering large areas of low population density with UMTS/IMT-2000 at 2 GHz is a real challenge for network operators in terms of a viable business case, also taking into account the fact that revenues are typically low in these geographical areas*".

The Forum Report recommends (i) that the RRC should harmonise the digital dividend within the band 470-600 MHz[14] , (ii) that a new IMT-2000 'coverage Extension Band be identified at these frequencies in the context of WRC-07 and (iii) that 2 x 30 MHz of paired spectrum, using 5 MHz channelling represents the minimum viable resource needed.

In practice, the RRC did not harmonise the digital dividend in this (or any other) part of the spectrum, and the spectrum identified will (apparently) continue to be used very intensively in most of Europe for DTT (and, in some cases, mobile TV).

It appears that, as the spectrum is required for wide area coverage, rather than additional 'hot spot' capacity, TDD technologies may not be appropriate, due to the guard intervals required between uplink and downlink transmission slots[15]. If FDD is to be used, however, there is a need to specify (and if possible harmonise) the frequency split between the uplink and downlink. This split is reflected in the filtering necessary in handsets, which represents a significant cost issue, and (unlike other parameters) cannot readily be made flexible through the use of digital signal processing. There is no current proposal for a specific frequency split.

An additional extension band for IMT-2000 was identified at 900 MHz at WRC-2000, with a recommended FDD duplex separation [M1] of 45 MHz (mobile transmit in the lower band). If the same separation is assumed for the lower frequencies, and applied to the lower DDR cleared spectrum block (see Figure 4.1), this would imply that five x 5 MHz channel pairs might be assigned, with a 10 MHz centre gap (potentially suitable for TDD use) and a further 10 MHz gap corresponding to the Radio Astronomy allocation on Channel 38.

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[14] i.e. UHF channels 21-37

[15] There is a range limitation in TDD systems, due to the 'time-of-flight' required for signals to reach a distant terminal, and for that terminal to reply within a single TDD timeslot.

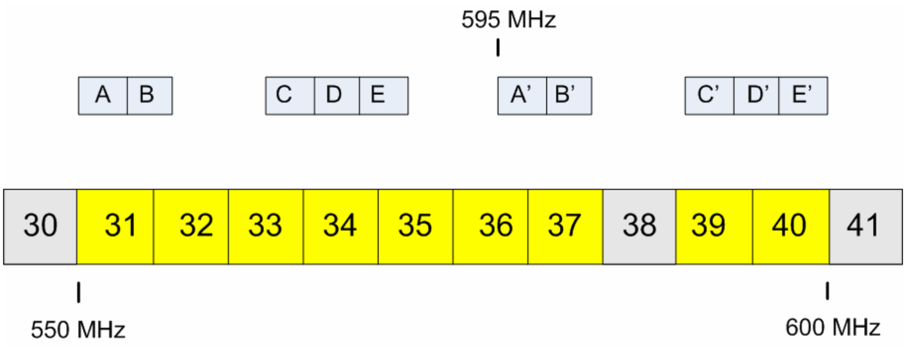

Figure 4.1: Possible FDD arrangement in DDR cleared spectrum (Source: Aegis)

If mobile transmit were assumed to use the lower band, this would simplify sharing with radio astronomy, though adjacent channel effects from mobile terminals to DTT receivers on channel 30 might be problematic.

Of course, as there is no sign of impending harmonisation of such an FDD split, it would be possible for the UK to act autonomously, or to initiate harmonisation of a split on any basis that might be appropriate for this spectrum.

A further factor that needs to be considered is the channelisation for such services; Most current work assumes that it will be necessary for UMTS services in this band to retain the standard 5 MHz channel spacing used elsewhere. This will complicate issues of co-ordination, where the UK would be in the position of ensuring that a service using 5 MHz channels was consistent with the RRC plan, which assigns spectrum rights on the basis of 8 MHz channels. This might significantly reduce flexibility, as the UMTS channels will generally overlap two RRC channels, and will need to accommodate the more stringent co-ordination requirements of the pair[16].

The UMTS forum report assumes that FDD operation is necessary, as the requirement for this spectrum is assumed to be to provide rural coverage, especially in developing countries. If the application were, rather, to allow a new entrant to the market, or to provide capacity extension in urban hotspots, the use of TDD might be envisaged.

In this case, the problems surrounding harmonisation are greatly simplified, as it is not necessary to specify a fixed FDD split. TDD would be better suited to providing capacity extension, rather than basic coverage, owing to the problems of frequency planning for contiguous, wide area use (basically, the need to

[16] It is worth bearing in mind, in this context, the situation in Band III, where the UK has suffered from a channelisation (for PMR) that is at variance to that used on the Continent (for TV).

ensure that base stations in one cell are not transmitting while those in an adjacent cell are receiving)

4.1.1 UMTS 500 parameters

As no specification for this system exists, the characteristics below have been based on those given for 2 GHz systems in an ITU-R report [M2] on compatibility calculations for UMTS. It must be stressed that these figures are intended only to give a 'rough order of magnitude' understanding of sharing issues. To derive a robust understanding of the intra-service compatibility of a hypothetical UMTS 500 service would be a substantial project in its own right.

4.1.1.1 UMTS 500 Base station

- Typical base station (BS) transmitter ERP: 100W[17]
- Assumed BS antenna gain: 10dBd
- BS receiver noise floor: - 98 dBm/3.84 MHz (-103.8dBm/MHz)
- BS receiver sensitivity: -121 dBm/3.84 MHz (-126.8 dBm/MHz)
- BS interference threshold: -108 dBm/ 3.84MHz (-113.8dBm/MHz)
- BS: Adjacent channel selectivity (ACS): 46dB

The field strength corresponding to the interference threshold is, at 600 MHz, 4.8 $dB\mu Vm^{-1}.MHz^{-1}$. The ACS performance figure implies that a field strength in the adjacent channel of around 51 $dB\mu Vm^{-1}.MHz^{-1}$ could be tolerated[18].

To put this in context, a DTT signal has a bandwidth of 7.6 MHz (8.8 dB_{MHz}), so if the adjacent channel interferer was a DTT service, and that polarisation discrimination applies, the applicable limit would be **76 $dB\mu Vm^{-1}$**. This is the field strength that might be expected[19] at up to around **23km** from a 10kW transmitter with an effective height of 300m.

It *may* be relatively straightforward to site base station receivers and tailor antenna characteristics, so as to avoid such adjacent channel interference from local DTT receivers. In addition, it seems likely that if a standard were developed for use in this band, attention would be paid to the improvement of BS receiver filtering.

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[17] Assumes 40dBm tx power with 10dBd net antenna gain

[18] Note that the ACS parameter relates to interference between fixed 5 MHz channels, whereas the current problem is more complex.

[19] From ITU-R Recommendation P.1546

The problem of co-channel interference from distant continental interferers may be harder to avoid, though such interference is likely to be present only for small percentage-times. The interference threshold quoted above relates to a 0.4dB degradation of the noise margin of the receiver (I/N=-10dB). For short-term (tropospheric) interference it is possible that this constraint can be reduced, perhaps to 0dB I/N. Discussions with some industry figures, however, suggest that this might introduce intolerable losses in coverage.

Correcting for the DTT bandwidth, the co-channel interference limit for the BS receiver is 13.6dBμV/m. The variability of incoming interference is illustrated in the figures below which show incoming levels of interference to the UK from a network of continental TV transmitters representative of the interference environment agreed at RRC. The interference contour represents a field strength level of 20dBμV/m .

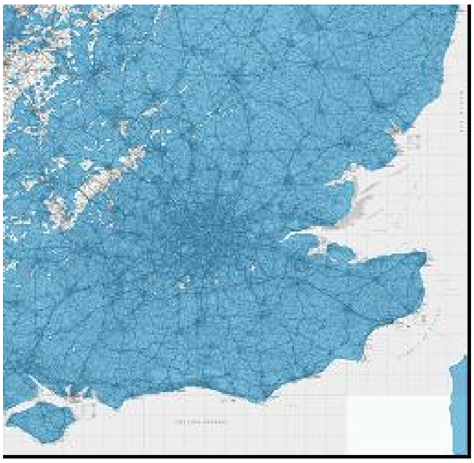
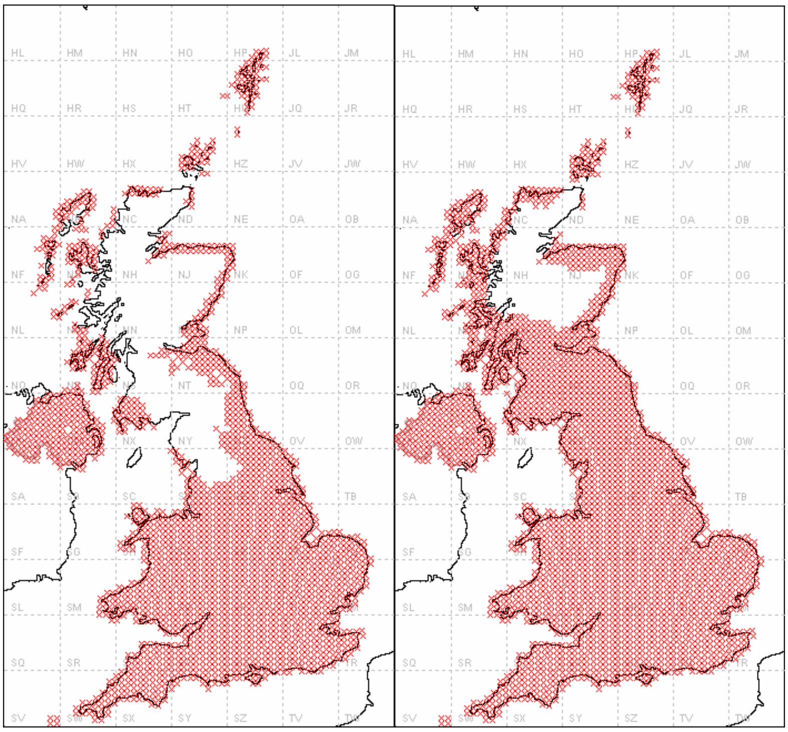


Figure 4.2a: Interference (50% time) Figure 4.2 b: Interference (1% time) (Source: Aegis)

It can be seen that such interference may pose a significant challenge to network design for any potential operator in this band. Predictions for the 13.6 dBμV/m limit at 1%-time for two example channels are shown in Figure 4.3 below.



Channel 31 channel 64

Figure 4.3: Incoming interference to Cellular BS receivers (1% time)

It should be emphasised that the continental interference will largely be rejected by cell sectors antennas bearing North and West. Furthermore, as noted above, the interference criteria assumed are speculative, in the absence of a specific system design.

4.1.1.2 UMTS 500 Mobile terminal

Mobile terminals (MS) will also be vulnerable to adjacent channel interference. The equivalent, assumed characteristics are:

- Typical mobile station (MS) transmitter ERP: 100mW[20]
- Assumed MS antenna gain: -7dBd
- MS receiver noise floor: - 99 dBm/3.84 MHz (-103.8dBm/MHz)
- MS receiver sensitivity: -117 dBm/3.84 MHz (-122.8 dBm/MHz)
- MS interference threshold: -105 dBm/ 3.84MHz (-110.8dBm/MHz)
- MS: Adjacent channel selectivity (ACS): 33dB

[20] Assumes 27dBm tx power with -7dBd (-5dBi) net antenna gain

The field strength corresponding to the interference threshold is, at 600 MHz, 24.9 dBμVm^{-1}.MHz^{-1}. The ACS performance figure implies that a field strength in the adjacent channel of around 58 dBμVm^{-1}.MHz^{-1} could be tolerated, or 67 dBμVm^{-1} from a transmitter with an 8 MHz nominal bandwidth.

Allowing for a 10dB height loss, this corresponds to a separation[21] of **21 km** from a **main station DTT** transmitter. This separation requirement seems severe, particularly when compared to that relating the base station receiver (22 km), but is due to the poorer ACS of the mobile receiver, and the lack of polarisation discrimination.

In the other direction, as has been noted above, a DTT receiver is able to offer a worst case adjacent channel protection ratio of -25dB. For a 64-QAM service, the median wanted signal will be 53 dBμV/m at edge of coverage, allowing an interfering field strength of up to 78 dBμVm^{-1} 7.6 MHz^{-1}.

For an MS in the vicinity of the **DTT** household, with a line of sight to the rooftop antenna, this corresponds to a required separation distance of around **300m**. This is a worst case situation in that, in most cases, (i) the DTT receiver will not be at the edge of coverage and (ii) up to 16dB of aerial directivity or polarisation discrimination will be available. An additional rejection of 16dB would reduce the required separation distance to some 45m, which may represent a tolerable risk where UMTS usage is not dense.

The same calculations for the case of image channel interference (interferer is on a frequency nine channels above that the DTT receiver is tuned to) give separation distances of 110m and 18m respectively.

For adjacent interference to other **cellular / BWA** services, and using the Okumura-Hata propagation model, a separation distance of **~2.2 km** is necessary to a **base** station receiver (assuming that the mobile transmitter provides no useful cross-polar discrimination), and around **350m** to another **mobile**. The latter value in particular, should be treated with caution, as propagation at these ranges will be entirely determined by specific local clutter. It is sufficient to note that mobile terminals that may have line of sight to each other will be unable to share. This might be a problem if TDD services were proposing to use adjacent channels, with no time synchronisation.

[21] Using P.1546, reference [P].

4.2 Wi-MAX (802.16)

'Wi-MAX' is a relatively new standard that emerged from Working Group 16 of the IEEE 802 LAN/MAN[22] standards committee. The original intention was to provide a means for broadband connectivity operating in the frequency range 10-66 GHz. The standard has since been extended to add support for the 2-11 GHz range, and mesh networking.

The most recent extension [WIMAX] has been the 802.16e variant, which will add mobility (i.e. handoff between cells, etc) to the standard. This will place WiMAX in direct competition with existing standards, such as UMTS.

The physical layer of WiMAX is based on OFDM modulation (using QPSK, 16-QAM and 64-QAM), and uses TDD. The standard allows for a number of bandwidths, with the spacing between OFDM carries held constant at 10.94 kHz. In the initial release, bandwidth of 5 and 10 MHz are specified, with variants ranging from 1.25 to 14 MHz. [It should be emphasised that no commercial equipment is yet available that is fully compliant with the specification].

The combination of TDD and scalable bandwidth should allow 802.11e to make opportunistic use of available frequency resources. In principle, it could also be used in a pure broadcast mode, with all the TDD frame allotted to the downlink. In this case, it would rather resemble other OFDM-based broadcast standards such as DVB-H, T-DMB and MediaFLO technologies. The author is not aware, however, of any proposal to use 802.11 in this way.

There is UK interest in the use of this technology in the UHF band. It has been suggested to the author that the sharing parameters would be very similar to those for UMTS systems. The same restrictions regarding the use of TDD for wide area, contiguous coverage provision would apply.

4.3 Interference to and from other services

4.3.1 Co-channel outgoing interference

In this study, these networks are assumed to make use of a relatively dense network of sites, and, for the purposes of this study it will be assumed that the base station interference potential is identical to that from a mobile TV network (see Table 4.1). In practice, there would be likely to be two significant differences; Firstly, sectorised base station antennas would be likely to be used, and secondly, the ERP from any transmitter is likely to vary with cell loading.

[22] Local Area Network / Metropolitan Area Network

A potentially more problematic issue relates to the possibility of interference from mobile / portable transmit terminals (i.e. cellular handsets, or wireless data cards in laptops or PDAs). It has been assumed, above, that such mobile devices will have an ERP of 100mW in an 8 MHz channel.

ITU-R P.1546 [P] was used in the calculations above, but is based on measurements relating to propagation from high broadcast transmit aerials to rooftop receive aerials. Consequently, for the case of propagation from a handset, at about 1.5m above ground, and likely to be immersed in clutter. Distances have therefore been assessed on the basis of the Okumura-Hata model, a empirical model that is simple, gives a (necessarily[23]) wide standard deviation of error, but is widely used.

On this basis, the following separation distances are implied, with respect to other networks:

[23] As propagation loss over these distances is largely determined by the presence or absence of clutter, which can only be determined using sophisticated ‘ray-tracing’ models.

Victim	Interference threshold (at 10m)	Condition	Separation Distance (Okumura-Hata, 1m tx, 10m rx)
DTT / Local TV	33 dBμV/m	Co-pol,on axis (0dB)	1.8 km
	49 dBμV/m	X-pol, or off-axis (-16dB)	**650 m**
Mobile TV	56 dBμV/m[1]		**400 m**
BWA / Cellular (other network)	13.6 dBμV/m[1]	BS receiver (on axis, co-pol)	**6 km**
	29.6 dBμV/m[1]	BS receiver (X-pol)	2.3 km
	43.7 dBμV/m[2]	MS receiver	**900 m**
PMSE	48 dBμV/m[3]	Outdoor	**700 m**
	58 dBμV/m[3]	Indoor	330 m

[1] From 4.8 dBμVm^{-1}.MHz^{-1} - see Section 2.3, above)

[2] From 24.9 dBμVm^{-1}.MHz^{-1} - see section 2.3, above, with 10dB height loss)

[3] From Section 2.5, above

Table 4.1: Co-channel separation distances assumed from Cellular/BWA handsets

The values in bold will be assumed to represent realistic distances in other modelling within this study.

5 LOCAL TV

In terms of the susceptibility of the receiver to interference, there is clearly no difference between the national and local TV scenarios.

The only significant difference is that any dedicated local TV transmitters at main station sites are likely to operate at a lower power (with correspondingly more robust modulation scheme) than for the national networks. Alternatively, new, more local sites may be used to allow higher field strengths to be provided in the target service area.

In this study, it is assumed that local TV services, whether radiated from a main station, or from a new, local site, will use QPSK modulation, to allow wide area coverage at lower power (14dB) than the PSB & COM multiplexes. Thus, a typical 10kW main station might achieve a similar coverage using only 400W of power for a local TV service.

5.1 Interference to and from other services

5.1.1 Co-channel outgoing interference

For a 400W transmitter, the separation distance required to offer protection to a (national) **DTT** service area can be estimated, as for local DTT, using the propagation model of P.1546 [P]. For an interfering transmitter effective height of 300m, a separation to the nearest edge of the DTT service area of 48km is required. It is likely that local TV services may be constrained, for reasons of cost, to use lower transmit aerials; at 150m effective height, a separation of **30 km** is required, and this is the value that will be assumed in other modelling .

The same calculation with respect to the handheld receivers of a **mobile TV** service gives separation distances of the order of **20km,**

A co-channel separation distance of **80km** is required to the to **base station** receiver of a **cellular / BWA** service, while protection of the associated **mobile terminal** receiver is achieved at only **34 km**.

5.1.2 Adjacent-channel outgoing interference

Local TV transmissions will probably need to be radiated using the same polarisation and aerial grouping as the existing DTT transmitter serving the area. Additionally, it will be necessary, either to co-locate the local transmitter with the existing transmitters, or to ensure that it is aligned with the aerials of the target population.

If transmissions are radiated from the same site, there will be no adjacent channel problems, as the 14dB power difference is within the -27dB protection ratio assumed for DTT receivers, even allowing for statistical effects.

If the transmissions are not co-sited, the possibility exists for ‘hole-punching’ to DTT services in an adjacent channel. As the ERP of a local TV transmitter is likely to be comparable with that assumed for mobile TV transmitters in section 2.2 above, the same separation distance (**600m**) will be assumed for the purposes of modelling in this project,. It must be stressed, however, that there will be a wide statistical spread associated with the possibility for such hole-punching, and this will need to be assessed on a case-by-case basis.

Adjacent channel interference to Mobile TV services will be possible; assuming the characterisation of such services in Section 3, separation distances (from a 400W ERP transmitter with an effective height of 150m) of 6.6 km and 6km to the base and mobile terminal would be required.

6 PMSE

The interface requirements for PMSE use are set out in Ofcom document IR 2038, and require UHF radio microphones to be limited to 10mW eirp, and to use 200 kHz channel bandwidth. The relevant standard is EN 300 422. Talkback applications operate with 12.5 / 25 kHz channel bandwidth at 1W (EN 300 086) and programme audio links at 5W in 200 kHz bandwidth (EN 300 454).

The main PMSE use in this band (in terms of spectrum demand) is for radio microphones; this study has modelled only this application.

6.1 Wanted signal

The following parameters have been assumed for radio microphone systems.

- Assumed height above ground (tx & rx): 1m
- Antenna gain: 0dBi (handheld) / -7dBi (bodyworn)
- TX power: 10 / 50mW
- EIRP: 10mW (6.3 mW ERP)
- RX bandwidth: 200 kHz
- Modulation: FM
- Base unit (RX) antenna gain: 0dBi
- Adjacent channel response: Similar to FM Band II receivers, as specified in [BS] and Analogue TV sound receivers as in [BT]
- Building penetration loss: 10dB
- Height gain (1m to 10m): 10dB

It is assumed that the radio microphone receiver has a performance similar to a (monophonic) FM broadcast radio receiver.

For 75kHz deviation, 15 kHz audio bandwidth and 5dB noise figure, the input power required for 60dB s/n is -115 dBW. The equivalent field strength (at 650 MHz) is, therefore **53 dBμV/m,** at the edge of coverage of the system.

6.2 Interference to and from other services

6.2.1 Incoming interference from DTT & Local DTT

ITU-R Recommendation BT.1368-6 [BT] gives protection ratios for FM sound carriers interfered with by DTT. For continuous interference, the value is 15dB for an 8 MHz DVB-T system, implying a maximum interference field of

53-15=38dBµV/m. Allowing for 10dB of height gain, the maximum interfering field at 10m is **48 dBµV/m** and for indoor radio microphones, **58 dBµV/m**.

A typical co-channel separation distance is required for use in the other modelling associated with this project. The 48 dBµV/m figure above, and an assumed 10kW main DTT transmitter with 300m effective height, give a required separation distance of **~60km**. This is comparable with, or rather greater than, the service radius of a typical DTT transmitter. For a 400W local TV transmitter, with effective height of 150m, the separation falls to **25km.**

The radio microphone will have an IF filter with a bandwidth of the order of 200 kHz. An adjacent channel discrimination of some 30dB (with respect to the co-channel case) would normally be expected (see, for example ITU-R Recommendation BS.412-9) for intra-system interference. As the DTT system uses an 8 MHz bandwidth, and few radio microphones will operate at the edge of an 8 MHz channel, a value of **40dB** is assumed in this study. For comparison, ITU-R Recommendation BT.1368-6 quotes a figure of 31dB (with respect to the co-channel case) at 250 kHz from the channel edge, falling to 42 dB at 500 kHz.

This implies maximum interfering field strength values from DTT (at 10m) of **88 dBµV/m** (outdoor) and **98 dBµV/m (indoor)**. No interference is assumed to arise from channels beyond those immediately adjacent.

For a main DTT transmitter (10 kW ERP, 300m effective height) this implies an adjacent channel separation distance of 12km (for outdoor use), while for a local TV service the distance falls to 2.5 km. If polarisation discrimination can be assumed for the PMSE receiver (which is likely for the outdoor case), and if the DTT services are horizontally-polarised, these figures will be reduced. A value of 10dB will be (tentatively) assumed for such discrimination, giving distances of **5km** and **1km** from main and local DTT transmitters respectively.

It must be emphasised that these values are very tentative, and will apply only to radio microphone receivers operating near to a channel edge.

6.2.2 Incoming interference from other services

The limits for interference from DVB-H will be identical to those given above for the DTT case, and other mobile TV technologies will impose similar constraints, as they all use OFDM techniques with similar interfering characteristics.

The only exception might be in the case of T-DMB operating in a different bandwidth; For co-channel interference, this might reduce the impact from T-DMB by approximately the ratio of the bandwidths (i.e. 10 x log (8.0/1.5) = -7.3dB). In practice, however, it is likely that multiple T-DMB transmissions would be radiated within a single 8 MHz channel, giving rise to the same interference as other technologies. For the adjacent channel case, the interference will be dominated by the power density close to the channel edge, and technology is again, largely irrelevant.

It is assumed, in this study, that both **Mobile TV** networks and **Cellular / BWA** networks may be modelled as using 500 W ERP base station transmitters with a 20m effective height[24]. This implies an adjacent channel sharing distance to an outdoor PMSE receiver of **1.3 km** (no polarisation discrimination will apply, as all services are vertically polarised). The separation distance from a **mobile handset** (100 mW ERP) will need to be around **100m**.

It is not expected that the power spectral characteristics of any other potential services would be sufficiently different (to a first order of magnitude) to make the assumption of different interference limits necessary.

While the interfering field strength assumption may be unchanged, the case of interference from mobile or transportable terminals clearly requires careful consideration. It is very likely, for example, that personal devices with transmit capability, such as cellular phones, may be operated within the ‘service area’ of a radio microphone receiver, particularly at public events. In this case, there is a very serious risk of interference, if there is not careful co-ordination between such use and radio microphones.

6.2.3 Co-channel outgoing interference from PMSE

The technical modelling of PMSE use, in this study, was limited to radio microphone systems. Such systems are modelled in this study as having an ERP of 6.3 mW (-22 dBW) in a 200 kHz channel. Owing to the low radiated power, and low gain antennas used, radio microphones have limited interference potential.

As many radio microphones can be accommodated in a single 8 MHz channel there is a likelihood that any interference will be as a result of aggregate entries, particularly near professional venues (concerts, TV outside broadcasts). It is therefore conservatively assumed, for the purposes of modelling, that interference is due to five simultaneous entries, giving an effective microphone power of 31.5 mW (-15 dBW) ERP.

On this basis, the following co-channel separation distances are implied, with respect to other networks:

[24] Representing the aggregate impact of a number of low-power transmitters.

Victim	**Interference threshold (at 10m)**	**Condition**	**Separation Distance (Okumura-Hata, 1m tx, 10m rx)**
DTT / Local TV	33 dBμV/m	Co-pol,on axis (0dB)	1.3 km
	49 dBμV/m	X-pol, or off-axis (-16dB)	**440 m**
Mobile TV	56 dBμV/m[1]		**300 m**
BWA / Cellular (other network)	13.6 dBμV/m[2]	BS receiver (on axis, co-pol)	**4.8 km**
	29.6 dBμV/m[2]	BS receiver (X-pol)	1.7 km
	43.7 dBμV/m[3]	MS receiver	**700 m**
PMSE	48 dBμV/m[4]	Outdoor	**400m**
	58 dBμV/m[4]	Indoor	230m

[1] See Section 3

[2] From 4.8 dBμVm^{-1}.MHz^{-1} - see Section 4, above)

[3] From 24.9 dBμVm^{-1}.MHz^{-1} - see section 4, above, with 10dB height loss)

[4] From Section 6.2.1, above

Table 6.1: Co-channel separation distances assumed from radio microphones

The values in bold will be assumed to represent realistic distances in the other project modelling.

It might be assumed in this study[25] that no interference to DTT services can arise; On the assumptions made above, outdoor radio microphones will only operate where the DTT field strength is below 48 dBμV/m, which is comparable with the limit of service for DTT. Indoor radio microphones can tolerate a higher DTT field

[25] It may be necessary, in more detailed work, to consider the possibility of interference to fringe area DTT reception, particularly in regard to the PSB multiplexes in the retained spectrum.

strength, but in this case, the potential interferer power is reduced, *pro rata*, by building attenuation.

6.2.4 Adjacent channel Interference to other Cellular / BWA

For adjacent channel interference to ‘cellular’ systems the thresholds derived above of 60 dBμVm^{-1} for the base station receiver and 67 dBμVm^{-1} for the mobile receiver (interference from an 8 MHz system) can be applied.

For an aggregate interference of -15dBW, at an assumed height of 1m, a separation distance of **400m** (BS) and **150m** (MS[26]) is implied. For the MS case this means, in effect, that interference may occur wherever the two terminals have a line-of-sight.

[26] The calculation for the MS assumes a 10dB height loss from 10m to 1m.

7 MUTUAL INTERFERENCE CONSIDERATIONS

Any technical modelling of the digital dividend spectrum will require a computer model to be developed to investigate optimum packing options for the spectrum, based on maximising the economic value to the UK.

This model will require, as an input, a description of the mutual constraints applying to the different services that might share this spectrum. For the case of high power DTT, and the constraints relating to the RRC plan, Aegis Systems have developed a computer model which describes such constraints in terms of field strength values at points on a 10km grid throughout the UK, as well as outgoing power limits from DTT transmitter sites. This approach has been necessary because of the dominant impact of the high power DTT network on spectrum use and compatibility, and the importance of geography and site-specific factors in assessing that impact.

For the other services, the physical scale is such that this approach is not possible (without a much more detailed technical model, implying very long run times). Consequently, the compatibility of these services is described in terms of generic separation distance requirements for both co- and adjacent channel cases.

These values, developed in the preceding text, are summarised in the tables below.

It is very important to understand the caveats associated with these values.

Firstly, where relatively short propagation paths are concerned (100m to a few km), the statistical uncertainty regarding loss is very great. The presence of a single obstacle (e.g. car or building) can change the path loss by tens of dB, implying a corresponding change of separation distance of many hundred percent. The figures in the tables are, therefore, only intended as ‘representative’ figures for the specific purpose of providing input assumptions for the optimisation engine.

Secondly, the receiver or network performance in many cases is either unknowable, as no devices yet exist (e.g. BWA/Cellular), or because no accepted rules for network design have yet been established (e.g. mobile TV). In these circumstances, it is not possible to undertake a fully-detailed statistical characterisation of the risk. Furthermore, there is a ‘chicken and egg’ situation in that, when the characteristics of a piece of spectrum are known (particularly with regard to adjacent channel issues) it becomes possible for designers to accommodate these characteristics. If no such assumptions can be made by any party, all parties may have to assume worst-case outcomes in assessing the risk of bidding for spectrum (e.g. “will my neighbour be a high power DTT network, or occasional indoor radio microphone use). A second-order effect is that, if more stringent filtering is needed, this is likely to degrade the noise performance of a receiver, implying that a more dense transmitter infrastructure is needed, which may, in turn, export more interference.

7.1 Co-channel separation distance matrix

	To DTT	To Local TV	To Mobile TV	To BWA / Cellular	To PMSE
From DTT	Model uses FS matrix Typically 130km between transmitters	Model uses FS matrix Typically 80km from TX to edge of local service area	Model uses FS matrix. Typically 35 km from TX	Model uses FS matrix. Typically 180 km to base RX & 70 km to mobile RX	Model uses FS matrix Typically 60km from TX
From Local TV	As for DTT, but -14dB. Typically 30km from TX to edge of local service area	As for DTT, but -14dB. Typically 30km from TX to edge of local service area	As for DTT, but -14dB. Typical distance 20km from TX	As for DTT, but -14dB. Typically 80 km to base RX & 34 km to mobile RX	As for DTT, but -14dB. Typical distance 25km from TX
From Mobile TV	18 km	18 km	12 km	220 km (BS) 24 km (MS)	19 km
From BWA / Cellular (BS)	18 km	18 km	12 km	220 km (BS) 24 km (MS)	19 km
From BWA / Cellular (MS)	650 m	650m	400 m	6 km (BS) 900m (MS)	700 m
From PMSE	440 m	440 m	300 m	4.8 km (BS) 700 m (MS)	400 m

NB: All distances are from transmitters. To correct to ‘edge of MSR’:

- Subtract ~35 km for DTT / local TV
- Subtract 5 km for Mobile TV / BWA
- Make no correction for PMSE

7.2 Adjacent -channel separation distance matrix

	To DTT	To Local TV	To Mobile TV	To BWA / Cellular	To PMSE
From DTT	0km (assumed co-sited)	Unlikely, as local TV will be closer, or co-sited	1 km	(BS) 22 km (MS) 21 km	5 km
From Local TV	600m if not co-sited	0km (assumed co-sited, or distant)	600 m	(BS) 6.6 km (MS) 6.0 km	1 km
From Mobile TV	600m if not co-sited	600m if not co-sited	600m if not co-sited	(BS) 3.2 km (MS) 3.0 km	1.3 km
From BWA / Cellular (BS)	600m if not co-sited	600 m	600 m	(BS) 3.2 km (MS) 2.2 km	1.3 km
From BWA / Cellular (MS)	300m	300 m	300 m	(BS) 2.2. km (MS) 350m	100 m
From PMSE	0 km	0 km	0 km	(BS) 400m (MS) 150m	Self-managed

NB: All distances are from transmitters. To correct to 'edge of MSR':

- Subtract ~35 km for DTT / local TV
- Subtract 5 km for Mobile TV / BWA
- Make no correction for PMSE

8 THE IMPACT OF INTRA-SERVICE FREQUENCY SEPARATION

In the majority of the modelling reported here, it has been assumed that services occupy adjacent channels with no additional frequency separation. This approach has been adopted partly to minimise the number of variables involved in the modelling, but also, in most cases, from necessity, as the data necessary for more complete modelling are not currently available.

If some degree of frequency separation can be arranged between two radio services, it is generally possible to reduce the geographical separation required by a significant degree. The calculation of such 'guard-bands' is however complex, and is necessarily technology-specific (and deployment specific) in a way that may conflict with the aim of flexible, technology neutral, spectrum release.

In drawing up the compatibility matrices described above, no guard bands have been assumed between services, beyond those implicit in systems such as DVB-T or UMTS whose channelisation includes a greater or lesser element of such guard bands.

In practice, the choice of appropriate guard bands between services will be essential to the achievement of compatibility between disparate services. To determine the necessary guard bands, however, requires not only detailed statistical modelling of interference probabilities, but also a clear definition of the technical characteristics of the systems involved.

This clearly poses problems where a technology-neutral approach to spectrum release is adopted, as it implies that guard bands can only be determined by incumbents following an award process, and may need to be re-determined if there is a change of use of the spectrum. It may be necessary, therefore, for bidders in any auction process to acquire sufficient additional (guard band) spectrum (as in Figure 8.1) to achieve sufficient isolation from foreseen neighbours, a requirement that will tend to increase uncertainty, and depress the value attributed to spectrum.

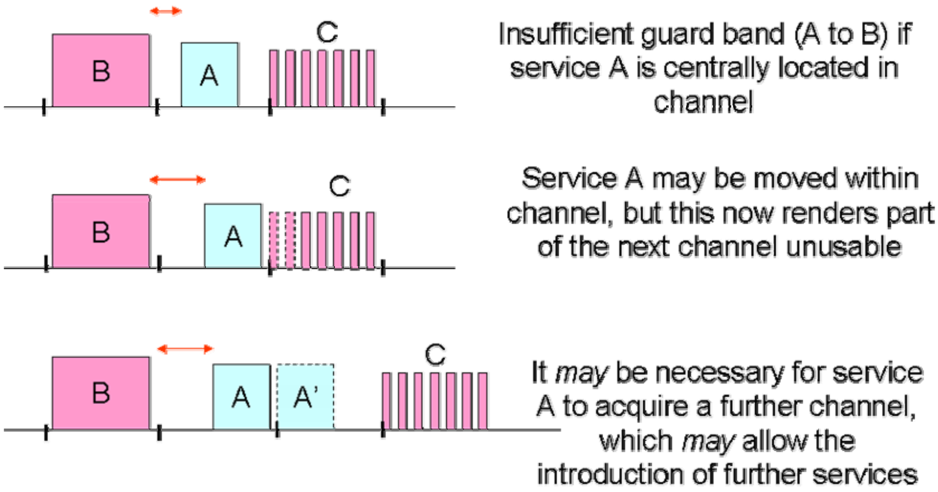


Figure 8.1: Channelisation and guard bands

As has been noted, the calculation of co-channel interference effects is relatively straightforward, as the impact of one service on the other is largely determined by the characteristics of the modulation and coding scheme(s) used, and is amenable to mathematical analysis. Determination of mutual system compatibility will, however, require the statistical modelling of propagation effects and, perhaps most crucially, the prediction of network topologies and terminal density, with appropriate allowance for growth over time.

The case of services operating in adjacent frequency bands involves another element of considerable uncertainty, relating to the modelling of filter characteristics and spectrum masks. All practical radio receivers will respond, to some degree, to signals outside the wanted channel, and all transmitters will radiate some energy outside the wanted channel. This is illustrated in Figure 8.2, in which the idealised transmitter (or receiver) frequency response is shown dotted, with a practical realisation shaded green.

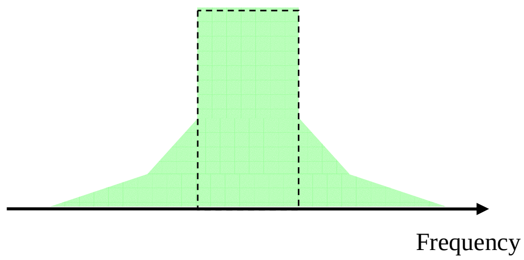


Figure 8.2: Practical filter response

The impact of this is sketched in Figure 8.3, which illustrates a receiver (green) and a transmitter, at different frequency separations. As the filter masks overlap by varying amounts, so the energy coupled from one system to the other varies.

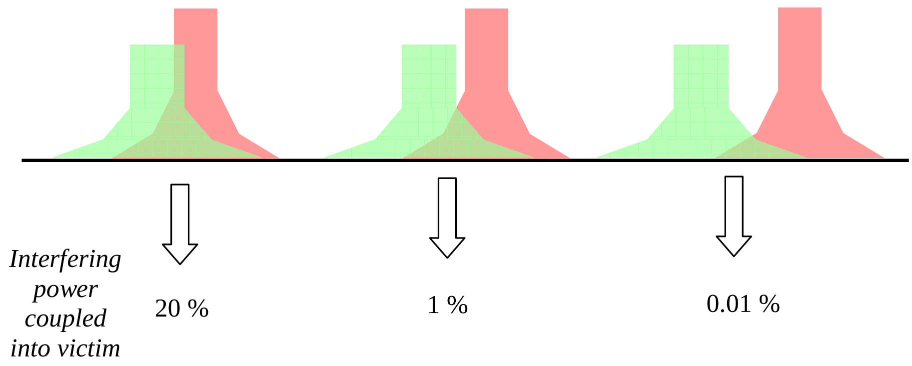


Figure 8.3: Adjacent channel interference vs frequency separation

In the first case, the wanted responses overlap, and the coupling between the systems is substantial, giving rise to a strong possibility of interference (depending on the details of power, location, sensitivity, etc). In the next case, one sidelobe of the transmitted signal lies within the main response of the receiver, and the main portion of the transmitted signal falls in a receiver sidelobe, leading to a reduced, but still significant coupling. In the final case, only sidelobe-to-sidelobe coupling can occur, and the likelihood of interference is diminished.

If the two filter responses are convolved, a curve showing the '*Net Filter discrimination'* is obtained, showing the degree of isolation between the services (with respect to the co-channel case) as a function of frequency separation. This function may then be applied in modelling to determine the frequency separation necessary to ensure a given grade of service.

8.1 Net filter discrimination

In principle, the modelling of such coupling is straightforward, but in practice it can be very hard to characterise the system filter responses adequately. The receiver response and transmitted spectrum will depend on a very large number of design factors, and random elements. The transmitted out-of-band spectrum for a system is generally specified by means of a mask, given in, for instance, an ETSI specification.

An example, of that for the DVB-T system, has been given in Figure 2.2. In this case, two limits are given, for the general case, and for instances where the control of unwanted emissions is particularly important.

To obtain the net filer discrimination, such a transmitter mask should be convolved with the receiver filter response, as obtained by using a swept CW source[27].

It is rare, however, for the receiver response to be specified in this way. It is generally necessary for laboratory measurements to be made to determine the response of the receiver to specific signals. In the case of the DVB-T system, for example, the vulnerability of the receiver to interference from other DVB-T signals at different channel spacing (multiples of 8 MHz), has been characterised (as described in section 2) to allow reliable system planning.

Such measurements effectively allow the net filter discrimination to be obtained directly (though it will generally be expressed as a protection ratio). Unfortunately, in this approach, it will be necessary to determine the receiver response to each interferer of interest. An attempt has been made to identify receiver protection ratio curves for the cases of interest in this study. In particular data on the susceptibility of DVB-T receivers to DS-CDMA interferers, and vice-versa, have been sought.

8.1.1 ITU-R WP8F report

An apparently comprehensive report on Mobile and Broadcast Service sharing issues is under preparation within ITU-R WP8F. This explicitly considers the compatibility of DVB-T and UMTS systems, and attempts to quantify the guard bands necessary. The report uses transmit and receive masks to determine the net filter discrimination for pairs of services (DVB-T, DVB-H, UMTS terminals and Node Bs). An annex to this report gives details of the transmit and receive masks assumed in the modelling, and it would seem straightforward to apply these in relation to the current study.

Unfortunately, the source of this data is not referenced, and some information is missing. It appears that the masks provided may not be appropriate for the modelling being attempted in the paper.

[27] E.g. using a network analyser

In lieu of a more comprehensive study, an illustration of the practical impact of frequency separation has been generated, using data from the ITU-R Report from RRC-04 [RRC].

8.2 Modelling approaches

Given an understanding of the net filter discrimination between services, it is possible to estimate the degree of interference between these services for different mutual frequency separations.

The simplest approach is to make a deterministic calculation, based on assumptions regarding input variables such as power levels, effective receive antenna gains, propagation losses, etc. Such an approach is often referred to as the 'minimum coupling loss' method. The statistical variability of many of the parameters mentioned, however, is such that (i) it may be difficult to determine appropriate values for the input variables and (ii) the results may give little useful information regarding the practical risks of inter-system interference. The method is illustrated in the first case study below (DVB-T interference to a CDMA system).

An alternative, and increasingly popular approach, is to apply Monte-Carlo modelling methods to such problems, in which many of the input variables to a model, and the output, are in the form of statistical probability distributions rather than fixed values. While this approach is structurally more complex, it is often simpler to derive the necessary input *distributions* than it is to agree on specific input constants. More importantly, the fact that the model output itself takes the form of a probability distribution makes it very much more informative. The Monte Carlo approach is illustrated in the second case study below (DVB-H interference to DVB-T receivers).

8.2.1 DVB-T transmitter adjacent to CDMA BS receiver

Chapter 4 of the RRC-04 report [RRC] gives information regarding the compatibility of DVB-T with other services with Primary status in the bands concerned.

Among this data is information relating to "*Protection criteria for digital equipment in the land mobile service in the band 790-862 MHz operating in countries listed in RR No. 5.316 and in the band 470-862 MHz in the Islamic Republic of Iran*". This provides "*protection ratios (PR) for the digital land mobile service (for example CDMA) interfered with by emissions from DVB-T (8 MHz)*". The protection ratio curve (for DVB-T into a base station receiver) is shown in Figure 8.4, below, and appears to relate to a mobile system with a nominal bandwidth of ~2 MHz.

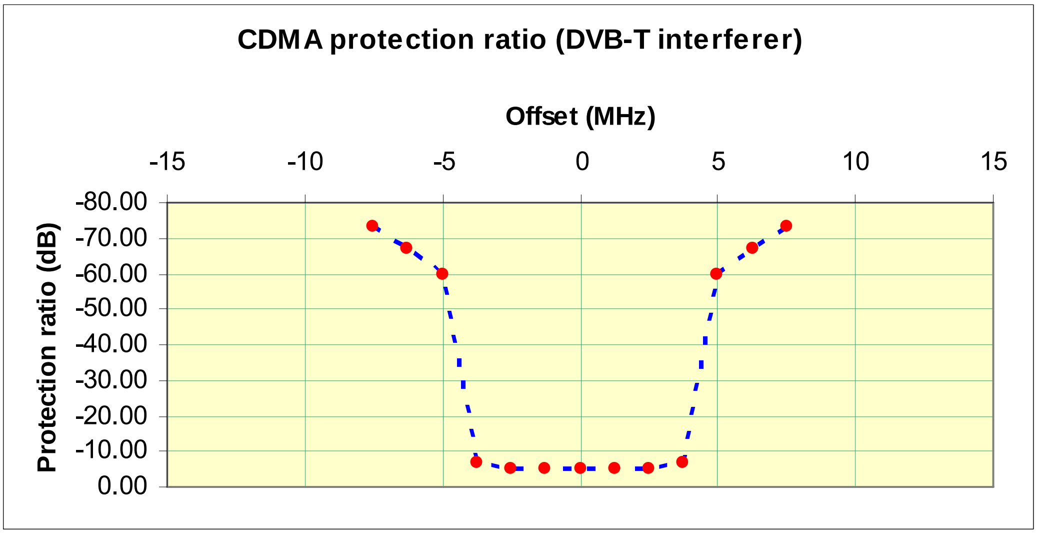


Figure 8.4: Protection ratio curve for DVB-T interference to unknown CDMA system

Such curves can be used to determine the relationship between the frequency and geographic separation between the services. On the basis of a 13 dBμV/m field strength at the mobile base station, the following distances from 1 kW and 10 kW ERP DTT transmitters[28] have been determined, using ITU-R P.1546-2:

[28] with an antenna height of 75m

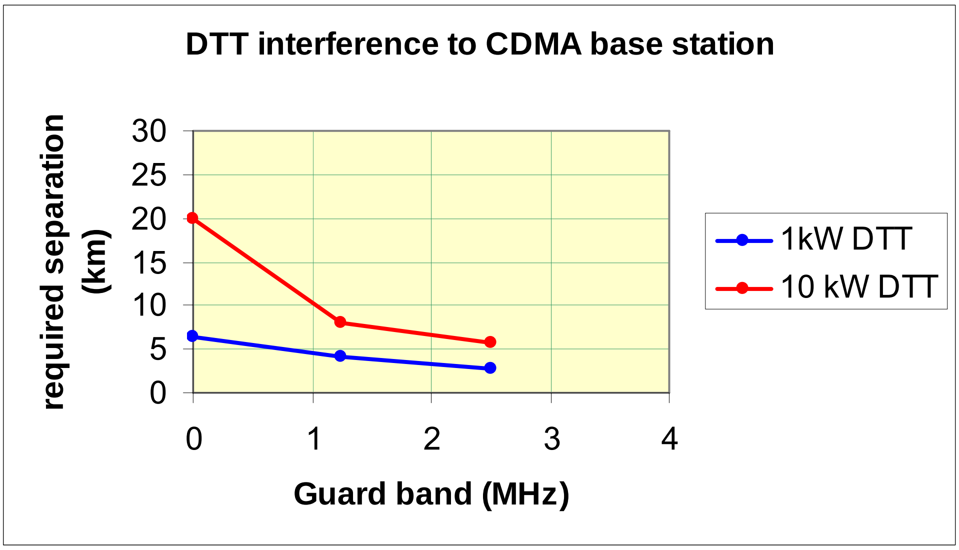


Figure 8.5: Dependence of required separation distance on frequency separation

It is usually found that, beyond a certain point, little advantage is gained from additional frequency separation. This can be seen here for the case of the 10kW DTT transmitter, where a guard band of ~1 MHz is likely to be optimum in terms of spectrum efficiency.

It should be noted that the protection ratio curve given above (in common with most of those in the WP 8F report) contains too few data points to allow a well-informed decision to be made.

8.2.2 Monte Carlo modelling

A common approach to the determination of guard bands is to make use of Monte Carlo models (see glossary for definition) to understand the statistical probabilities of interference between services under different scenarios.

As noted above, such an approach may be hard to apply in a technology-neutral context. It is, however, valuable to examine some sharing scenarios in this way, to inform debate on the determination of spectrum rights, either prior to spectrum release, or on a mutual basis between eventual incumbents.

A limited modelling exercise has been undertaken by way of illustration, for the case of adjacent channel interference (hole punching) from a DVB-H service to a DTT coverage area. In this exercise, the SEAMCAT tool, made available by the CEPT has been used. Technical details, and the software itself, may be found at www.seamcat.org.

In the model, it has been assumed that a DTT service is provided by a transmitter of 100kW ERP, with an aerial height of 200m above ground. The interference to this service is due to a relatively dense network of DVB-H transmitters, each with an ERP of 500W and an aerial height of 30m.

The assumed spectrum mask of the interfering transmitter, and the response of the receiver have been simplified from the DVB-T specifications, and the JPP assumptions, and are illustrated below in Figures 8.6 and 8.7.

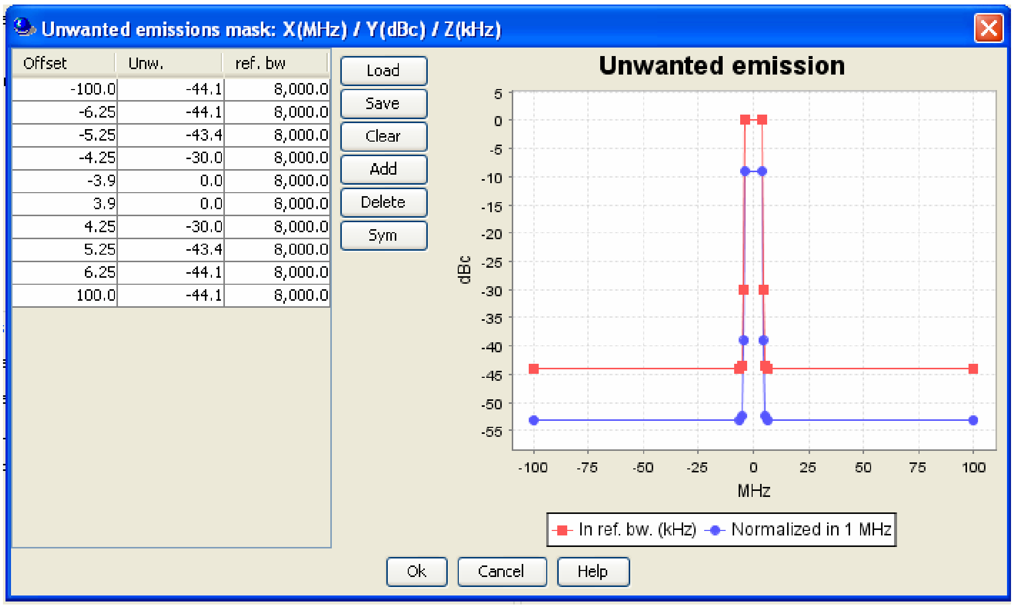


Figure 8.6: Transmitter mask assumed in modelling

It should be noted that the use of the receiver response mask of Figure 8.7 (derived from that of Figure 2.2) is not, strictly, applicable in this case, as the measurements on which it is based implicitly account for the transmitter spectral response, and there is, therefore, an element of double counting. Furthermore, the response only allows the examination the net filter response at integer multiples of an 8 MHz channel separation. As no other information is currently available, this response is used here for illustrative purposes.

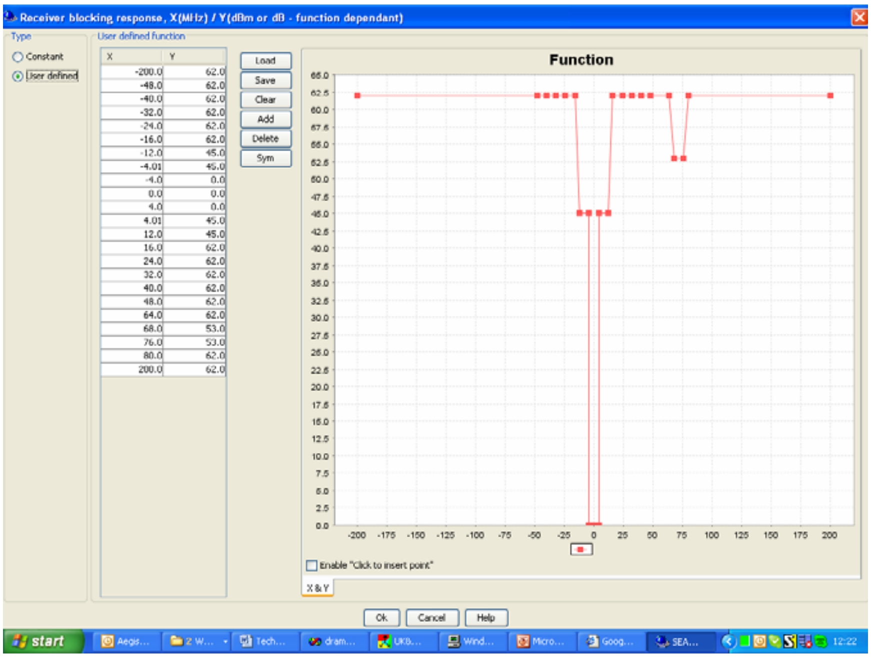


Figure 8.7: Receiver response assumed in modelling

The model runs for a large number of iterations, at each of which a victim DTT receiver is modelled at a random distance from the transmitter, and surrounded by randomly-placed DVB-H transmitters to the required density (see figure below). The overall interference power from these transmitters is then aggregated, taking into account the transmit and receive frequency responses, receive aerial directivity, frequency offset, and appropriate propagation models. The ITU-R P.1546 propagation model is assumed for the wanted path, and the Hata model for the interference path.

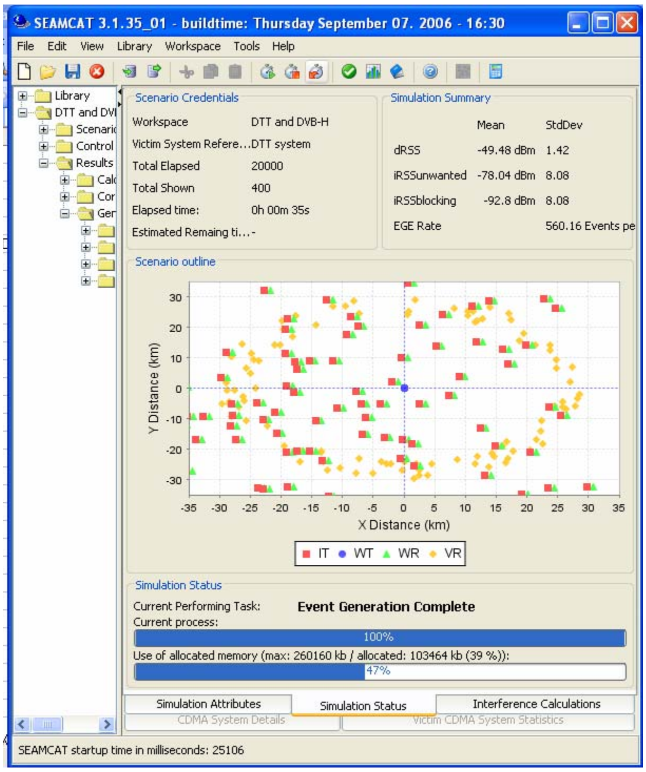


Figure 8.8: SEAMCAT model running a simulation

The results from this model are most simply available in the form of a percentage of instances where the DTT receiver interference criterion is exceeded, and this value is tabulated below for a range of input parameters.

DVB-H TX density (/km²)	Offest (Channels)	DTT receivers considered	TX mask	Interfering path propagation	DVB-H height	Probability of interference
0.02	0	All	Std	Hata	30m	**74.3 %**
0.02	1	All	Std	Hata	30m	**2.7 %**
0.02	2	All	Std	Hata	30m	**0.4 %**
0.02	9	All	Std	Hata	30m	**0.4 %**
0.02	2	24-30 km	Reduced	Hata	30m	**0.05 %**
0.02	9	24-30 km	Reduced	Hata	30m	**0.2 %**
0.02	0	24-30 km	Std	Hata	30m	**1.0 %**
0.02	1	24-30 km	Std	Hata	30m	**13.6 %**
0.02	2	24-30 km	Std	Hata	30m	**1.7 %**
0.02	9	24-30 km	Std	Hata	30m	**1.7 %**
0.02	1	24-30 km	Std	P.1546	30m	**1.9 % (13.6%)**
0.01	1	24-30 km	Std	Hata	30m	**6.9 % (13.6%)**
0.02	1	24-30 km	Std	Hata	15m	**2.8 % (13.6%)**

Table 8.1: Results of Monte Carlo modelling exercise

In the first four rows, interference to all receivers within a DTT service area of 30km is evaluated. Even with co-channel transmission, some 25% of the DTT receivers are sufficiently close to the main station, and sufficiently far from a DVB-H site, to avoid interference. On an adjacent channel, only 2.7% of the whole receiver population suffer interference (though this may represent thousands of households). Beyond the adjacent channel, the interference level falls to 0.4% of receivers.

It is interesting to note that the receiver image response at n+9 is not seen in this model, as it is masked by the out of band transmitter power (Figure 8.6) entering the main response of the receiver. In practice, the out of band transmitter power will be well below the limits given in the specification, and this is modelled in the next two rows, where the out of band power is reduced to -70dBc. This change allows the image channel response to be seen.

In the next four rows, the statistics of interference only to the receivers towards the edge of the service area are considered. As the wanted signal is lower, the percentage of receivers suffering interference is clearly greater, with 13.6 % of receivers suffering interference from adjacent channel transmissions.

The remaining rows show the effect of changing the assumed propagation model (the interference is reduced, but the model may not be appropriate), the DVB-H transmitter density (interference probability falls *pro rata* with density) and DVB-H transmitter height (lower height gives lower interference levels).

It is not intended that the absolute values presented here be used to draw conclusions on the compatibility of these particular services, but rather to illustrate the process involved in such assessments.

Of particular importance to note is the sensitivity of the model to changes in each of a large number of possible parameters. It is very simple to bias the results in a particular direction by the judicious choice of such values, and this may mean that agreements based on such modelling, while appearing rigorous and objective to the outsider, simply reflect political horse-trading of parameters to achieve a required outcome. This comment is not intended to minimise the value of such a modelling approach, which is capable of producing much more realistic results than alternative methods, such as the 'Minimum Coupling Loss' approach illustrated above.

8.2.3 Conclusions

The results presented above are intended for illustration only; it had been hoped to produce a more rigorous analysis of the mutual frequency separations required to permit the co-existence in the UHF band of several technologies. This has not been possible, however, as little of the necessary transmitter and receiver performance data has been available. Furthermore, such a study would, necessarily, be very 'technology-specific' and as such, fell outside the remit of the current project.

A programme of laboratory measurements to investigate the susceptibility of DTT receivers to interference from some other systems has recently been instigated by Ofcom. The results from this study will be made publicly available.

The results of such measurements should allow stakeholders to undertake more detailed modelling. In such modelling, the following points should be noted:

- Care should be taken to ensure that any measurements made are appropriate for the modelling intended. In many cases, existing measurement data relate to the compatibility between specific systems under a limited range of conditions[29]. Measurements of receiver response to CW signals, and to Gaussian noise of variable bandwidth may provide more generally-applicable data.

- As seen in the results above, it is crucial that receive and transmit performance masks are representative of real, measured, performance. In many cases, worst-case ‘envelope’ values are taken from standards, and applied in such models, which will inevitably lead to pessimistic results.
- The choice of propagation model is crucial, as this can influence results by an order of magnitude of more. It is not generally sufficient to select from a limited range of models offered by a particular piece of software, without consulting experts to ensure that the model chosen is truly applicable to the scenario modelled.
- Perhaps the greatest importance must be attached to the choice of an appropriate metric and limit, for application in the determination of guard bands. In the case shown above, for instance, would it be acceptable for the risk of adjacent channel interference to a DTT receiver to be 2.7%? How would such a limit relate to the overall availability target of a DTT network with a 98.5% nominal population coverage, at 99% time, to 70% of receive locations? The statistical relationship of such targets must be considered formally if such modelling is to be used in informing decisions on spectrum use.

[29] e.g. DTT receiver performance measured with respect to interference from a DTT interferer spaced in multiples of 8 MHz, or UMTS receiver performance in the presence of interfering UMTS signals spaced in multiples of 5 MHz

9 PROTECTION OF RADIO ASTRONOMICAL USE OF CHANNEL 38

Channel 38 will continue to be used, in the UK, for radio astronomical observations. In the UK Frequency Allocation Table, this frequency is protected at three sites: Jodrell Bank (Cheshire), Cambridge and Defford (Worcestershire).

Interference criteria appropriate to the Radio Astronomy Service are set out in ITU-R Recommendation RA.769-2 ("Protection criteria used for radio astronomical measurements"). Table 1 of that document gives "threshold levels of interference detrimental to radio astronomy continuum observations".

9.1 Modelling

The modelling reported here seeks to give an indication of the constraints that may be imposed on the use of channels 37 and 39 by the requirement to protect radio astronomy.

Interference to the Lovell telescope at Jodrell Bank is evaluated, on the assumption that this instrument has a sidelobe gain towards the horizon of 0dBi, and an effective height of 40m above ground.

Two interfering sources are considered; a 10kW (ERP) transmitter with an effective height of 200m and a 500W (ERP) transmitter with an effective height of 20m. Both are assumed to radiate power according to the 'critical' transmission mask for DVB-T.

At 611 MHz it is assumed in RA.769-2 that the RA receiver has a bandwidth of 6 MHz, with a minimum antenna temperature of 20K and a receiver noise temperature of 60K. This implies a threshold level of interfering power of -202 dBW. It is stated that a gain of 0dBi should be considered representative of sidelobe levels, towards the horizon, of the RA antenna. The limit can therefore be stated in terms of a power density, not to be exceeded from an isotropic antenna, of -210 dBW/MHz.

The critical emission mask for a DVB-T transmission is given in EN 300 744, which provides the following values:

Relative frequency (MHz)	Relative dBc	Measurement bandwidth (kHz)
-100	-120	4
-20	-120	4
-12	-120	4
-6	-95	4
-4.2	-83	4
-3.8	-32.8	4
3.8	-32.8	4
4.2	-83	4
6	-95	4
12	-120	4
100	-120	4

Table 9.1: Assumed DTT emission mask

Normalising the bandwidth to 1 MHz, gives values of -59 dBc at -4.2 MHz, -71dBc at – 6 MHz and -96dBc at -12 MHz.

It is assumed that the RA receiver bandwidth is centred in Channel 38, providing an effective 1 MHz guard band. The emission mask value at 6 MHz offset (i.e. 1 MHz within the RA receiver bandwidth) is therefore used in the modelling.

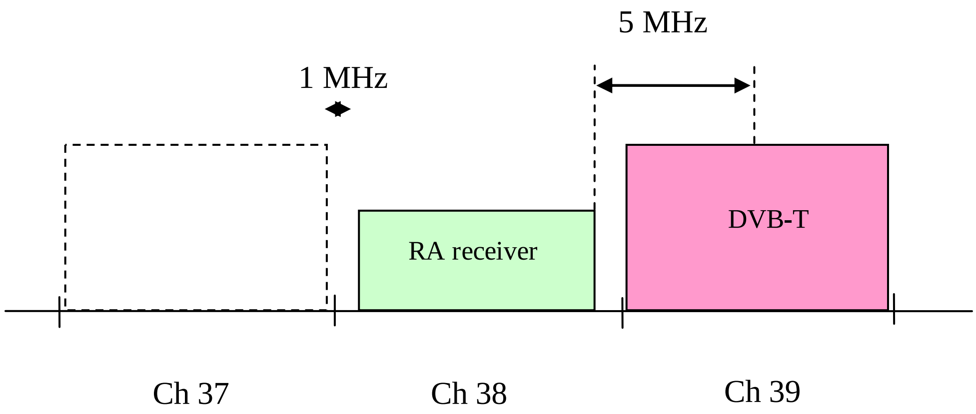


Figure 9.1: Assumed channel occupancy

(NB: The modelling below applies equally to use of Channels 37 and 39)

9.2 Estimate of required separation distance

A simple estimate may be made of the separation distance required to fulfil the criterion of RA.769-2 using the path-general propagation curves given in P.1546 (which take no account of specific terrain details).

500W ERP in an 8 MHz channel corresponds to an EIRP of 29.2 dBW. At -6 MHz offset, the EIRP (in 1 MHz) should be 71 dB below this, at -41.8 dBW/ MHz. To meet the criterion of -210dBW/MHz, this implies a required basic path loss (between isotropic antennas) of 168 dB.

The separation distance required to achieve this can be estimated from P.1546. The conversion of Annex 5, Section 14 equates a basic loss of 168 dB, at 611 MHz, to a field strength of 27 dBμV/m from a 1kW transmitter. This would correspond (land curves, 50%-time) to a distance of ~40km for a receiver at 10m above ground. The height of the antenna at Jodrell Bank is, however, some 40m, and Annex 5, section 9 estimates that a height gain of some 12 dB will apply. This increases the required separation distance to ~70km.

The same calculation for the case of the 10kW, 200m transmitter gives a required separation distance of ~180km.

9.3 Site-specific prediction

The same scenarios have been used to determine the contour, around the Jodrell Bank telescope, within which interference would be predicted in these two scenarios.

In this case, the propagation model is that of P.452, at 50% time with a 50m resolution terrain database. Clutter is not modelled.

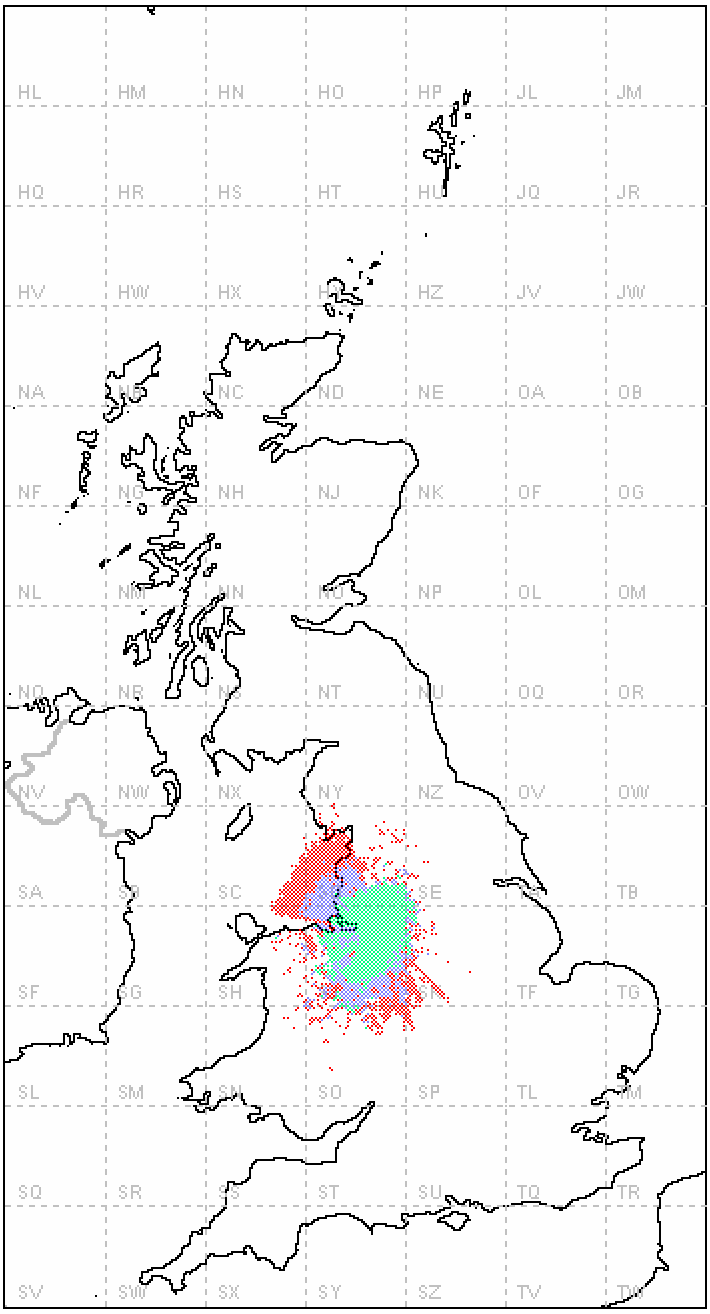


Figure 9.2: Interference zone for 500W transmitter at 20m

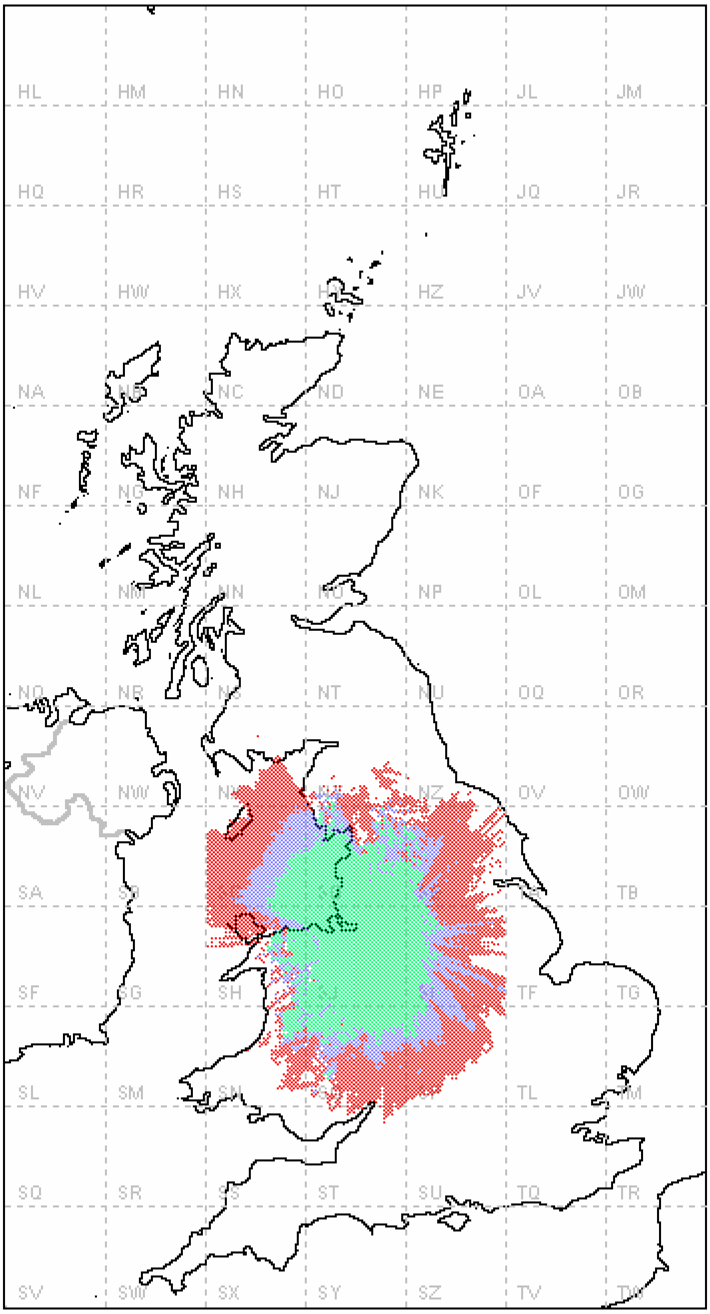


Figure 9.3: Interference zone for 10 kW transmitter at 200m

In the figures above, the blue shading represents areas in which a single interfering transmitter would exceed the RA.769 criterion. The red and blue areas represent a change of the criterion by -10 and +10 dB respectively, to illustrate the impact that changes, for example, due to improved transmit filtering or higher transmit power might have.

9.4 Commentary

The results presented here serve to illustrate the potential severity of the constraints arising from any need to protect radio astronomy observations in channel 38, but must be interpreted in the light of regulatory considerations and technical uncertainties.

The models above make a particular assumption about the level of out-of-band emissions from DVB-T transmitters, and these would need to be verified. The sidelobe levels given in published masks are generally a poor indicator of actual performance, the statistical variability of which may be considerable.

No account has been taken of any transmitter aerial directivity, which might be used to provide additional protection.

It is likely that some form of co-ordination regime will need to be established by which radio astronomers, and the users of channels 37 and 39 might agree appropriate mitigation techniques for interference. Both channels are currently used for high-power television in the UK, with, for instance, a 1MW analogue transmitter at Lichfield, only some 70km from Jodrell Bank. It is understood that considerable filtering has been employed at both sites to allow such co-existence.

Where the interfering networks make use of relatively few, high-power transmitters, such co-ordination and mitigation might not represent a great burden, in relation to the capital costs of the transmission plant. For a more dense network, of low-power sites, the need to implement (and maintain) stringent filtering may be more onerous.

10 SUMMARY AND CONCLUSIONS

This section attempts to summarise the most significant interference issues that will need to be accounted for in releasing UHF spectrum. It should be emphasised that the selection of issues below is subjective on the part of the author; and that *all* the effects described in the body of this document should be taken into account in planning.

10.1 'Hole punching' in PSB and COM multiplexes by new services

In channels adjacent to the retained spectrum, there is a very real danger that significant interference will be caused to 'Freeview' DTT multiplexes. The measured performance of DTT receivers suggests that this effect will be limited to the channels immediately adjacent, i.e. channels 31, 40 and 63.

There is also a lesser problem due to the image channel response of DTT receivers, that may give rise to interference to DTT services operating 9 channels below a new service. This could affect DTT services in channels 22-28, 30 and 54-59.

If such interference were found to be a significant problem, the most likely solution would be for a DTT relay transmitter to be set up (possibly in a single frequency network with its parent) on the same site as the interferer. Alternatively, if only a few households are affected, it may be possible to provide substitute services using satellite or cable delivery.

In the specific case of Channel 36, it must be borne in mind that use of this channel, before DSO is complete, is likely to be constrained by the need to avoid adjacent channel interference to 'Five' analogue services on Channels 35 and 37. As analogue TV receivers are significantly more sensitive to ACI than digital receivers, this will not be a trivial constraint.

10.2 The impact of RRC constraints on network design

Some potential users of the UHF cleared spectrum will be heavily constrained by the incoming interference environment from the continent and Ireland. This applies particularly to DTT and cellular/broadband mobile networks (base stations), which make use of elevated, high-gain antennas to receive wanted signals that may be of low signal strength. There will be a strong incentive for such networks to make use of channels in which the UK has obtained spectrum rights at the RRC that ensure low levels of incoming field strength.

All services will also be constrained in the power that may be transmitted towards the Continent and Ireland. This will have the greatest impact on a new entrant seeking to build a traditional DTT network, the main stations of which will be constrained to use only a few specific channels (particularly in southern England and Northern Ireland).

This may be illustrated using an extract from the Aegis matrix describing the power constraints on UK transmitters due to outgoing interference limitations.

	21	22	23	24	25	26
ANGUS	-23.4	-16.4	-16.4	-23.4	-16.4	-16.4
BEACON HILL	2.4	7.2	0.7	2.4	7.2	0.7
BELMONT	-18.2	-19	-23.1	-17.1	-19	-22.4
BILSDALE	-18.7	-18.7	-20.2	-18.7	-18.7	-20.2
BLACK HILL	-4.4	3.9	3.9	-4.4	3.9	3.9
BLAENPLWYF	23.6	23.6	23.5	23.6	23.6	23.5
BLUEBELL HILL	-9.7	-12.8	-16.6	-9.7	-12.8	-9.7
BRESSAY	-999	-30.8	-32.2	-34.7	-29.2	-32.2
BROUGHER MOUNTAIN	12.4	12.4	18.3	12.4	18.3	18.3
CALDBECK	-1.2	-1.2	-2.3	-1.2	-1.2	-2.3
CARADON HILL	8.7	3.2	0.9	8.7	3.2	0.9
CARMEL	-1.8	-1.8	-8.7	-1.8	-1.8	-8.7
CHATTON	-28.8	-22.9	-22.9	-28.8	-22.9	-22.9
CRAIGKELLY	-19.5	-12.6	-12.6	-19.5	-12.6	-12.6
CRYSTAL PALACE	-3.6	-4.8	-8.6	-3.6	-4.8	-3.6
DARVEL	-10.4	1.3	1.3	-10.4	1.3	1.3

Figure 7.1 Outgoing compatibility constraints

This table shows, for each channel at each site what reduction (if any) of the nominal DTT power is required to meet continental restrictions. Positive values (i.e. reductions are flagged in red, while marginal cases are shown in blue. The green and yellow shading indicates current assignments for PSB and COM use respectively. In many cases (Bleanplwyf, Caradon Hill) nominally incompatible use has been agreed bi-laterally. If a new service were seeking channels at Black Hill, however, it might be expected that channels 21 and 24 would have a higher value than, for example, channels 22 and 23. While the latter might be usable, they would require the use of a lower-power transmitter, or the uncertainty of entering into further bi-lateral negotiations.

10.3 The implications of free-roaming BWA/Cellular transmit terminals

As shown in Section 4.1, a single UMTS / Wi-MAX terminal might cause adjacent channel interference to DTT receivers (with rooftop aerials) over a range of several hundred metres. The statistical likelihood of such interference in any area is dependent on a wide range of variables, mostly outside the control of network operators (e.g. quality of DTT aerial installation, local environment).

The same issue will apply to interference between such an active mobile device, and a mobile TV receiver – adjacent channel interference may be expected whenever the two devices are within line of sight of each other.

11 GLOSSARY

Allotment: The right to use a specific frequency within a given area, based on certain general assumptions about the service that may be deployed (transmitter density, power, etc)

Assignment: The use of a specific frequency at a given power at a specific transmitter site

COM One of the three UK commercial DTT multiplexes

CW: (Continuous Wave): An un-modulated radio emission at a single frequency.

DTT ‘Digital Terrestrial Television’. General term, encompassing the use of standards such DVB-H and ATSC

DVB-H ‘Digital Video Broadcasting – handheld’. An extension to the DVB-T standard to support the broadcasting of video content to handheld devices.

DVB-T: The terrestrial part of the DVB (Digital Video Broadcast) group of standards.

ERP: Effective Radiated Power. The power radiated from a transmitter site, taking into account the gain of the aerial system. Thus a transmitter unit may have an output power of 10W, but if fed to an aerial system with a gain of $20dB_d$ will have an ERP of 1kW.

FDD (Frequency Division Duplex): The use of separate frequencies for transmit and receive.

Guard Interval A characteristic of the DTT transmission format that can be varied to allow SFNs to operate without self-interference. While increasing the guard interval allows wider-area networks, it reduces the useful data capacity.

HD(TV) ‘High Definition TV

HP (horizontal polarisation): See Polarisation.

IF: (Intermediate Frequency). In a radio receiver, a frequency to which the incoming frequency is converted to allow filtering and amplification.

IMT-2000: The ITU term covering all 3G wireless technologies (International Mobile Telecommunications-2000).

MFN ‘Multi Frequency Network’. The traditional form of transmitter network in which transmitters serving adjacent areas use different channels to avoid interference.

Monte Carlo: A form of modelling in which the values of physical parameters (e.g. terminal locations, antenna heights) are drawn randomly from appropriate statistical distributions. If a sufficiently large number of trials are made, the statistical behaviour of an overall system (e.g. in terms of interference to a DTT receiver) may be determined.

PDA: (Personal Digital Assistant). A small handheld computer, typically designed primarily as a personal organiser, but generally capable of running more general computer applications (word processing, internet browsing, etc).

Polarisation: The alignment of the electrical component of an electromagnetic wave (e.g. light, radio) with respect to the horizon. Main station TV transmitters in Europe normally use horizontal polarisation, so the rods of the receiver aerials are horizontal. If different services use different polarisations, mutual interference may be reduced.

PSB One of the three UK Public Service Broadcasting DTT multiplexes

QPSK: (Quadrature Phase Shift Keying). The most robust form of modulation used in the DVB-T specification. Information is carried by the instantaneous phase of a radio carrier, which can take one of four values. Each value signals the state of two bits.

RRC: The Regional Radio Conference held by the ITU-R in Spring 2006, with the remit of developing an international frequency allotment/assignment plan for broadcast bands I, III, IV and V.

SFN ‘Single Frequency Network’. A form of network made possible by digital techniques in which all transmitters make use of the same frequency.

TDD (Time Division Duplex): The use of the same frequency for transmission and reception, which are carried out in different timeslots.

UMTS (Universal Mobile Telecommunications System): The European standards forming part of the IMT-2000 family. Both FDD and TDD versions have been developed.

VP (Vertical polarisation): See Polarisation.

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