PMSE: Future Spectrum Access

Identification of post-DSO digital interleaved spectrum which could be useable by PMSE applications and development of a PMSE user migration plan

SAGENTIA

This document is prepared for Ofcom

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Executive Summary

As part of the DSO process, some PMSE users of 'interleaved spectrum' will have to move out of the "cleared spectrum" that is to be auctioned or switch operating channel to avoid clashes with TV broadcasting.

Sagentia was commissioned by Ofcom to provide a migration plan for PMSE users, identifying where migration actions are required and providing data in a form for the band manager to use for licensing purposes.

The major deliverable was a post DSO PMSE interleaved spectrum availability database, accessible online through JFMG at www.jfmg.co.uk.

This report describes the approach used to derive this database and associated advice, under three headings:

- Coexistence Parameters (Chapter 1)

  The existing approach risks not providing sufficient protection to post switchover digital TV services.

- Post-switchover interleaved spectrum availability (Chapter 2)

  When the proposed alternative coexistence parameters are applied to calculate available post switchover spectrum there appears to be sufficient bandwidth available for PMSE users. The number of available frequencies at many locations is reduced, requiring some users to be more efficient in their use of radio microphones across frequencies. This will result in a number of existing users having to migrate to one or more different frequencies. There are a small number of locations where our analysis suggests a potential shortfall in capacity, and this number may increase if demand increases significantly between 2005 and 2012. However, as a number of these locations are indoor and/or do not require the full 100m operating range, it is likely that most of these shortfalls do not occur in practice. We therefore recommend PMSE users consider their own requirements and use the JFMG website to identify available capacity at their location.

- PMSE Migration plan (Chapter 3)

  The spectrum availability database is available on the JFMG website and can be used by current license holders to determine what channels are likely to be available in any given location post switchover.

Contents

1 Co-existence Parameters

We were asked to examine the existing parameters for coexistence between PMSE and broadcast television and propose any necessary modifications.

1.1 Current protection of TV reception

The current approach to protection of TV reception uses the concept of protection ratio (PR). This is the number of dBs below the wanted TV signal that the PMSE (usually microphone) signal must be to avoid visible interference effects. The PR is determined empirically by a simple measurement for any two pieces of equipment (one generating the interference and one receiving it).

A complication arises where more than one microphone is being used in a single TV channel. TV channels are 8MHz wide in the UK. Wireless microphone channels are 200kHz or less. It is quite common to have several microphones operating in a single TV channel. Current protection ratios are only measured for one microphone, however.

Analogue microphones into analogue TV

The current PR for analogue TV from wireless microphones is 47dB.

Analogue microphones into digital TV

The protection ratio recommended in section 3.3.1 of ERC Report 88[1]. for analogue microphones into digital TV is -3dB.

This reflects the very rugged nature of the digital TV (DTT) signal in the presence of narrow band interference. This is a design feature of the digital TV signal to ensure that it doesn't suffer from interference from analogue TV transmissions.

For interfering signals of less than 1MHz bandwidth the forward error correction (FEC) incorporated in the digital TV signal corrects for the disruption from even very high levels of interference. The coding system is particularly suited to 'peaky' analogue interference as it can tolerate several of the OFDM subcarriers being blocked. The lost data is recovered using FEC.

An analogue microphone has a peaky spectrum approximately 150kHz wide. Beyond about 6 microphones the total bandwidth blocked reaches 1MHz and the FEC becomes unable to cope.

Digital microphones into digital TV

If the interfering microphone is digital, the situation is different. The spectrum of a digital signal is likely to be wider and flatter with a bandwidth of about 200kHz. This means that more subcarriers of the DTT signal are likely to be blocked by a single digital microphone than by an analogue one. As a result, fewer digital microphones can be tolerated in a single 8MHz channel than analogue microphones.

[1] ERC Report 88, "Compatibility and sharing analysis between DVB-T and radio microphones in bands IV and V", Naples, February 2000

Multiple microphones into digital TV

While it is common to pack several microphones into one 8MHz channel, we have been unable to find published results for protection ratios for DTT with multiple analogue or digital microphone interference. Published results have tended to concentrate on single microphone interferers.

1.2 Proposed protection of digital TV reception

The different types of PMSE equipment operate in different bandwidths to each other and to broadcast TV. This results in the current protection ratio approach being not very meaningful as the different signals are measured in different bandwidths. In particular digital and analogue microphone are treated the same despite having different interference characteristics into DTT. Protection ratios should also vary with the number of microphones as the DTT receiver is sensitive to all the interference received not just that from each microphone individually. Our approach, therefore, is to define coexistence criteria that provide appropriate protection to broadcast TV in this worst case, multiple microphone interferer, situation.

Rather than "start from scratch" our approach has been to start from an existing, recognised publication considering interference from a single microphone into broadcast TV and then modify this as required. The basis of our approach is the co-existence analysis in ERC Report 88[2]. The full process is defined in this document and is not repeated here but some parameters, such as minimum field strength and maximum interferer levels were modified to reflect agreed planning parameters in Document JPP/MB/1[3].

ERC Report 88 calculates protection distances separately for single hand-held and body worn microphones. For countries, such as the UK, that have adopted ERC Recommendation 70-03, ERC Report 88 recommends using the calculation defined for 50mW e.r.p. body worn radio microphones be applied to both body worn and handheld devices.

Our approach starts by considering the minimum median field strength associated with DTT reception for the DTT encoding scheme employed. From JPP/MB/1, the minimum value defined for this is Variant I use in Band IV and is 53.8dBµV/m. This is based on a minimum receivable field strength of 46.8dBµV/m.

ERC Report 88 then applies a location correction factor to take account of the standard deviations in the distributions of both the wanted (DTT) and unwanted (microphone) signals. For distances above 100m, reflecting our worst case scenario, the factor is 13dB.

The UK spec for broadcast DTT (post DSO as in JPP ref) requires 19.8dB SIR (Signal to Interference Ratio) at the receiver to operate. This is the protection used for incoming DTT interference. In the worst case there may be multiple microphones interfering across a channel therefore we use this value as the limit for PMSE interference. ERC Report 88 calculates a protection ratio for a single microphone of -3dB. We have already indicated that this ratio must be modified to protect for multiple, rather than single, microphones. A modified approach for calculating allowable PMSE field strength relative to the broadcast TV field strength at the edge of a DTT service is needed.

There is already interference being received from other broadcast DTT transmitters. To take account of this we add an additional 3dB to the protection required.

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[2] ERC Report 88, "Compatibility and sharing analysis between DVB-T and radio microphones in bands IV and V", Naples, February 2000

[3] JPP/MB/1 Version 2, 4 July 2003, Technical Planning Parameters and Algorithms

Protection is not to be provided for portable reception and we assume that no PMSE use will be allowed co-channel within the predicted coverage area of a TV transmission. Our approach is to protect all predicted receivable channels and we therefore assume that the front to back ratio of the TV receiving antenna will provide additional interference rejection. We assume this to be 16dB as defined in reference JPP/MB/1.

After all these factors are taken into consideration this leads to a limit for PMSE field strength of 53.8 - 13 - 19.8 - 3 + 16 = **34dBμV/m** which we adopt as the limit. This is the maximum field strength allowed for any PMSE microphone. Note that this is a cautious limit that does not allow any carriers of the OFDM signal to suffer any interference induced errors.

We then use the same piece-wise propagation model for path loss used in ERC Report 88 diagram 9 to calculate the relevant protection distance:

- 20dB per decade up to 100m;
- 30dB per decade between 100m and 1km;
- 40dB per decade beyond 1km.

This is the basis that used to calculate channel availability at a given location and indicates where a microphone is “allowed” to be used as it will not interfere with broadcast TV. Whether interference from broadcast digital TV impacts radio microphone use at that location is considered later.

Spectrum availability is calculated for indoor and outdoor radio microphone use. In the case of indoor use, 7dB is added to the PMSE field strength limit (reference ERC report 88) to allow for in building attenuation.

This method calculates an outdoor protection distance of 1.4km and an indoor protection distance of 900m for rural locations.

We were not able to find directly suitable published sources for calculated the effect on propogation in moving from rural to urban environments. The current licensing approach applies an extra 12dB attenuation in urban environments. Comparison of Hata propogation predictions for urban environments with the predictions using the path loss model from ERC report 88 found an extra urban attenuation of 13dB.

If 12dB additional path loss is assumed in an urban environment, the protection distances for outdoor and indoor reduce to 0.65km and 0.4km respectively.

One consequence of protecting against multiple microphone interferers across a channel is that DTT is over-protected in locations of low radio microphone demand, however in these situations there is likely to be sufficient capacity to meet this demand. It should also be noted that as we protect all broadcast TV services that are predicted to be receivable post DSO (and in a number of cases digital coverage is improved over analogue), it is possible that in locations where a number of transmitter service areas overlap there are some TV services being protected which are not being used by a large number of households. These situations cannot be easily or reliably identified from simple database analysis, however if this results in a predicted capacity shortfall a simple site survey will determine what transmitters local households are actually using.

1.3 Spectrum use inside the protected area

When considering whether to grant a license for PMSE use at a given location one not only has to consider protection of broadcast digital TV, but also whether converse is true: will broadcast TV interfere with radio microphone operation to an unacceptable level.

We adopt the same approach outlined in ERC Report 88:

- Use the 68dBµV/m maximum DTT field strength quoted in Chester '97. Apply the 12dB protection ratio indicated in Chester '97 for a radio microphone 1.5m a.g.l. at the DTT channel centre frequency

1.4 Guard band for PMSE in adjacent channels to DTT.

The DTT channel bandwidth is 8MHz. However real DTT receivers have intermediate frequency (IF) bandwidths that are greater than the 8MHz TV channel. This means that signals from beyond the 8MHz bandwidth are able to enter a DTT receiver and interfere with wanted signals in adjacent channels. Operation of PMSE equipment within this wider bandwidth i.e. at the edge of the adjacent channel, is likely to give rise to interference within a DTT receiver. The question is how big the guard band needs to be in order to protect receivers in the adjacent channel.

We conducted a brief survey of IF filters made for DTT receivers. This suggests that they have significant attenuation beyond 5MHz from their centre frequency. Protecting a guard band of 1MHz each side of the used TV channel should give adequate protection from PMSE use.

ERC report 88 has measured the actual adjacent channel performance of receivers in the presence of PMSE interference and suggests that a guard band of 500kHz is required, although this report notes that only professional receivers were used in the testing.

We understand that some newer DTT receivers are using a direct conversion architecture and have less good adjacent channel rejection. Further investigation of these is required and this may result in revision to the above recommendation.

We believe that a 1MHz guard band should be adopted until it is demonstrated that a narrower guard band is safe.

1.5 Comparison of old and new regimes

When considering the overall effect of DSO on capacity for PMSE there are many factors to be taken into account. Digital TV has negative protection ratios throughout most of the adjacent channel compared with the significant protection required for analogue TV reception. This in itself means that more of the adjacent channel to a Digital TV broadcast is usable for PMSE than the channel adjacent to an analogue TV broadcast.

2 Post-switchover interleaved spectrum availability

We were asked to use the modified co-existence criteria to generate predicted channel availability databases and "white space" maps to provide guidance to the PMSE community.

2.1 Approach

The modified co-existence criteria were used in conjunction with DTT coverage and field strength databases to predict the number of channels available across the UK, with a 1km square resolution. This was provided in two forms:

- A database, to be used as the basis of a JFMG predicted channel availability website, indicating for each DSO TV channel whether it is both "allowed" to be used (i.e. would not interfere with DTT) and "able" to be used (i.e. DTT interference into the radio microphone was not to high).
- Channel availability coverage maps:
  - Per-channel coverage maps indicating indoor and/or outdoor channel availability
  - Coverage maps showing the number of channels available at each location, for indoor and outdoor separately.

A number of DTT protection and field strength databases were provided by NGW to support this activity. These are defined in more detail in Appendix A.

2.1.1 PMSE channel availability database

A database format was agreed on the following basis:

- Availability is shown to 1km square resolution;
- Indoor and outdoor availability indicated separately;
- Separate availability calculations for each of channels 21-30 and 41-62;
- Any channels containing a receivable DTT service within the calculated protection distances are marked as unavailable;
- For the DPSA[4] defined preferred transmitter, any channel indicated by Ofcom as being considered likely to be used for another service (listed in Appendix B of this report) was marked as unavailable;
- Where a channel was indicated as available, and estimated radio microphone operating range was provided (maximum 100m), based upon interfering DTT field strengths;
- The availability of adjacent channels is also provided;

This database provides the underlying data used for the post DSO PMSE channel availability prediction website available at www.jfmg.co.uk.

[4] DPSA – digital preferred service area. Each 100m pixel is assigned to the station offering the best service. In this case the best service being defined as a 3PSB service and the greatest number of multiplexes from the same station

A 1km resolution TV protection database was supplied by NGW. This is derived from the UK planning model and identifies any channel that can be received 99% of the time at locations within that 1km. This comes from the 100m pixel UKPM data with a channel indicated as used if it is usable in any of the 100 pixels in the 1km rectangle. It is for 70% of locations (in the pixel). The exact details of the NGW databases used are provided in Appendix A. Note that the database used is non-DPSA and therefore protects all receivable services, not just those from the preferred transmitter.

The protection distances of 1400m (outdoor) and 900m (indoor) were used to identify which other 1km pixels in TV protection database should be included. Any TV channel occurring as a protected service in any of the identified 1km pixels was protected and marked in the database as unavailable.

When considering each 1km square, the protection distance was measured between the square centres.

This process is repeated across channels 21-30 and 41-62, for indoor and outdoor protection distances.

NGW provided a 100m resolution DPSA database (see Appendix A) indicating the preferred transmitter for each location and which only protects channels from that transmitter. This was used to identify the DPSA transmitters for the 1km squares within the protection distance. Ofcom provided a list (see Appendix B) indicating their current view of transmitter channels likely to be reserved for future services e.g. Local TV. Any such channels associated with a preferred transmitter at a location were also marked as unavailable.

Note that while a channel may be marked as available for PMSE use, no guarantee is provided that incoming DTT signals will not interfere with the radio microphone and effectively shorten its useful operating range. This is consistent with the current JFMG licensing approach. Therefore for each location another database is examined which indicates the average TV field strength for each channel, 50% of the time. Using a 20dB per decade path loss model a “radio microphone operating range” is calculated based upon achieving the minimum 12dB protection ratio over incoming DTT interference. This range is not used to determine channel availability and is provided purely as a guide.

It should be noted that as the non-DPSA protection database protects all receivable DTT services, in some locations with overlapping transmitter coverage this can result in large numbers of channels being protected. The use of DPSA has been proposed to protect only the preferred transmitter at each location. The adoption of the DPSA protection model would increase the availability of spectrum for PMSE use. As this is not current Ofcom policy it has not been considered here.

2.1.2 Channel availability coverage maps

The same underlying process used for creating the predicted channel availability database is also used for creating channel availability maps.

The significant difference is that in addition to protecting DTT from radio microphone interference the maps also mark locations as unavailable where we estimate a radio microphone operating range of less than 100m. A number of different availability maps are provided which indicate channel availability indoor and outdoor on the following basis:

- **Available Outdoor**: This is set when:
  - none of the 1km squares in the DTT protection database within 1.4km of the square being modelled (including itself) indicate this channel is a protected TV service AND;
  - the 50% time average DTT field strength for the location being modelled is below 56 dBµV/m (derived from the 68dBµV/m maximum DTT field strength quoted in Chester '97 with12dB protection ratio indicated in Chester '97 for a radio microphone at a height of 1.5m a.g.l. at the DTT channel centre frequency)
- **Available Indoor**: This is set when:
  - none of the 1km squares in the DTT protection database within 0.9km of the pixel being modelled (including itself) indicate this channel is a protected TV service AND;
  - the 50% time average DTT field strength for the location being modelled is below 63 dBµV/m (based on the outdoor limit of 56dBµV/m with an additional 7dB building attenuation)
- **Indoor and other availability**: Set to match **Available Outdoor**
- **Indoor only**: Set if the location is **Available Indoor** and not **Available Outdoor**
- **None**: Set if the location is not **Available Indoor** and not **Available Outdoor**.

Maps are provided which indicate:

- Indoor and outdoor availability separately per channel;
- Number of channels available, calculated across channels 21-30/41-60/69 separately for indoor and outdoor.

These channel availability maps can be found on the Ofcom website at http://www.ofcom.org.uk/consult/condocs/ddr/statement/.

Not surprisingly the individual channel maps are strongly correlated to transmitter coverage maps. There are small differences, primarily due to removing locations where incoming DTT interference reduces the microphone operating range below 100m.

3 PMSE User Migration Plan

We were asked to identify situations where PMSE users will have to change frequencies as a result of DSO and provide a high level migration plan for these users.

In general, PMSE users may need to migrate to a different frequency for one of three reasons:

1. DSO;
2. Their channel is no longer available for PMSE use as a result of the DDR. This applies to channels 31-40, 61 – 68;
3. The number of channels (and therefore radio microphone frequencies) available for PMSE use at any given location is lower than the demand for PMSE channels. These locations are referred to as “pinch points”.

Those users in the first two situations are easily identified from the current JFMG managed license database therefore our analysis focussed on identifying “pinch points”.

We identify a pinch point as any location where the demand for channels is greater than the supply. The post DSO channel supply is defined by the outdoor channel availability database described in Section 2, modified to mark channels where incoming DTT limits the estimated radio microphone range to less than 100m. The channel demand was calculated as follows:

- JFMG provided a database of the top 1000 venues, as indicated by number of license requests, for 2005. Figures for 2005 were used as the last year where full demand data could be obtained;
- This database identified the number of channels allocated to radio-microphone use at these venues;
- Results within the same 1km square as the venue were combined to give a 1km square, rather than venue, based total channel demand.

Using this data, we identified ‘pinch point’ locations where the number of channels that will be available after DSO does not meet the peak channel demand in 2005. For this analysis channels 61 and 62 were excluded from the number of available channels. This identified potential pinch points, shown in Table 1 below.

Location	2005 Channel Demand	Channels available	Deficit
GLASGOW G3	18	6	-12
TOWCESTER NN12	12	1	-11
MANCHESTER M3	19	10	-9
SHEFFIELD S9 2DF	13	4	-9
LONDON E16	17	9	-8
BOREHAMWOOD WD6	14	6	-8
LONDON TW1	14	7	-7
LONDON SW5 9TA	19	14	-5
LONDON N11	13	8	-5
LEICESTERSHIRE DE74	10	5	-5
MANCHESTER	13	8	-5
LONDON TW17	7	2	-5
HAYES UB3	7	2	-5
KINROSS KY13	14	10	-4
LONDON HA9	12	8	-4
MANCHESTER M13	9	5	-4
SUNBURY-on-THAMES TW16	6	2	-4
LONDON W12	17	14	-3
LONDON W6	13	10	-3
LEEDS LS3	6	3	-3
LONDON - Hyde Park	26	24	-2
CHELMSFORD CM1	9	7	-2
BAKEWELL DE4	8	6	-2
BIRMINGHAM B1	11	9	-2
NEWCASTLE NE1	10	8	-2
IVER SL0	9	7	-2
BELFAST BT6	5	3	-2
VIRGINIA WATER GU25	4	2	-2
SHEFFIELD S6	3	1	-2
BASILDON	3	1	-2
BRIGHTON BN1	15	14	-1
EDINBURGH EH12	10	9	-1
NOTTINGHAM NG1	6	5	-1
EPSOM KT18	6	5	-1
BRISTOL BS1	6	5	-1
BLACKPOOL FY1	12	11	-1
GLASGOW G5	9	8	-1
GLASGOW G42	6	5	-1
MANCHESTER M1	6	5	-1
EDINBURGH EH7	5	4	-1
TUNBRIDGE WELLS TN1	2	1	-1
HORSHAM RH12	2	1	-1
DAVENTRY	2	1	-1

Table 1: Pinch point analysis

These results indicate that, based on 2005 demand, there are a few locations where may be a constraint on capacity for PMSE users. However there are a number of situations where the modelling approach produces overly cautious estimates:

- These results are based on outdoor channel availability only. It is highly likely that a large proportion of these licensees require indoor use only and therefore will have more channels available to them;
- These results are based on excluding channels where incoming DTT interference limits radio microphone minimum estimated operating range to below 100m. In situations where a lower operating range is acceptable the channel availability is often higher. The estimated operating range for radio microphones in channels limited by incoming DTT interference is provided in the online database at www.jfmg.co.uk.
- We protect all broadcast TV services that are predicted to be receivable post DSO. It is possible that in locations where a number of transmitter service areas overlap there are some TV services being protected which are not being used by a large number of households. The adoption of the DPSA protection model would increase the availability of spectrum for PMSE use.
- It is worth noting that a working rule of 8-12 radio microphones per TV channel is a reasonable assumption and that in locations with no historical shortage of spectrum (and therefore no strong incentive to use channels efficiently) the ratio of “radio microphones used” to “PMSE channel licenses” can be much lower than 8 to 1. As a result Ofcom analysed JFMG’s licensing database to see how many microphones were actually being used for those venues with the highest 2005 demand. The results of that analysis are available in Annex 5 of the DDR statement available at http://www.ofcom.org.uk/consult/condocs/ddr/statement/statement2/statement.pdf

Conversely, it should also be noted that PMSE demand could increase in some locations between 2005 and DSO in 2012.

We would therefore recommend PMSE users estimate their future radio microphone demand and consult the PSME channel availability database at www.jfmg.co.uk.

The combination of this pinch point analysis and channel availability database provide guidance to PMSE users in identifying whether there is a potential capacity deficit and whether the channels currently being used are likely to be available post DSO. Where a PMSE user needs to change channels, further guidance is provided in the online database regarding which channels to migrate to.

The PMSE channel availability calculation is based on current TV channel allocations: while consultation is ongoing the situation may change.

The NGW provided 100m resolution DPSA database (see Appendix A), indicating preferred transmitter for each location, was used to identify the “local” transmitter for the 1km squares within the protection distance.

Appendix A : Planning model databases

NGW provided Ofcom channel usage data and field strength for each 1km square of the UK.

The data was based on predictions carried out using the UK Planning Model. The UKPM is a set of algorithms developed as part of the Joint Planning Project (Ofcom, Arqiva, NGW and the BBC) for use in planning DTT in the UK.

The UKPM predicts field strength using a modified Deygout algorithm. Predictions are at 100m resolution but use terrain and clutter data at 50m resolution. The predictions take into account UK and Continental stations and use best information on antenna patterns and powers[5].

Channel Usage
Channel usage in any 1km square is based on 100m predictions carried out using the UKPM. Two methods were used for defining channel usage.

1) Any channel that provides a service in any 100m square within the 1km square.
2) Any channel in a 100m square that is within its DPSA[6] and within a 1km square.

For both cases a service is defined as a service being predicted as being available at 70% of locations or more within the 100m prediction pixel.

For the first method as services overlap it is possible that many stations will provide a service at a particular 100m pixel. As there are one hundred 100m pixels in a square kilometre it is possible for all channels to be available in a 1km square.

The second method restricts the number of channels in a 100m pixel to the best from a station. This limits the number of channels to a maximum of either six if the pixel is assigned to a station carrying commercial multiplexes or three if the station only has PSB services. In any 1km square individual 100m pixels may be assigned to a number of different stations.

Field Strength
For each channel the maximum field strength in a 1km square has been predicted for 50% and 1% time, at 10m a.g.l. The 1km value is the highest of the one hundred 100m pixels predictions have been made to.

[5] Planning Parameters are detailed in Document JPP/MB/1 Version 2 4 July 2003, Technical Planning Parameters and Algorithms.
[6] DPSA – digital preferred service area. Each 100m pixel is assigned to the station offering the best service. In this case the best service being defined as a 3PSB service and the greatest number of multiplexes from the same station.

Appendix B : Reserved channels (not available for PMSE use)

These frequencies are identical to the list of frequencies presented in table A1 of Ofcom's statement entitled "Access to interleaved spectrum for programme-making and special events after digital switchover" which is available here:

http://www.ofcom.org.uk/consult/condocs/ddr/statement/statement2/statement.pdf

Site ID	Site name	Channel
12000	Belmont	21
11600	Bilsdale	24
10500	Black Hill	51
13700	Caldbeck	21
14700	Craigkelly	52
10100	Crystal Palace	29
10700	Divis	30
11300	Dover	57
10400	Emley Moor	45
12600	Hannington	43
13900	Heathfield	54
13001	Londonderry	48
11000	Mendip	55
11700	Oxford	49
10900	Pontop Pike	56
14900	Ridge Hill	30
10800	Rowridge	29
12400	Sandy Heath	49
11500	Sudbury	49
10200	Sutton Coldfield	51
11400	Tacolneston	57
12100	The Wrekin	48
11100	Waltham	55
10600	Wenvoe	51
10300	Winter Hill	56
	All locations	61 & 62

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