

PMSE sharing in the 960 MHz band

Safety assurance case

Vaughan John

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Introduction

- Ofcom is the communications regulator in the UK and operates under a number of Acts of Parliament, including in particular the Communications Act 2003 and the Wireless Telegraphy Act 2006
- Responsible for managing the radio spectrum
- Under the WT Act 2006 Ofcom may take enforcement action against those operating without a licence or in contravention of their licence conditions
- Penalties for operating without a licence include imprisonment and/or a fine
- Ofcom is also an enforcement authority for the RED and EMC regulations concerning the making available and putting into service of radio and electrical equipment
- Ofcom has a duty to enforce the above regulations to protect and manage the radio spectrum

New spectrum sharing opportunity

- Looked at all bands from 790 MHz to 2 GHz
- 960 – 1164 MHz provides the best sharing option
- Carried out theoretical and practical compatibility studies
- Practical coexistence measurements carried out by JCSys Ltd for analogue and digital microphones
- Measurements used to determine the Spectrum Management Rules (SMRs). Exclusion zones added to SMRs at 1090 MHz
- Consulted October 2015 – Statement setting out decision to share in March 2016
- Details can be found:

<https://www.ofcom.org.uk/consultations-and-statements/category-2/new-spectrum-audio-pmse>

| Band (MHz) | Main use | Sharing potential | Long term | Harmonised use |
|-------------|-------------|-------------------|-----------|----------------|
| 960-1164 | Aero RNav | Yellow | Green | Green |
| 1164-1215 | ARN + GNSS | Red | Green | Green |
| 1215-1300 | ARN + GNSS | Red | Green | Green |
| 1300-1350 | RADAR | Red | Green | Green |
| | | | | |
| 1525-1559 | MSS (s → E) | Yellow | Yellow | Green |
| 1559-1610 | RNSS | Red | Green | Green |
| 1610-1626.5 | Aero RNav | Red | Green | Green |
| 1626.5-1660 | MSS (E → s) | Red | Green | Green |
| 1660-1710 | Met Sat etc | Yellow | Yellow | Yellow |

Safety assurance case (1)

- SAC has been developed consistent with assumptions and data presented in the JTIDS safety case
- Operating within the SMRs and in accordance with a licence is not a concern – the success case
- Hazards are:
 - **H1.** Interference with 1030/1090 MHz systems
 - **H4.** Interference with GNSS systems above 1164 MHz
- H1 and H4 fully mitigated by implementation of guard bands within equipment (± 15 MHz for H1 and 10 MHz for H4)
 - **H2.** Loss of DME facility (including detected corruption and delay)
 - **H3.** Undetected corruption of a DME facility
- H3 (undetected corruption of DME) is not considered credible (this was also argued in the JTIDS safety case)

Safety assurance case (2)

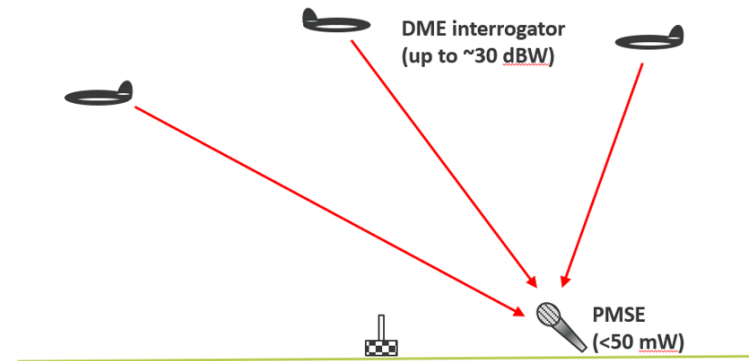
- Only events that have the operational need to use the 960 MHz band will do so i.e. the peak demand use cases (we assume >50 freq assignments)

| Date | Total venues (Assigns) | Venues >50 assigns (assigns) | Venues >99 assigns (assigns) | Locations with >99 authorised assignments | | | | | Ad hoc peak demand events (Assignments including breakdown) | | |
|---------------------------------|------------------------|------------------------------|------------------------------|---|-----------|------------|--------------|-------------|---|--|--|
| | | | | Royal Society + | Barbican+ | ITN (Lon)+ | BBC Salford+ | Media City+ | | | |
| 30 th Jan 2017 (Mon) | 1311 (11573) | 24 (1885) | 6 (676) | 123 | 134 | 113 | 100 | 100 | Theatre, Nottingham (106 54 annual 52 x 14 days) | | |

- 945 (peak) freq assignments per day – 90% are long term, indoor assignments
- SAC assumes mics are set up and used every day which is a gross over-estimation
- Equipment will be installed/operated by professional users – PMSE required high QoS and system failure is not tolerable
- Ofcom applies the SMRs to determine available frequencies for use (see slide 8)
- Ofcom attends a number of events every year to carry out spectrum monitoring
- Spectrum availability tool is part of Ofcom’s BCM framework
- Licensing can be carried out online

Safety assurance case (3)

- Risk of interference into PMSE from aeronautical services will mitigate risk of PMSE interfering with ground receivers (i.e. PMSE will not be able to operate on a freq used by aero)

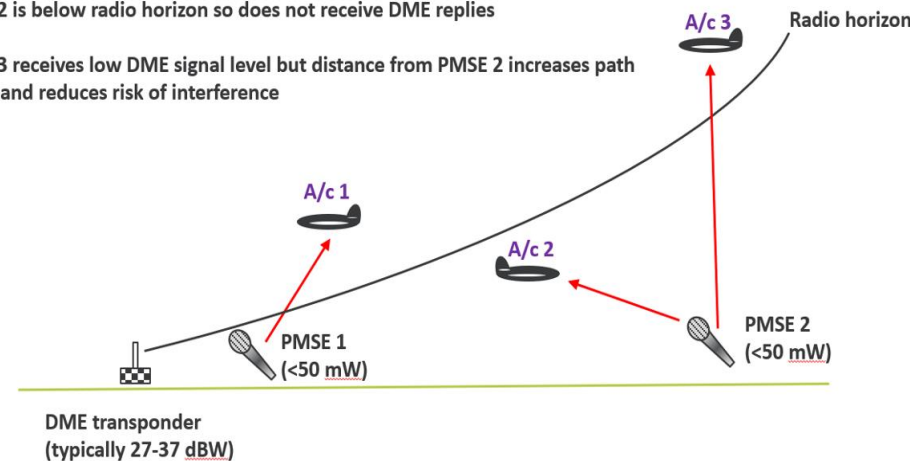


- Geometries reduce risk of interference into airborne receivers

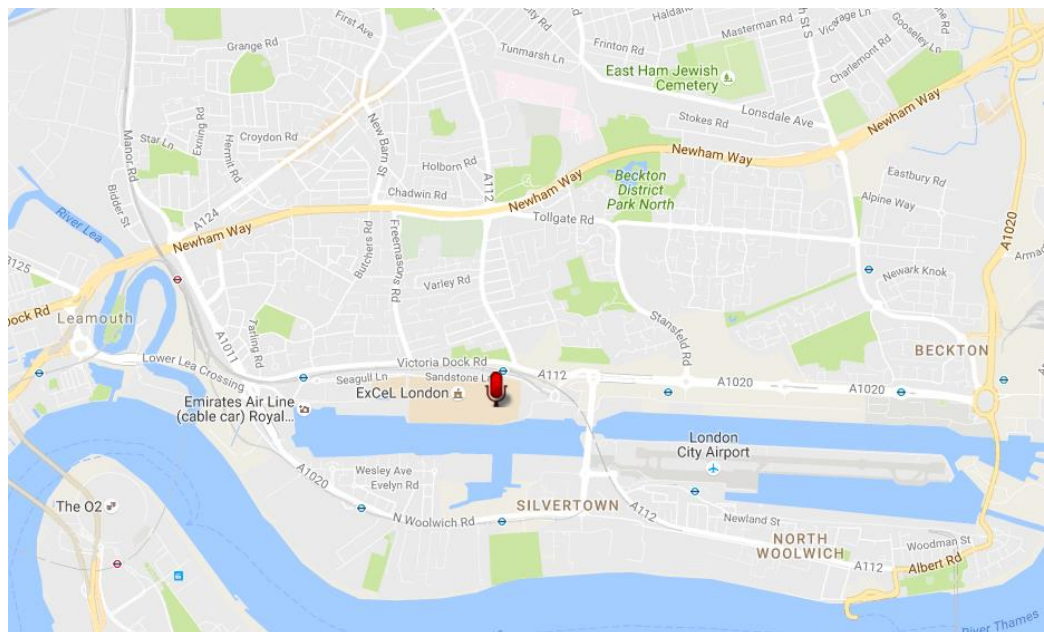
A/c 1 receives high DME signal level so can tolerate higher unwanted signals

A/c 2 is below radio horizon so does not receive DME replies

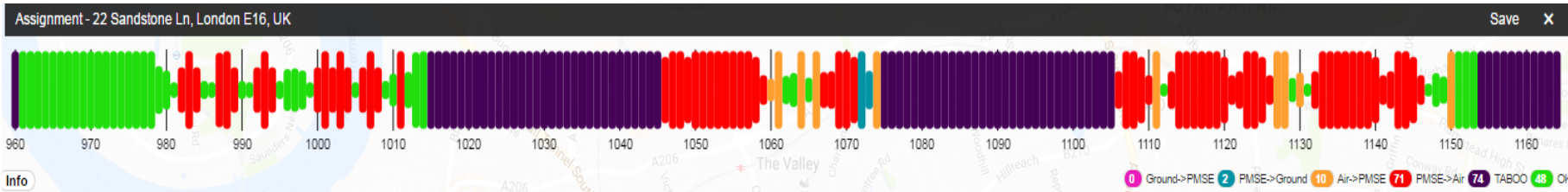
A/c 3 receives low DME signal level but distance from PMSE 2 increases path loss and reduces risk of interference



Safety assurance case (4)



- PMSE trials have been in operation since 2016



Spectrum management rules and their application

Principles of sharing

- Within the 960 – 1164 MHz band there are two coexistence scenarios:
 1. Coexistence with systems that operate at 1030 & 1090 MHz, e.g. SSR, TCAS, ADS-B, IFF etc
 2. Coexistence with systems that operate across the band but not at 1030/1090 MHz, e.g. DME, TACAN (as the operation of TACAN is similar to DME, for simplicity we refer only to DME from this point)
- Systems at 1030/1090 MHz receive wanted signals at any point in space at any time, therefore it is not possible to technically coordinate shared access to these channel. Consequently, these frequencies (plus appropriate guard bands) are excluded for use by PMSE
- DME is a planned service with defined coverage areas and frequency reuse utilising a channel raster based on 1 MHz channels. It is therefore possible to allow low power audio PMSE (wireless mics radiating <50 mW) to interleave with this planned network similar to how PMSE interleaves with DTT
- Sharing with DME requires protecting signals received on the ground and those received in the air
- In addition there is a compatibility requirement with RNSS above 1164 MHz. Guard band is implemented to protect RNSS

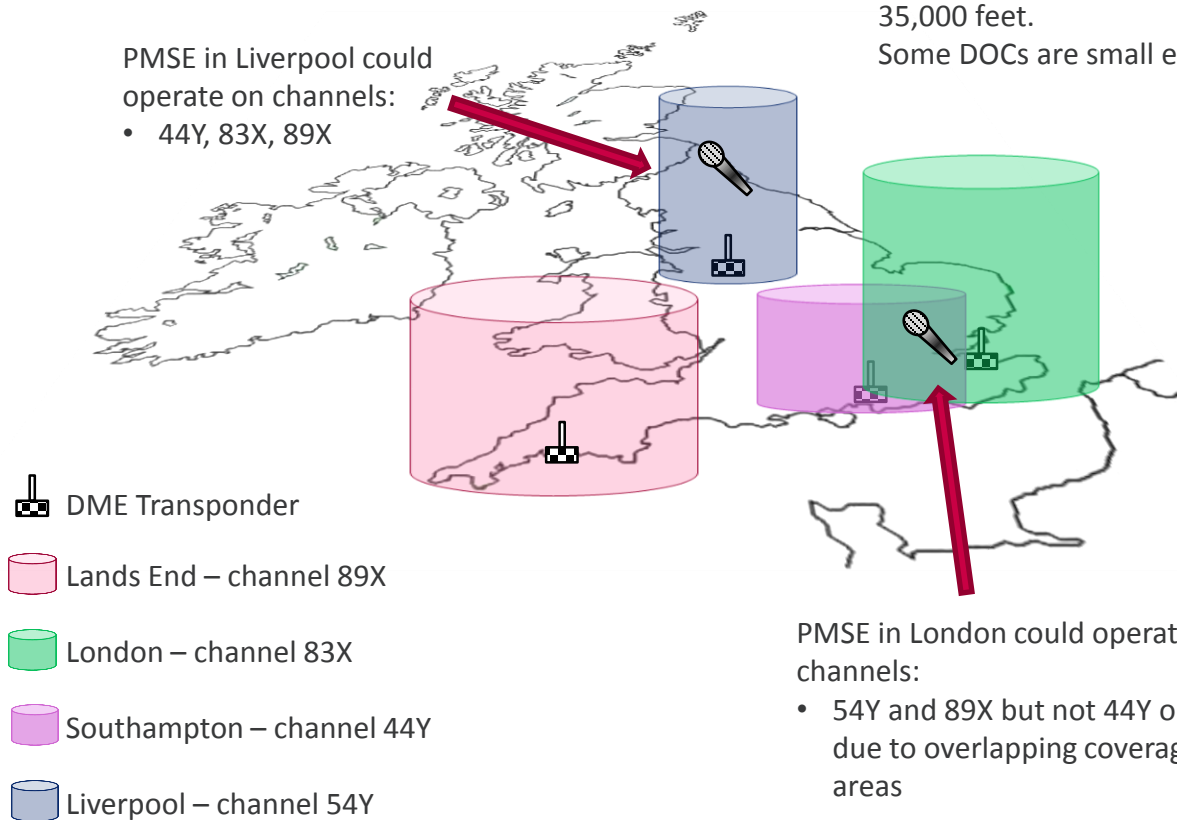
Sharing with DME

The designated operational coverage area (DOC) of a DME ground station is defined as a volume of airspace with distance in nautical miles and height in hundreds of feet e.g. 100/350 would be 100 nautical miles and 35,000 feet.

Some DOCs are small e.g. 25 nm

PMSE in Liverpool could operate on channels:

- 44Y, 83X, 89X



PMSE in London could operate on channels:

- 54Y and 89X but not 44Y or 83X due to overlapping coverage areas

Sharing criteria

- Maximum interference thresholds into DME were derived from practical measurements for ground and airborne equipment and both X and Y modes. These measurements included the full Link16 signal environment as defined in the Frequency Clearance Agreement between the CAA and MOD (https://www.ofcom.org.uk/data/assets/pdf_file/0024/57840/annex6.pdf)
- Compatibility with 1030/1090 MHz was derived from practical measurements with the recommendation that no PMSE transmissions should occur within ± 10 MHz of either frequency
- In response to comments received from the public consultation, and review of the Minimum Operational Performance Standards for SSR, TCAS and ADS-B it was decided to extend the guard bands to ± 15 MHz
- In addition to in-band compatibility a 1 MHz guard band is included at 960 MHz (to protect adjacent mobile services below 960 MHz), and a 10 MHz guard band is included at 1054 MHz (to protect RNSS above 1164 MHz)

Interference thresholds

Spectrum Management Rules

- Spectrum management thresholds are derived from the most restrictive for each frequency offset across the range of DME equipment tested
- Thresholds were measured against a minimum wanted DME signal level as defined in standards
- Thresholds the Link16 signal environment - UK Any Point In Space, 70NM radius Geo Area, 60% Time Slot Duty Factor, (Frequency Clearance Agreement between the CAA and MOD).
- For higher levels of wanted signal a higher level of interference can be tolerated

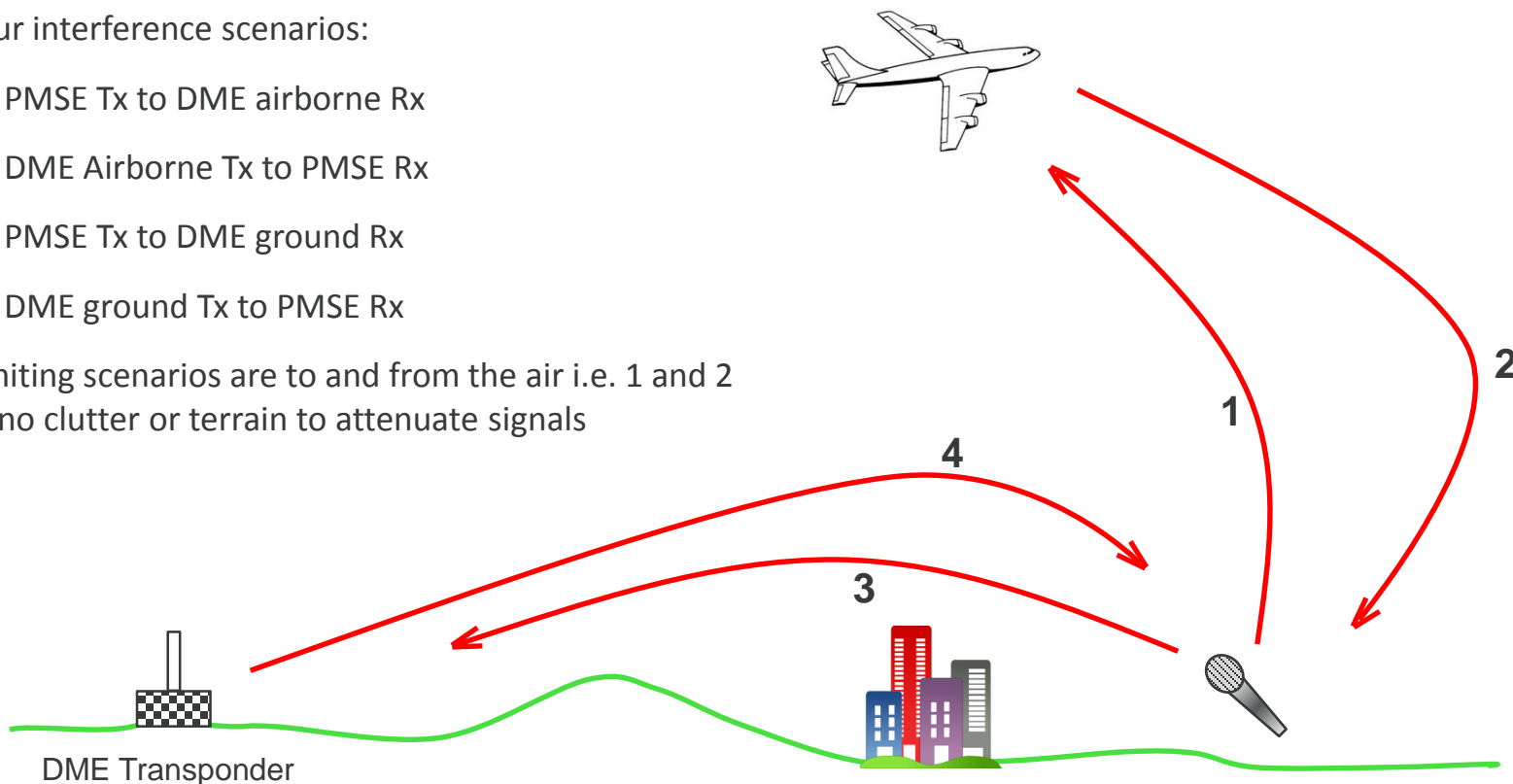
| Delta F (MHz) | DME Ground transponder maximum interference threshold | | DME airborne interrogator maximum interference threshold | |
|---------------|---|--------------|--|--------------|
| | X-mode (dBm) | Y-mode (dBm) | X-mode (dBm) | Y-mode (dBm) |
| -8 | -56 | -50 | | |
| -7 | -56 | -50 | | |
| -6 | -56 | -50 | -20 | -32 |
| -5 | -64 | -55 | -20 | -35 |
| -4 | -72 | -70 | -29 | -41 |
| -3 | -81 | -75 | -38 | -48 |
| -2 | -89 | -87 | -47 | -58 |
| -1 | -100 | -102 | -61 | -75 |
| 0 | -111 | -115 | -100 | -100 |
| 1 | -100 | -100 | -61 | -69 |
| 2 | -87 | -89 | -46 | -55 |
| 3 | -74 | -82 | -37 | -48 |
| 4 | -60 | -77 | -29 | -40 |
| 5 | -47 | -74 | -20 | -36 |
| 6 | -45 | -68 | -20 | -29 |
| 7 | -45 | -63 | | |
| 8 | -45 | -63 | | |

Compatibility scenarios

Four interference scenarios:

1. PMSE Tx to DME airborne Rx
2. DME Airborne Tx to PMSE Rx
3. PMSE Tx to DME ground Rx
4. DME ground Tx to PMSE Rx

Limiting scenarios are to and from the air i.e. 1 and 2
as no clutter or terrain to attenuate signals



Radio planning assumptions

- For PMSE transmitter to aeronautical airborne receiver ITU-R Recommendation P.528 (IF77) is applied and for PMSE transmitter to aeronautical ground receiver ITU-R Recommendation P.452 is applied.

| | IF77 (airborne scenario) | ITU-R Recommendation P.452 (terrestrial scenario) |
|----------------------|--------------------------|---|
| Percentage time | 1% | 1% |
| Percentage location | n/a | 50% |
| Clutter loss (Urban) | n/a | 22.9 dB (Note 1) |
| Clutter loss (Rural) | n/a | 17.9 dB (Note 1) |
| Building entry loss | 0 dB | 11 dB |
| Terrain path profile | n/a | Optional (not applied by default) |

- Note 1: Clutter loss is only applied in the terrestrial scenario at the PMSE end on the assumption that the DME transponder is generally free of clutter. These values are taken from ITU-R Recommendation P.1812, as these are appropriate to a point-to-area model rather than the clutter shielding model in P.452 which is appropriate to cases where clutter is modelled specifically to provide protection from interference

Equipment parameters

DME parameter values

| | DME Transponder | DME interrogator |
|----------------|---|---|
| Reference freq | 960 MHz | 960 MHz |
| Max EIRP | From ICAO COM3 | 62.4 dBm |
| Antenna height | 10 m | From 328 to 98,425 ft (0.1 to 30 km) |
| Antenna gain | 6 dBi (dB Systems 5100AD/7 0° to the horizon) | 5.4 dBi (maximum) ITU Rec M.1642 (Note 1) |
| Location/DOC | From ICAO COM3 database | From ICAO COM3 database (Note 2) |

- Note 1: From Table 1 of Annex 2 of ITU Rec M.1642. Applied for different elevation angles from the PMSE transmitter to airborne receiver
- Note 2: The DOC is adjusted in accordance with ARINC 424 'Figure of Merit' (see slides 16 to 18)

PMSE parameter values

| | PMSE |
|----------------|---------|
| Reference freq | 960 MHz |
| Max EIRP | 17 dBm |
| Antenna height | 1.5 m |
| Antenna gain | 0 dB |

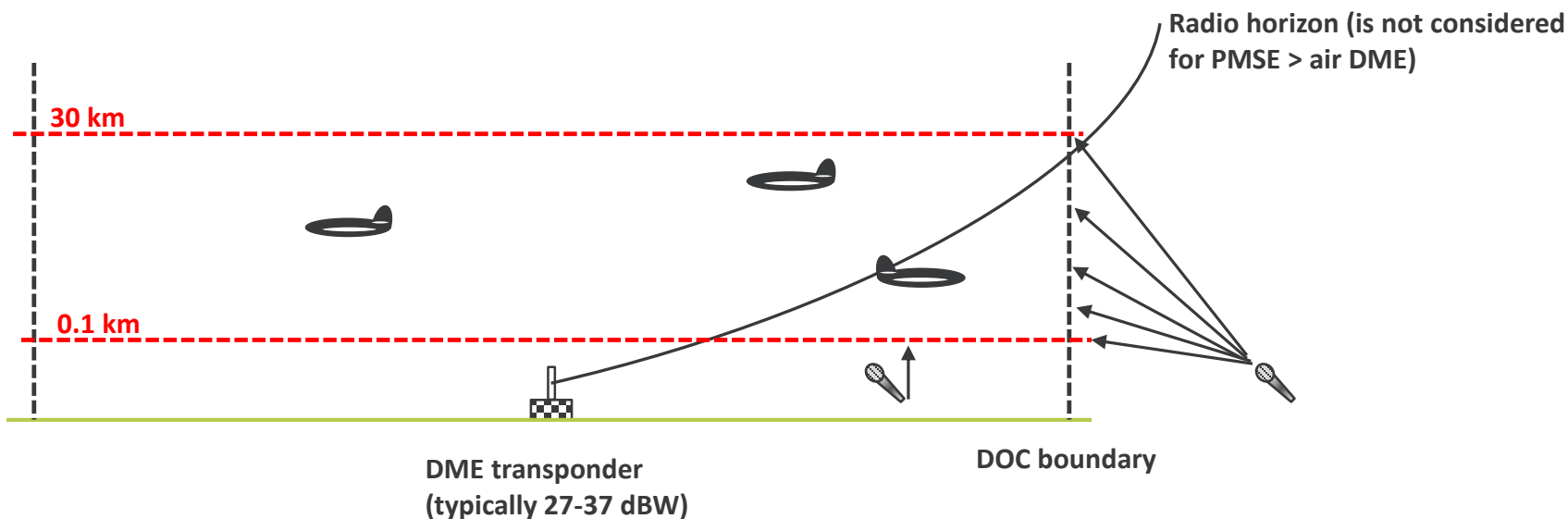
PMSE transmitter to DME ground receiver

- For every DME transponder within 500 km of the PMSE transmitter:
 - Calculate the geographical separation distance between the DME ground station and the PMSE location (using the great circle distance)
 - Derive the signal level from PMSE at each DME ground station using the technical parameters and radio planning assumptions previously defined (in this scenario using ITU-R Recommendation P.452)
 - Test the derived signal level against the co- and adjacent channel thresholds relevant to the appropriate X or Y mode value
 - In geographic locations where the interference threshold is exceeded the channel is excluded

PMSE transmitter to DME airborne receiver

- For every DME transponder within 500 km of the PMSE transmitter assume aircraft can operate anywhere within the DOC (this is the adjusted DOC range in accordance with the ARINC 424 Figure of Merit) from 100 m to 30,000 m height regardless of distance from the ground beacon i.e. the radio horizon is not considered:
 - Calculate location of PMSE with respect to the DOC
 - For venues within the DOC derive the signal level from PMSE at the aircraft using the technical parameters and radio planning assumptions previously defined (in this scenario using IF77). This assumes a minimum vertical separation of 100 m between PMSE and the aircraft
 - For venues outside the DOC derive the signal level is derived for a range of aircraft heights every 100 m to 30 km along the DOC boundary and incorporates the aircraft antenna pattern to find the most limiting geometry
 - Test the derived signal level against the co- and adjacent channel thresholds relevant to the appropriate X or Y mode value
 - In geographic locations where the interference threshold is exceeded the channel is excluded

PMSE transmitter to DME airborne receiver



- Across the whole volume of the DOC the minimum interference threshold is applied, regardless of the level of wanted signal
- For PMSE located within the DOC it is assumed that an aircraft is 100 m away from the PMSE transmitter
- For PMSE located outside the DOC the most limiting geometry is determined from 100 m to 30,000 m
- The radio horizon is not considered

PMSE compatibility at 1030 and 1090 MHz (1)

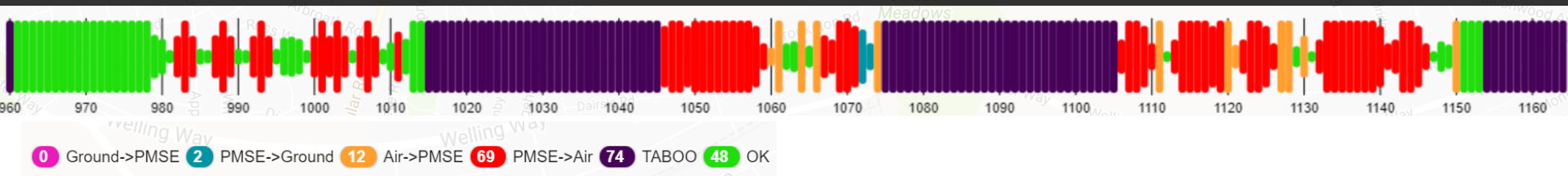
- As previously discussed it is not possible to technically coordinate access to the 1030 and 1090 MHz frequencies as systems that operate on these frequencies may do so at any location at any time
- Guard bands of ± 15 MHz are applied at 1030 and 1090 MHz. In addition, at 1090 MHz the following geographical exclusion zones are applied (see next slide for parameters and methodology)

| Exclusion zone (1090 MHz) | SSR | WAM |
|------------------------------|---------|---------|
| $< \pm 15$ MHz | No PMSE | No PMSE |
| ± 15 MHz to ± 25 MHz | 500 m | 100 m |
| $> \pm 25$ MHz | 100 m | 0 m |

Example output from planning tool (1) outdoor mic, rural environment

Assignment - Memorial Hospital, London SE18 3SA, UK

Save X



- Spectrum availability is location dependent due to the configuration of aeronautical assignments
- Each bar represents a 1 MHz DME channel. Length of the bar represents how close to the particular threshold
- **Green – OK:** PMSE does not cause interference into aero services or receives interference from them
- **Pink - Ground->PMSE:** ground beacon interferes with PMSE. There is no regulatory restriction
- **Blue - PMSE->Ground:** PMSE interferes with the ground beacon. If the threshold is exceeded this channel cannot be used, i.e. it's a regulatory restriction
- **Orange - Air->PMSE:** airborne interrogators interfere with PMSE. There is no regulatory restriction
- **Red - PMSE->air:** PMSE interferes with airborne DME receivers. This is a regulatory restriction so these channels cannot be used
- **Purple –Taboo:** guard band channels to protect SSR, TCAS, ADS-B, IFF etc at 1030 and 1090 MHz and GNSS above 1164 MHz and cannot be used

Example output from planning tool (2) outdoor mic, rural environment

| Frequency [MHz] | Type | Relative Int [dB] | Beacon | SAFIRE REF | Ch | Interference [dBm] | Pathloss [dB] | Delta F [MHz] | Distance [km] | DoC [km] |
|-----------------|------|-------------------|--------|------------|----|--------------------|---------------|---------------|---------------|----------|
|-----------------|------|-------------------|--------|------------|----|--------------------|---------------|---------------|---------------|----------|

| | | | | | | | | | | |
|------|-----------|-------|-----------------|------|------|-------|-------|----|--------|--------|
| 1065 | Air->PMSE | -4.8 | ROTTERDAM | 2060 | 41X | -69.8 | 126.8 | | 309.28 | 240.76 |
| 1065 | OK | | | | | | | | | |
| 1065 | PMSE->Air | -13.3 | BARKWAY | 1540 | 109Y | -48.3 | 70.7 | -5 | 57.14 | 240.76 |
| 1066 | Air->PMSE | 51.3 | LONDON/STANSTED | 1752 | 42X | -13.7 | 70.7 | | 45.39 | 74.08 |
| 1066 | Maybe | | | | | | | | | |
| 1066 | PMSE->Air | -7.3 | BARKWAY | 1540 | 109Y | -48.3 | 70.7 | -4 | 57.14 | 240.76 |

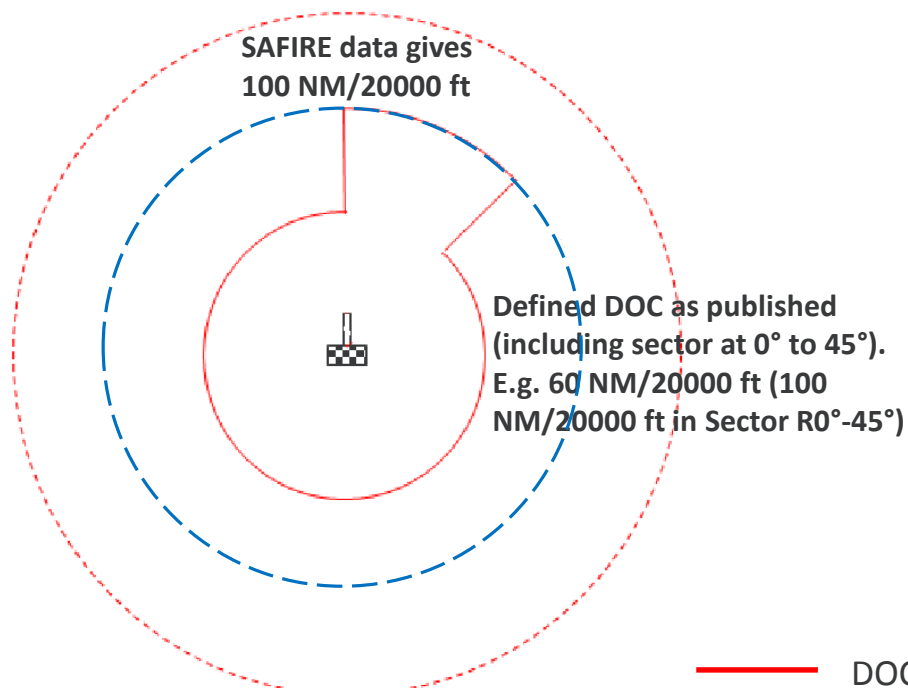
| | | | | | | | | | | |
|------|--------------|-------|-------------|------|------|--------|--------|---|--------|--------|
| 1072 | Air->PMSE | 51.3 | LONDON CITY | 6265 | 48Y | -13.7 | 70.7 | | 3.56 | 74.08 |
| 1072 | NO | | | | | | | | | |
| 1072 | PMSE->Air | 6.7 | BARKWAY | 1540 | 109Y | -48.3 | 70.7 | 2 | 57.14 | 240.76 |
| 1072 | PMSE->Ground | 17.78 | LONDON CITY | 6265 | 48Y | -97.22 | 120.22 | | 3.56 | 74.08 |
| 1073 | Air->PMSE | -8 | PARIS/ORLY | 1310 | 49X | -73 | 130 | | 346.22 | 240.76 |
| 1073 | NO | | | | | | | | | |
| 1073 | PMSE->Air | -0.3 | BARKWAY | 1540 | 109Y | -48.3 | 70.7 | 3 | 57.14 | 240.76 |
| 1073 | PMSE->Ground | 6.78 | LONDON CITY | 6265 | 48Y | -97.22 | 120.22 | 1 | 3.56 | 74.08 |
| 1074 | Air->PMSE | 51.3 | SOUTHEND | 6541 | 50Y | -13.7 | 70.7 | | 45.23 | 74.08 |

| | | | | | | | | | | |
|------|-----------|-------|------------------|------|------|--------|-------|--|--------|--------|
| 1129 | Air->PMSE | -14.9 | CASEMENT | 2286 | 105X | -79.9 | 136.9 | | 486.54 | 240.76 |
| 1129 | OK | | | | | | | | | |
| 1129 | PMSE->Air | -4.4 | CALAIS/DUNKERQUE | 4886 | 42Y | -104.4 | 126.8 | | 143.43 | 74.08 |

Designated operational coverage (DOC)

- DME DOCs are published in Aeronautical Information Publications (AIPs), for En route and aerodrome DMEs.
- DOC combines operational height and operational range as, e.g. '40 nm/25000 ft'
- Some DOCs have sectorised ranges, e.g. DOC: 40 nm/50000 ft (200 nm/50000 ft in Sector R229°-349°)
- DME data can also be exported from SAFIRE (Spectrum and Frequency Information Resource). These data typically give the largest DOC range from any sectorised ranges, e.g. 200 nm/50000 ft from the example above
- DOC range is encoded (in the Figure of Merit field - FOM) in the navigation database used by onboard flight management systems according to the ARINC specification 424 which:
 - "...sets forth the air transport industry's recommended standards for the preparation of airborne navigation system reference data tape. The data on these tapes are intended for merging with airborne navigation computer operational software to produce tapes (or other suitable data stores) for use by such computers on board aircraft."
- The Ofcom planning tool imports a data extract from SAFIRE and applies the next largest FOM range for DOCs less than 130 NM. If the DOC range is greater than 130 NM the value from SAFIRE is used

Application of DOC in planning tool



| Field Content | Description |
|---------------|---|
| 0 | Terminal Use (generally within 25NM, 46.3km) |
| 1 | Low Altitude Use (generally within 40NM, 74.08km) |
| 2 | High Altitude Use (generally within 130NM, 240.76km) |
| 3 | Extended High Altitude Use (generally beyond 130NM, 240.76km) |
| 7 | Navaid not included in a civil international NOTAM system |
| 9 | Navaid Out of Service |

- DOC as defined in the AIP (60 NM with 100 NM in sector 0° to 45°).
- - - DOC as defined in SAFIRE (100 NM from largest sector)
- ⋯ DOC as derived from FOM (130 NM)

In this example the Ofcom planning tool will apply the FOM range in its calculation i.e 130 NM – (See examples on next slide)

USE of FOM to represent the DOC

In the 960 MHz spectrum availability planning tool the FOM is adopted for DOC ranges less than 130 NM. For ranges greater than 130 NM the DOC range as given in SAFIRE is used. Adopting this approach in the examples given on Slide 15 we have:

| Beacon | DOC as published in SAFIRE | DOC used in planning tool (as derived from FOM) |
|------------------|----------------------------|---|
| Rotterdam | 100 NM | 130 NM (FOM:2) |
| Barkway | 40 NM | 130 NM (FOM:2) |
| London/Stansted | 25 NM | 40 NM (FOM:1) |
| London City | 25 NM | 40 NM (FOM:1) |
| Paris/Orly | 60 NM | 130 NM (FOM:2) |
| Southend | 25 NM | 40 NM (FOM:1) |
| Casement | 80 NM | 130 NM (FOM:2) |
| Calais/Dunkerque | 25 NM | 40 NM (FOM:1) |

Summary of assumptions

- The assumptions outlined in this presentation lead to a conservative approach to sharing:
 - Interference threshold derived from minimum wanted signal level and includes Link16
 - Interference threshold is applied across the whole DOC
 - Maximum separation distance between PMSE and aircraft is 100 m at any point in DOC, i.e. radio horizon is not assumed
 - No building loss applied in the airborne scenario
 - DOC applied is the greater of the ARINC FOM (up to 130 NM) or SAFIRE if greater than 130 NM
 - Results from most limiting geometry are used