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| **Radiocommunication Study Groups** |  |
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| Source: Document 5A/TEMP/234(Rev.1) | **Annex 19 to Document 5A/597-E** |
| **10 June 2022** |
| **English only** |
| Annex 19 to Working Party 5A Chairman’s Report | |
| WORKING DOCUMENT TOWARDs A PRELIMINARY DRAFT NEW  REPORT ITU-R M.[AUDIO-PMSE\_LMS] | |
| [Status and trends regarding regional and global usage of audio applications of PMSE in the land mobile service] | |

[Editor’s note: This document will require further discussion and revision in future meetings based on input contributions.]

[Editor’s note: Table of Contents needs to be updated.]

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[Editor’s note: Renumbering is required for the figures and tables.]

*[Editor’s note: Material needs to be reviewed to ensure that only land mobile service applications are being addressed.]*

# 1 Scope

This Report provides an overview of audio applications of Programme Making and Special Events (PMSE), which are meant for Services Ancillary to Programme making (SAP) / Services Ancillary to Broadcasting (SAB), [Outside Broadcasting (OB)] in the land mobile service, in accordance with *resolves* 1 and *resolves* 2 of Resolution ITU-R 59-2.The Report is segmented in sections regarding overview, technical characteristics, frequency usage, standardization, application and use of radio spectrum.

# 2 Background

Resolution ITU-R 59-2 invites studies on availability of frequency bands for worldwide and/or regional harmonization and conditions for their use by terrestrial electronic news gathering systems and resolves

– to carry out studies regarding possible solutions for global/regional harmonization of frequency bands and tuning ranges for ENG use, focused on bands already allocated, on a primary or secondary basis, to the fixed, mobile or broadcasting services, taking into account:

– that some frequency bands have more favourable properties suitable for ENG use;

– available technologies to maximize efficient and flexible use of spectrum;

– system characteristics and operational practices which facilitate the implementation of these solutions;

– to develop ITU‑R Recommendations and/or ITU‑R Reports based on the aforementioned studies, as appropriate.

# 3 Related ITU-R Recommendations and Reports

*[Editor’s note: Lists to be expanded to indicate titles.]*

**ITU-R Recommendations**: M.1824, F.1777, M.1637, BT.1868, BT.1871, BT.1872, BS.1116, BS.1283, and BS.1284

**ITU-R Reports**: BT.2069, BT.2338, and BT.2344

# 4 List of acronyms and abbreviations

*[Editor’s note: This Section needs to be updated to include more acronyms and abbreviations.]*

3GPP 3rd Generation Partnership Project

AV Audio-Video

AC Alternating Current

BAS Broadcast Auxiliary Systems

CEN European Committee for Standardization

CEPT European Conference of Postal and Telecommunications Administrations

DECT Digital Enhanced Cordless Telecommunications

DMR Digital Mobile Radio

ECC Electronic Communications Committee

ENG Electronic News Gathering

ETSI European Telecommunications Standards Institute

FCC Federal Communications Commission

FDMA Frequency Division Multiple Access

IEEE Institute of Electrical and Electronics Engineers

IEM In-Ear Monitoring

IMT International Mobile Telecommunications

IrDA Infrared Direct Access

ISO International Organization for Standardization

MPX Multiplexed

NB Narrow Band

NPN Non-Public Network

[OB Outside Broadcasting]

PLMN Public Land Mobile Network

PMR Personal Mobile Radio

PMSE Programme Making and Special Events

PSD Power Spectral Density

RF Radio Frequency

SAB Services Ancillary to Broadcasting

SAP Services Ancillary to Programme making

TDD Time Division Duplex

TDMA Time Division Multiple Access

WMAS Wireless Multi-channel Audio System

## 4.1 Terms and Definitions

*[Editor’s note: Section might be amended with additional definitions.]*

*[Editor’s note: Add definition for PMSE.]*

Radio link: A link for a wireless microphone consists of portable transmitter and a receiver as the fixed part.

A link for an IEM consists of a portable receiver with earphones and a transmitter as the fixed part.

# 5 Overview on PMSE

Programme Making and Special Events (PMSE) comprises applications and Services Ancillary to Programme making (SAP), applications and Services Ancillary to Broadcasting (SAB), [Outside Broadcasting (OB)], Broadcast Auxiliary Systems (BAS) including applications used in meetings, conferences, cultural and education activities, trade fairs, local entertainment, sport, religious, political and other public or private events.

There are three main groups of PMSE equipment:

– audio PMSE – the most commonly used audio PMSE applications are wireless microphones (handheld and body worn), in-ear monitors, intercom, conferencing solutions and talkback systems – relevant content is provided by this document;

– video PMSE – the most commonly used video PMSE applications are portable or mobile wireless video links and cordless cameras;

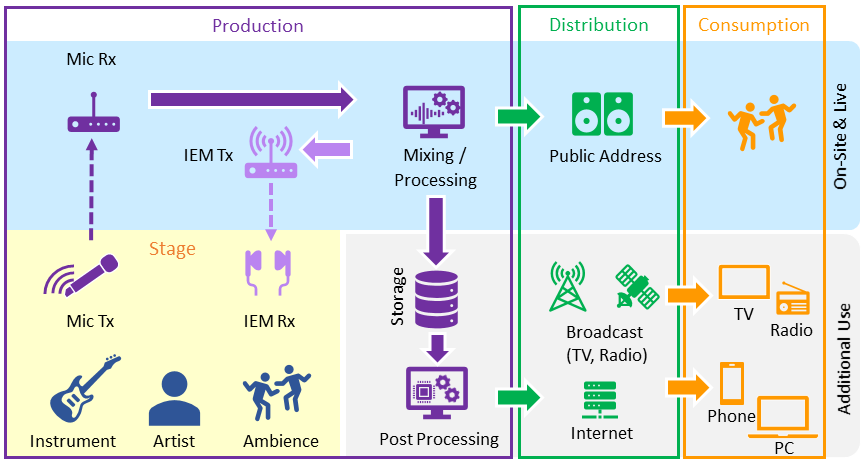
– PMSE service links – PMSE equipment that is used for data transmission for production such as effect and remote control and team connection) including OB, BAS and SNG.

This report addresses audio PMSE in the land mobile service.

Figure 1 below provides an overview for a typical audio PMSE usage scenario:

Figure 1

Audio PMSE usage scenario from production to consumption



# 6 Audio PMSE in the land mobile service

## 6.1 Overview

Audio PMSE applications transmit typically with low power, require mission critical low latency audio transmission in an indoor or outdoor service area (e.g. venue, festival location, arena, conference center, hotel, interviews at arbitrary locations, etc.). The scope of audio PMSE use covers ad-hoc, mobile, nomadic or fixed locations.

Typical applications are Wireless Microphone, In-Ear Monitor (IEM), Intercom, conferencing solution, tour guiding and Talkback systems.

Traditionally, audio PMSE systems follow a link-based approach like many other Audio-Video (AV) systems that are based on a dedicated transmitter-receiver pair for uni-directional transmission. Thus, the required resources in radio spectrum scales with the number of links to be employed.

Currently the audio PMSE industry make use of analogue and digital technologies employing narrowband modulation techniques with each link typically occupying a 200 kHz wide RF channel.

A wireless link consists of a portable and a fixed part, or two portables.

Portables

– can be a handheld, body worn or table-top equipment,

– can be transmitters, receivers or transceivers (transmit and receive),

– are battery driven requiring a typical operation time of 6-10 h.

Fixed parts

– can be table-top or rack-mountable equipment,

– can be transmitters, receivers or transceivers (transmit and receive),

– have typical a power supply by AC mains.

The implementation defines the transmission direction and functions of each side of the link:

– for a wireless microphone consists of portable transmitter and a receiver as the fixed part.

– for an IEM consists of a portable receiver with earphones and a transmitter as the fixed part.

The favorable propagation conditions of sub-1-GHz frequencies are employed to support the low power transmission of battery driven portables and to overcome wireless channel effects and propagation losses (e.g. fading) by complex stage sets and body loss (handheld and body worn equipment, moving and turning artists).

Live music events can involve hundreds of microphone, IEM, intercom, and talkback channels, so that the link-based approach results in quite complex setups.

[The forthcoming Wireless Multi Audio-channel System (WMAS) follow a system-based approach integrating wireless microphones, IEMs and other applications in one system concept and radio interface. The system concept of WMAS offers multiple bi-directional audio planes and bi‑directional control planes. Depending on the application, an audio plane might be used in one direction only. In WMAS the fixed part is a base station and operates with all portables on the same radio interface.]

## 6.2 Wireless Components

A wide number of applications and components are covered under the Audio PMSE term. The key components are:

– wireless microphones

– in-ear monitoring systems

– audio links

– wireless conference systems

– talkback systems.

Depending on the usage and deployment scenario, additional wireless components such as Personal Mobile Radio (PMR) / Digital Mobile Radio (DMR), mobile service-based applications and others are used.

## 6.3 Typical Deployment Scenarios

Table 1 below provides an overview on possible deployment scenarios of audio PMSE for applications. Deployment is distinguished in location (everywhere, dedicated site), type (nomadic, fixed, mobile, air borne – ad-hoc or scheduled) and area of use (indoor or outdoor).

Table 1 also provides the typical spectrum requirement per listed deployment scenario.

For further explanation and more details regarding the introduced deployment scenarios see Annex 1.

Table 1

Land Mobile Service Deployment Scenarios of Audio PMSE and typical spectrum requirement \*/\*\*

| Use |  | Deployment | | |
| --- | --- | --- | --- | --- |
| Required spectrum (typical value \*\*\*) | Location of use | Type of use | Area of use |
| Live Event – Music, Theater – Sport, Olympics | Small: 20 MHz Medium: 45 MHz Large: 90 MHz Mega: > 150 MHz  > 95% in the band 470 – 694 MHz; Talkback might use DECT technology | Everywhere including dedicated sites or along race track | Scheduled Nomadic or Fixed; Air-borne possible | Indoor and outdoor |
| Presentation, Conferencing | Small: 8 MHz Medium: 20 MHz  Large: 45 MHz  Mega: 100 MHz + | Everywhere | Nomadic or Fixed | Predominantly indoor, but also outdoor |
| News Gathering: Local News, International News | 1-2 teams: 5 MHz 10 teams: 20 MHz  50 teams: 50 MHz Mega event: 100 MHz + | Everywhere | Ad-Hoc Nomadic or Mobile, Air‑borne possible | Predominantly outdoor, but also indoor |
| Studio – Studio Production | Small: 20 MHz Medium: 45 MHz Large: 90 MHz | Everywhere including dedicated sites / media villages | Nomadic or Fixed | Predominantly indoor |
| Studio – Project Studio Production | 10 MHz | Everywhere | Nomadic or Fixed | Predominantly indoor |
| \* For so-called Mega-events, up-to-date spectrum from government departments on a basis of a spectrum lease, however, it may already be allocated to other services and thus not available.  \*\* The required spectrum in the table does not consider Hot Spot areas, where several event places are close to each other. Hot Spot areas require a different frequency management setup resolving in higher required spectrum use.  \*\*\* Calculation of typical required spectrum in MHz: Audio PMSE manufacturers are offering frequency compatibility calculation tools / frequency management tools. Those tools calculate available frequencies for e.g. wireless microphones and IEM considering:  – Available interference free spectrum  • Avoiding DTT allocations  • Considering other audio PMSE devices already in use  – Technical specifications  • Tuning range of the equipment  • Intermodulation Products  • Filter options of antenna systems, receivers and transmitters  The required spectrum [MHz] listed in Table 1 provides a typical number in MHz. | | | | |

## 6.4 Introduction of temporary event-specific solutions

Mega Events (see Table 1) and increasingly other large events might require every single available and suitable piece of spectrum that is usually not allocated to PMSE so that the required wireless microphones, IEM’s, talkbacks etc. can reliably operate during the setup and of course the event itself. The expectations of the PMSE users before and during these events are very high. In some cases, it is thus necessary to lease spectrum from other bands that usually other applications use at least for this limited time period. These spectrum sharing arrangements require careful professional planning far in advance. Only such an “all hands-on board approach” will make it possible that the users who attend these events, such as news crews and teams, are able to work with their own PMSE equipment. Such users typically bring along and expect to use their own equipment for the event from other countries or regions, which the regulators would not allow to be deployed at the event location under usual circumstances.

# 7 Audio PMSE spectrum use

## 7.1 Introduction

Frequency ranges for possible audio PMSE use are mainly dependent on national assignments even though significant cross border use of equipment takes place.

Some frequency bands are common across ITU-R Regions and countries and, therefore, are the most commonly used frequency ranges for audio PMSE.

*[Editor’s note: Clarify the sentence below with regards to the broadcast service vs the land mobile service.]*

[Examples of the available frequency ranges for Audio PMSE are provided in Recommendation ITU‑R BT.1871 and Reports ITU-R BT.2344 and BT.2069.] It should be noted that audio PMSE equipment is operated on a tuning range basis and not in a pre‑defined channel raster.

A primary task of the engineer in charge of the wireless links is to identify if there is sufficient permitted spectrum available at the event location for the number of wireless audio specified by the production. Shortage of available spectrum results in direct restrictions of the possible applications or their performance.

The spectrum available to the individual user depends on:

– the tuning range supported by the used audio PMSE equipment,

– the existing radio spectrum occupancy in the service area (e.g. venue),

– the frequency planning within the service area and the restrictions in place via policies applicable at the venue,

– the applicable license terms and/or the national frequency regulation.

Availability of audio PMSE equipment to the market for the various tuning ranges depends on the global or at least regional availability of such tuning ranges and the market size they are representing.

Users of audio PMSE must be able to use their equipment in multiple scenarios and environments. A shortage of spectrum resources is frequently part of their daily business. Therefore, manufactures of audio PMSE equipment have reacted by offering equipment with selectable operational modes. These modes allow the user to pack more audio channels into a given amount of available radio spectrum, while accepting to restrict the audio performance and/or range. A significant shortage of radio spectrum resources is especially likely for large music events (including nomadic uses), studios, media villages, and venues in densely populated areas, where PMSE is expected to deliver the best audio performance possible. Further, the growing number of content productions and the demand for a higher resolution audio capture including 3D immersive recordings drive the development of new equipment and radio spectrum demand for audio PMSE.

## 7.2 Advantages and disadvantages, from a propagation perspective, of the frequency ranges used by Audio PMSE

The advantages and disadvantages, from a propagation perspective, of the frequency ranges that are typically used for audio PMSE are shown in Table 2 depending on the frequency range. [reference rep ECC 204]

*[Editor’s note: Consider replacing table below with text.]*

Table 2

Advantages and disadvantages, from a propagation perspective, of the frequency ranges used by Audio PMSE

| Frequency range | Advantages | Disadvantages |
| --- | --- | --- |
| 29.7 to 47.0 MHz | − Good propagation, minimum wall absorption, no reflection or diffraction. | − Shielding from metal structures is low.  − Only very low or lowest body absorption in this frequency range.  − This band may not be practicable for all types of audio PMSE applications due to the high ambient noise levels.  − It requires the implementation of very large antennas, it is not suitable for body‑worn equipment.  − Not suitable for large multi-channel systems due to the limited bandwidth. |
| VHF band above 174 MHz | − Good propagation, minimum wall absorption, low reflection or diffraction.  − Shielding from metal structures is low.  − Body absorption in this frequency range is low. | − Low frequencies require large antennas. − The RF noise floor and clock frequencies in electronic equipment may create interference to audio PMSE applications. |
| UHF band below 1 GHz | − Good propagation, some wall absorption, depending on the surrounding structures reflection or diffraction can occur.  − Wall absorption and shielding effects of metal structures can be beneficial in reusing available frequencies in larger system setups. | − Shielding from metal structures occurs.  − Significant body absorption.  − Small antennas possible.  − System performance can be optimized by the use of directional antennas. |
| UHF 1 to 1.7 GHz | − Wall absorption and shielding effects of metal structures can be beneficial in reusing available frequencies in larger system setups.  − Small antennas possible.  − System performance can be optimized by the use of directional antennas. | − Acceptable propagation, wall absorption, depending on the surrounding structures reflection or diffraction occurs.  − Shielding from metal structures occurs.  − Significant increased body absorption. |
| UHF 1.7 to 2.5 GHz | − Wall absorption and shielding effects of metal structures can be beneficial in reusing available frequencies in larger system setups.  − Small antennas possible.  − System performance can be optimized by the use of directional antennas. | − Acceptable propagation, wall absorption, depending on the surrounding structures reflection or diffraction occurs.  − Shielding from metal structures occurs.  − Critical body absorption. |

## 7.3 Frequencies used by Audio PMSE

*[Editor’s note: Text to be added, target is to deliver a more high-level description.]*

### 7.3.1 Introduction

Terrestrial audio links are used for a number of PMSE applications. The range of applications covered by PMSE spans from theatrical productions and corporate events to various levels of media production activities.

[When considering the spectrum identified for use by PMSE on a tuning range basis, it can appear that there is a large amount of spectrum available.] However, PMSE has always shared spectrum with a wide range of services and to manage use, individual licenses can be issued for a specific use on a specific date and at a specific location. The sharing conditions in a given country depend on the license regime under which the new service operates. The available spectrum within the tuning ranges in any particular country is determined on a national basis; each tuning range may be wholly, partially or not available on a given day, in a given location, in a given country. Additional information can be found in [13]. [Add reference]

*[Editor’s note: Specific/national can be provided in separate annexes for each Member.]*

### 7.3.2 Efficient use of spectrum for audio PMSE

Audio PMSE as a local area low power application specially designed to operate on a free tuning basis is able to integrate well in a channel raster predominant due to incumbent use. Spectrum sharing is for example globally practiced since decades with Terrestrial Television in a common audio PMSE tuning range for ad-hoc, nomadic and fixed deployments of audio PMSE uses.

Spectrum sharing is especially technically viable for Audio PMSE if the incumbent use at a given geographic location is not coincident with the audio PMSE use (in time and frequency range) and thus leaves sufficient suitable spectrum resources unused at the geographic location. Interference and receiver blocking due to adjacent incumbent use or other uses might limit the suitability of spectrum for audio PMSE use.

In the perspective of audio PMSE users the spectrum use by the existing users must be in general:

– observable, e.g., by spectrum scanning procedures or other information means,

– projectable, which means that it must be stable in its of operational times and frequency occupancy for a reasonable duration at the geographic location of audio PMSE use.

### 7.3.3 Spectrum Planning for Audio PMSE use

Audio PMSE equipment typically operates on a free tuning concept to accommodate specific spectrum deployment conditions and to account for existing spectrum occupancy within their service area. Further, standards like EN 300 422 and other Audio PMSE related ETSI standards define transmit spectrum masks, which are tailored to foster multi-link, multi-vendor uses of the available frequency bands.

The time parallel operation of audio PMSE applications e.g. wireless microphones, IEM and/or WMAS in the same service area require suitable frequency separations.

Many different licensing schemes are implemented on national level. Those schemes can vary from license free usage to a restricted use limited to a set of specific frequencies limited on time and location.

Examples of implementation in Region 1 (in various countries):

– 470-694 MHz (audio-PMSE is a allocated to the land mobile service on a secondary basis in the countries listed in RR No. **5.269**)

– Option 1\*: no license required

– Option 2\*: user must register

– Option 3\*: user must apply for a use license, which allows him to use a specific number of devices

– Option 4: license required, frequency authority defines a list of individual frequencies

– Option 5: license required, specific frequencies for a given time and location

\* In case of Options 1 to 3, the frequency planning is performed on site. The planning is managed by the user with the help of available planning tools from the manufacturers of the equipment or in case of large events with national interest with governance by the frequency administration.

Frequency planning and coordination in the service area are assisted by spectrum scanning procedures and software tools including the support for mixed vendor deployments. This also supports the possible ad-hoc and nomadic deployments of audio PMSE in service areas where audio PMSE is already in use.

## 7.4 Spectrum for Audio PMSE

### 7.4.1 Region 1

#### 7.4.1.1 Spectrum for Audio PMSE in CEPT Countries

For the CEPT countries in Region 1, ERC REC 25-10 recommends the frequencies listed in Table 3 for audio-PMSE use. ERC REC 70-03 provides technical conditions for audio PMSE frequencies.

NOTE: “The bands identified for PMSE use are predominantly shared with other services. The use of the band by these other services can reduce the amount of spectrum available for PMSE at a given location. The extent of the reduction is dependent on local conditions and can be significant.” [13] [Add reference]

[Editorial note: Consider deletion of Table 3 by adding a hyperlink to ERC Rec 25-10 or insert the revised ERC Rec. 25-10.]

[Editorial note: Table 3 needs to be reviewed in detail, including the table title.]

Table 3

Frequency ranges for use by audio PMSE applications

| Type of link | Frequency range | Technical information | Background information |
| --- | --- | --- | --- |
| Radio microphones and In-ear monitors | 29.7-47.0 MHz | See ERC/REC 70-03 [5] Annex 10 | Non-professional PMSE use. Legacy systems still in use. No broadcast quality equipment available. Shared use. ETSI EN 300 422 [8] |
| Radio microphones and In-ear monitors | 174-216 MHz (Radio microphones) | See ERC/REC 70-03 Annex 10 | Shared use. EN 300 422 |
| Radio microphones and In-ear monitors | 470-694 MHz (Radio microphones) | See ERC/REC 70-03 Annex 10 | Currently a core band for professional PMSE use. Changes to the band will limit its utility for PMSE. The extent of the impact is dependent on national decisions (see ECC/DEC (15)01 [7]). Shared use. EN 300 422 |
| Radio microphones and In-ear monitors | 823-832 MHz | See ERC/REC 70-03 Annex 10 and EC Decision 2014/641/EU [9] | Risk of out of band emissions from adjacent mobile services means there is limited utility for broadcast quality audio Harmonised (within EU member states). EN 300 422 |
| Radio microphones and In-ear monitors | 863-865 MHz | See ERC/REC 70-03 Annex 10 and EC Decision 2013/752/EU [10]. | Risk of out of band emissions from adjacent mobile services and other short range devices means there is very limited utility for broadcast quality audio. Shared use (1). EN 300 422 and EN 301 357 [11] |
| Radio microphones and In-ear monitors | 1 350-1 400 MHz | See ECC Report 245 [20] and ERC/REC 70-03 Annex 10 | Newly recommended tuning range in 2016. Shared use EN 300 422 |
| Radio microphones and In-ear monitors | 1 518-1 525 MHz | ECC Report 253 [19] and ERC/REC 70-03 Annex 10 | Newly recommended tuning range in 2016. [Individual license required and restricted to indoor use.] Shared use EN 300 422 |
| Radio microphones and In-ear monitors | 1 785-1 805 MHz | See ERC/REC 70-03 Annex 10 and EC Decision 2014/641/EU [9] | Harmonised (within EU member states). EN 300 422 |
| Portable audio links, Mobile audio links and Temporary point-to-point audio links (2), Talkback and Production communications (3) | 174-216 MHz (Audio links) | ERC Report 42 [4] | Shared use. EN 300 454 [13] |
| Portable audio links, Mobile audio links and Temporary point-to-point audio links (2), Talkback and production communications (3) | 470-694 MHz (Audio links) | ERC Report 42 | Shared use. EN 300 422 and EN 300 454 |
| Portable audio links, Mobile audio links and Temporary point-to-point audio links (2), Talkback and production communications (3) | 694-790 MHz (Audio links) | ERC Report 42; ERC Report 89 [12] | Changes to the band will limit its utility for PMSE. The extent of the impact is dependent on national decisions. Shared use. EN 300 422 and EN 300 454 |
| 1 The band 863-865 MHz is available for radio microphones; however due note should be taken that it is used also for non-professional and consumer radio applications (cordless audio, etc.).  2 Depending on application scenario, channel width and required transmitter power, the portable, mobile and temporary point-to-point audio links may be accommodated either in the frequency bands 174-216 MHz/470-694/694-790 MHz identified for professional radio microphones (typically for low power/wideband applications) or in other VHF/UHF bands, including Private Mobile Radio (PMR) bands (typically for high power/narrowband applications).  3 These applications are service links that operate in the audio PMSE bands. | | | |

For the frequency band 470 MHz to 694 MHz one should note that in the countries listed in RR No **5.296**, this band is also allocated on a secondary basis to the land mobile service, intended for applications ancillary to broadcasting and programme making. Stations of the land mobile service listed in the footnote shall not cause harmful interference to existing or planned stations operating in accordance with the Table in countries other than those listed in the footnote.

[Editor’s note: Entries of additional frequency bands required? 2.4 GHz, 1.9 GHz, 5 GHz …, bi‑directional data transmission for control and monitoring.]

### 7.4.2 Region 2

*[Editor’s note: Text to be added.]*

### 7.4.3 Region 3

[Editor’s note: Text to be added.]

## 7.5 Use Scenarios for Audio PMSE

[Editor’s note: This text needs to be reviewed and probably moved to Section 6.3 “Typical Deployment Scenarios”.]

[CEPT has developed a report to provide guidance to the administrations on handling the PMSE requirements of large events [ECC Rep 44].

The spectrum demand for PMSE is dependent on the usage scenario.

The density and deployment of audio PMSE equipment is high in urban areas and areas where production facilities are located (studios and media villages). In these hot spot areas, fixed deployments have a high probability of use. The actual use is dependent on the work/ rehearsal / performance schedule. During such phases, the probability of use is 100%. In phases of no activity the probability of use is low. To a certain extend the use and activity of audio PMSE use can be planned and coordinated. In the cases where the duration of use and the required spectrum is well known.

Regular Large Events

In many cases where an event is known in advance, planning and coordination of spectrum use can take place. Depending on the requirement of the event, some administrations currently “borrow” spectrum from other spectrum users. Examples for such events are Formula 1, G8, as well as especially extraordinary events such as the Olympics. Such “borrowing” will become more difficult considering different sharing situations in the future due to the characteristics, and developments of new services that are currently occupying the “borrowed” spectrum within the tuning ranges of audio PMSE equipment available on the market. Notably, the availability of audio PMSE equipment to the market for the various tuning ranges depends on the global or at least regional availability of such tuning ranges and the market size they are representing.

Hot Spot Scenarios

have a high demand for spectrum. The spectrum demand will vary depending on the time of day and other factors. Studios and media villages show an almost permanent use of audio PMSE applications such as wireless microphones, in-ear monitors, and intercoms as content production and contribution happens daily, almost 24 h / 7 days per week. For example theaters use a high number of audio PMSE applications such as wireless microphones, in-ear monitors, and wireless audio links during rehearsals and shows.

Other scenarios have a lower demand for spectrum.

The demand may vary depending on the application, time of day and other factors. There are situations where only 1-2 wireless microphones are used in combination with a small loudspeaker system for presentation or speech purposes.

Peak vs. Aggregate Demand

While assessing the spectrum requirements for PMSE, the normal regular demand for spectrum should be distinguished from the “peak demand.” ”Peak demand” may be temporary or geographically limited (see CEPT Report 32 [19]).

– The geographical peaks are triggered by the long-term use within fixed sites in certain geographical areas (e.g. large urban conglomerations) where there is always a continuous heavy demand (typically multi-equipment, multi-channel users), thus most of the available UHF spectrum will be needed to satisfy this demand. Every country has geographical peaks these in a number of locations.

– The temporary peaks are triggered by special events of a short-term nature (large concerts, festivals etc.). When temporary events are staged at existing geographical peak locations, they result in a complex spectrum demand requiring detailed intervention by a band manager or the administration, as this results in a “double overload.” Spectrum planning using all available technics including building attenuation between outdoor and indoor us along with geographical shielding and borrowing spectrum must then be employed.

It should be noted that the scenarios of peak demand are most often triggered by professional users. Additional details are given in CEPT Report 32 Annexes 3 and 4.

Spectrum demand is heaviest for large-scale, professional productions, and for touring musicals and rock concerts, and it is these areas on which the following discussion concentrates. Typically, this usage scenarios will be most prominent in the locations with highest density of professional theatres, e.g. the West End in London.]

# 8 Technical and operational characteristics of current systems

## 8.1 Overview

{Editor’s note: This Section is a placeholder for a possibly needed overview at a later stage}

## 8.2 Description of systems employing audio PMSE-specific technology

### 8.2.1 Overview

The ETSI standard EN 300 422-1/2/3 [1][2][3] (see Section 7.1) describes the following three radio interfaces:

a) Narrow-Band Analogue – following a link-based approach;

b) Narrow-Band Digital – following a link-based approach; and

c) Wireless Multi Audio-channel System (WMAS) – following a system-based approach to serve N portables.

Scaling the number of links to support multi-audio channel applications in the link-based approach forms complex systems with microphone receivers and IEM transmitters being mounted to separate racks to avoid blocking. Each link requires its own centre frequency and RF channel.

Figure 2 shows the general setting for the link-based approach. The radio interface can employ analogue or digital modulation techniques for the audio plane, while the control plane is realized with an additional SRD link or IrDA interface.

Figure 2

Radio interface for link-based approach

Diagram

Description automatically generated

Figure 3 outlines the radio interface of a WMAS that offers multiple audio and control planes integrated in a single wideband radio interface. The direction of each dedicated audio plane is defined by the portable type connected. WMAS can support up to N devices.

Figure 3

Radio interface WMAS for #N portables

Ein Bild, das Text enthält.

Automatisch generierte Beschreibung

All audio PMSE equipment operate typically on a free tuning concept to accommodate specific radio spectrum deployment conditions and to account for existing radio spectrum occupancy within their service area.

The time parallel operation of PMSE applications e.g. wireless microphones, IEM and/or WMAS in the same service area require suitable frequency separations.

Frequency planning and coordination in the service area are assisted by spectrum scanning procedures and software tools including the support for mixed vendor deployments. This approach also supports the possible ad-hoc and nomadic deployments of Audio PMSE in service areas where Audio PMSE is already in use.

### 8.2.2 Narrow-Band Analogue

This is defined as an audio PMSE radio interface employing analogue modulation techniques (as summarized in Table 4) with a link-based approach (dedicated transmitter-receiver pair for a single audio link transmission on a dedicated centre frequency). The audio content plane is uni‑directional carrying a Mono or MPX-Stereo signal. Additional audio links are established via deployment of additional, unique RF channels.

Table 4

Parameters Audio PMSE Narrow-band Analogue

|  |  |  |
| --- | --- | --- |
| Parameter | Description | Notes |
| Application | PMSE – link-based approach |  |
| Channel bandwidth / Channel Spacing | typical 200 kHz /  free tuning, placement on non-equidistant grid to account for transmitter intermodulation products. | 1 |
| Modulation / Occupied Bandwidth | Analogue: Frequency Modulation |  |
| Direction | Audio plane: uni-directional  Control data plane: employing separate SRD radio interface |  |
| Transmit Power / PSD | Typical:  max. 50 mW e.r.p. below 1 GHz  max. 50 mW e.i.r.p. above 1 GHz | 2 |
| Transmit Spectrum Mask | EN 300 422/ EN 301 357 / EN 300 454 | 3 |
| Channel Access and occupation | Constant duty cycle, up to 100% occupancy in time. |  |
| Frequency planning assumptions |  | 4  5 |
| Relevant Standard | EN 300 422/ EN 301 357 / EN 300 454 |  |
| Notes:  1 EN 300 422 enable certain other channel bandwidths within the range 50 kHz to 600 kHz  2 Configuration of portables via IrDA and/or a control plane is established via additional other radio interface in different frequency band.  3 The maximum transmit power is defined in national radio regulations and interface descriptions. Higher maximum transmit power may be allowed by licensing terms / special permits.  4 Audio PMSE, being a low latency critical application, does not allow co-channel operation by other radio interface technologies.  5 Frequency Planning assisted by spectrum scanning procedures and software includes support for mixed vendor deployments. Time parallel operation of radio microphones, IEM and/or WMAS in same coverage area require suitable frequency separation. | | |

### 8.2.3 Narrow-Band Digital

This is an audio PMSE radio interface employing digital modulation techniques (as summarized in Table 5) with a link-based approach (dedicated transmitter-receiver pair for a single audio link transmission on a dedicated centre frequency). Audio is Mono or Stereo. Additional audio links are established via deployment of additional, unique RF channels.

Table 5

Parameters Audio PMSE Narrow-band Digital

|  |  |  |
| --- | --- | --- |
| Parameter | Description | Notes |
| Application | PMSE – link-based approach |  |
| Channel bandwidth / Channel Spacing | typical 200 kHz /  free tuning, allowing equidistant grid, placement with typical 200 kHz to 600 kHz channel separation. | 1 |
| Modulation / Occupied Bandwidth | Digital Modulation |  |
| Direction | Audio plane: uni-directional  Control data plane:  employing separate SRD radio interface | 2 |
| Transmit Power / PSD | Typical:  max. 50 mW e.r.p. below 1 GHz  max. 50 mW e.i.r.p. above 1 GHz | 3 |
| Transmit Spectrum Mask | EN 300 422/ EN 301 357 / EN 300 454 |  |
| Channel Access and occupation | Constant duty cycle, up to 100% occupancy in time. |  |
| Frequency planning assumptions |  | 4 5 |
| Relevant Standard | EN 300 422/ EN 301 357 / EN 300 454 |  |
| Notes:  1 EN 300 422 enable certain other channel bandwidths within the range 50 kHz to 600 kHz  2 Configuration of portables via IrDA and/or a control plane is established via additional other radio interface in different frequency band.  3 The maximum transmit power is defined in national radio regulations and interface descriptions. Higher maximum transmit power may be allowed by licensing terms / special permits.  4 Audio PMSE, being a low latency critical application, does not allow co-channel operation by other radio interface technologies.  5 Frequency Planning assisted by spectrum scanning procedures and software includes support for mixed vendor deployments. Time parallel operation of radio microphones, IEM and/or WMAS in same coverage area require suitable frequency separation. | | |

### 8.2.4 Wireless Multi-channel Audio System (WMAS)

WMAS is an audio PMSE radio interface establishing a system-based approach (as summarized in Table 6) for multi-channel audio applications serving e.g. microphone, IEM and talkback in a single RF channel. Additional scaling of capacity (e.g. more audio channels as supported by a single WMAS base) via deployment in additional RF channels is possible. WMAS allows a flexible configuration of each audio channel regarding direction (IEM or Mic), mapping of audio channels to a device, latency, audio quality and link reliability.

Table 6

Parameters Audio PMSE WMAS

|  |  |  |
| --- | --- | --- |
| Parameter | Description | Notes |
| Application | PMSE – system-based approach |  |
| Channel bandwidth / Channel Spacing | Typical {6,7,8} MHz (international DTT channel grid) or 10 MHz /  Free tuning but accommodating predominant channel raster of incumbent. | 1 |
| Modulation / Occupied Bandwidth | Digital Modulation |  |
| Direction | Multiple audio planes, bi-directional  Multiple control data planes, bi-directional | 2 |
| Transmit Power / Power Spectral Density (PSD) | Typical:  max. 50 mW e.r.p. below 1 GHz  max. 50 mW e.i.r.p. above 1 GHz | 3  4 |
| Transmit Spectrum Mask | EN 300 422 |  |
| Channel Access and occupation | Typical TDD TDMA  Constant duty cycle, up to 100% occupancy in time. | 5 |
| Frequency planning assumptions | ETSI TR 103 450 | 6  7 |
| Relevant Standard | EN 300 422 |  |
| Notes:  1 EN 300 422 enables a channel bandwidth of up to 20 MHz for WMAS. However, based on practical considerations, WMAS is likely to be utilized in the channel grid employed by an incumbent service (e.g. broadcasting or other). EN 300 422 requires WMAS to support at least one mode supporting in minimum three audio channels / MHz.  2 Bi-directional control data plane is available, enabling permanent control and reconfiguration of all portables. This enables resource re-assignments at run-time to other portables.  3 The maximum transmit power is defined in national radio regulations and interface descriptions. Higher maximum transmit power may be allowed by licensing terms / special permits. Larger occupied bandwidth results in lower PSD because maximum transmit power is per device. Example: PSD of an 8 MHz-wide WMAS is 16 dB lower than the one of a single 200 kHz link.  4 In systems employing TDMA, the total transmit power in a given RF channel is not scaled with the number of WMAS devices deployed because each device only transmits in a short time slot and is limited to the maximum transmit power.  5 ETSI TR 103 450 also envisions other duplex and multiple access schemes.  6 Audio PMSE, being a low latency critical application, does not allow co-channel operation by other radio interface technologies.  7 Frequency planning assisted by spectrum scanning procedures and software includes support for mixed vendor deployments. Time parallel operation of radio microphones, IEM and/or WMAS in the same coverage area require suitable frequency separation. | | |

### 8.2.5 DECT

Some limited PMSE applications are deployed in the bands which are assigned for DECT use, e.g., 1 880-1 900 MHz in Europe. It has been used primarily used for talkback systems and lower quality wireless microphone systems. By delivering audio link latencies (e.g. audio pick-up to audio-plug) of below 4 ms and immediate availability by current chipsets, DECT evolution enables music entry market applications (e.g. audio for video, music hobbyist, garage bands). Further it provides significant improvements for conferencing, intercoms, and radio microphones for presentations and lectures.

The DECT NR+ technology offers potential higher quality audio for the future.

[Editor’s note: Placeholder for other technologies, if necessary.]

# 9 Trends for Audio PMSE

[Editor’s note: Discuss and verify the purpose and scope of this Section.]

[Audio performance demands, ease of use and production workflow requirements including the topics of spectrum availability and licensing will be the most likely innovation drivers for PMSE.

Audio PMSE-specific technologies will also lead to innovations by enabling new features to support audio production workflows, by the integration of connectivity and 3rd party services, and by improving digital audio performance in terms of quality (going towards studio audio quality in wireless) and latency (coming closer to the latency of analog transmission, which is almost 0 ms).

Topics like wireless 3D audio capture, 3D immersive audio playback and object-oriented audio production provide additional future scenarios for the innovative fields of professional audio.

Higher resolution audio capture including 3D immersive recordings and flexibility in use will promote the development of new equipment, but it will also lead to growing demands for spectrum resources. Especially capturing of 3D audio from a microphone array needs to account for more audio channels (3 to 36+ microphone capsules per array) and to be on higher audio resolution (e.g. 24 bit) and sampling rate (e.g. 96 kHz).

Narrowband technology by making use of the new channel bandwidths up to 600 kHz will continue innovating in the digital transmission domain. This will affect audio performance and further more flexible use in workflows by integrating a control data plane within its radio interface, like it is known by C-PMSE and WMAS.

WMAS is the newest audio PMSE radio interface and system concept. The system-based approach for multi-channel audio applications will ease the deployment and operation of audio PMSE in large events due to the integration of the microphones, IEMs and talkbacks. WMAS allows fully synchronized operation and flexible configuration of each audio channel regarding direction (IEM or Mic), mapping of audio channels to a device, latency, audio quality and link reliability.

Automation of spectrum licensing and access procedures will likely become an important topic of the future as users of audio PMSE request a hassle-free deployment and coordination at any location of the world and at any time. A possible future solution is database-driven or certificate‑based spectrum sharing approaches, e.g. eLSA (under development by ETSI TC RRS).

As studied by the LIPS project [10] – in the future, open interfaces and open access for seamless interworking of various radio access technologies in ad-hoc, nomadic or fixed local area deployments with Wide Area Networks (PLMN, fiber, satellite) seem to be of major importance to generate value-adds for future production workflows. Future audio production workflows will incorporate remote production, remote rehearsals, and professional networked music performances but will also require incorporating new audience services like remote participation and on-site assistive listening.]

[Editor’s note: Include reference to work done/being done in WP 5D on ‘specific applications’.]

# 10 Summary

{Editor’s note: Text to be added}

# 11 References

[Editor’s note: check the references.]

[1] ETSI EN 300 422-1: “Audio PMSE up to 3 GHz; Part 1: Class A Receivers; Audio PMSE up to 3 GHz; Part 1: Class A Receivers; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”, <https://www.etsi.org/deliver/etsi_en/300400_300499/30042201/02.01.02_60/en_30042201v020102p.pdf>

[2] ETSI EN 300 422-2: “Audio PMSE up to 3 GHz; Part 1: Class A Receivers; Audio PMSE up to 3 GHz; Part 1: Class B Receivers; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”, <https://www.etsi.org/deliver/etsi_en/300400_300499/30042202/02.01.01_60/en_30042202v020101p.pdf>

[3] ETSI EN 300 422-3: “Audio PMSE up to 3 GHz; Part 1: Class A Receivers; Audio PMSE up to 3 GHz; Part 1: Class C Receivers; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”, <https://www.etsi.org/deliver/etsi_en/300400_300499/30042203/02.01.01_60/en_30042203v020101p.pdf>

[4] ETSI EN 301 357: “Cordless audio devices in the range 25 MHz to 2 000 MHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”, <https://www.etsi.org/deliver/etsi_en/301300_301399/301357/02.01.01_60/en_301357v020101p.pdf>

[5] ERC Rec 70-03, Annex 10 – “ANNEX 10: RADIO MICROPHONE APPLICATIONS INCLUDING ASSISTIVE LISTENING DEVICES (ALD), WIRELESS AUDIO AND MULTIMEDIA STREAMING SYSTEMS”,  
<https://www.ecodocdb.dk/download/25c41779-cd6e/Rec7003e.pdf>  
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[7] 3GPP TR 22.827: “Study on Audio-Visual Service Production”, <https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3520>

[8] 3GPP TS 22.263: “Service requirements for Video, Imaging and Audio for Professional Applications (VIAPA)” , <https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3648>

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[10] Research Project LIPS, Online: <http://lips-project.de/>

[11] ETSI TR 102 546

[12] ETSI EN 300 454

[13] ERC-REC 25-10

[14] ERC Report 25

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[16] ETSI TR 103 514: "Digital Enhanced Cordless Telecommunications (DECT); DECT‑2020 New Radio (NR) interface; Study on Physical (PHY) layer".

[17] ECC Report 204

Annex 1  
  
Examples for PMSE Use

[Editor’s note: This material needs to be reviewed, as some appears to be repetitions of material included in the main body.]

This section is not intended to give a full overview on all deployment scenarios of audio PMSE use in the field but gives an overview on typical and regularly occurring uses.

The field of audio PMSE can be separated into the following major use case areas:

A) Live Event – Music, Theater – Sport, Olympics

B) Presentation, Conferencing

C) News Gathering: Local News, International News

D) Studio - Studio Production

E) Studio - Project Studio Production

**Calculation of typical required spectrum in MHz**

Audio PMSE manufacturers are offering frequency compatibility calculation tools / frequency management tools. Those tools calculate available frequencies for e.g. wireless microphones and IEM considering:

– Available interference free spectrum

• Avoiding DTT allocations

• Considering other audio PMSE devices already in use

– Technical specifications

• Tuning range of the equipment

• Intermodulation Products

• Filter options of antenna systems, receivers and transmitters

The required spectrum [MHz] listed in the below sections provides a typical number in MHz.

## A) Live Event

The band 470-694 MHz is the primary used band for audio-PMSE in live events. Talkbacks are using the DECT technology (e.g. 1880-1900 MHz in region 1) as well.

For so called Mega-events spectrum sharing with government agencies has occurred, but these spectrum resources may no longer be available for sharing as the available spectrum has been allocated to other services.

### A.1) Music Event

Doing business in the music industry has significantly changed over the years. In the past, media (albums, DVD) was the predominant income source of the artists beside touring. As of today, music events and touring are the predominant source of income for artists. Notably, audio streaming platforms have only delivered low payouts per play and so far, all existing audio streaming platforms are not earning money with their service (see <https://www.digitalmusicnews.com/2018/12/25/streaming-music-services-pay-2019/>).

A picture containing outdoor, dark, light, night

Description automatically generated

[Picture: pixabay-License]

Latency requirement:

– Latency from audio input (microphone used by artist) to audio output (IEM with fold back mix used by same artist) needs to be below 4 ms.

Typical Events, Venue or Locations: Eurovision Song Contest, Live concerts… event locations up to large halls, sport stadiums, indoor and outdoor

Typical audio channel count:

– Small event, e.g. local distribution: Wireless Microphones 16 or more; In-Ear Monitors 4-8+   
(typical required spectrum ~ 20 MHz)

– Medium event, e.g. regional distribution: Wireless Microphones 24 or more; In Ear Monitors 8-16+   
(typical required spectrum ~ 45 MHz)

– Large event, e.g. national festivals: Wireless Microphones 64 or more; In-Ear Monitors 16-24+  
(typical required spectrum ~ 90 MHz)

– Mega event with international distribution: Wireless Microphones 192 or more (sometimes over 1 000); In-Ear Monitors 44+   
(typical required spectrum >150 MHz)

The above channel counts are for the productions themselves. Large national or international events will also call for broadcast crews requiring roaming wireless microphone use for interviews, camera video-links, live-broadcasting of the event.

Other PMSE use:

– Light and effect control

– Multiple fixed, mobile, line or flying video cameras to capture stage, backstage, audience

– Large Intercom setup for event direction and security

### A.2) Theater, Musicals

Typical Event, Venue or Location: Dedicated buildings with fixed installations but also touring at indoor and outdoor event locations.

Typical audio channel count:

– Small event, e.g. school: 16 or more   
(typical required spectrum ~ 8 MHz)

– Medium event, e.g. regional theater: 24 or more  
(typical required spectrum ~ 20 MHz)

– Large event, e.g. national tours, New York Broadway, London WestEnd: 62 or more, sometimes over 100  
(typical required spectrum > 60 MHz)

### A.3) Sports Event

Sporting events require individual audio content by multiple reporters from various countries.

Moreover, it is becoming increasingly common for officials at sporting events to also use wireless microphones and in-ear monitor solutions to talk to remote services. E.g. Video-assisted referees (Premier League & Bundesliga), Television Match Officials (Rugby Union). For redundancy purposes, each official typically uses two wireless transmitters and one in-ear monitor system.

Match officials: 8+ wireless microphones, 4+ in-ear monitors

Broadcasters and leagues are also working to make sports television more interactive, and this new approach includes attaching microphones to the players themselves. The U.S. National Basketball Association (NBA), for instance, currently uses wireless microphones on each player to capture on‑court audio.

The PGA European Tour is investigating adding wireless microphones to professional golfers to capture on-course dialogue for broadcast. See - <https://www.bbc.co.uk/sport/golf/52841949>

Cases, where the PMSE service area is moving along with the athletes (e.g. Tour de France: bicycle race; U.S. Super Bowl; Olympics).

Olympics and other sport events of national or global interest

Mega Events (see Table 1) might require every single available piece of spectrum. In some cases, it is necessary to lease spectrum from other allocations, applying PMSE technology typically used in other countries or regions, which would not be allowed to be deployed at the event location under normal circumstances.

Typical audio channel count: 190 and more (sometimes over 1000).

## B) Presentation, Conferencing

This scenario covers person(s) giving a presentation, speech, lecture, sermon, moderation employing handheld or body-worn wireless microphones. Free movement of equipped person(s) during use.

Additional handheld wireless microphones might be in use to pick-up questions from the auditorium and for podium discussions involving multiple persons.

Additional IEM-like devices might be in use for hearing assist, especially in schools and universities.

Audio is immediately distributed via the public address (PA) system, but also available for recording or live streaming to the Internet.

Person(s) might be equipped with earphones (IEM) to receive instructions from event direction or security.

Latency requirement:

– Latency of play back via PA needs to be low enough, so that the presenter(s) and audience are not distracted.

Typical Venue or Locations:

– Dimension: board room, Larger Rooms, Hall, Lecture Theatre

– Deployments include schools, universities, conference centers, hotels, trade fairs, shopping centers, restaurants, churches, multi-purpose halls, press conference, political event areas and public places including streets and parks.

Typical wireless audio channel count:

– Small event, e.g. local outreach: 4 or more  
(typical spectrum requirement ~ 8 MHz)

– Medium event, e.g. regional outreach: 12 or more  
(typical spectrum requirement ~ 20 MHz)

– Large event, e.g. national: 24 or more  
(typical spectrum requirement ~ 45 MHz)

– Mega event with international outreach: 48 and more, plus multiple interpretation channels  
(typical spectrum requirement > 60 MHz, 100 MHz +)

Other PMSE use:

– Light control

– Multiple video cameras

– Intercom for event direction and security

– Wireless voting

– Interpretation, multi-language transmission.

## C) Electronic News Gathering

Focus is on news.

Wireless audio link between video camera and wireless microphone handheld or body worn.

Video camera might provide remote link.

Audio and video (remote or OB van) are typically linked to the production facilities.



[Figure: Pixabay-License]

Typical wireless audio channel count:

– 1-2 ENG teams: 1-4 or more  
(typical spectrum requirement 2-5 MHz)

– 10 ENG teams: 12 or more  
(typical spectrum requirement ~ 20 MHz)

– 50 teams: 25 or more  
(typical spectrum requirement ~ 50 MHz)

– Mega news event: 48 and more, plus multiple interpretation channels  
(typical spectrum requirement ~ 90 MHz +)

### D.1) Local News

Each market area generally has several independent news crews that provide information to local residents.

### D.2) National / International News

ENG team follow the news event so that cross border use is routine.

Huddle of multiple ENG teams in one news event location, if event is of major importance. Wireless audio channel count can reach well over 100 (national) and more than 300 if international.

### D.3) Video blogger

– streaming or new media portals, e.g. youtube

– Video bloggers have discovered that wireless audio provides significant improvements in audio quality and flexibility in deployment, while producing content in daily routine.

Beside sharing specific community news. Video bloggers deliver content like product testimonials, advertising and entertainment: 2-5 audio PMSE channels

## E) Studio

### E.1) Studio Production

Production facilities in media villages or at broadcaster sites including mobile studios.

Studio production might be nomadic to event venues.

### E.2) Project Studio Production

There has been a business shift from studio-based audio production to project studio audio productions by musicians and sound engineers, so that more geographic locations and more stakeholders are involved. Such studios are demand very high audio standards as well.

E.3) Movie Production Sound Recording

Significantly more entities in addition to traditional broadcasters and movie studios are now producing content, e.g. video streaming platform providers, independent film makers and project studios.

Action scenes require high mobility and reliability in audio transmission as the number of film shoots are limited due to cost and safety reasons.

Sound recordists typically carry 4+ channels of wireless microphones for capturing dialogue on a set. They also have additional wireless transmitters for camera-links and fold-back to the directors and producers on set. A large movie set may have 30+ channels of wireless.

Typical wireless audio channel count:

– Project studio: 10  
(typical spectrum requirement ~ 20 MHz)

– Small studio production: 12 and more  
(typical spectrum requirement ~ 20 MHz)

– Medium studio production: 25 or more  
(typical spectrum requirement ~ 45 MHz)

– Large studio production: 48 and more   
(typical spectrum requirement ~ 90 MHz)

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