

Report on spectrum requirements for Audio PMSE



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Table of Content

1. Summary	3
2. Definition of terms	3
3. Methodology	4
3.1. Analysed frequency range	4
3.2. Analysed dataset	4
3.3. Data aggregation	4
3.4. Evaluation of spectrum requirement	5
4. Results in details	6
4.1. Daily spectrum requirements for PMSE in Switzerland	6
4.1.1. Small Events	6
4.1.2. Medium Events	8
4.1.3. Large Events	10
4.1.4. Campus/Venue – permanent use	12
4.2. Exceptional spectrum requirement for PMSE in Switzerland	13
4.3. Spectrum requirements for PMSE at international events	14
4.4. Coordinated links vs. measured links	16
5. Analysis & conclusions	17
5.1. Number of links vs. number of locations	17
5.2. Coordinated vs. measured links	17
5.3. Data analysis & conclusions	18

1. Summary

According to the results of this report the daily required spectrum for PMSE Audio in the UHF-TV band today is **110 MHz**. With this amount of spectrum, the requirement of the most of Campus/Venues and Events can be fulfilled. Nevertheless, for major events the average of the required spectrum is **174 MHz**, while the peak demand could be the whole available UHF spectrum of **224 MHz**.

2. Definition of terms

The following terms are used in chapter 4:

Term	Explanation
Small Event	Events with 1-49 coordinated links in the frequency band 470 - 865 MHz
Medium Event	Events with 50-99 coordinated links in the frequency band 470 - 865 MHz
Large Event	Events with 100-199 coordinated links in the frequency band 470 - 865 MHz
Major Event	Events with 200 and more coordinated links in the frequency band 470 - 865 MHz
Intermodulation (IM)	Undesired products caused by two or more carrier-frequencies (links), because of non-linear components in their rf signal chain. Intermodulation needs to be considered and occurs mostly when two or more transmitters have a spatial distance less than 1 meter. Carrier frequencies of PMSE links cannot be planned on an IM product, if it's not guaranteed, that the specific transmitters will not be operated closer than 1m at any time (incl. rehearsals & setup).
Number of locations	Number of so-called "locations" or "zones" on an event, which are considered when a frequency set up is calculated. Locations needs to have a spatial separation to other locations, therefore intermodulation between locations don't need to be considered.
Number of links	Total number of coordinated links
Proportion of IM-free links	Percentage of intermodulation-free links in relation to all coordinated links. These links create very low-level intermodulation among them, so that in the frequency calculation intermods can be ignored. An equidistant frequency grid is possible among IM-free links and this leads to less spectrum demand for this part of the links.
Required spectrum for PMSE	Value of required spectrum for PMSE-Audio between 470 – 865 MHz. It does not include any occupied spectrum (e.g. the occupied spectrum for DVB-T transmitters).
Net available spectrum for PMSE	Discounting the DVB-T occupation from the gross available spectrum results in the net available spectrum for PMSE-Audio.
DVB-T occupation	Sum of occupied spectrum by DVB-T. In Europe one DVB-T Channel occupies 8 MHz. Included in this sum is also a 600kHz guard band on each side of the DVB-T Channel.
Gross available spectrum	Available spectrum for PMSE-Audio as a secondary user of DVB-T between 470 – 865 MHz. Spectrum assigned to IMT-Providers and unusable guard bands are already discounted from this value.

3. Methodology

3.1. Analysed frequency range

Today, in most countries the range from 470 – 694 MHz is useable for PMSE-Audio on a secondary basis. Before the digital dividend II, the useable range was from 470 – 790 MHz and before digital dividend I it was from 470 – 865 MHz. In this analysis event data from various years will be analysed. To make the data throughout the years comparable, the analysed band is 470 – 865 MHz, always discounting the spectrum which is not useable for PMSE-Audio.

3.2. Analysed dataset

In this report data from 326 events between 2014 – 2021 have been analysed. The biggest part of the data is provided by SRG-events coordinated with SRF's WebApp FreqCoord¹. Some further parties have contributed data of events and campus/venue which is included in this report.

3.3. Data aggregation

There are different ways how the demand of the spectrum of the individual events can be concluded in one value. The author decided to work with the 80th percentile, which means that the spectrum demand of 80% of the summarized events can be covered with the concluded value. On the other hand, 20% of the events would not have sufficient spectrum to be realized in the same way and the frequency users need to make compromises.

¹ FreqCoord: <https://www.freqcoord.com>

3.4. Evaluation of spectrum requirement

The following factors are considered in the spectrum requirements calculation reported in chapter 4:

Factor	Explanation
Number of links	Each PMSE link needs a minimal frequency spacing to the next PMSE link. This minimal spacing is given by the manufacturer's device specification. It is not the same value as the effective RF bandwidth. The exact specified value of each individual link is considered.
Intermodulation-free links	For these links only the minimal frequency spacing is considered as suggested in ECC-Report 323 ² . For these links no further spectrum is needed for the consideration of intermodulation.
Intermodulation-affected links	The spectrum need for these links is calculated with the model suggested by ECC-Report 323, page 12, but additionally considering the number of locations.
Number of locations	Depending on the spatial circumstances at an event, it's possible to calculate with a certain number of locations, which affect the spectrum demand in a positive way (more locations → less spectrum demand). Nevertheless, it's not always possible to calculate with multiple locations due to the spatial circumstances. The model in ECC-Report 323 on page 12 only considers only one location. For this analysis the model was extended for multiple locations.
Guard band between Mic and IEM	Between carrier-frequencies of Wireless Microphones and In-ear Monitor Systems which are potentially worn/used by the same person, a guard band of 15 MHz is suggested to avoid receiver blocking. If there are any DVB-T transmitters receivable at an event, they could be used as "natural" guard band. If there isn't any DVB-T transmitter present, a guard band of 15 MHz is included in the spectrum requirement.

Figure 1: Spectrum requirement of intermodulation-affected links

Total number of wireless microphones	Number of 8 MHz TV channels	Total amount of spectrum (MHz)	Number of wireless microphones per 1 MHz
12	1	8	1.5
98	18	144	0.7

Source 1: ECC Report 323 – page 12

² ECC Report 323: <https://docdb.cept.org/download/3470>

4. Results in details

4.1. Daily spectrum requirements for PMSE in Switzerland

4.1.1. Small Events

Table 1 shows that with 41.9 MHz spectrum in the UHF band 80% of the today's small events can be realized.

Year	Number of Events	Sum of event days (excl. setup & rehearsal)	Frequency Band 470 - 865 MHz								
			Event specific conditions		Requirements PMSE-Audio				Available spectrum for PMSE-Audio		
			Number of locations average	Proportion of IM-free links - average	Number of links		Required spectrum		Net available for PMSE [MHz]	DVB-T occupation [MHz]	Gross available [MHz]
					Average	80 th percentile	Average [MHz]	80 th percentile [MHz]			
2014	12	31	1	0%	26	37	28.0	44.9	314.7	15.3	330.0
2015	22	36	2	0%	29	41	32.2	60.3	310.7	19.3	330.0
2016	35	113	2	17%	31	42	32.7	42.0	310.8	19.2	330.0
2017	47	153	1	20%	29	41	29.6	45.0	297.1	32.9	330.0
2018	39	231	2	22%	30	39	32.2	48.7	301.9	25.7	327.6
2019	37	145	1	24%	28	37	30.4	43.8	214.7	20.3	235.0
2020	16	43	2	11%	24	38	34.5	61.5	227.7	7.3	235.0
2021	29	104	2	12%	24	33	26.8	37.6	211.5	23.5	235.0
2019 - 2021 (today's requirement)	82	292	2	17%	26	37	29.9	41.9	216.1	18.9	235.0

Table 1: PMSE spectrum requirement for small events in Switzerland

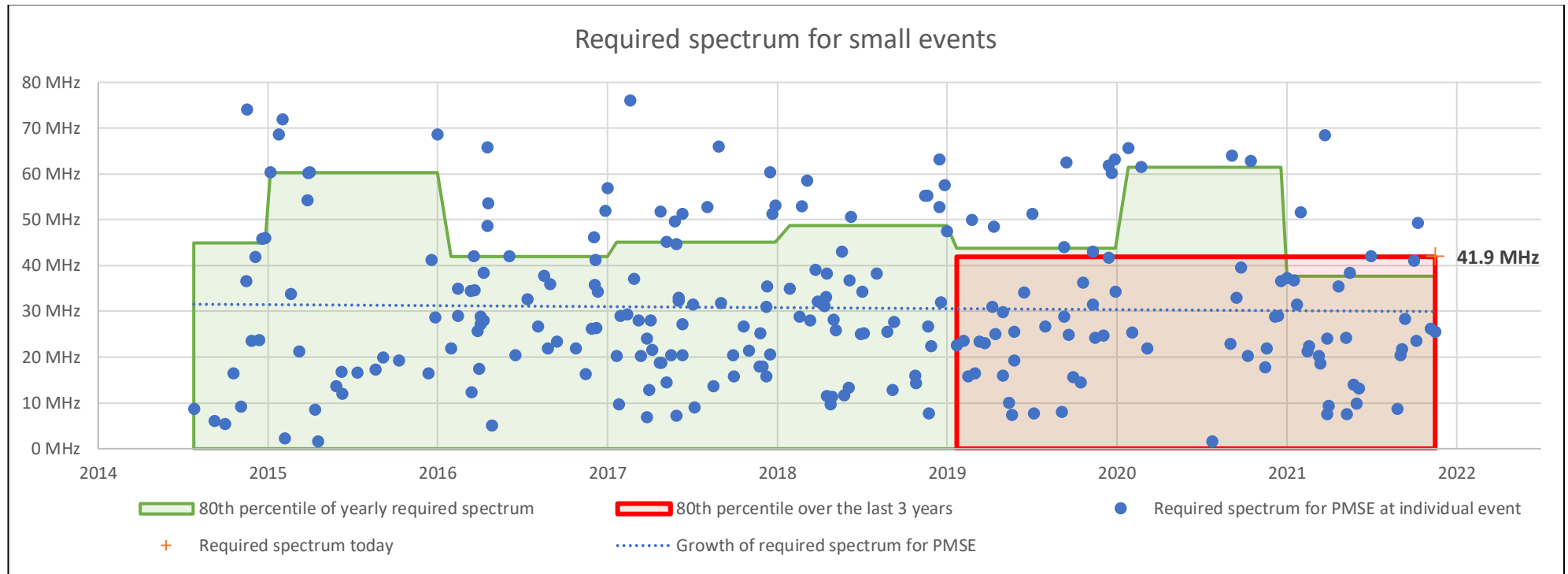


Chart 1: PMSE spectrum requirement for small events in Switzerland

4.1.2. Medium Events

Table 2 shows that with 69.2 MHz spectrum in the UHF band 80% of the today's medium events can be realized.

Year	Number of Events	Sum of event days (excl. setup & rehearsal)	Frequency Band 470 - 865 MHz								
			Event specific conditions		Requirements PMSE-Audio				Available spectrum for PMSE-Audio		
			Number of locations average	Proportion of IM-free links - average	Number of links		Required spectrum		Net available for PMSE [MHz]	DVB-T occupation [MHz]	Gross available [MHz]
					Average	80 th percentile	Average [MHz]	80 th percentile [MHz]			
2014	1	2	4	0%	59	59	37.9	37.9	320.8	9.2	330.0
2015	5	14	3	0%	64	66	63.3	79.2	308.4	21.6	330.0
2016	10	23	8	9%	66	78	51.8	66.3	319.0	11.0	330.0
2017	10	35	7	4%	65	79	36.7	45.1	304.5	25.5	330.0
2018	14	44	7	22%	63	79	41.1	54.4	300.4	29.6	330.0
2019	10	80	6	17%	64	78	49.4	55.5	206.0	29.0	235.0
2020	3	51	5	3%	59	64	59.1	76.0	202.5	32.5	235.0
2021	5	22	7	16%	66	71	57.0	65.4	235.0	0.0	235.0
2019 - 2021 (today's requirement)	18	153	4	14%	64	74	53.1	69.2	213.4	21.6	235.0

Table 2: PMSE spectrum requirement for medium events in Switzerland

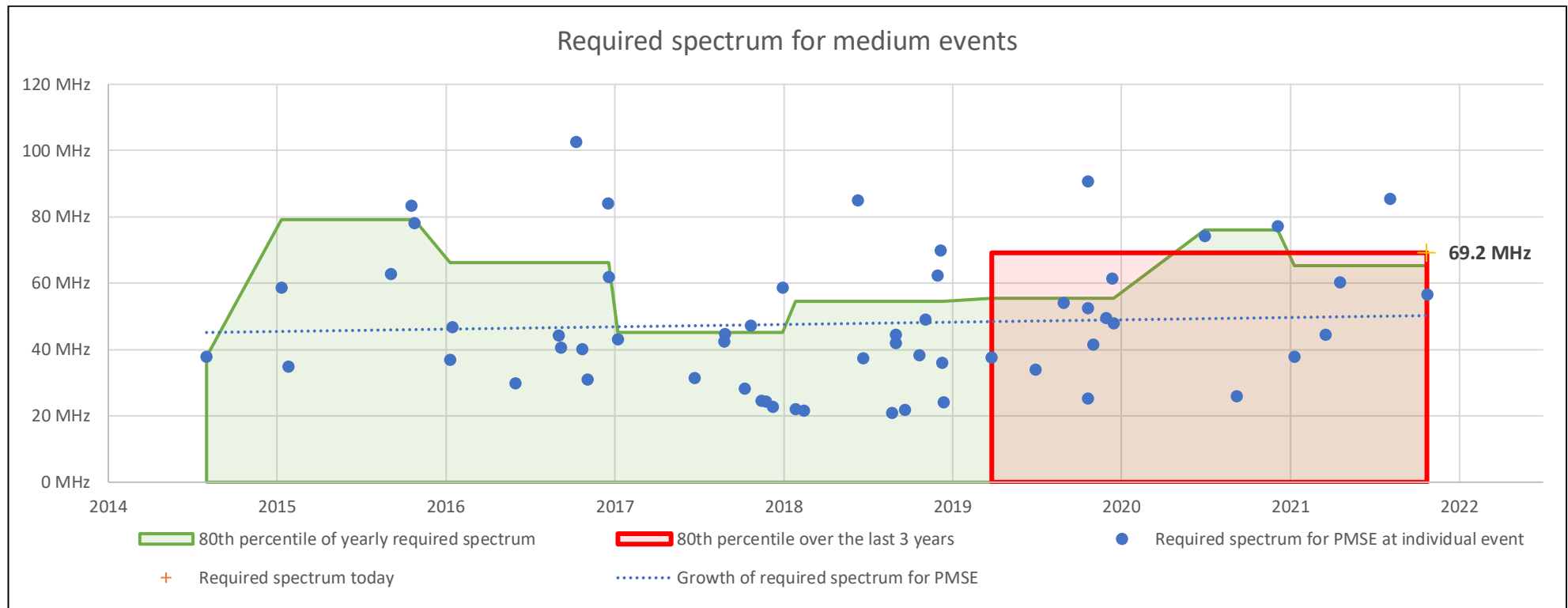


Chart 2: PMSE spectrum requirement for medium events in Switzerland

4.1.3. Large Events

Table 3 shows that with 114.6 MHz spectrum in the UHF band 80% of the today's large events can be realized.

Year	Number of Events	Sum of event days (excl. setup & rehearsal)	Frequency Band 470 - 865 MHz								
			Event specific conditions		Requirements PMSE-Audio				Available spectrum for PMSE-Audio		
			Number of locations average	Proportion of IM-free links - average	Number of links		Required spectrum		Net available for PMSE [MHz]	DVB-T occupation [MHz]	Gross available [MHz]
					Average	80 th percentile	Average [MHz]	80 th percentile [MHz]			
2015	2	7	5	0%	100	100	64.0	64.9	320.8	9.2	330.0
2016	3	11	5	2%	111	114	68.3	69.6	302.8	27.2	330.0
2017	2	6	8	5%	126	132	68.5	69.0	316.2	13.8	330.0
2018	4	15	7	5%	134	148	80.0	93.3	311.6	18.4	330.0
2019	4	15	6	5%	120	131	79.2	89.9	225.8	9.2	235.0
2020 (before Covid Lockdown)	3	9	6	6%	127	141	88.2	107.6	228.9	6.1	235.0
2018 - 2020 (today's requirement)	11	39	6	5%	127	140	82.0	114.6	223.3	11.7	235.0

Table 3: PMSE spectrum requirement for large events in Switzerland

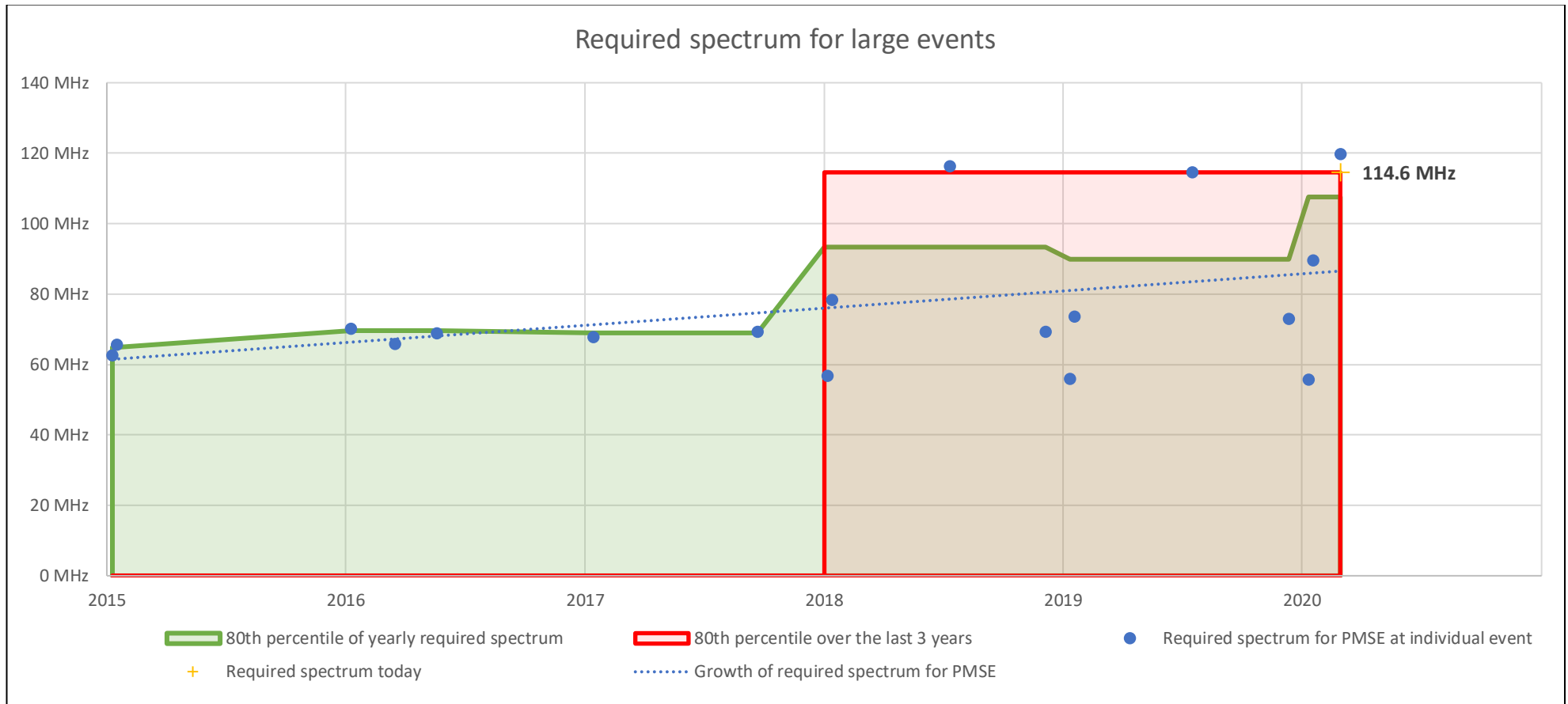


Chart 3: PMSE spectrum requirement for large events in Switzerland

4.1.4. Campus/Venue – permanent use

Table 4 shows that some specific Campus/Venues in Switzerland require 365 days per year between 40.4 MHz and 112.7 MHz.

Campus/Venue Name permanent use - 365d/y	Frequency Band 470 - 865 MHz						
	Venue specific conditions		Requirements PMSE-Audio		Available spectrum for PMSE-Audio		
	Number of locations	Proportion of IM-free links	Number of links	Required spectrum [MHz]	Net available for PMSE [MHz]	DVB-T occupation [MHz]	Gross available [MHz]
SRF Campus Leutschenbach 2021	15	37%	254	112.7	235.0	0.0	235.0
RTS Campus Geneva 2021	5	51%	87	81.7	216.6	18.4	235.0
RSI Campus Comano 2021	5	0%	60	40.4	187.0	48.0	235.0
Zurich lake district 2021	6	0%	160	97.0	235.0	0.0	235.0

Table 4: PMSE spectrum requirement of Campus/Venue in Switzerland

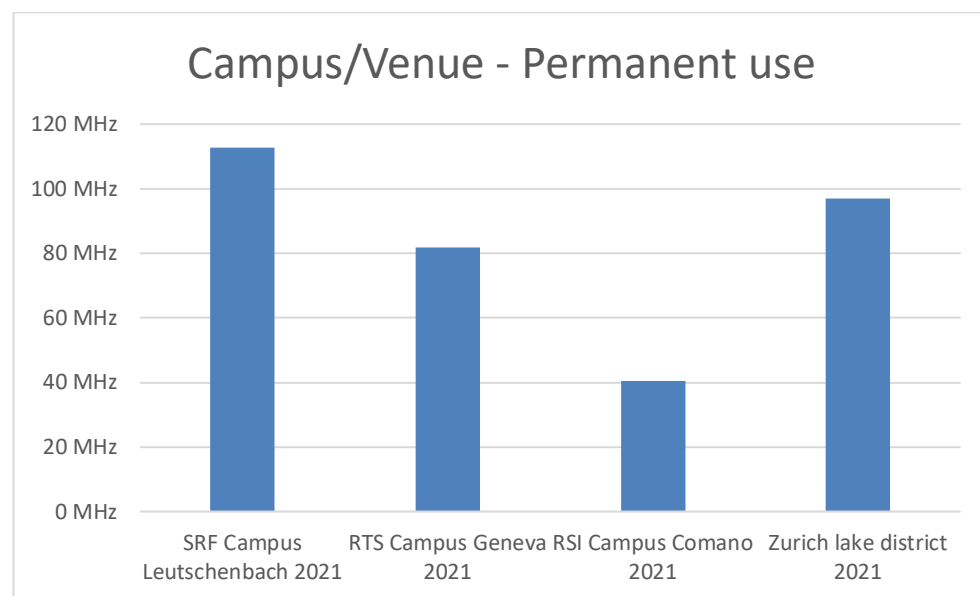


Chart 4: PMSE spectrum requirement of Campus/Venue in Switzerland

4.2. Exceptional spectrum requirement for PMSE in Switzerland

Table 5 shows that with 174 MHz available spectrum in the UHF band 60% of the major events can be realized. However, for an 80% percentile 221 MHz would be needed.

Event name	Sum of event days (excl. setup & rehearsal)	Frequency Band 470 - 865 MHz						
		General conditions		Requirements PMSE-Audio		Available spectrum for PMSE-Audio		
		Number of locations	Proportion of IM-free links	Number of links	Required spectrum [MHz]	Net available for PMSE [MHz]	DVB-T occupation [MHz]	Gross available [MHz]
Gotthard-Basistunnel Eröffnung 2016	8	13	3%	445	207.4	311.6	18.4	330.0
FIS Alpine World Ski Championships St. Moritz 2017	14	21	5%	554	277.8	303.6	26.4	330.0
Swiss Skills 2018	5	13	1%	214	112.0	330.0	0.0	330.0
Eidg. Schwing & Älplerfest 2019	3	23	10%	205	116.0	235.0	0.0	235.0
Fête des Vignerons 2019	24	1	90%	364	156.4	181.0	54.0	235.0

Table 5: PMSE spectrum requirement for Major Events in Switzerland

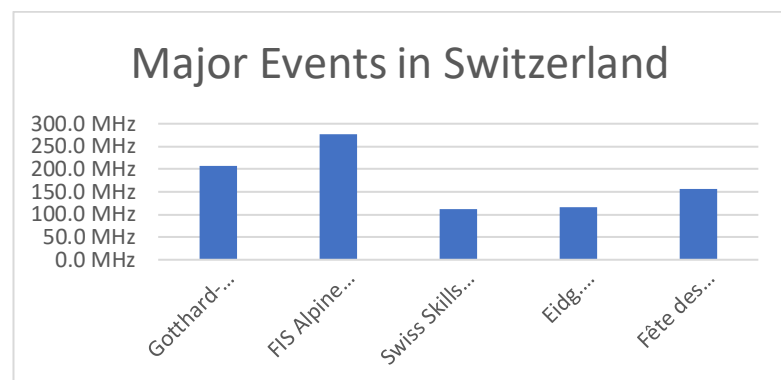


Chart 5: PMSE spectrum requirement for Major Events in Switzerland

4.3. Spectrum requirements for PMSE at international events

Table 6 shows the spectrum requirements at some specific international major events.

Event name	Event Country	Sum of event days (excl. setup & rehearsal)	Frequency Band 470 - 865 MHz						
			General conditions		Requirements PMSE-Audio		Available Spectrum for PMSE-Audio		
			Number of locations	Proportion of IM-free Links	Number of links	Required spectrum [MHz]	Net available for PMSE [MHz]	DVB-T occupation [MHz]	Gross available [MHz]
UEFA Champions League Final 2019	Spain	1	11	5%	222	112.2	167.0	164.0	331.0
UEFA EURO 2020 - Olimpico in Rome - Opening Game	Italy	1	14	3%	88	46.0	101.0	230.0	331.0
UEFA EURO 2020 - Wembley Stadium - Final Game	United Kingdom	1	8	3%	203	110.8	182.0	62.0	244.0
UEFA EURO 2020 - Football Arena Munich – Quarterfinals	Germany	1	9	6%	133	69.5	100.6	128.4	229.0
UEFA EURO 2020 - La Cartuja de Sevilla - M39 - R16	Spain	1	10	14%	140	75.4	119.8	111.2	231.0
UEFA EURO 2020 - Parken Stadium - M3/ DEN - FIN	Denmark	1	10	1%	80	43.3	131.8	103.2	235.0
UEFA EURO 2020 - National Arena Bucharest M41 - R16	Romania	1	9	6%	121	64.8	179.8	55.2	235.0
Expo 2020 Dubai - Pavillons	United Arab Emirates	242	161	0%	1360	256.0	258.0	0.0 MHz	258.0

Table 6: PMSE spectrum requirements at international events

International Events

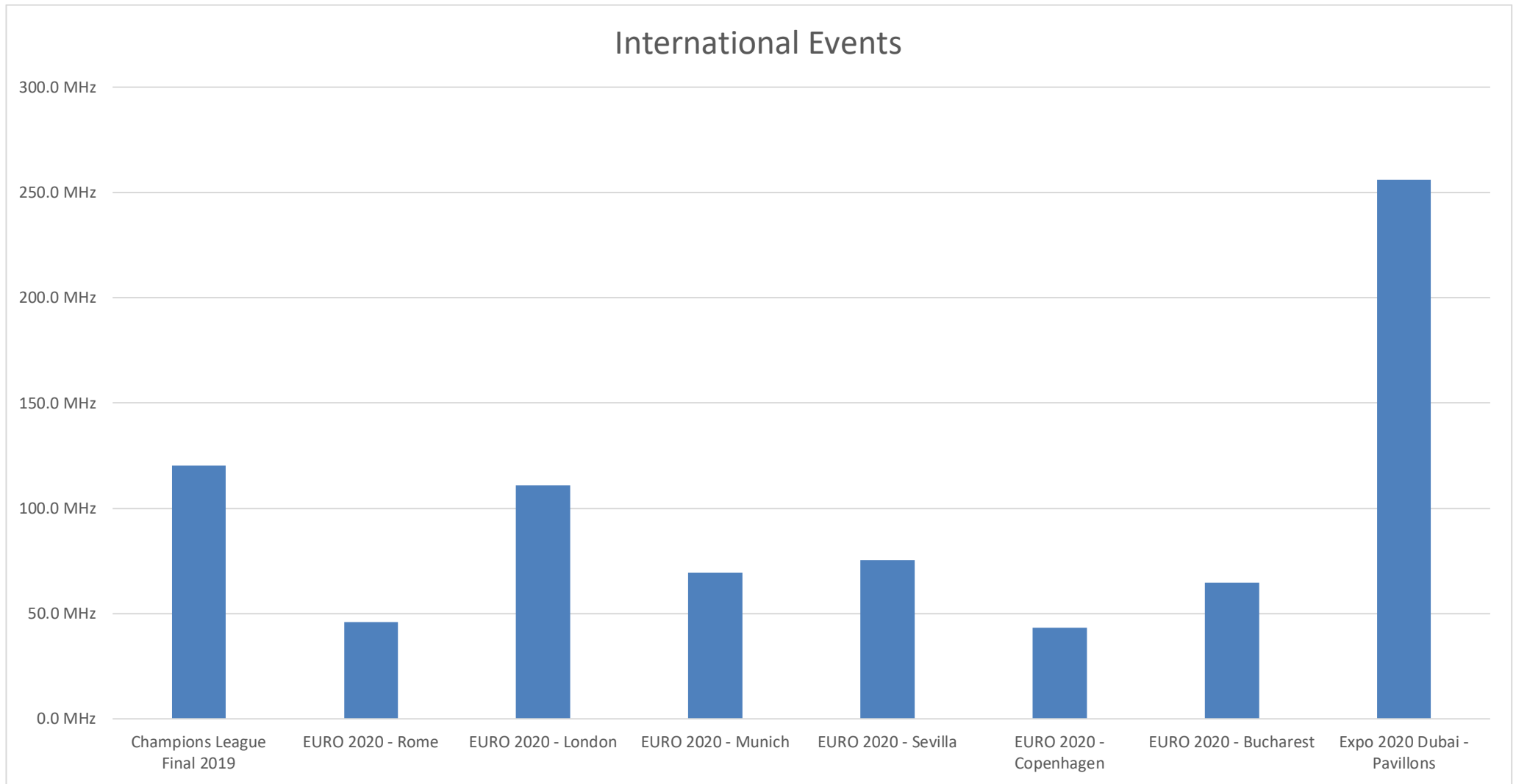


Chart 6: PMSE spectrum requirements at International Major Events

4.4. Coordinated links vs. measured links

For some of the 327 events analysed in this report, measurements on site were carried out during the whole event. These measurements were conducted and analysed by PMSE OR³ software. The detailed measurement reports are published on the website of IKHF⁴.

Event name	Country	Month/Year	Event size	Number of links		
				coordinated	measured	% measured
Weltklasse Zürich 2015 - IAAF Diamond League	SUI	September 2015	Medium	94	59	62.77%
Gotthard-Basistunnel Eröffnung	SUI	Mai 2016	Major Event	445		
- Südportal	SUI	Mai 2016	Major Event	234	170	72.65%
- Nordportal	SUI	Mai 2016	Major Event	211	-	-
Weltklasse Zürich 2017 - IAAF Diamond League	SUI	August 2017	Medium	83	25	30.12%
Bundesratswahlen 2017	SUI	September 2017	Large	135	50	37.04%
Weltklasse Zürich 2018 - IAAF Diamond League	SUI	August 2018	Medium	87	33	37.93%
Bundesratswahlen 2018	SUI	December 2018	Large	131	62	47.33%
Ski Weltcup Adelboden 2019	SUI	January 2019	Large	106	69	65.09%
89. Int. Lauberhornrennen 2019	SUI	January 2019	Large	128	54	42.19%
UEFA Champions League Final 2019	ESP	June 2019	Major Event	222	147	66.22%
Weltklasse Zürich 2019 - IAAF Diamond League	SUI	August 2019	Medium	89	44	49.44%
Parlamentswahlen 2019	SUI	October 2019	Medium	82	56	68.29%
Bundesratswahlen 2019	SUI	December 2019	Large	110	54	49.09%
Ski Weltcup Rennen St. Moritz 2019	SUI	December 2019	Medium	76	36	47.37%
Ski Weltcup Adelboden 2020	SUI	January 2020	Large	101	47	46.53%
90. Int. Lauberhornrennen 2020	SUI	January 2020	Large	144	61	42.36%
Swiss Music Awards 2020	SUI	February 2020	Large	136	58	42.65%
Fussball NL Schweiz - Deutschland	SUI	September 2020	Medium	61	26	42.62%
Crans-Montana Ladies World Cup 2021	SUI	January 2021	Small	29	28	96.55%
UEFA EURO 2020 - Olimpico in Rome - Opening Game	ITA	June 2021	Medium	88	65	73.86%
UEFA EURO 2020 - Parken Stadium - M3/ DEN - FIN	DEN	June 2021	Medium	80	32	40.00%
UEFA EURO 2020 - National Arena Bucharest M41 - R16	ROM	June 2021	Large	121	32	26.45%
UEFA EURO 2020 - Wembley Stadium - Final Game	UK	July 2021	Major Event	203	45	22.17%
UEFA EURO 2020 - La Cartuja de Sevilla - M39 - R16	ESP	June 2021	Large	140	27	19.29%
Weltklasse Zürich 2021 - IAAF Diamond League	SUI	September 2021	Large	108	75	69.44%

Table 7: Coordinated vs. measured links at specific events

³ PMSE OR: Measurement, analyze and statistics software provided by IKHF, Matthias Fehr

⁴ IKHF: Ideen und Konzepte für Hochfrequenz, <https://www.pmocre.info>

5. Analysis & conclusions

5.1. Number of links vs. number of locations

The determination of the required spectrum requirement of PMSE Audio in the UHF-Band, is a complex task and several factors need to be considered, as explained in chapter [3.4](#). The most impacting factors on the spectrum requirement for PMSE Audio are the number of links and the number of locations. The number of locations to be defined in the frequency calculation, depend on the spatial circumstances at the event location and the event's requirements/giveness. It can be said, the more locations can be defined in the calculation, the less spectrum is needed. The theoretical minimum of needed spectrum would be if the number of links equals to the number of locations. In practice the number of locations is always much lower than the number of links as among locations a spatial distance has to be assured. For example, it must be sure that each specific transmitter at no time leaves his assigned location and never approximate another location.

Defining the required spatial distance between locations in meters cannot be generalized, as it depends on the location and event. In the opinion of the author 20 meters separation of locations can be considered as a safe value for not considering intermodulation. To use the same specific frequency more than once in a project, a spatial distance more than 150m need to be assured at any time.

It can be said that the local conditions and the events requirements, resulting in the number of locations, of each event affects the required spectrum significantly. Therefore, it can happen that the same number of links require not the same amount of spectrum.

5.2. Coordinated vs. measured links

The analyzed data in chapter [4.4](#) shows, that in average at least 50% of the coordinated links were measured during the event. At a first glance, that could look like a low usage number, but there are several reasons why not more links were detected in the measurement. The first and most important reason is, that normally the measurement device and its antenna cannot observe the whole event area. For example, links used far away from the measurement antenna or indoors couldn't be detected. Additionally, to the 50% detected links, the author is assuming, that in average 30-40% of the links at an event remain undetected due to the previous mentioned fact.

Also, a small percentage of links were coordinated but remained unused. The author is assuming that these links were spare frequencies or the user at the end didn't show up at the event. In the case of the spare frequencies, these ones, need to be kept free to allow the user to switch in case of any unexpected interference on the main operation frequency. That users did not show up at the event can be concluded with certainty at the end of an event. Users can suddenly show up during the event. (e.g. News crews). Therefore, all coordinated frequencies have to be kept free during the whole event, unless the user cancel the frequency requests. Canceled requests are not part of the declared required spectrum in this report. To conclude, it can be said that the coordinated links reflects the effective spectrum demand of an event.

5.3. Data analysis & conclusions

The results in chapter 4 shows that the required spectrum grows each year for medium and large events. Therefore, to determine the today's spectrum need for PMSE Audio only the data of the last three significant years were considered. Due to the global Covid-19 pandemic also events suffered from cancelation and restrictions which had an impact on the number of links used at events during this period. Because of the same reason, there was no large event in the year 2021.

Analyzing the data of 111 events over the past three relevant years, shows the following spectrum requirements for PMSE Audio:

Daily spectrum requirement:

Permanent use

- Campus-Installations, which were considered in this analysis, require up to **110 MHz** spectrum in the UHF Band:
 - Example: Campus SRF Leutschenbach
 - Example: Seebecken in Zurich

Events

- Today the 82 analysed **Small Events** (Events with less than 50 coordinated links) require prevailing **42 MHz** in the UHF Band:
 - Example sport: Engadiner Skimarathon, Fussball Super League
 - Example culture: Zürcher Sächsilüte, SRF bi de Lüt
- Today the 18 analysed **Medium Events** (Events with 50-100 coordinated links) require prevailing **69 MHz** in the UHF Band:
 - Example politics: Local elections in Tessin
 - Example sport: Football national team games, Swiss Indoors Basel
 - Example culture: eidg. Jodlerfest, Film Festival Locarno
- Today the 11 analysed **Large Events** (Events with 100-200 coordinated links) require prevailing **115 MHz** in the UHF Band:
 - Example politics: Federal council elections
 - Example sport: Ski races in Adelboden and Wengen (Lauberhorn)
 - Example culture: Gurtenfestival

Exceptional spectrum requirement:

- Major Events (events with more than 200 coordinated links) do not take place periodically. They have an exceptional cultural value and large media response at national and international level. There were 5 Major Events between 2016 and 2019 analysed. They had together during **54 event days** (excl. setup & rehearsal) and average spectrum requirement of **174 MHz** in the UHF Band:
 - Example sport: Ski World Championship St. Moritz
 - Example culture: National wine festival «Fête de Vignerons»