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Considerations on the frequency resource of professional wireless microphone systems

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Abstract. This Paper presents the results of spectral observations in the UHF TV Bands IV and V from 470 MHz up to 862 MHz with focus on the TV-Channels 61 to 63 and 67 to 69. Concerning the discussions on WRC (2007) this frequency range is in great demand of several applications and is usually treated as a ”white space” in the TV-Bands. According to typical scenarios, two different spectral loads will be presented considering the requirements of professional wireless microphone receivers with respect to in-band intermodulation.

1 Introduction

In the course of the digitalisation of the UHF TV-Bands a reallocation of the UHF frequency spectrum will take place. This is based on the presumption that Digital Video Broadcasting (DVB-T) will occupy less spectrum than the analogue counterpiece. On the other hand the increasing demand on digital broadcasting for hand-held devices (DVB-H) may require the vacant frequency resource, especially in urban areas. Furthermore several providers are interested in installing new mobile multimedia-based services in UHF in so called “white spaces“. Applications like Professional Wireless Microphone Systems (PWMS) which actually use these “white spaces” are not often mentioned as secondary users of the UHF frequency spectrum. Additionally unlicensed devices with cognitive skills may become access to the UHF frequency spectrum. On WRC (2007) the possibility to hold an auction on the upper TV channels was discussed. According to BNetzA (2005) PWMS are allowed to operate on these channels without individual permission until 2015, named channel 61 to 63 (f=790 MHz to f=814 MHz) and channel 67 to 69 (f=838 MHz to f=862 MHz) which were former used by military applications. PWMS is a strongly growing application with high demands on reliability, latency and sound quality which in practice can only be faced with an assured access to the frequency resource. For the protection of PWMS a default signal strength of (68 dBμV/m) is specified in CEPT (1997). This value is also used for several other governmental issues (e.g., ERC Report 88, 2000). PWMS manufacturers suppose that this level is about more than (10 dB) too high for a secure PWMS connection in on stage environments. According to ETSI (2006) a new suggestion for the default protected signal strength in PWMS for future frequency allocation in UHF is given, adapted from the demands on PWMS in Sect. 2 of this paper. In Sect. 3 the spectral loads of two different applicable cases are presented. Futhermore one of them is evaluated from an objective point of view by the aid of frequency availability and from a subjective point of view with respect to in-band intermodulation in PWMS receivers as well. Finally, in Sect. 4 the results are concluded.

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2 PWMS – an application with high demands

PWMS is a common application in the cultural industry and includes wireless microphones for professional usage, In-Ear Monitoring Systems (IEM), Electronic News Gathering (ENG) and wireless audio systems. These applications can be found in studios, theatres, musicals, politics, sports, broadcasting and on stage. Thus PWMS is a core application in the production of multimedia content and is used for recording and archiving unique events. This leads to very high demands on the reliability and sound quality of PWMS. Furthermore sound engineers and musicians have high demands on latency. Therefore PWMS, unlike wireless microphones, headphones or loudspeakers for consumer applications, are not able to operate on Industrial, Scientific, and Medical Bands (ISM). In contrast to daily usage, today’s mass events, for example in sports, generate a temporary much higher demand on a useful frequency resource.

2.1 Requirements of PWMS

According to ETSI (2006) a high audio quality can be achieved with an Audio Signal-to-Noise Ratio SNR_{AF} of

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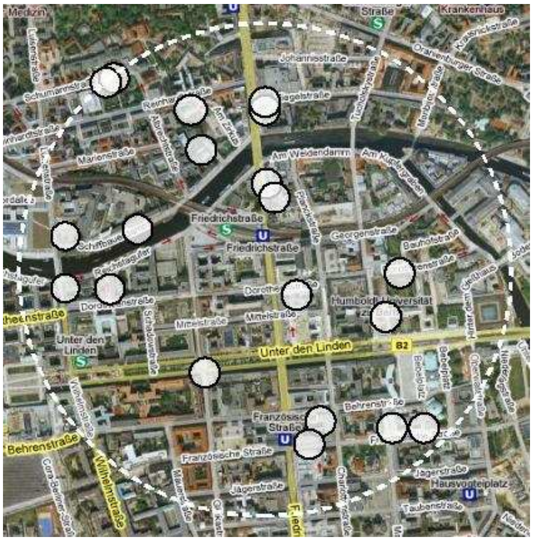

Fig. 1. Measurement location in the center of Berlin within a diameter of 1 km (marked by white, dotted circles), with known PWMS users (marked by black circle).

(80 dB (A)) at the NF-Path of a PWMS receiver. The associated Radio Frequency Signal-to-Noise Ratio SNR_{RF} can be calculated from

$$\mathrm{SNR}_{RF} = \frac{\mathrm{SNR}_{AF}}{K_{\mathrm{compand}}} - G_{\mathrm{demod}} \quad (1)$$

where K_{compand} represents a coefficient for the degree of companding (typically K_{compand}=2) and G_{demod} represents the demodulation gain of the used modulation scheme. Actually PWMS works with frequency modulation (FM) with G_{demod}=20 dB. This leads to a minimum $\mathrm{SNR}_{RF,min}$ of typically 20 dB. The thermal noise level $N_{thermal}$ for a PWMS channel with 200 kHz Bandwidth is about −120 dBm. According to ETSI (2006) other technical on-stage-applications, for example light installations, add a cumulative man-made-noise N_{ManMade} of 10 dB. With a typical noise figure F of a PWMS receiver the minimum receiving level P_{sens} can be calculated by

$$P_{\mathrm{sens}} = N_{\mathrm{thermal}} + N_{\mathrm{ManMade}} + F \; . \quad (2)$$

The output power of PWMS is limited to 17 dBm. With a typical stationary antenna gain G_{static}=5 dBi and a mobile antenna gain G_{mobile}=0 dBi of a hand-held or of a body-mounted device, the maximum path loss L for a gaussian channel is given with L_{gauss}=87 dB including the absorption of the human body D_{human}=30 dB defined in ETSI (2006). For a reliable PWMS link, fading break-ins up to 30 dB have to be considered and lead to L_{rayleigh}=57 dB. According to Meinke et al. (2005) the range r for f=800 MHz is calculated with

$$L = 32.44\mathrm{dB} + 20 log \frac{r}{1000\mathrm{m}} + 20 log \frac{f}{\mathrm{MHz}} \; . \quad (3)$$

Hence, the maximum range for a secure and reliable PWMS link considering the antennas in use, human body absorption and fading effects is about r=21.1 m without and $r_{\mathrm{diversity}}$=47.3 m with an additional diversity gain $G_{\mathrm{diversity}}$=7 dB. For the most applications, this range is barely adequate. Thus, we suppose P_{sens}=−80 dBm for the PWMS protection level. With $\mathrm{SNR}_{RF,\mathrm{min}}$=20 dB the resulting maximum interference level is P_{if}=−100 dBm. The corresponding field strengths are 51.5 dB$\mu V/m$ and 31.5 dB$\mu V/m$ with an antenna factor k=24.5 for isotropic antennas operating at f=800 MHz. The calculated value for the protected field strength is lower than the one given in CEPT (1997) for PWMS [1] with 68 dB$\mu V/m$.

3 Spectral load

For the spectral loads the concrete PWMS application is not necessary. However, it is important to distinguish two different applicable cases, on the one hand the daily use of PWMS in an urban area with a high concentration of PWMS users with a moderate frequency load, on the other hand a mass event with a high frequency load (see Sect. 2). For recording the daily use of PWMS, an area with a diameter of 1 km within the center of Berlin was chosen (see Fig. 1). In this area at least 20 PWMS users were known (marked with black circles). The measurement took place from 17th to 18th July 2007. For a mass event the biggest international music fair ("Musikmesse") was chosen. This Measurement took place from 28th to 31th March 2007 in the exhibition hall 4, Frankfurt/Main.

The spectral load was recorded in both cases using as receiving antenna a Sennheiser type A 5000 CP , which is an applicable, directional antenna installed by many PWMS users, connected to a Rohde & Schwarz FSP 3 spectrum analyzer. The data was measured with Δf=20 kHz, RMS detection and a reference level P_{ref}=−20 dBm. The analyzer was software controlled and the measured data stream was mapped with a measurement PC. The whole analysis was performed by use of MATLAB. The surface plots in Fig. 2 and Fig. 3 show the recorded signal levels $P_{\mathrm{Musikmesse}}$ and P_{Berlin} (color coded) over frequency (abscissa) and measurement cycle (ordinate) and will be discussed in detail in the following subsections.

3.1 PWMS in daily use

In Fig. 2, an overview of the spectral load in Berlin is displayed. The measurement equipment was placed in a car. The car stopped at numerous stop stations, as close as possible to the known PWMS users, and continued in place for several measurement cycles. The recording was continued during driving from one stop station to another. The light

[1] PWMS are part of Service Auxiliary Broadcasting (SAB) / Service Auxiliary Program making (SAP) in CEPT (1997)

blue horizontal bars between measurement cycle 350 and 400 result from a temporary increase of the noise floor because of problems with the measurement equipment. In spite of the at least 20 known PWMS users the spectral load is very weak. This leads to the presumption, that not all known devices were in use during the measurement periode. Probably this is caused by the fact that the measurement period coincided with the holiday season in Berlin. Thus a higher spectral load than the one displayed in Fig. 2 might be more representative for PWMS in daily use. Moreover, because of the overall measured weak levels, we suppose that not all PWMS in indoor use can be recorded by observing the outdoor area using the chosen measurement technique. The whole measurement took place in parallel to a measurement campaign of BNetzA which observed the same frequency range at the same stop stations. The results are nearly equal. By simply cumulating the amount of measured levels higher -100 dBm (excluding the light blue horizontal bars between measurement cycle 350 and 400) multiplicated with Δf=20 kHz the used frequency can be calculated. In maximum 5.04 MHz are in use simultanously. With a typical bandwidth of 200 Hz this value corresponds to 25 PWMS.

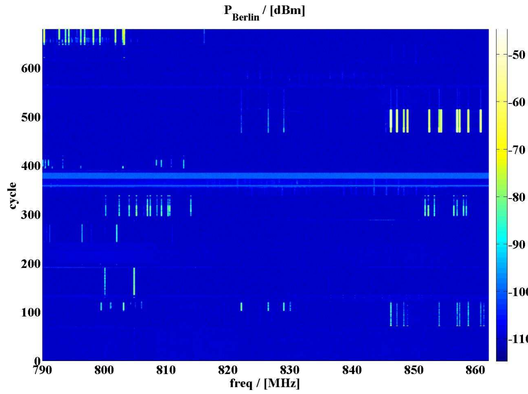

Fig. 2. Spectral load from 17th to 18th July 2007 between f=790 MHz and f=862 MHz in the center of Berlin.

3.2 PWMS during mass event

In contrast to the low daily spectral load Fig. 3 gives an overview of the spectral load of a mass event. The measurement equipment was placed in an office at the face side of the exhibition hall with an antenna height of 5 m. The hall is 145 m in width and 133 m in length. With a 3 dB-angle of 60° and a 0dB-angle of nearly 180°, the antenna covers the whole exhibition hall. The lowest expected level was calculated to -70 dBm excluding attenuation or fading. Via a simple test measurement with a hand-held microphone, the level calculation could be confirmed. The spectral load in Fig. 3 has a very strong variance in time especially in the lower TV-channels (below f=814 MHz) in conjunction with the opening hours of the fair. The measurement started at the 28th March at about 01:00 p.m. After door closing at 07:00 p.m. only some PWMS did not switch off, because of corporate functions in the evening hours. The same behaviour can be seen after door opening at about 8am between cycle 500 to 900, analogue to the second measurement day as well as above cycle 1125, analogue to the third measurement day on 30th March till about 02:00 p.m. At the upper TV-channels (above f=838 MHz) also continuous PWMS signals can be identified, presumptively belonging to not battery powered IEM. On TV-channel 64 (f=814 MHz to f=822 MHz) a deadbeat DVBT signal can be recognized, because of an everlasting increase of the noise floor. Additional PWMS is apparent between f=814 MHz and f=838 MHz out of the operable frequency range according BNetzA (2005), including TV-channel 64. Additionaly, weak PWMS signals below the supposed levels belonging to PWMS placed inside the exhibition hall can be detected, probably transmitted from another exhibition hall or pavillion. By simply cumulating the amount of measured levels higher -100 dBm multiplicated with Δf=20 kHz the used frequency range can be calculated. In maximum 11.32 MHz are in use simultanously. With a typical bandwidth of 200 kHz this value corresponds to 56 PWMS. On the average f=5.58 MHz are in use, corresponding to 28 PWMS.

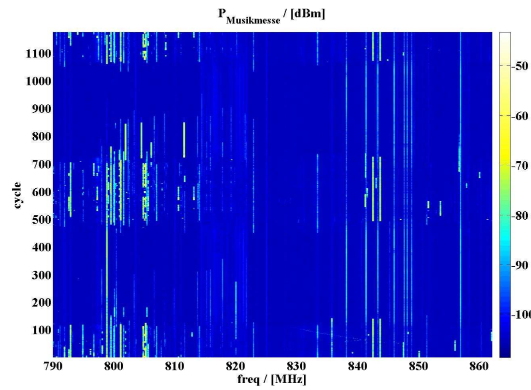

Fig. 3. Spectral load from 28th to 31th March 2007 between f=790 MHz and f=862 MHz in the exhibition hall4, “Musikmesse”.

3.2.1 Frequency availability

In the following the spectral load of the ”Musikmesse” will be evaluated more objectively. Therefore the frequency availability is calculated by

$$AV = \tilde{P}_{\text{meas}} + \mu\sigma_{P_{\text{meas}}} \tag{4}$$

where $\tilde{P}_{\text{meas}}$ represents the median of the measured spectral load and $\mu\sigma_{P_{\text{meas}}}$ the weighted variance in time. According to Konstantinos et al. (2005) a frequency availability of 99% corresponding with μ=2.33 is determined as a suitable avail-

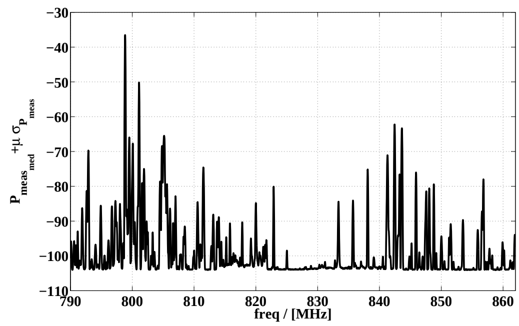

Fig. 4. 99% availability at "Musikmesse".

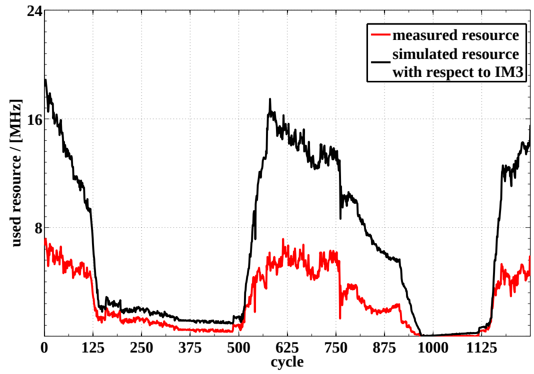

Fig. 5. Subjective spectral load with respect to IM3, "Musikmesse"

ability for PWMS. [2] The availability AV (see Fig. 4) is now compared with $P_{if}=-100$ dBm defined in section 2.1. This leads to

AV_{61-63}=11.88 MHz/24 MHz for the frequency range from f=790 MHz to f=814 MHz,

AV_{67-69}=18.06 MHz/24 MHz for the frequency range from f=838 MHz to f=862 MHz and

AV_{total} =50.78 MHz/72 MHz for the frequency range from f=790 MHz to f=862 MHz.

3.2.2 Spectral load with respect to in-band intermodulation

For the usage in different scenarios a PWMS receiver has to be designed with a tradeoff between frequency selectivity, to avoid in-band intermodulation, and frequency agility for the option to cover different operating frequencies. In Germany, a typical front end bandwidth is 24 MHz or 3 TV-channels. The spectral load of a mass event like the "Musikmesse" causes in-band intermodulation inside the receiver front end, resulting from the huge amount of PWMS in use. This leads to a subjective higher spectral load inside the PWMS receiver than the objective one presented in Sect. 3.2.1. The amount of the increase of spectral load due to in-band intermodulation cannot be generalized. Therefore a nonlinearity of a typical PWMS with an input intercept point IP_3=0 dBm was burdened with the measured spectral load at several measurement cycles in a system simulation, considering only intermodulation of the third order (IM3). The resulting spectral load was again compared with $P_{if}=-100$ dBm. The simulation results are displayed in Fig. 5. It is obvious, that the peak-periode of the spectral load with respect to IM3 at cycle 0 to 125, 500 to 750 and above 1125 exceeds twice the amount of the objective spectral load. In the cycles between 125 and 500, IM3 raises the spectral load insignificantly. The maximum load was detected for cycle 1 with a spectral load of 7.2 MHz excluding IM3 and 18 MHz including IM3.

[2]In the following this value will be used, although PWMS users and manufacturers suppose that a higher frequency availability might be necessary for a reliable PWMS link.

4 Conclusions

This paper shows that PWMS in daily use only requires a small part of the available spectrum and that not all PWMS in use can be made visible easily. In contrast the results based on the objective frequency availability as well as on the subjective spectral load including IM3 show that a generously determined headroom of the allocated frequency resource for PWMS is strongly required for mass events and the recording of unique multimedia content.

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