THEORY AND METHODS OF SIGNAL PROCESSING

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MEASUREMENT THE OCCUPIED BANDWIDTH OF DIGITAL TELEVISION EMISSION BY METHOD *X* dB

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Abstract—*Occupied bandwidth of digital television emission is measured by $\beta/2$-method. Use of the method X dB limits the uncertainty of the spectrum level, which corresponds to the occupied bandwidth. The article is devoted to the definition of this level on the basis of measurement data.*

Index Terms—Occupied bandwidth; emission; method *X* dB; spectrum.

I. Introduction

Measurement the occupied bandwidth of emission at monitoring stations contributes to the efficient use of the radio-frequency spectrum.

According to Rec. ITU-R SM.443-4 [1] occupied bandwidth is measured by direct $\beta/2$ method at monitoring station and can be estimated from the *X* dB bandwidth when the conditions for accurate measurement of occupied bandwidth are not met. The main limitation for the use of $\beta/2$-method is the difference between spectrum reference level and the noise level should be greater 30 dB.

Experimental studies of the spectrums of digital television, the results of which are provided by The Ukrainian State Centre of Radio Frequencies (UCRF) as well as measurements conducted by the authors, show that the level of noise -30 dB from reference level in Kyiv is achievable only under certain conditions. The difference in 30 dB is obtained during the measurement in a separate points at a distance of about 2 km from the transmitter. For this reason conditions of occupied bandwidth measurement using $\beta/2$-method are not convenient.

It is obvious that a reliable estimate of occupied bandwidth in urban conditions by $\beta/2$-method can be obtained in the measurement process within direct visibility from the transmitting antenna to the receiving point at short distances.

By definition [2] the *X* dB bandwidth is the width of a frequency band such that beyond its lower and upper limits any discrete spectrum component or continuous spectral power density is at least *X* dB lower than a predetermined 0 dB reference level.

The accuracy of the method *X* dB depends on the shape of spectrum, resolution bandwidth by intermediate frequency RBW and *X* dB level over the noise level. Spectrum shape of digital television is convenient for method *X* dB due to the steep slopes towards the edges. Value of resolution bandwidth must corresponds to the steep slopes of spectrum. The minimum 5 dB is a recommended difference between *X* dB and noise levels.

There are two approaches [1] to compare the *X* dB bandwidth with necessary bandwidth and occupied bandwidth. Estimation of necessary bandwidth can be obtained from the -26 dB bandwidth using a conversion factor. But -26 dB bandwidth corresponds not less than 31 dB level of a signal spectrum and should be greater. Conversion factor is known for a few classes of emission.

The second approach implies direct measurement of occupied bandwidth from *X* dB bandwidth. This approach limits the uncertainty of *X* dB levels for a number of digital radio technologies, including digital television of DVB-T, DVB-T2 standards.

This paper considers the estimation of occupied bandwidth of digital television emission using the method *X* dB in order to mitigate the restrictions on the conditions under which measurements are made.

Mathematical modeling was performed using a parts of CPS platform (transmitter and channel), which were supplemented by the software unit to obtain a spectrum [3].

Results of mathematical modeling of emission spectrum coincide with the spectrum provided by the regulations on the system of digital TV and are different from the results of measurement provided by USCR in part of the slopes steepness (Tables 1, 2).

The width of the spectrum slopes at mode 8 *k* and level of -20 dB for AWGN channel, Ricean channel and Rayleigh channel with greater delays is approximately equal to 8 kHz, which is the width of the slopes of the regulatory spectrum.

Modeling results correspond to resolution bandwidth RBW $\leq$ 1 kHz. But this value is only 0,013 % from

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necessary bandwidth of digital television emission and control of occupied bandwidth taking into account slope width is conducted at greater values of RBW.

TABLE 1

SLOPE WIDTH BY MODELING DATA AT LEVEL – 20 DB

Channel	Slope width, kHz	
	Left	Right
AWGN	2.6	8
Ricean	8.3	8.3
Rayleigh	28.2	8.5
Rayleigh with lower delays	14.3	17.8
Rayleigh with greater delays	7.6	8.3

TABLE 2

AVERAGE SLOPE WIDTH OF SPECTRUM OF EIGHT EMISSIONS AT DIFFERENT FREQUENCIES AT RESOLUTION RBW = 10 KHZ

Standard	Slope	Slope width at the level -20 dB, kHz	Slope width at the level -30 dB, kHz
DVB-T2	Left	111.0	188.8
	Right	160.8	196.5
DVB-T	Left	136.3	223.3
	Right	131.3	203.0
DVB-T2, DVB-T	Left and right	134.8	202.9

Due to inconsistency of the results of mathematical modeling and the spectrums obtained at radio control it is advisable to determine the *X* dB level based on the statistical processing of experimental data.

II. MEASUREMENTS AND PROCESSING

Experimental studies were conducted in Kyiv in the vicinity of the television tower by UCRF using a spectrum analyzer R&S U3772 Advantest at SPAN = 10 MHz, *RBW* = 10 kHz and RBW = 3 kHz, Fig. 1.

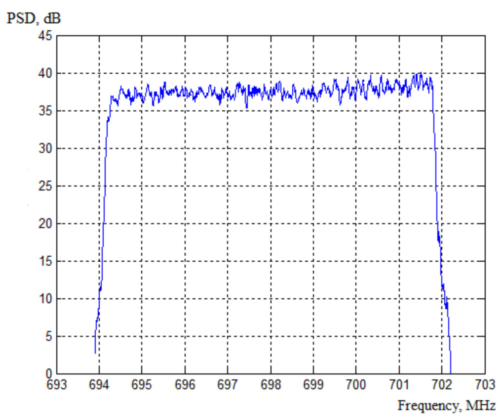

Fig. 1. Example of spectrum using spectrum analyzer R&S U3772 Advantest at RBW = 10 kHz and software of mobile monitoring station

In order to increase the amount of experimental data the authors used Software Defined Radio (SDR) platform HackRF One [4].

Accuracy characteristics of platform were checked by measuring output level of the signal generator R&S SMJ Vector Signal Generator using the spectrum analyzer Rohde & Schwarz FSH8 and HackRF One in a frequency range up to 1000 MHz.

Maximum measurement error of the generator output signal does not exceed level 1.5 dB. The average value of error is 0.98 dB. According to the European standard [5] maximum uncertainty in the measurement out-of-band emission at frequencies up to 2.2 GHz is ± 2.5 dB at 95 % confidence level. Measurement error platform HackRF One of 1–1.5 dB can be considered acceptable.

During measurement of digital television emission the output signal of platform is recorded in the file. Emission spectrums are obtained using FFT in computer, Figs 2 and 3. The data in the sample at each frequency includes averaged over 10 spectra measurements for each place of acceptance.

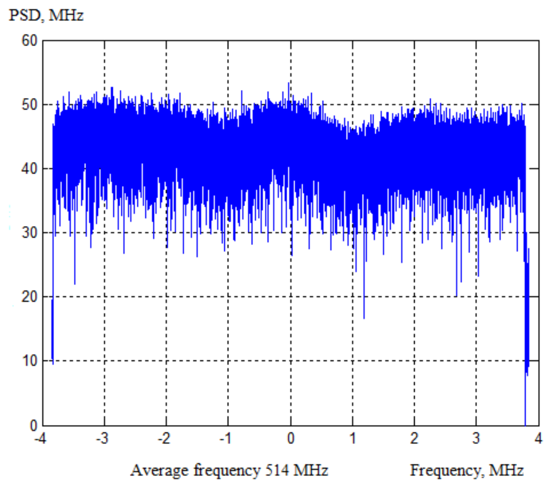

Fig. 2. Example of spectrum using SDR platform HackRH One at resolution 305 Hz

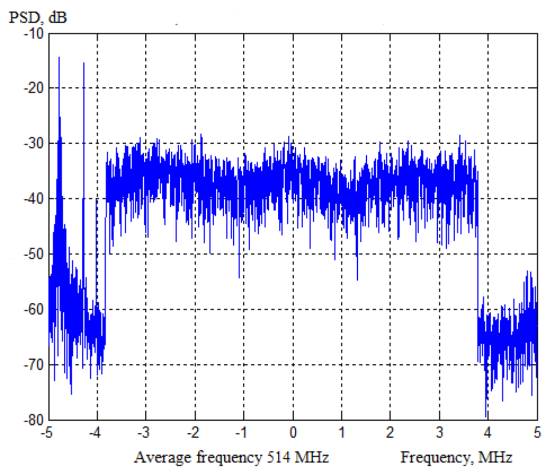

Fig. 3. Example of spectrum using SDR platform HackRH One at resolution 2441 Hz

Algorithm of occupied bandwidth determining by $\beta/2$ -method firstly set the spectrum boundary. As the experience shows, the borders of frequency spectrum can be taken as ± 3.9 MHz from the center frequency. In this case, on the spectrum boundary the signal level is at least -30 dB from level, taken as reference. Occupied bandwidth values are in the range 7.4 MHz – 7.52 MHz.

Noisy spectrums need subsequent processing for properly determination the reference level in automatic mode.

Matlab environment offers a number of tools to smooth the sample, including the method of rolling averaging, Savitzky-Golay (SG) filter, local regression weighted and with robustness or without them.

For all smoothing methods the spectrum noisiness and shape depends on the number of points in the local sequence. According to results of calculations [6], the best results by the criteria of the spectrum smoothing and preserving the value of occupied bandwidth enables the use of the Savitzky-Golay filter 3-4 order of polynomial with: 201 points in the local sequence for resolution 305 Hz (Fig. 4), 101 points for resolution 2441 Hz and 51 points for resolution 9766 Hz.

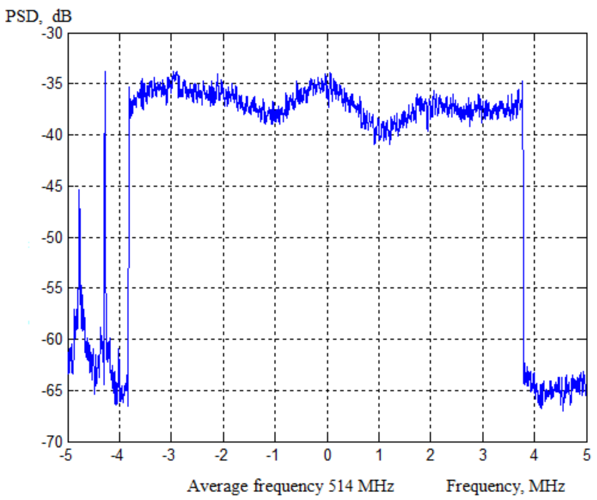

Fig. 4. Smoothing spectrum on Fig. 2 using SG filter of 4 order with a local set of 201 points

Recommendation ITU-R SM.1541 notes that reference level of spectrum can be found in two ways: to determine the maximum power level or the average value of "shelf". The shape of the signal digital television DVB-T2 corresponds to both methods of determining the reference level.

From the results of processing follows that reference level defined by average value of "shelf" does not depend on the number of point in a moving set. Reference level by the maximum value becomes stable at a number of points in the set, which suitable for spectrum smoothing. Processing procedure is simpler at using determination of reference level by maximum value.

Algorithm by $\beta/2$ -method, in which the frequency range gradually narrows on each spectrum side before reaching the border, outside each is 0.5 % of the total power cannot be directly used for finding the appropriate X level.

The borders of occupied bandwidth emissions of digital television standards DVB-T, DVB-T2, sometimes are placed not on the slopes but on the "shelf" of the spectrum. The spectrum "shelf" is characterized by low steepness that reduces the accuracy of the X dB method. Besides level on the slopes of the spectrum, corresponding to 0.5 % of the total power is different for each spectrum side.

It was proposed to determine occupied bandwidth of digital television emission using the modified method of X dB, which is as follows:

– in order to increase the accuracy the measurement of the spectrum bandwidth is determined in points with high slope at the level -10 dB from the reference level;

– occupied bandwidth is equal to the difference of spectrum bandwidth at -10 dB level and amendment, which value depends on different apparatus adjustments.

Results of occupied bandwidth estimation by method $\beta/2$ and amendment to -10 dB bandwidth using spectrum analyzer R&S U3772 Advantest are in the Tables 3 and 4.

The measurements using SDR platform HackRF One were carried out in 13 different locations around TV tower in Kyiv. Due to the greater samples only average values are included to the Table 5.

TABLE 3

ESTIMATION OF OCCUPIED BANDWIDTH AND AMENDMENT TO -10 DB BANDWIDTH USING R&S U3772 ADVANTEST AT SPAN = 10 MHZ, RBW = 10 KHZ

Frequency, MHz	Occupied bandwidth, MHz	Bandwidth at -10 dB, MHz	Amendment, kHz
514	7.470	7.608	138
538	7.480	7.582	102
554	7.410	7.568	158
634	7.570	7.660	90
650	7.550	7.678	128
698	7.551	7.685	134
714	7.471	7.635	164
818	7.501	7.643	142
Average values	7.500	7.632	132

TABLE 4

ESTIMATION OF OCCUPIED BANDWIDTH AND AMENDMENT TO -10 DB BANDWIDTH USING R&S U3772 ADVANTEST AT SPAN = 10 MHZ, RBW = 3 KHZ

Frequency, MHz	Occupied bandwidth, MHz	Bandwidth at -10 dB, MHz	Amend-ment, kHz
514	7.496	7.588	92
538	7.490	7.610	120
554	7.448	7.588	140
634	7.549	7.614	65
650	7.505	7.613	108
698	7.513	7.609	96
818	7.509	7.607	98
Average values	7.501	7.604	103

TABLE 5

ESTIMATION OF OCCUPIED BANDWIDTH AND AMENDMENT USING SDR PLATFORM HACKRF ONE

Resolu-tion, kHz	Occupied bandwidth, MHz	Bandwidth at -10 dB, MHz	Amend-ment, kHz
0.3	7.488	7.586	98
2.44	7.491	7.579	88

The data Table 5 are obtained from averaging many measurements, which gives reason to hypothesize about the normal distribution law. Verification of compliance distribution amendments to the occupied bandwidth definition to normal distribution can be made according to the standard ISO 5479-97. The advantage for the small volumes of samples ($8 \le n \le 50$) is given to Shapiro-Wilk normality test. Besides Shapiro-Wilk test also is used for the data Table 3.

The reason for the use Shapiro-Wilk test (Table 6) is to meet the constraints on the curvature of the empirical curvature

$$b_2 = \frac{\mu_4}{\mu_2^2} < 3,$$

and empirical asymmetry

$$\sqrt{b_1} = \frac{\mu_3}{\sigma^3} < 0.5,$$

here μ_2, μ_3, μ_4 are the second, third and fourth normalized central moments; σ is the root-mean-square deviation.

TABLE 6

PARAMETERS OF SHAPIRO-WILK TEST

Device	*RBW*, kHz	b_2	$\sqrt{b_1}$	Sam-ples	Statistic W
R&S U3772	10	2.13	-0.46	8	0.9396
HackRF	2.44	2,0	-0,13	34	0.9419
HackRF	0.3	2.07	0,39	42	0.9417

Results of occupied bandwidth estimation in places around the Kyiv TV tower obey the normal distribution law with significance level α = 0.05. There is definite difference in amendment values for resolution *RBW* = 3 kHz by R&S U3772 and *RBW* = 2.44 kHz by HackRF One, which for similar measurement conditions can be explained by difference in accuracy characteristics devices.

III. CONCLUSION

Proposed algorithm of *X* dB method ensures the same accuracy of occupied bandwidth estimation as $\beta/2$ -method but permits to carry out control on a larger distances from transmitter antenna.

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Л. В. Сібрук, О. А. Басанський. Вимірювання займаної ширини смуги частот радіовипромінювання цифрового телебачення за методом *X* дБ

Розглянуто визначення займаної ширини смуги частот радіовипромінювання цифрового телебачення за допомогою модифікованого методу *X* дБ. Результати статті дозволяють проводити радіоконтроль займаної ширини смуги частот на більших відстанях від антени передавача у порівнянні з $\beta/2$-методом.

Ключові слова: займана ширина смуги частот; радіовипромінювання; метод *X* дБ, спектр.

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Л. В. Сибрук, А. А. Басанский. Измерение занимаемой ширины полосы частот радиоизлучения цифрового телевидения по методу *X* дБ

Рассмотрено определение занимаемой ширины полосы частот радиоизлучения цифрового телевидения при помощи модифицированного метода *X* дБ. Результаты статьи позволяют проводить радиоконтроль занимаемой ширины полосы частот на больших расстояниях от антенны передатчика по сравнению с $\beta/2$-методом.

Ключевые слова: занимаемая ширина полосы частот; радиоизлучение; метод *X* дБ, спектр.

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