DRM DIGITAL BROADCASTING SYSTEM AUDIO PATH QUALITATIVE CHARACTERISTICS

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ABSTRACT

The Digital Radio Mondiale (DRM) digital broadcasting system is the only ITU-approved digital broadcasting system for the LF, MF and HF bands. Numerous theoretical and field studies, as well as operating experience over the past 20 years, have allowed a good study of digital broadcasting networks organization according to this standard. However, some of the issues related to the audio path formal characteristics were not considered. The article discusses the audio coders used in the DRM system and the available data rates in various immunity modes. A set of test signals for instrumental measurements and listening has been developed. The results of experimental measurements for various data rates are presented. It is shown that the range of modulating frequencies in 7 modes of immunity is not narrower than for FM transmitters. In another 5 modes of noise immunity, the range of modulating frequencies is narrower than for FM transmitters, but wider than for AM transmitters. It is confirmed that at data rates of more than 16.5 kbps, the DRM transmitter signal quality becomes no worse than AM signal transmitter quality. Above 24 kbps, the DRM transmitter signal quality becomes comparable to that of an FM transmitter.

KEYWORDS: *digital broadcasting, DRM, transmitter, sound quality, instrumental measurements.*

I. INTRODUCTION

The Digital Radio Mondiale (DRM) [1] digital broadcasting system is the only ITU-approved digital broadcasting system for the LF, MF and HF bands. The DRM also has an option for the VHF band called DRM+. In the well-known scientific literature, there are many studies related to the requirements for DRM receivers [2], transmitters [3, 4], methods for their construction [5-8], measuring equipment [9], antenna systems [10], results of on-air measurements [11- 12], planning of coverage areas [13-15] and territories [16-20], including Simulcast [21] and single-frequency networks [22-23] modes.

The issues of the DRM system sound path qualitative characteristics were studied by subjective listening tests [24], but were not confirmed by formal instrumental measurements. The article discusses the DRM digital broadcasting system sound path qualitative characteristics in various immunity modes. A comparison is made with analogue broadcasting systems with amplitude and frequency modulation. The results of the conducted instrumental measurements allow broadcasters and operators to make an initial selection of the DRM immunity modes they desire, refining it through subsequent subjective listening tests.

The article is organized as follows. The second section discusses the audio coders used in the DRM system and the available bit rates in various immunity modes. In the third section, a set of test signals is developed and the results of experimental measurements are presented. Finally, the conclusions are collected in Section 4.

II. MATERIALS AND METHODS

Unlike analog broadcasting transmitters with amplitude (AM) or frequency modulation (FM), for the quality parameters of broadcasting (i.e. audio) paths of which there are corresponding regulatory documents, for transmitters operating in the DRM standard, there are currently no such documents. This circumstance is quite natural for digital technology in general, since distortions (frequency, non-linear, etc.) that occur in the transmitter do not affect the quality of the decoded signal - until the threshold allowed for decoding is exceeded. That is why the standards for DRM transmitters are mainly set only for the parameters that determine electromagnetic compatibility [25]. The only normalized parameter that determines the transmitter "quality" is the allowable Modulation Error Ratio (MER) value, which defined in [25] as:

$$MER = 10 \times \log_{10} \left\{ \frac{\sum_{j=1}^{N} (I_j^2 + Q_j^2)}{\sum_{j=1}^{N} (\delta I_j^2 + \delta Q_j^2)} \right\}, dB$$

where Ij, Qj are the values of the received symbol coordinates, δIj, δQj are the distance from the ideal position of the chosen symbol (the centre of the decision box) to the actual position of the received symbol. The value of MER in the transmitter output signal must be at least 30 dB [25]. As a rule, when fulfilling the Out-of-band emission regulations, the requirements for the allowable MER value are met automatically.

Thus, the broadcasting transmitter quality parameters (in the usual sense, these are the range of transmitted audio frequencies, harmonic distortion, intermodulation distortion, crosstalk between stereo channels, etc.) in the DRM system are determined solely by the audio coding parameters. The possibility of using one or another type of audio coders provided in the DRM system and their operation modes are determined by the available transmitted digital stream bit rate (Fig. 1 [26]), which, in turn, is determined by the occupied frequencies bandwidth and immunity modes.

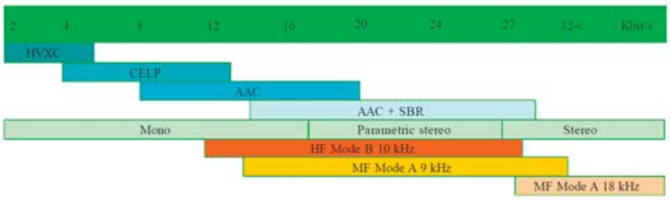

Fig. 1. Bit rate requirements for the different audio coders used in the DRM system

The main characteristics of these audio coders:

For HVXC – Harmonic Vector Excitation Coding (speech only) – bit rate 2000-6560 bps, SBR technology can be used to extend the audio frequency range from 4 kHz to 8 kHz. It can be used when organizing additional speech channels, for example, when transmitting multilingual news;

For CELP – Coded Excited Linear Prediction coder (speech, music at higher speeds possible) - data rate 3860-14000 bps, SBR technology can be used to extend the audio frequency range to 14 kHz;

For AAC (speech, music) coder, as the data rate increases from 8 to 20 kbps, the audio frequency range expands from 4 to 6 kHz. Universal audio coder, designed mainly for "complex" HF channels with low data rates;

The AAC+SBR coder has three audio bandwidth limits:

– 0 875 Hz – at data rates of 14 000-18 460 bps;
– 13 125 Hz – at data rates of 18 480-22 460 bit/s;
– 5375 Hz – at data rates of 22480-28460 bps.

The main application is in standard HF channels with speeds of 17-21 kbps;

Parametric Stereo – minimum bit rate 16480 bps, three audio frequency ranges – same as AAC+SBR mono. It can be used in the LF and MF bands or in "good" single-hop HF channels;

AAC+SBR Stereo – minimum bit rate 26480 bps, two audio frequency ranges:

– 13 125 Hz - at data rates of 26 480-28 480 bit/s;
– 5375 Hz – at data rates of 28480 bps.

It can be used in the LF and MF bands and in dual (18 kHz) MF channels.

The bit rates available in the main service channel (MSC) of the DRM system for the immunity modes used in the LF and MF bands are given in Tables 1 and 2 [26].

Table 1

Data rate (bit/s) in standard mode, Mode A (ground wave)

Parameters ⇓	Bandwidth (kHz)					
	4.5	5	9	10	18	20
64-QAM, rall = 0.5	9 392.5	10 620	19 695	22 142.5	40 935	45 840
64-QAM, rall = 0.6	11 272.5	12 740	23 625	26 570	49 115	54 995
64-QAM, rall = 0.71	13 305	15 045	27 892.5	31 367.5	57 982.5	64 940
64-QAM, rall = 0.78	14 745	16 660	30 910	34 770	64 260	71 970
16-QAM, rall = 0.5	6 262.5	7 080	13 125	14 760	27 285	30 555
16 QAM, rall = 0.62	7 827.5	8 850	16 412.5	18 452.5	34 112.5	38 200

Table 2

Data rate in standard mode, Mode B (skywave)

Parameters ⇓	Bandwidth (kHz)					
	4.5	5	9	10	18	20
64-QAM, rall = 0.5	7 200	8 280	15 332.5	17 477.5	31 817.5	35 760
64-QAM, rall = 0.6	8 640	9 930	18 402.5	20 975	38 180	42 905
64-QAM, rall = 0.71	10 200	11 730	21 720	24 750	45 065	50 660
64-QAM, rall = 0.78	11 300	12 990	24 075	27 450	49 950	56 140
16-QAM, rall = 0.5	4 800	5 520	10 222.5	11 655	21 210	23 835
16-QAM, rall = 0.62	6 000	6 900	12 777.5	14 565	26 515	29 800

It should be noted that options with a minimum data rate (i.e., with maximum immunity) do not suit either broadcasters or listeners in terms of the audio signal quality and can only be used to transmit voice information. "Acceptable quality" of audio content is achieved at bit rates of at least 14 kbit/s (preferably more than 20…22 kbit/s), for which, when using a bandwidth of 9 or 10 kHz, SNR at the receiving point is required from 11 dB to 13 dB (and 15 dB to 20 dB, respectively) depending on propagation conditions.

The ability to use higher bit rates (and get better audio quality) requires higher SNR, and therefore higher transmitter power while maintaining coverage, which broadcasters are usually reluctant to do.

At the same time, the concept of "acceptable quality" has not yet been standardized and formalized. In the DRM consortium promotional materials and in numerous publications, the concept of "quality comparable to VHF broadcasting" appears, based on subjective listening tests (for example, [24]) without specifying technical characteristics.

It is known that the quality of lossy audio encoders can be determined only on the subjective listening tests basis, and instrumental methods for measuring their characteristics do not give an adequate idea of the correctness of their work.

However, the large number of immunity modes provided by the DRM standard, and the corresponding number of different data rates with fine steps between them, make subjective listening tests task for all possible combinations difficult and prohibitively expensive. At the same time, broadcasters and operators who are used to focusing on standardized "quality classes" constantly have questions about what audio bandwidth will be available in a particular mode.

III. Instrumental Measurements

To answer these questions and in order to formalize the audio coding qualitative parameters in various DRM system immunity modes (i.e., at various data rates), a series of instrumental measurements was carried out - with the full understanding that they will not give an adequate idea of the actual audio quality.

When carrying out instrumental measurements, all parameters were checked that are normalized when testing both AM and FM transmitters (bandwidth of modulating frequencies, frequency response permissible deviation, harmonic distortion, intermodulation distortion, immunity from integral noise, crosstalk between stereo channels). The results of these measurements allow interested structures (broadcasters and operators) to compare the DRM transmitters qualitative characteristics with the AM and FM broadcast transmitters parameters and make an initial selection of the DRM immunity modes they desire, refining it through subsequent subjective listening tests.

A summary list of parameters characterizing the broadcast path of AM and FM transmitters quality, is given in Table 3.

Table 3

A summary list of parameters characterizing the broadcast path of AM and FM transmitters quality

Parameter	AM	FM stereo
1. Nominal modulating frequencies range, Hz	50-10000	30-15000
2. Frequency response permissible deviation, dB, not more than: FM AM: Up to 75 Hz and over 6600 Hz AM: 75 Hz to 6600 Hz	 +0,7;-1,3 ±0,7	 ±0,8
3. Harmonic distortion, %, no more than: FM (m=100%, up to 7000 Hz) AM: Up to 100Hz (m=10%, 90%/m=50%) AM: 100Hz to 4000Hz (m=10%, 90%/m=50%) AM: Over 4000Hz (m=10%, 90%/m=50%)	 3,8/1,5 2,0/1,0 4,0/2,0	 0,5
4. Intermodulation distortion, %, no more than: AM: m=90% AM: m=50% FM, 3/5 orders, dB, no more	 10 6	 -50/-55
5. Unweighted (integral) noise level, dB, no more	-58	-62
6. Weighted (psophometric) noise level, dB, no more	-60	-65
7. Crosstalk attenuation between stereo channels, dB: 1000 Hz 120 Hz, 400 Hz, 5000 Hz, 10000 Hz		 50 40

Instrumental measurements of the DRM transmitter broadcasting path parameters were carried out with TRAM-100 transmitter, and DRM coder-modulator DMOD3. A DT700 measuring and control receiver from Fraunhofer was used as a measuring demodulator.

The prepared set of test signals included all the necessary signals to determine AM and FM transmitters parameters in accordance with Table 3, as well as a set of musical fragments for subsequent subjective listening tests.

To reduce measurements time, if possible, common measurement series of frequencies are used, which are a combination of measurement series provided for by the standard measurement methods. The single test signal duration is chosen equal to 2 seconds, which allows to carry out Fourier analysis with sufficient accuracy to determine the harmonic distortion and measure the signal amplitude without taking into account the transient process. Single test signals are separated by 1 second pauses to facilitate their identification. In addition to frequency response measurements were introduced both on a noise signal with a uniform spectrum in the frequency band from 20 Hz to 22 kHz, and using a swept frequency source (sweep generator from 20 Hz to 20 kHz). The nominal range of modulating frequencies is determined by the tolerance for uneven frequency response.

In view of the above, the following set of test signals is defined:

– to measure the frequency response and harmonic distortion according to AM standards, 50% modulation: 1000 Hz, 30, 50, 63, 125, 500, 2000, 4000, 5000, 6000, 7000, 8000, 10000, 15000, white noise 20 seconds;

– for measuring the harmonic distortion according to AM standards, 10% modulation: 1000 Hz, 30, 50, 63, 125, 500, 2000, 4000, 5000, 6000, 7000, 8000, 10000, 15000;

– to measure the harmonic distortion according to AM standards, 90% modulation: 1000 Hz, 30, 50, 63, 125, 500, 2000, 4000, 5000, 6000, 7000, 8000, 10000, 15000;

– to measure frequency response and harmonics distortion according to FM standards, 100% deviation: 1000 Hz, 30, 50, 63, 125, 500, 2000, 4000, 5000, 6000, 7000, 8000, 10000, 15000;

– a ditional pause 1 sec;

– to measure intermodulation distortion according to AM standards m=90%: 80 Hz – 72%, 8000 Hz – 18% (products are calculated relative to 8000 Hz);

– a ditional pause 2 sec;

– to measure intermodulation distortion according to AM standards m=50%: 80 Hz – 40%, 8000 Hz – 10% (products are calculated relative to 8000 Hz);

– to measure intermodulation distortion according to FM standards: equal tones 5000 Hz and 7000 Hz, up to 100% deviation;

– a ditional pause 2 sec;

– to measure the levels of weighted and unweighted noise: 1000 Hz, 100%, 2 sec, then 2 sec pause;

– to measure crosstalk between stereo channels: 120Hz – 4 sec (2 sec in one channel, then 2 sec in another channel), 1s pause, then similarly at frequencies of 400, 1000, 5000, 10000 Hz;

– to measure the frequency response, a sweep frequency from 20 Hz to 20 kHz is additionally used, the duration is 4 seconds (100%).

A pause at the beginning of a set of test signals is 20 seconds, at the end - 10 seconds. The total duration of a set of test signals is 4 minutes 25 seconds. This set of test signals was generated in the Cool Edit Pro program and recorded on a CD that was used for instrumental measurements. The timing diagram of the signals recorded on the measuring disk is shown in Figure 2.

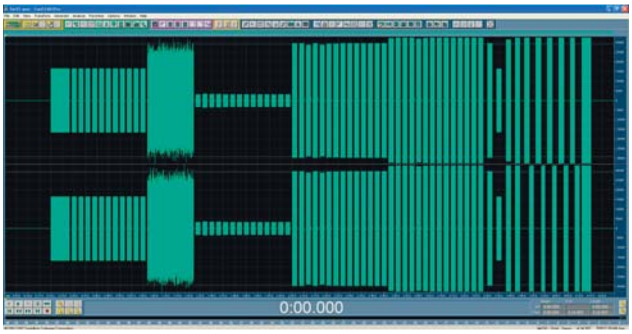

Fig. 2. The timing diagram of the signals recorded on the measuring disk

For all available bandwidths (4.5; 5; 9 and 10 kHz), for immunity mode "A" was set for 16 QAM modulation with immunity levels "0" and "1" and for 64 QAM modulation with noise immunity levels "0", "1", "2", "3". At sufficient transmission rates, the SBR (AAC +) mode was turned on. For some immunity modes, in addition to the "mono" mode, parameters were also measured in the "stereo" and "parametric stereo" modes. The output decoded signal recorded files with test signals were saved for further processing, and with musical fragments - for subjective listening tests. As an example, Fig. 3 shows the timing diagram of the output demodulated signal for mode "A", 9 kHz, 64 QAM, immunity level "1". The spectrum envelope of the swept frequency fragment, illustrating the range of reproducible frequencies for this mode, is shown in Figure 4.

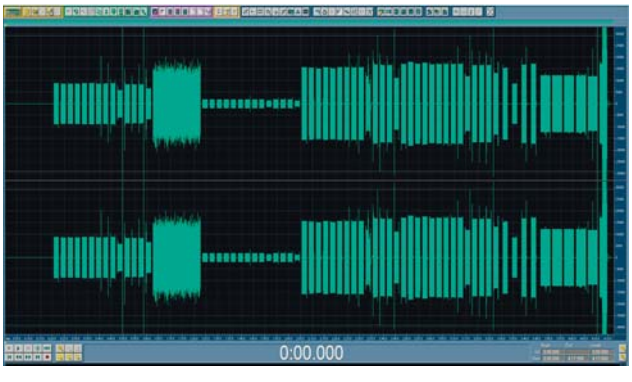

Fig. 3. Timing diagram of the output test signal for mode "A", 9 kHz, 64 QAM, immunity level "1"

The instrumental measurements results showed that the levels of unweighted (integral) noise and weighted (psophometric) noise in all modes of operation were less than -75 dB with the norm for AM no more than -58/-60 dB and the norm for FM no more than 62/-65 dB respectively.

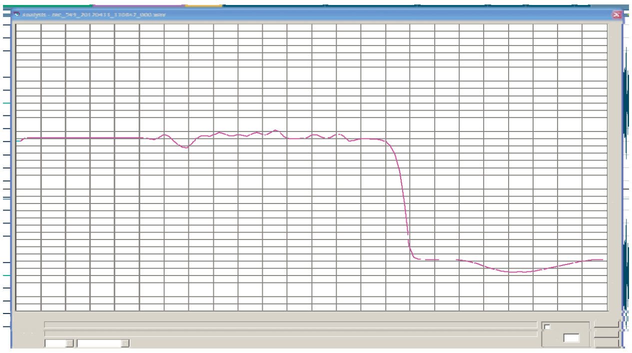

Fig. 4. Sweep spectrum envelope illustrating the reproducible frequency range for mode "A", 9 kHz, 64 QAM, immunity level "1"

Crosstalk attenuation between stereo channels in stereo modes was -77/-78 dB, while the norm in FM mode was -40/-50 dB. The crosstalk between stereo channels in the "Parametric stereo" mode, in accordance with its operation algorithm, depends on the frequency and is -9 dB at a frequency of 120 Hz; -11.6 dB at 400 Hz; -14 dB at 1000 Hz; -21 dB at 5000 Hz and -35 dB at 10000 Hz. The remaining results of instrumental measurements are given in Table 4.

Table 4

Instrumental measurements results

Parameter / ***Mode***	**Modulating frequency range, Hz**	**Harmonic distortion, %**	**Intermodulation distortion, dB**
DRM A10/64/3	16700	0,1	-75
DRM A10/64/2	16700	0,05	-75
DRM A9/64/3	16700	0,05	-75
DRM A10/64/3 Stereo	15000	0,1	-75
DRM A10/64/3 Param. stereo	15000	0,1	-75
DRM A9/64/3 Stereo	15000	0,2	-75
DRM A9/64/1	15000	0,1	-75
FM Stereo Norm	30-15000	0,5	-50/-55
DRM A9/64/2	13800	0,1	-75
DRM A10/64/1	13700	0,2	-75
DRM A9/64/0	12700	0,05	-60
DRM A10/64/0	12000	0,05	-75
DRM A10/16/1	10800	0,05	-60
DRM A10/16/0	10700	0,05	-60
DRM A9/16/1	10700	0,1	-60
DRM A5/64/3	10700	0,2	-60
DRM A5/64/2	10700	0,05	-60
DRM A4,5/64/3	10700	0,05	-60
AM Norm	50-10000	3,8/1,5 2,0/1,0 4,0/2,0	-20/-24
DRM A4,5/64/2	3700	0,05	-
DRM A5/64/1	3100	0,05	-
DRM A4,5/64/1	2800	0,1	-
DRM A4,5/64/0	2600	0,1	-
DRM A9/16/0	2500	0,05	-
DRM A5/64/0	2500	0,05	-

The harmonic distortion given values correspond to the worst case in the entire frequency range. Intermodulation distortion is defined only for those modes, the bandwidth of which allows them to be measured.

As can be seen from Table 4, the transmitter in all studied DRM immunity modes has significantly lower intermodulation distortion and harmonic distortion than required by the standards for AM and FM broadcast transmitters. The range of modulating frequencies in 7 modes of immunity is not narrower than for FM transmitters. In another 10 modes of immunity, the baseband frequency range is narrower than for FM transmitters, but wider than for AM transmitters. A graphical representation of the modulating frequencies range dependence on the immunity mode and the corresponding data rate is shown in Figure 5.

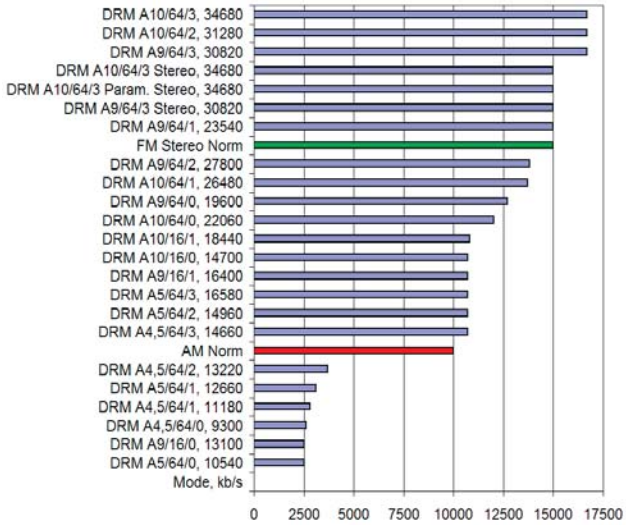

Fig. 5. The range of modulating frequencies vs. immunity mode and the corresponding data rate

If you measure the broadcast transmitter parameters in the DRM mode using traditional analog measuring instruments as a "black box", i.e. without a priori knowledge that it uses digital coding, you can get very high performance, unattainable for AM and FM transmitters. The applied method of instrumental measurements, using spectral analysis, made it possible to reveal some well-known features of low-speed digital coding. In particular, individual spectral components in the high-frequency part of the spectrum can be shifted from their original position.

So, in Fig. 6, the spectrum of the input test signal fragment is shown in blue, and the spectrum of the output signal corresponding to it in mode “A”, 10 kHz, 64QAM, immunity level “3” is shown in pink. The figure shows that the input frequencies of 7, 8, 10 and 15 kHz at the output are represented by slightly different frequency values. This is a well-known feature of this type of audio encoders, due to the algorithm of their work, which cannot be detected when measuring the frequency response with a voltmeter.

The noted circumstance once again confirms the above statement that it is expedient to determine the lossy audio encoders operation quality must based on the results of subjective listening tests, and the instrumental measurements results of their characteristics can only be used for preliminary selection of immunity modes and their comparison.

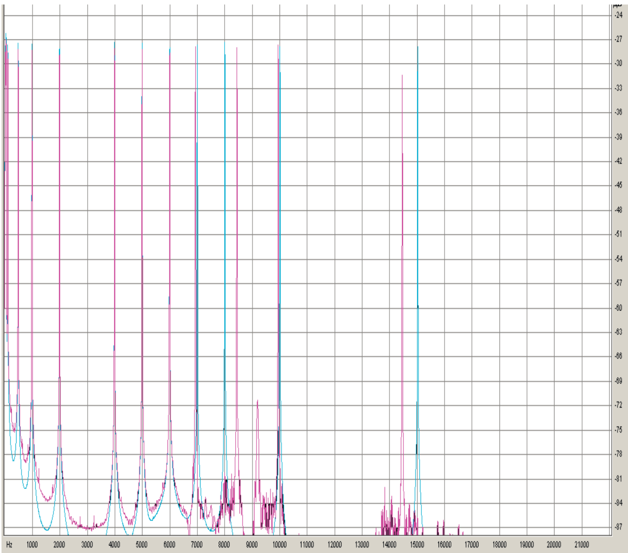

Fig. 6. Comparison the input (blue color) and output (pink color) spectra of the test signal fragments in the "A" mode, 10 kHz, 64QAM, immunity level "3"

The data obtained using instrumental measurements confirm the results of many studies that at data rates of more than 16.5 kbps, the signal quality of a DRM transmitter becomes no worse than AM transmitter signal quality. Above 24 kbps, the signal quality of a DRM transmitter becomes comparable to that of an FM transmitter.

When listening to recorded speech and music fragments encoded at rates of more than 20...24 kbit/s, digital processing artifacts were hardly noticed by ear, and the quality of the sound content could be called "comparable to FM". New xHE-AAC (Extended High Efficiency Advanced Audio Coding) codec allows you to get even higher quality audio content at the same encoding speeds.

IV. CONCLUSION

To study the parameters of the DRM broadcast transmitter, the following work was performed:

– a technique for instrumental measurements of the parameters of the DRM broadcast transmitter has been developed;

– a set of test signals for instrumental measurements and listening was prepared;

– instrumental measurements of the DRM broadcast transmitter parameters with different data rates in the MSC (in various immunity modes) were performed and fragments for instrumental analysis and listening were recorded.

Processing and measurement results analysis showed:

– the measured levels of unweighted (integral) noise and weighted (psophometric) noise in all modes of operation were less than -75 dB with the norm for AM not more than -58 / -60 dB, and the norm for FM not more than -62 / -65 dB, respectively;

– the transmitter in all studied immunity modes has significantly lower intermodulation distortion and harmonic distortion than the norms for AM and FM broadcast transmitters;

– the range of modulating frequencies in 7 modes of immunity is not narrower than for FM transmitters. In another 5 modes of noise immunity, the range of modulating frequencies is narrower than for FM transmitters, but wider than for AM transmitters;

– crosstalk between stereo channels in stereo modes was -77/-78 dB, while the norm in FM mode was -40/-50 dB. The crosstalk between stereo channels in the "Parametric stereo" mode, in accordance with its operation algorithm, depends on the frequency and is -9 dB at a frequency of 120 Hz; -11.6 dB at 400 Hz; -14 dB at 1000 Hz; -21 dB at 5000 Hz and -35 dB at 10000 Hz.

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