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ANALYSIS OF THE ACOUSTIC CLIMATE DURING THE DRILLING OF GAS WELLS IN POST-MINING AREAS**

1. INTRODUCTION

The global economy needs more and more clean energy carriers. Natural gas seems to be an ideal response for this demand. However, extraction and production and other activities for unconventional hydrocarbon (shale gas, tight gas, coalbed methane, coal mine methane) development may cause lots of environmental and human health threats. Over the last decade, the extraction of natural gas from shale formations was widely discussed in many publications and reports (e.g. U.S. Energy Information Agency [36]). Due to the shale gas revolution, the prices of natural gas in the US dropped from more than $12 per BTU (2005–2009) to less than $3 today. Despite the optimistic prognosis of the implementation of American experiences on the European market [37, 38] all attempts have thus far been unprofitable and only a few companies have retained concessions for unconventional gas extraction.

Large-scale development of unconventional gas production has an indisputable impact on life comfort and the level of environmental contamination. Complex issues of the negative influence of unconventional gas extraction have been presented in articles and government reports (e.g. NIOSH [27] [and articles: 15, 24, 25, 26]. Shonkoff et al. [35] pointed out and summarized the body of evidence associated with exposure pathways in order to evaluate the potential environmental public health impact of shale gas development. The authors identified data gaps and research limitations in the field of air quality, water contamination, toxicity and possible exposure pathways. Detailed issues concerning the impact of hydraulic fracturing of shale plays on human health were published by Finkel et al. [5, 6]. Similarly, the Law et al. [17] article discusses the potential impact of hydrocarbon extraction on public health. Werner et al. [39] published a review article based almost 110 other peer-reviewed articles, public reports or gray literature. The majority of references were focused on the short-term

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health impact rather than the long-term. Additionally, most of the published papers related to environmental issues described the quality of typical media like air and water (before and after hydraulic fracturing processes) Werner et al. [39] Public health impact, air pollution and ground water contamination, water demand for hydraulic fracturing, legal aspects and other issues of shale gas extraction based on Polish experiences were published in numerous articles. The environmental impact of exploration from unconventional gas deposits were discussed in Macuda & Konieczyńska [21]. The occurrence and measurements of radioactivity in waste generated during shale gas development works in the northeast of Poland can be found in Jodłowski et al. [14] The evaluation of environmental hazards during shale gas exploration processes in Poland between 2012 and 2014 was made by Konieczyńska et al. [16].

As mentioned above, large-scale unconventional gas production became successful only in the US while European attempts did not give satisfactory/commercial gas rates. Finally, taking advantage of the US experiences and knowledge, Castro-Alvarez el al. [4] provide some helpful advice and guidelines in sustainable unconventional gas production for Mexico and other emerging hydrocarbon developers. Among the various aspects associated with environmental pollution/contamination, noise will be detailed discussed within this article.

American examples of noise measurements during unconventional oil and gas development

Noise or unwanted, annoying sound could be described as a biological stressor and potential human health hazard (according Hays et al. [9]). The authors summarized and concluded numerous noise measurements results associated with O&G extraction that had been published within articles and government reports (BoLM [3], NYCDEC FSGEIS [27], McCawley [23]; Garfield Country Colorado [8]; Ambrose and Florian [1], Witter et al. [40], Behrens and Associetes Inc [2]; MIfAEH [22]). Based on the publications listed above, Hays et al. [9] extracted measurements or estimations of average noise level or range (dBa) during: general works, access road construction, site preparation and well pad preparation, truck traffic, vertical and horizontal drilling, fracturing and flowback, flaring and compressor station works.

Table 1 shows all of the available measurements/estimated data collected by Hays et al. (2017). According to the articles and reports, noise level occurred during general works reached 70–90 dBA (on site < 50 feet). Other publications suggested noise emissions between 30 dBA and 87 dBA (depend on distance from pad center). Road construction and site access works generated noise from 89 dBA to 57 dBA (estimated from 50 ft to 2000 ft). Site/pad preparation processes emitted between 84 dBA and 52 dBA of noise. The highest values are reached during hydraulic fracturing operations (up to 105 dBA, nearer than 50 ft from the wellhead). Within the article [9] the authors compared measured noise levels with its thresholds with various health outcomes. Another article worthy of note is Fry [7] which discusses urban gas drilling and distance ordinances in the Texas Barnett Shale. The author pointed out that because of the shale gas fiver, the drilling pad was moving nearer and nearer to urban area. He summarized all municipal noise and emissions standards in Danton Country (North Texas).

Table 1

Noise levels (measurements and estimations) associated with unconventional hydrocarbon development after Hays et al. [9]

Category	Distance [m]	Average [dBA]	Range [dBA]	Data type	Reference
General works	<15	–	70–90	measurement	BoLM, 2016 [3]
Access road construction	15	89	–	estimation	NYSDEC FSGEIS, 2015 [28]
	76	75			
	152	69			
	305	63			
	457	59			
	610	57			
Site preparation	191	58–69	–	measurement	McCawley, 2013 [23]
Well pad preparation	15	84	–	estimation	NYSDEC FSGEIS, 2015 [28]
	76	70			
	152	64			
	305	58			
	458	55			
	610	52			
Truck traffic	<152	–	65–85	estimation	Garfield County, Colorado, 2011 [8]
	191		56–73	measurement	McCawley, 2013 [23]
Horizontal drilling	15	76	–	estimation	NYSDEC FSGEIS, 2015 [28]
	76	62			
	152	56			
	305	50			
	457	47			
	610	44			
Vertical drilling	191	54	–	measurement	McCawley, 2013 [23]
Drilling (unspecified)	100	57.4–62		estimation	Ambrose and Florian, 2014 [1]
	300	52.5		measurement	
	1055	36.9			
	2300	30.4			
	191	75–80			Witter et al. 2013 [40]

Table 1. cont.

Category	Distance [m]	Average [dBA]	Range [dBA]	Data type	Reference
Drilling (unspecified)	30	–	75–87	measurement	behrens and Associates, Inc., 2006 [2]
	61		71–79		
	91		65–74		
	122		60–71		
	152		56–68		
	183		54–59		
	213		51–55		
	244		51–54		
Hydraulic fracturing	15	99–104	–	estimation	NYSDEC FSGEIS, 2015 [28]
	76	85–90			
	152	79–84			
	305	73–78			
	457	69–74			
	610	67–72			
	191	52	47–60	measurement	McCawley, 2013 [23]
Hydraulic fracturing/ flowback	191	58	55–61	measurement	McCawley, 2013 [23]
Compressor station(s)	<305	63.15	35.3–94.8	measurement	MIfAEH, 2014 [22]
	305–610	55.48	35.3–77.6		
	610–762	54.09	35.3–80.3		
	>1067	51.50	35.3–74.1		
	On-site	69–86	–	measurement	BoFM, 2006 [3]
	1609	58–75			
	2012	54			
	100	53,8		estimation	Ambrose and Florian, 2014 [1]
	140	50,9		measurement	

Polish examples of noise measurements during unconventional gas extraction

Between 2009 and 2015, Poland tried to repeat the American success with unconventional gas extraction. From 2010 to the end of 2015, 16 horizontal and 54 vertical wells were competed [12]. During that period noise level was measured. Łukańko & Macuda [18, 19] described the survey methodology based on Polish regulations [30–34] and published environmental noise emitted (measured at day and night) by a MASS 6000E rig equipped with three power generators KATO, top drive PTD-500, three mud shakers SWACO, and three mud pumps T1300. In total, 32 measured points were established. Eight points at a distance of 50 m from well and 32 points between 100 m and 400 mfrom the drilling pad center. The highest values of noise emissions, 50 m from well, were equal to 85.2 dB (day) and 85.3 dB (night). The lowest were equal to 57.1 dB (day) and 57.2 dB (night). At the farthest measurement points (400 meters from the well pad), the highest noise values were equal to 46.2 dB (day), 45.4 dB (night) and the lowest survey results were equal to 36.3 dB (day) and 34.7 dB (night).

2. NOISE LEVEL MEASUREMENTS DURING DRILLING BOREHOLES BY DOWN-THE-HOLE HAMMER TECHNOLOGY

Typical, rotary drilling technology, rotary table or top-drive systems are commonly used to drill vertical boreholes up to 1000 m. However, this technique could not be employed during the drilling of gas wells through unconsolidated layers and crushed strata formed due to underground hard coal mining extraction. During the realization of the ZEC-AGH "GEKON" project (grant no GEKON1/O1/213764/10/2014) at the AGH Drilling Oil & Gas Faculty, implementation of Casing-While-Drilling (CwD) technology was proposed to solve this problem. Investigators also suggested using top hammer or down-the-hole hammer technology to increase success probability and cut the total costs of operations. Detailed information was presented in papers [11, 20, 21]. Gas wells drilled from the surface in the post-mining area are most frequently realized in highly urbanized areas and close to the existing residential quarters. This creates a real hazard of exceeding admissible noise levels for the night and for day hours. Therefore it is very important to assess the noise level emitted during drilling operations and determines the range of 45 dB and 55 dB isophones for various terrain conditions [33]. Possessing such information, one can properly localize the well pad at the stage of designing and place objects which require acoustic protection at a safe distance.

To establish the level of noise emitted to the environment during the drilling experimental gas well Wieczorek-AGH-1, noise analyses were performed within the well pad area and its closest vicinity. Noise level was measured during the day and at night hours, while drilling the upper part of the well with the rotary method with right mud circulation, and during the drilling of the lower part of the well with the percussion-rotary method using a down-hole hammer. To establish the acoustic background within the well pad, noise level was measured after finishing the drilling operations during the day and at night hours.

Noise measurements were performed with the reference method discussed in the Regulation of the Environment Minister of 30 October 2014 about requirements on the analyses of emission and quantity of water consumption (Official Journal of 2014, item 1542), hereinafter referred to as Regulation [34].

Location of the experimental Wieczorek-AGH-1 well

The experimental gas well Wieczorek-AGH 1 was located at lot no. 948/55 at Kosmiczna Street (near Roździeński Shaft) in Katowice, Silesian voivodeship. The location of the well pad is presented in Figures 1 and 2.

Fig. 1. Study area

Source: www.GoogleEarth.com

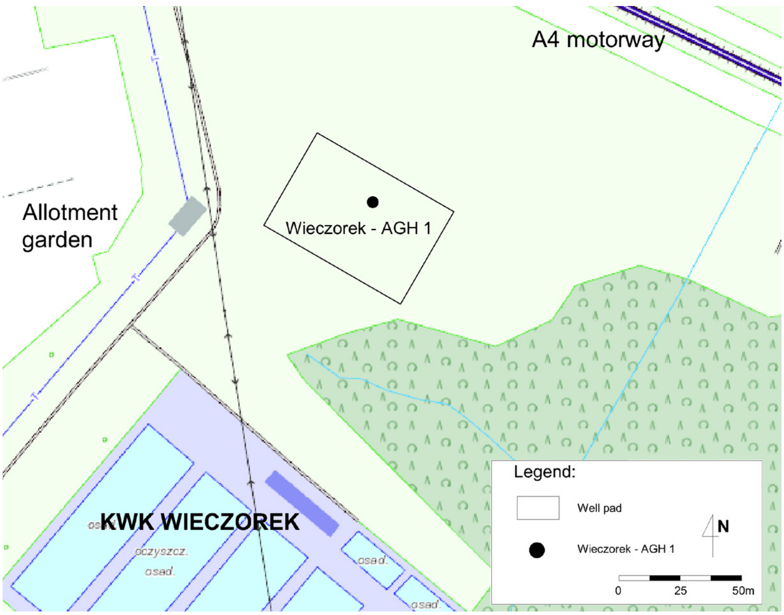

Fig. 2. Map of the location of experimental gas well Wieczorek-AGH-1

The well pad is located about 100 m from the A4 motorway to the north and 150 m from the Coal Mine Wieczorek to the south. It borders a forest on the eastern side and allotment gardens to the west, separated by a coal conveyor from the rig pad.

Description and characteristics of noise sources

Owing to the character of the works performed, all sources of noise at particular stages of drilling were active 24 hrs a day. The experimental well Wieczorek-AGH-1 was realized with a Wirth B-3A rig. The rig was equipped with a driving head, with which the drilling could be realized with the rotary method with right mud circulation, and with the percussion-rotary method using a down-hole hammer.

During measurements in the well pad are, a the noise level was established at a distance of 1 m from the main sources of noise. Measured values of noise emitted from these sources were as follows: driving head – 87.2 dB, mud pump EMSCO HTF 500 – 97.7 dB, air compressor Atlas Copco XRVS336 – 87.5 dB, air compressor Atlas Copco type XRXO667 – 98.9 dB. The localization of major sources of noise on the well pad is presented in Figure 3.

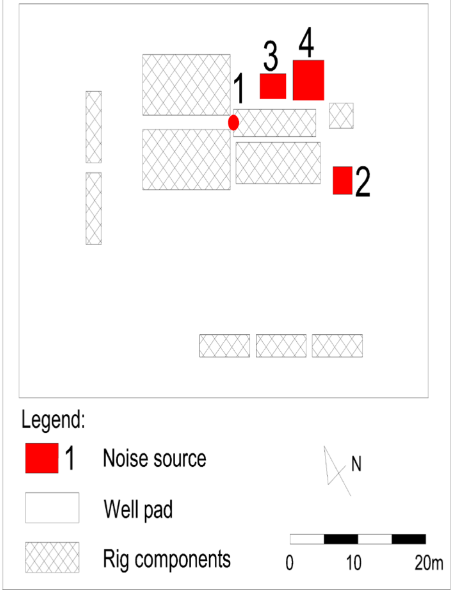

Fig. 3. Major sources of noise during the realization of the gas well Wieczorek-AGH-1 (1 – driving head, 2 – mud pump EMSCO HTF 500, 3 – air compressor Atlas Copco XRVS336, 4 – air compressor Atlas Copco XRXO667)

Location of noise measurement points

Measurement points of noise level were located according to criteria defined in appendix no. 7 of the ministerial Regulation [34], taking into account major sources of noise on the well pad. Eleven measurement points were defined for determining noise level during the realization of the well Wieczorek-AGH-1: 8 measurement points on the border of rig, numbers 1–8 and 3 measurements points on the rig pad (numbers 9–11). The location of noise measurement points is presented in Figure 4.

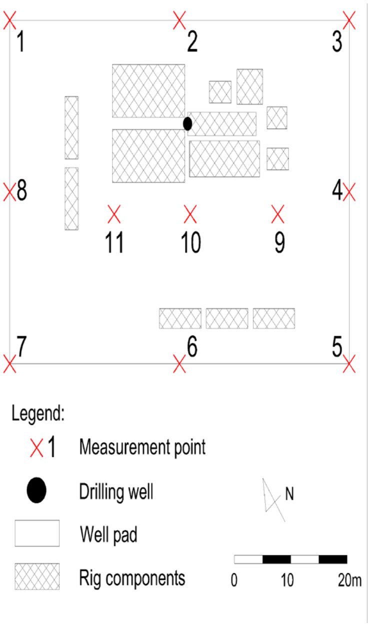

Fig. 4. Map of the location of noise measurement points

Noise level measurements during the realization of experimental gas well Wieczorek-AGH 1

The noise level was measured with the reference method, i.e. noise measurements were performed in the environment. The noise came from the devices and systems, except the impulse noise, as in appendix no. 7 to the Regulation [34]. The measurements were performed directly in the field and the elementary noise samples in reference (sampling) time T were taken. The measuring time totaled to 60 seconds. The microphone was placed at 1.5 m a.s.l. [13, 29–32]. Noise measurements were performed with a noise meter SVAN 971 and a microphone 7052E no. 66800. Atmospheric conditions during noise measurements were observed at the meteorological station Vantage Vue. The results of noise measurements during the drilling of the experimental well Wieczorek-AGH 1 were worked out on the basis of formulae in appendix no. 7 to the Regulation [34]. Accordingly, the following parameters should be established for assessing the noise level:

- average noise level L_{Asr},
- level of noise emission L_{Aek},
- noise level at measurement point, expressed with equivalent noise level A in reference time L_{Aeq}.

Determining average noise level L_{Asr}

The average noise level was determined on the basis of equation (1), as in the Regulation [34]:

$$L_{Asr} = 10\lg\left(\frac{1}{n}\sum_{k=1}^{n}10^{0.1L_{Ak}}\right) \tag{1}$$

where:

n – number of samples in a measurement series,
L_{Ak} – measured noise level in time t_0 [dB].

Level of noise emission

The noise emission level L_{Aek} measured in time interval t_p was determined with equation (2), as in the Regulation [34]:

$$L_{Aek} = 10\lg\,(10^{0.1L_{Asr}} - 10^{0.1L_t}) \tag{2}$$

where:

L_{Asr} – average noise level for time interval t_p or average noise level for a given source [dB],
L_{At} – average noise level of acoustic background [dB].

Determining noise level at measurement point expressed with equivalent noise level A for reference time *T* ($L_{Aeq,T}$)

Noise level at a given measurement point was calculated on the basis of determined average noise levels L_{Asr} in particular time intervals with equation (3), as in the Regulation [34]:

$$L_{AeqT} = 10\lg\left(\frac{1}{T}\sum_{j=1}^{m}t_j 10^{0.1L_{Aekj}}\right) \tag{3}$$

where:

m – number of time intervals t_p,
L_{Aekj} – level L_{Aek} for j-th time interval t_p [dB],
t_j – duration of j-th time interval t_p [s],
T – reference time [s].

The time intervals t_p and reference time T can be expressed in other units, e.g. in minutes, hours, provided the same units have been assumed. Parameter L_{AeqT}, calculated with the equation corresponding to the noise index [34]:

- $L_{Aeq\,D}$, if parameters and calculations were referred to reference time T = 8 hrs (28800 s) during the day (6:00–22:00),
- $L_{Aeq\,N}$, if parameters and calculations were referred to reference time T = 1 hr (3600 s) at night (22:00–6:00).

The results of the measurement of environmental noise emitted during the drilling of experimental well Wieczorek-AGH-1 are presented in Tables 2–5.

Table 2

Noise level measurement during the rotary drilling method – day hours

No. measurement point	Measured noise level of a sample L_{Ak} [dB]	Duration of measure-ment t_0 [s]	Average noise level $L_{Aśr}$ [dB]	Average level of acoustic background L_{At} [dB]	noise level emission L_{Aek} [dB]	Time interval duration t_p [h]	Equivalent noise level L_{AeqT} [dB]
1	66.1; 66.3; 66.2	60	66.2	55.8	65.8	28800	65.8
2	71.8; 71.7; 72.3	60	71.9	55.6	71.8	28800	71.8
3	72.2; 72.9; 72.0	60	72.4	55.5	72.3	28800	72.3
4	75.2; 75.1; 75.3	60	75.2	55.3	75.2	28800	75.2
5	71.9; 72.2; 72.6	60	72.2	54.1	72.1	28800	72.1
6	68.5; 68.9; 68.3	60	68.6	53.2	68.5	28800	68.5
7	69.1; 68.9; 69.6	60	69.2	54.5	69.1	28800	69.1
8	65.2; 65.4; 65.9	60	65.5	55.5	65.0	28800	65.0
9	90.1; 89.6; 90.4	60	91.6	55.2	91.6	28800	91.6
10	80.5; 81.0; 81.2	60	80.9	55.3	80.9	28800	80.9
11	77.7; 78.3; 78.4	60	78.1	55.4	78.1	28800	78.1

Table 3

Noise level measurement during the rotary drilling method – night hours

No. measurement point	Measured noise level of a sample L_{Ak} [dB]	Duration of measure-ment t_0 [s]	Average noise level $L_{Aśr}$ [dB]	Average level of acoustic background L_{At} [dB]	noise level emission L_{Aek} [dB]	Time interval duration t_p [h]	Equivalent noise level L_{AeqT} [dB]
1	68.7; 68.5; 68.6	60	68.6	51.6	68.5	3600	68.5
2	73.8; 73.6; 74.1	60	73.8	51.7	73.8	3600	73.8
3	74.9; 75.6; 75.0	60	75.2	51.6	75.2	3600	75.2
4	77.8; 78.2; 78.4	60	78.1	50.7	78.1	3600	78.1
5	74.1; 74.6; 74.3	60	74.3	49.7	74.3	3600	74.3
6	70.5; 71.2; 70.9	60	70.9	48.2	70.9	3600	70.9
7	71.3; 71.7; 70.9	60	71.3	50.1	71.3	3600	71.3
8	68.3; 67.9; 67.9	60	68.0	51.2	67.9	3600	67.9
9	91.9; 91.5; 91.6	60	91.7	50.8	91.7	3600	91.7
10	83.0; 83.4; 83.8	60	83.4	50.9	83.4	3600	83.4
11	80.2; 79.5; 79.3	60	79.7	51.0	79.7	3600	79.7

Table 4

Noise level measurement during the percussion-rotary method – day hours

No. measurement point	Measured noise level of a sample L_{Ak} [dB]	Duration of measure-ment t_0 [s]	Average noise level $L_{Aśr}$ [dB]	Average level of acoustic background L_{At} [dB]	noise level emission L_{Aek} [dB]	Time interval duration t_p [h]	Equivalent noise level L_{AeqT} [dB]
1	72.5; 73.0; 72.7	60	72.7	55.8	72.6	28800	72.6
2	74.2; 74.7; 75.2	60	74.7	55.6	74.6	28800	74.6
3	66.2; 66.0; 66.8	60	66.3	55.5	65.9	28800	65.9
4	72.6; 72.5; 72.7	60	72.6	55.3	72.5	28800	72.5
5	64.4; 64.8; 64.4	60	64.5	54.1	64.1	28800	64.1
6	69.7; 69.6; 69.3	60	69.5	53.2	69.4	28800	69.4
7	65.1; 65.2; 65.1	60	65.1	54.5	64.7	28800	64.7
8	71.5; 72.2; 71.8	60	71.8	55.5	71.7	28800	71.7
9	77.9; 77.2; 77.7	60	77.6	55.2	77.6	28800	77.6
10	78.9; 78.5; 78.2	60	78.5	55.3	78.5	28800	78.5
11	78.3; 78.7; 78.3	60	78.4	55.4	78.4	28800	78.4

Table 5

Noise level measurement during the percussion-rotary method – night hours

No. measurement point	Measured noise level of a sample L_{Ak} [dB]	Duration of measure-ment t_0 [s]	Average noise level $L_{Aśr}$ [dB]	Average level of acoustic background L_{At} [dB]	noise level emission L_{Aek} [dB]	Time interval duration t_p [h]	Equivalent noise level L_{AeqT} [dB]
1	72.4; 73.1; 72.8	60	72.4	51.6	72.4	3600	72.4
2	74.1; 74.5; 75.1	60	74.6	51.7	74.6	3600	74.6
3	66.4; 66.1; 66.1	60	66.2	51.6	66.0	3600	66.0
4	72.4; 72.2; 72.6	60	72.4	50.7	72.4	3600	72.4
5	64.1; 64.4; 64.2	60	76.4	49.7	66.0	3600	66.0
6	69.3; 69.2; 69.5	60	69.3	48.2	69.3	3600	69.3
7	64.8; 65.0; 65.2	60	65.0	50.1	64.9	3600	64.9
8	71.1; 71.3; 71.3	60	71.2	51.2	71.2	3600	71.2
9	77.7; 77.6; 77.9	60	77.7	50.8	77.7	3600	77.7
10	78.9; 78.4; 77.9	60	78.4	50.9	78.4	3600	78.4
11	77.9; 78.3; 78.7	60	78.3	51.0	78.3	3600	78.3

2. CONCLUSIONS

The analysis of the results of measurements of noise emissions to the environment during drilling operations reveals that the noise level accompanying the realization of the well with the right mud circulation was higher than while drilling the lower part of the well using a down-hole hammer. The biggest difference in the measurement of noise level was observed at point 9 (measurement in the first measurement session 77.6 dB(D), 77.7 dB(N)) and equaled 14.0 dB both for the day and night hours. The noise measured 1 m from the mud pump equaled 97.7 dB. During the drilling of the well with the rotary method with right mud circulation, the noise at the border of the well pad was higher at measurement points 3, 5 and 6 than when using a down-hole hammer. These points were located close to the main source of noise, i.e. the mud pump. During the drilling of the well with the percussion method, the noise level was measured at point 2, i.e. close to air compressors. Noise measurements performed during drilling using a down-hole hammer were carried out for only one operating compressor, the Atlas Copco XRVS336. The compressor sufficed to drive the down-hole hammer and remove the cuttings. The noise level measured 1 m from the compressor equaled 87.5 dB. Another compressor, the Atlas Copco XRXO667 operated sporadically, especially when purging the well. For further analyses, noise measurement was also performed at a distance of 1 m from the operating compressor Atlas Copco XRXO667 and the result equaled 98.9 dB.

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