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Verification Methodology of Fade Characteristics in a DAB+ SFN in Wroclaw

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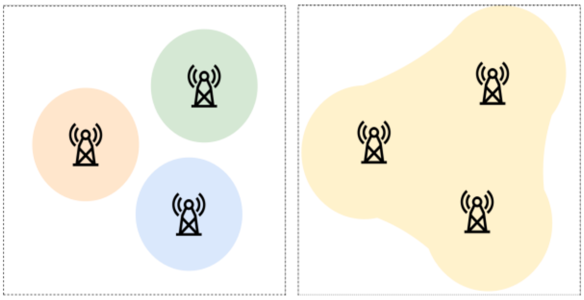
Abstract—The article presents the methodology for measuring verification of the phenomenon of fades in the DAB+ SFN. The verification is related to comparing the characteristics of the fades determined theoretically with the occurring fades in the real environment of a large city. The conditions favorable for the occurrence of fading are presented and by selecting the appropriate propagation analysis tool, the places where the occurrence of fading is most likely were selected. In these places an analysis of the characteristics of fades was carried out and the conditions for their verification were determined.

Keywords—single frequency network (SFN), DAB+, fade characteristics, fade measurements

I. INTRODUCTION

THE Single Frequency Network (SFN) are now often used in both DVB-T digital terrestrial television and DAB+ digital radio, especially in European countries and Australia [1]. In Poland, coverage is at 56% (2019). Their main advantage of this type of networks is the much more efficient use of spectral space. A network of multiple transmitters operating at the same frequency, transmitting the same signals and meeting the relevant synchronization requirements [2] can cover a much larger area and fill the gaps in the range (gap filling technique), while minimizing the total radiated power [3]. Thanks to the radio interface with orthogonal frequency division multiplexing OFDM, the signals from the transmitters are superposition in the receiving antenna and leading to an increase in antenna output power in the receiver band. The phenomenon of increasing the received power in the receiver band, referred to as network gain, was presented in [4], while in relation to the DAB+ network in Wroclaw for unified emission parameters of transmitters using a propagation model over perfectly conductive flat ground in [5]. Symbolically, the effect of increasing coverage is shown in Fig. 1.

Many publications were devoted to methods of determining network gain and coverage in the SFN network compared to these obtained in MFN (Multi-Frequency Networks) [6], the impact of coding efficiency and network gain on coverage [7] and testing the quality of the audio signal received in the DAB+ network [8,9,10], comparing this quality to streaming [11,12]. Due to the sum of signal strengths transmitted in the SFN network, an increase in the signal level at the output of the receiving antenna should be expected in relation to the level when this antenna receives the signal from only one transmitter. In extreme cases, network gain can be 6 dB when two signals are being considered and 9.5 dB for three signals.



a) b)

Fig. 1. Coverage obtained in the multi-frequency network (a) and in the single-frequency network (b)

In the literature, you can find numerous publications presenting the principles of SFN network design, which presents methods of network optimization in terms of interference and maximizing coverage [13, 14].

However, the superposition of electromagnetic waves of the same frequency also causes fading. For broadband signals, these fades will be selective and will occur only if the relationship (1) is met:

$$\Delta d_{i+1} = (2n-1)\cdot\frac{i}{N}\lambda \quad \text{for } N \text{ even} \tag{1a}$$

$$\Delta d_{i+1} = 2n\cdot\frac{i}{N}\lambda \quad \text{for } N \text{ odd} \tag{1b}$$

wherein:

Δd_{i+1} – path difference between the ith signal (i > 0) and the reference signal (i = 0),
λ – wavelength,
n – multiple of the i/N wavelength shift from the reference signal,
n = 1, 2, …,
i – number of signal reaching the receiver, i = 0, 1, 2, …, N-1,
N – total number of signals reaching the receiver.

In the case of two interfering signals, the relationship (1) can be represented in the form (2):

$$\Delta d_k = |d_1 - d_2| = (2\cdot k+1)\cdot\frac{\lambda}{2} = (2\cdot k+1)\cdot\frac{150}{f_{[MHz]}} \quad [\mathrm{m}] \tag{2}$$

wherein: $k = 0, 1, 2, \ldots$

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In the years 2015 - 2017, a project called "Single Frequency Network Using the DAB+ Broadcasting Platform for the Needs of Local Broadcasters in Poland" - LokalDAB [15] was implemented by the Wrocław University of Science and Technology (WUST), the National Institute of Telecommunications (NIT) and Polish Radio Wroclaw (PRW). The main goal of the project was to develop a single frequency network demonstrator based on a set of three broadcast platforms working in the DAB+ standard, based on universal programmable circuits and "open source" software. The indirect goal was to encourage and propagate the idea of digital radio in the environment of local broadcasters by constructing a relatively inexpensive, complete broadcasting platform. As at February 27, 2020, as part of the LokalDAB multiplex, 11 local stations were broadcast with diverse program themes, including Academic Radio LUZ, Disco Radio or Radio Rodzina [16]. Therefore, there was a real possibility of verifying the results obtained through theoretical analyzes with the results of measurements. Such studies have not yet been published in technical literature. Due to the need to maintain the continuity of radio program emissions, the test program and procedures had to take into account the prohibition to turn off transmitters and the need to perform measurements on a normally operating network. While a number of publications have been devoted to the positive phenomena associated with the use of single-frequency networks, e.g. [17], the phenomenon negatively affecting the reception of signals from many transmitters operating in the SFN network has been devoted to a small number of publications.

With regard to SFN, the potential adverse effect on signal reception problems was noticed in [18], [19] and developed in [20], [21], [22] and [23]. The author in [18] presents the problem of fading in single-frequency networks of the DRM+ system, where due to the use of 9 kHz or 10 kHz wide channels, the probability of loss of communication due to interference becomes very likely. In the analyzed DAB+ system, due to the use of 1536 subcarriers with a width of 1 kHz each (broadband transmission), the risk of breaking the reception of signal decreases. However, it is anticipated that a fade will result in an incorrect receipt. In works [20], [21], [22] and [23] the gradual development of the model for analysis based on propagation over perfectly conductive flat ground was presented. In the first of these, you can find a general formulation of the problem for two and three transmitters. The next publication presents the loss analysis in the network of two transmitters. Expected fade levels are shown. The last of these contains a description of the model for three transmitters with a broad description of the predicted levels of electric field strength for different routes. In [5], for the first time, the selective nature of fading is strongly associated with the difference in the length of signal propagation paths to the observation point, and [23] presents changes in the fading characteristics in a network in which one of the three transmitters stops working.

II. LOKALDAB NETWORK CHARACTERISTICS

Three transmitters were built as part of the LokalDAB project. Their location was closely related to the possibilities of installing broadcasting systems in the facilities of the consortium members of the project and they are shown in Fig. 2.

Fig. 2. Distribution of transmitters in the network LokalDAB.

In order to verify the results of theoretical analyzes, it should be ensured that these results include the theoretical model that best describes the propagation environment in which the measurements will be carried out. One of the possible models is the ITU-R P.1546 [24] model, dedicated to determining the level of electromagnetic field strength from digital radio and television transmitters. The use of this model requires knowledge of a number of parameters related to the location of transmitting antennas and emission parameters of transmitters. These parameters are listed for three transmitters in Table I.

TABLE I
LOCALDAB NETWORK TRANSMITTER PARAMETERS

Parametr	WUST	NIT	PRW
City	Wroclaw		
Street	Dluga 67	Swojczycka 38	Karkonoska 10
Middle frequency	216,928 MHz (block 11A)		
Latitude	51^{0}07’37’’ N	51^{0}06’55’’ N	51^{0}04’21’’ N
Longitude	17^{0}00’32’’ E	17^{0}06’48’’ E	17^{0}00’25’’ E
Transmitter power	20.0 dBW	24.0 dBW	21.0 dBW
Fieder attenuation	1.21 dB	0.87 dB	0.94 dB
Transmitting antena gain	15.04 dBd	12.64 dBd	12.64 dBd
ERP	33.83 dBW	35.77 dBW	32.70 dBW
Polarization	Vertical		
Antenna height	36.0 m	24.0 m	16.5 m

The antennas used in the LokalDAB network are not omnidirectional. Therefore, their radiation patterns must be taken into account when determining the e-m field strength. They are presented in Fig. 3-5.

Places where measurement verification of fade characteristics should be carried out must meet a number of conditions. First of all, they must be available and be in the area of similar signal levels from two or three transmitters. This requires a series of preliminary propagation calculations.

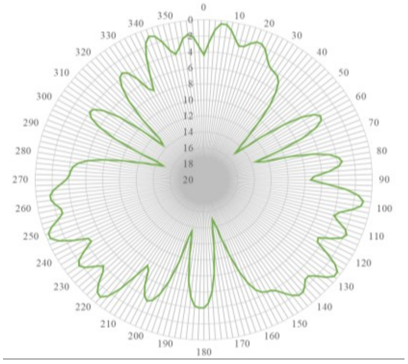

Fig. 3. Horizontal radiation pattern of antenna system at the WUST station.

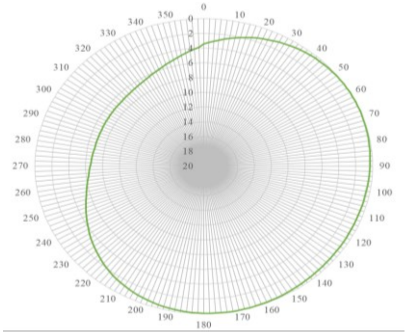

Fig. 4. Horizontal radiation pattern of antenna system at the NIT station.

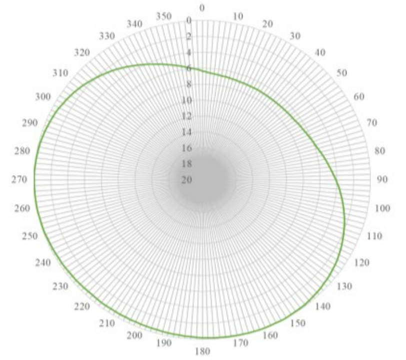

Fig. 5. Horizontal radiation pattern of antenna system at the PRW station.

III. CHOICE OF MEASUREMENT POINTS

The procedure for selecting measuring points has been presented in [25] and divided into two stages. The first one independently analyzes the median electric field strength (50% of time, 50% of places) at a height of 1.5 m above ground level (mobile reception) from each of the transmitters. For this purpose, the special software was used, which allows determining the distribution of electric field strength in accordance with ITU-R P.1546 [15] and taking into account the simulation conditions [13], [14]. The parameters of the broadcasting stations in accordance with Table I and the radiation characteristics of the antennas shown in Fig. 3 to Fig. 5 are adopted for the calculations. The simulation results are shown in Fig. 6.

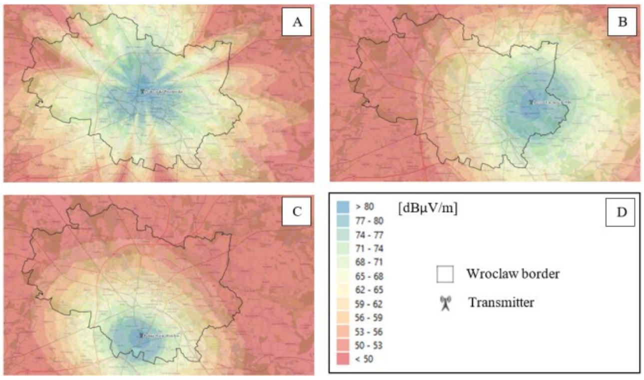

Fig. 6. Electric field strength distribution from LokalDAB transmitters (A – WUST, B – NIT, C – PRW, D – map legend)

In order to observe clear effects related to fades, it is necessary to designate places where the electric field strength from all stations is as equal as possible or for M of N signals is as equal as possible, and the remaining N - M signals reaching the observation point have a much smaller amplitude. Taking this into account, two cases were distinguished: with two dominant transmitters and with three equivalent transmitters.

A. Case with two transmitters

For the case with two transmitters, three possible variants were considered in which the dominant signals came from the station:

- WUST and PRW (Fig. 7),
- NIT and PRW (Fig. 8),
- WUST and NIT (Fig. 9).

Each of the drawings shows the boundaries of areas with the same electric field strength, with one decibel envelope. The curves plotted on the drawings are hyperbolic arms whose shape was chosen experimentally by choosing the appropriate parameter n (1). In the places where the hyperbole intersects the overlapping envelopes of the electric field strength from two transmitters, measuring points were determined. All designated measuring points are located in accessible places (streets, squares or green areas). Table II shows the designated locations for the measurement points and the calculated median electric field strength at these points.

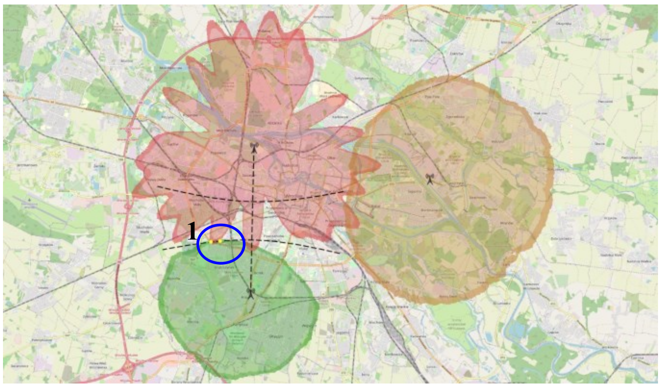

Fig. 7. Designated measuring locations for WUST – PRW route, n = 1 150, Δd = 1 589.70 m.

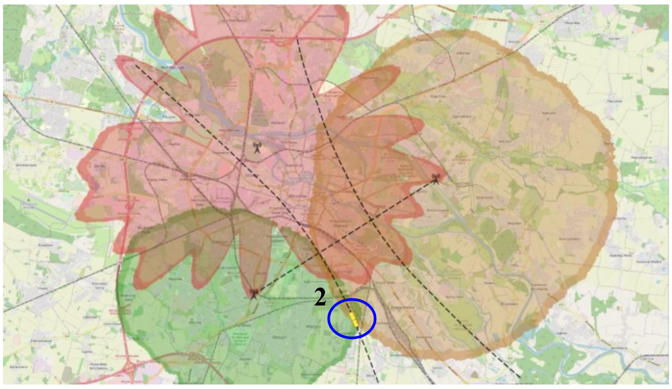

Fig. 8. Designated measuring locations for NIT – PRW route, n = 1 800, Δd = 2 488.61 m.

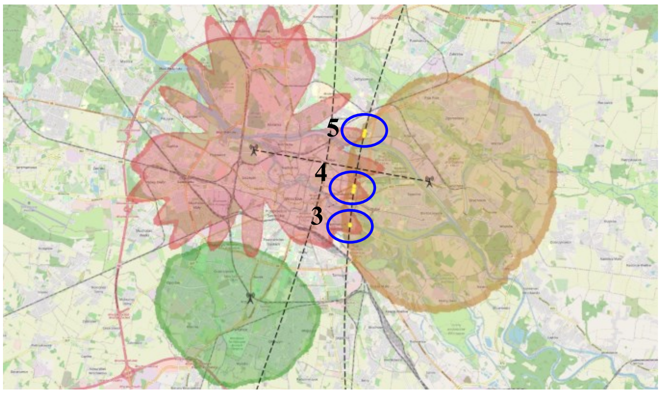

Fig. 9. Designated measuring locations for WUST – NIT route, n = 950, Δd = 1 313.11 m.

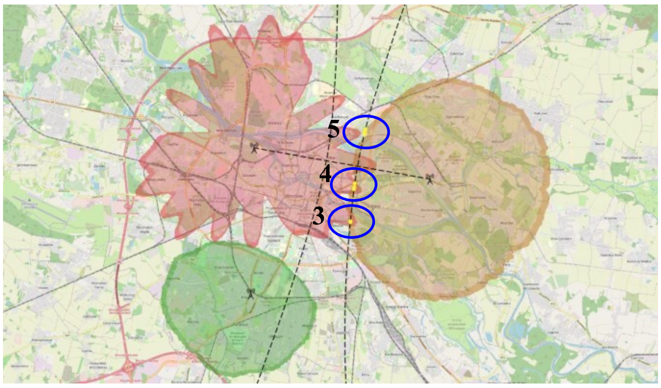

Fig. 10. Designated measuring locations for WUST – NIT route, n = 1 150, Δd = 1 589.70 m.

For each of the measuring points presented in Table II, the electric field strength and fade characteristics were determined for two dominant transmitters and three transmitters. The resultant level of the e-m field was calculated according to (3)

$$\overline{E}_w = \sum_{i=1}^{N} \overline{E}_i = \sum_{i=1}^{N} E_i \cdot e^{j\phi_i} \qquad (3)$$

in which the field strength of the i-th transmitter E_i was substituted from Table II (after converting to a linear scale) while the phase shift from the i-th transmitter φ_i at the analyzed point was calculated according to (4):

$$\phi_i = -\frac{2\pi}{\lambda} \cdot d_i \qquad (4)$$

where: λ - wavelength [m], d_i - distance between the i-th transmitter and the analyzed point [m], i - the number of the transmitter, $i = 1, 2, ...$ The results of the theoretical analysis of the signal level distribution as a function of frequency for points 1-5 are shown in Fig. 11 – 15.

TABLE II
LOCATION OF MEASURING POINTS AND MEDIAN ELECTRIC FIELD STRENGTH FROM THE STATION

No.	Street	Field strength median value dB(μV/m)		
		WUST	NIT	PRW
1	Hallera	57.33	42.47	60.90
2	Konduktorska	48.73	54.37	55.71
3	Okolna	59.83	60.87	43.59
4	Plac Grunwaldzki	61.73	60.27	44.63
5	Gizycka	59.23	59.97	40.30

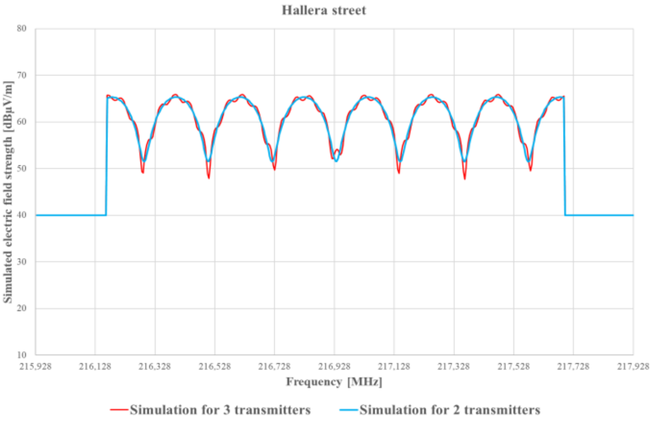

Fig. 11. Resultant electric field strength at the measuring site on Hallera street (51°05'32.80" N, 16°58'54.60" E) considering 2 dominating transmitters and 3 transmitters, d_{WUST} = 4 281.92 m, d_{NIT} = 9 537.86 m, d_{PRW} = 2 881.84 m (electric field strength from transmitters according to Table II).

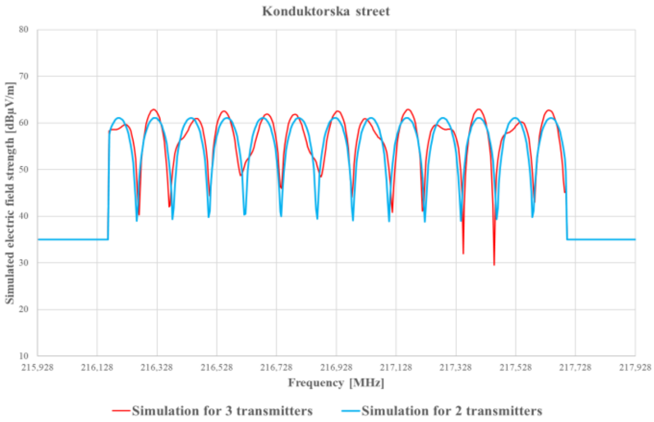

Fig. 12. Resultant electric field strength at the measuring site on Konduktorska street (51°03'54.20" N, 17°03'53.00" E) considering 2 dominating transmitters and 3 transmitters, d_{WUST} = 7 907.68 m, d_{NIT} = 6 540.13 m, d_{PRW} = 4 049.34 m (electric field strength from transmitters according to Table II)

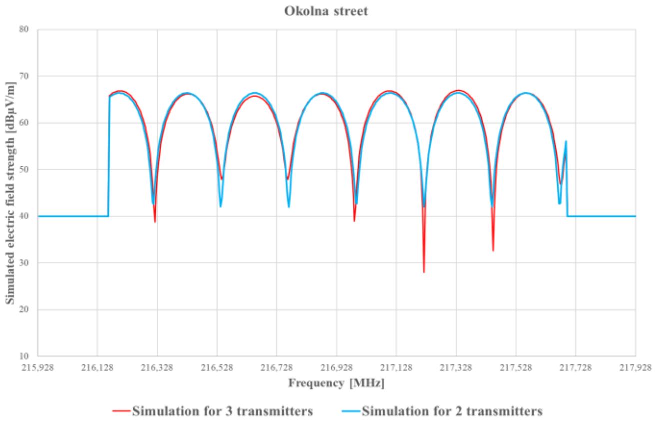

Fig. 13. Resultant electric field strength at the measuring site on Okolna street (51°05'50.30" N, 17°03'58.20" E) considering 2 dominating transmitters and 3 transmitters, $d_{WUST} = 5\ 185.13$ m, $d_{NIT} = 3\ 861.34$ m, $d_{PRW} = 4\ 933.80$ m (electric field strength from transmitters according to table II).

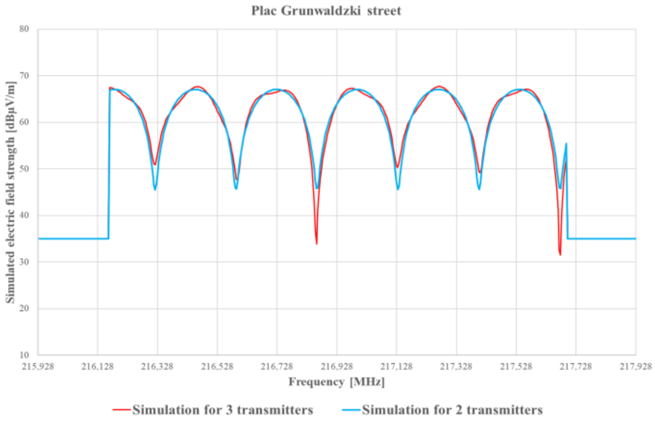

Fig. 14. Resultant electric field strength at the measuring site on Plac Grunwaldzki street (51°06'49.20" N, 17°04'02.00" E) considering 2 dominating transmitters and 3 transmitters, $d_{WUST} = 4\ 341.24$ m, $d_{NIT} = 3\ 233.83$ m, $d_{PRW} = 6\ 208.05$ m (electric field strength from transmitters according to Table II).

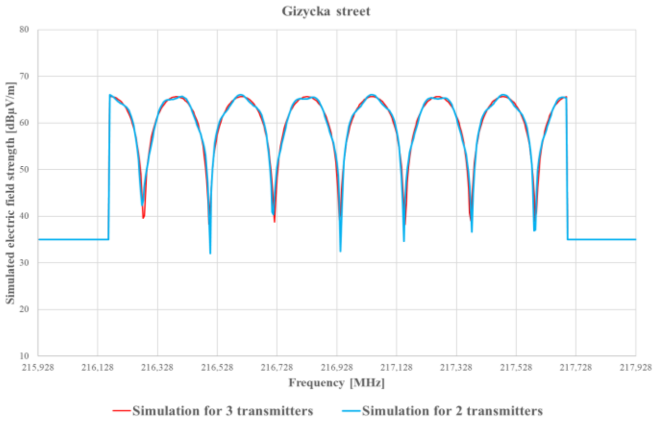

Fig. 15. Resultant electric field strength at the measuring site on Gizycka street (51°07'57.70" N, 17°04'25.80" E) considering 2 dominating transmitters and 3 transmitters, $d_{WUST} = 4\ 754.39$ m, $d_{NIT} = 3\ 381.84$ m, $d_{PRW} = 8\ 143.61$ m (electric field strength from transmitters according to table II).

Based on the analysis of the results (Figs. 11-15), it can be stated that taking into account the third transmitter, from which the field strength is lower by 10-20 dB, causes that the channel produces small, very frequent fades. It is also clear that the greater the difference in paths between the transmitters, the more fades will occur. The formation of deeper fades is also observed when three signals are added together, even if the third signal has a significantly smaller amplitude.

The impact of path length difference on the number of fades and the impact of electric field intensity differences on the depth of fades for the case of two and three transmitters is also presented in [5] and [23]. Theoretical predictions, however, have not been subjected to measurement verification.

B. *Case with three transmitters*

When analyzing the interference of signals from three transmitters, it is possible to find only one area where the intensity of the electric field from each of the transmitters is at a comparable level. At this point, the fades should be the deepest. Table III shows the selected measuring points that meet this condition. Contrary to intuition, these points are not in the center of the triangle whose vertices are transmitters, but were near the straight line connecting the PRW and NIT transmitters (Fig. 16). This shift from the center of the triangle is caused by the dominant influence of WUST transmitter due to the height of the antenna system above ground level.

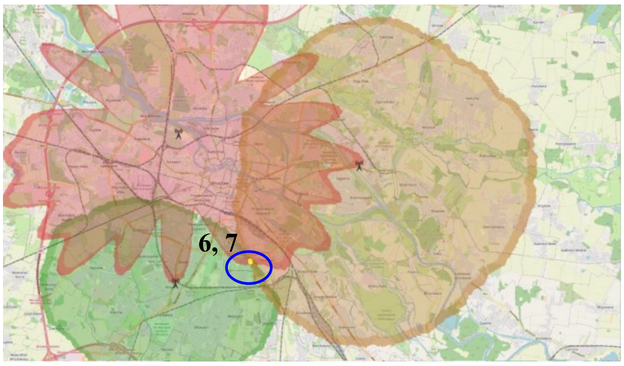

Fig 16. Designated measuring locations for 3 transmitters

TABLE III
LOCATION OF MEASURING POINTS AND MEDIAN ELECTRIC FIELD STRENGTH FROM THE STATION FOR THE CASE WITH THREE TRANSMITTERS

No.	Street	Field strength median value dB(µV/m)		
		WUST	NIT	PRW
6	Armii Krajowej	54.13	54.57	55.5
7	Swieradowska	53.30	54.27	56.10

For point 6 with coordinates (51°04'54.69" N, 17°02'56.69 "E) (Table III), shown in Fig. 16, simulated electric field strength with fades are shown (Fig. 17).

CONCLUSION

The publication presents works aimed at verifying the phenomenon of selective fades in the SFN on the example of the DAB+ digital radio network, which was built in Wrocław. This work aimed to check whether the phenomenon of selective fades in this type of networks in large city environments is measurable and behaves in accordance with approximate theoretical models. These models assume that the field strength at a given observation point is calculated according to the relevant theoretical model (in this case, according to the ITU-R P.1546 method), while the phase shift of the electromagnetic wave results only from the distance from the transmitting antenna to the observation point.

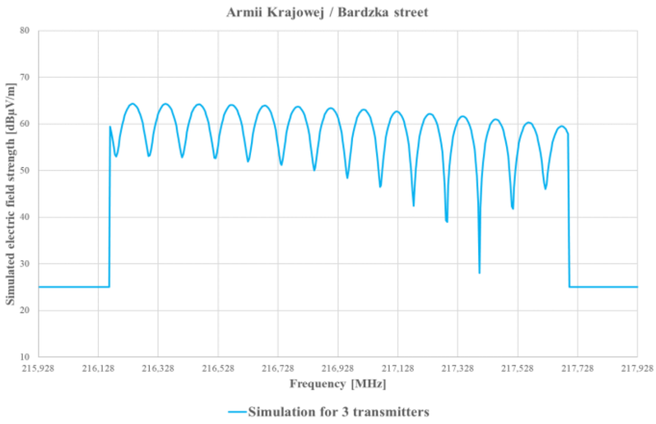

Fig. 17. Resultant electric field strength at the measuring site on Armii Krajowej / Bardzka street (51°04'54.69" N, 17°02'56.69" E) considering 3 transmitters, $d_{WUST} = 5\ 750.12$ m, $d_{NIT} = 5\ 833.36$ m, $d_{PRW} = 3\ 072.52$ m (electric field strength from transmitters according to Table III).

In the real SFN system covering the area of a large city, several propagation phenomena and associated with the operation of networks on one frequency can be expected, which can reduce the phenomenon of fades. The phenomena include, above all, multi-path propagation. The wave runs from the transmitter to the observation point along different length paths, which causes the phase change of the resulting signal. The conditions of multi-path propagation are constantly changing rapidly. In addition, SFN is not perfectly synchronized [2]. The synchronization is good enough to ensure correct signal reception with OFDM multiplexing but not precise enough to ensure stability not only of the frequency but also of the phase of the signal emitted by the transmitters. This can cause frequency shifts of fades over time and affect their depth. Therefore, for the purpose of verifying the phenomenon of selective fades, it was necessary to designate those places where this phenomenon may occur at its greatest intensity. In the article, such points were indicated on the basis of propagation analysis. At these points, the characteristics of the signal level as a function of frequency were calculated. Theoretical depths of fades and their frequency in the signal spectrum were determined. It was noticed that according to the theory, the larger the difference in the paths of the interfering signals, the greater the number of fades and the more even the levels of the interfering signals are, the deeper the fades are. In this way, data was prepared that will be used for measurement verification and will allow to answer the question whether in the real environment of a large city the phenomenon of selective fading of the signal coming from SFN transmitters occurs in an observable way and whether it can cause problems with the correct reception of the signal.

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