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Investigation of the Influence of the Interference Distribution Law by Different Types of Modulation for Modern Wireless Technologies on the Electromagnetic Environment

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Processes in electronic systems powered by an alternating current (AC) power frequency network with wireless interfaces, in particular, with the ability to transmit audio signals, which, in the presence of radio frequency interference with probabilistic characteristics corresponding to typical distribution laws, affect the parameters of electromagnetic compatibility. The influence of the electromagnetic environment created by electronic systems with a wireless interface, depending on the laws of radio frequency interference distribution and the applied wireless access technology, has been investigated. Simulation of the processes of transmission of sound information in the channels of WiFi and Bluetooth technologies under the influence of interference with probabilistic characteristics, in particular, additive white Gaussian noise, has been carried out. Simulation models of the Matlab application is presented, taking into account the peculiarities of communication and modulation channels used in these technologies, as well as the peculiarities of interference. This model contains transceiver blocks of Bluetooth devices operating in duplex mode, a block of transmission channel properties and a block for generating channel interference. This model provides for the choice of power, transmission channel and intensity of interference. An assessment of the electromagnetic environment for the situation of joint operation of electronic devices with the simultaneous operation of wireless channels of WiFi and Bluetooth technologies has been carried out. The audio fragment for assessing the transmission quality was selected from the sound composition Hard As A Rock. Simulation results are presented in frequency and time domains. The ratio of the number of received erroneous bits in the stream to the total number of received bits for the master and slave devices, depending on the distance between them, has been determined. It is shown that the quality of the transmitted content significantly depends on the features of the distance. Recommendations for improving the structures of electronic systems with several wireless interfaces have been developed, providing for the choice of technology for transmitting audio content based on the results of monitoring the electromagnetic environment.

Keywords: electromagnetic compatibility; multystandard interfaces; semiconductor converters; simulation; wireless transmission

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Introduction

The object of research is the processes in electronic systems connected to the alternating current (AC) network with multi-standard wireless interfaces. In particular, the ability of audio signal transmissions, which, in the case of unintentional interference with probabilistic characteristics corresponding to typical distribution laws, require an assessment of not only the quality of service, but also the parameters of electromagnetic compatibility. Bluetooth and Wi-Fi collaboration has been researched for more than 20 years. Papers [1, 2] proposed models and performed performance evaluations taking into account packet loss and BER, confirming the presence of an electromagnetic compatibility (EMC) problem. However, the disadvantages of these works include the lack of an assessment of the impact of the existing electromagnetic environment (EME).

In the paper [3], the influence of noise levels is estimated, however, by default, the typical law of their distribution AWGN is adopted, which narrows the generality of the conclusions. In [4], using the MATLAB Simulink simulation environment, evaluations of a Bluetooth voice packet called synchronous, connection oriented with retransmission (SCORT) were performed to study the performance improvement.

Paper [5] describes possible compatibility issues with 802.11n devices. The authors of work [6] propose a further improvement in collaboration through a new Bluetooth network construction mechanism that takes into account the frequencies occupied by Wi-Fi and thus creates an efficient Bluetooth network, seeking to minimize interference from Wi-Fi transmissions when they coexist in the same space. Further improvement of standards, such as Bluetooth Low Energy (BLE) and an increase of the number of such devices in a real environment, for example, a basketball sports complex is shown in paper [7]. The results of this work have shown that the BLE system is capable to maintain a low transmission failure rate when operating in heavy interference environments, unless the environmental noise floor is close to the interference detection threshold used. In the listed works, the possible compatibility problems of multistandard devices, which are modern smartphones, were not investigated.

In paper [8], the results of a study of the influence of modulation types on EMC and BER indicators were presented, and in paper [9] the influence of interference distribution laws on the reliability of audio content transmission was evaluated and a new multi-standard transmission mechanism was proposed to ensure the required sound quality indicators. Further improvement of this mechanism is possible by applying the results proposed in [10] based on a machine learning prediction method for an adaptive frequency hopping (AFH) map by collecting packet statistics and determining the spectrum.

Existing electronic systems with a wireless interface do not meet the requirements of quality of service and electromagnetic compatibility if the concentration of individual devices with a nominal characteristic exceeds a certain threshold or environmental conditions significantly degrade the electromagnetic environment. At the same time, the content they transmit is significantly degraded due to a decrease of the bit error rate (BER) even with an acceptable signal-to-noise ratio (SNR). Typically, the factors that create these problems include the presence of a large number of such devices in residential or office premises, both in a limited area, for example, small offices in case of their simultaneous operation, and open areas for mass events in the entertainment industry, as well as the configuration elements of building structures, which are elements of a screen that reflects most of the radiated energy.

The complication of the EMC problem is associated with both intrasystem and intersystem aspects. The generation of radiation by power supply elements and the amplification of conductive interference due to induced EMF signals of the transceiver path require the use of a set of interference suppression measures summarized in the paper [11]. However, this publication does not take into account the features of real EME and modern communication technologies. Fixed and migrating sources of radiation in modern spaces of the entertainment industry significantly complicate EME, as shown in the example of a cinema and concert hall in the paper [12]. At the same time, the features of the transmitted content and the influence of the space structure on the characteristics of interference remained outside of the research scope.

The paper [13] analyzes the impact of scalability of multi-standard wireless networks and proposes a Blank Burst algorithm that can effectively eliminate internetwork interference, thereby significantly improving the overall system performance by taking into account the difference in the transmission rate of two standards to avoid packet collisions. The paper [14] attempts to evaluate the effectiveness of detecting the frequency band above 2.48 GHz, which can be used by Wi-Fi or Bluetooth protocols to avoid interference from common household wireless sources of interference, such as a microwave oven, in the smart home paradigm.

The grounding of the choice for the preferred connection technology in the multistandard conditions and in the case of a large number of wireless sensors in the paper [15] was carried out on the basis of a full-scale experiment, and an algorithm for controlling the influence of Wi-Fi interference on the wireless sensor network was proposed. Based on the results of these works, the conclusion can be made that the EMC problem is complex in the case of a combination of these factors.

A working hypothesis for identifying the advantages of such capabilities may be the assumption that there is a certain relationship between the factors affecting the EME and the laws of interference distribution, changes in which, to a greater or lesser extent, affect the bit error rate in the transmitted information. An indirect confirmation of this hypothesis for three wireless communication standards – GSM, WiFi and WiMAX is contained, for example, in studies [16–18].

Therefore, based on the analysis of BER values for a specific SNR level, it is possible to establish a relationship between a specific interference distribution law and the noise immunity level for a set of wireless communication standards of a multistandard device. On the base of obtaining this dependence and carrying out the procedure of statistical analysis, it is possible to determine which of them is more preferable for the transmission of the signal under these conditions of the EME and to select the technological modes of operation of the multimedia device based on the monitoring results.

1 Investigation of EMC support for electronic systems with Bluetooth and Wi-Fi interfaces when transmitting audio information

Since Bluetooth technology operates in the unlicensed 2.4 GHz frequency range, it is of interest to provide EMC for systems with Bluetooth and Wi-Fi interfaces that both use this frequency range. The analysis was carried out when choosing the type of modulation for Bluetooth Gaussian Frequency-Shift Keying (GFSK) and for Wi-Fi 802.11b - binary phase shift Keying (BPSK) in order to provide a comparable bit rate.

For the study, we used the Bluetooth Full Duplex Voice and Data Transmission model (see Fig. 1).

The model contains transceiver blocks of two Bluetooth devices operating in full duplex mode: Device 1 - master and Device 2 - slave, as well as a block of transmission channel properties (Channel AWGN and 802.11) and a block for generating channel interference (Interference). At the input of the master and slave devices given the fragment of the sound composition "Hard As A Rock", which is saved as an mp3 file [1], in the form of files Input1.wav and Input2.wav, respectively. The simulation results are displayed using the Scopes Display blocks (time diagrams and spectra) and BER Display (bit error rate).

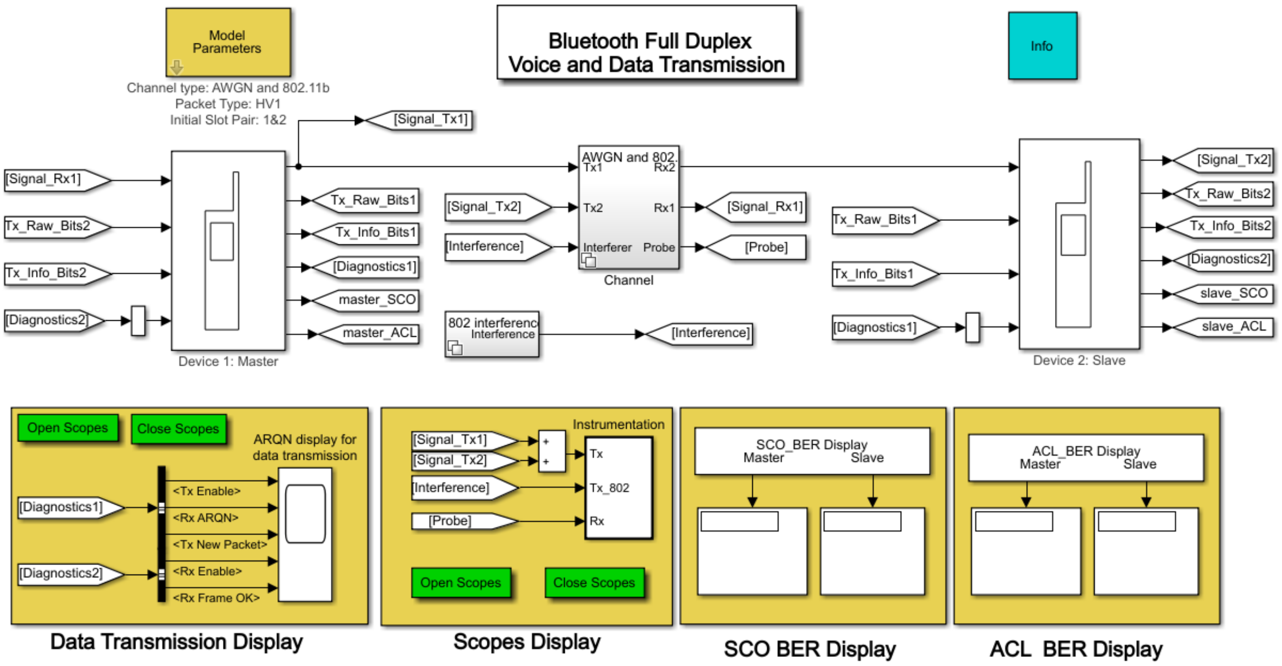


Fig. 1. Bluetooth Full Duplex Voice and Data Transmission Model to Study the Influence of Wi-Fi Systems on a Bluetooth System

The influence of the Wi-Fi system on the audio information transmission via Bluetooth technology wesimulated by placing the source of interference (Wi-Fi Interferer) at the same distance from both Bluetooth devices. To measure the signal levels from the interference source and Bluetooth transmitting devices, a measuring probe (Probe) is installed between them. The configuration of the transmission channel with the specified distances between the master and slave Bluetooth devices, the source of interference and the measuring probe is shown in Fig. 2. The distance between the Bluetooth devices master and slave (Tx1 - Rx2, Tx2 - Rx1) is equal 1 m, between the measuring probe and Bluetooth devices (Tx1 - Probe, Tx2 - Probe) - 0.5 m. During the study, the distance to the source of interference was changed (Interferer - Rx, Interferer - Probe).

The channel jamming unit contained a corresponding settings menu, in which the power, transmission channel and intensity of the RFI can be set for the model.

Let's consider the block and its menu in more detail (see Fig. 3). The block of interference for the 802.11b protocol (Fig. 3, a) describes the parameters of the transmitter, creates interference. These parameters include (Fig. 3, b):

- Average Rate – the average intensity of the appearance of the interference;
- Mean Length — average duration of the noise;
- Power (dBm) – power of RFI in a given channel;

– Frequency Number – the number of the channel in which the interference appears – from 0 (2402 MHz) to 78 (2480 MHz).

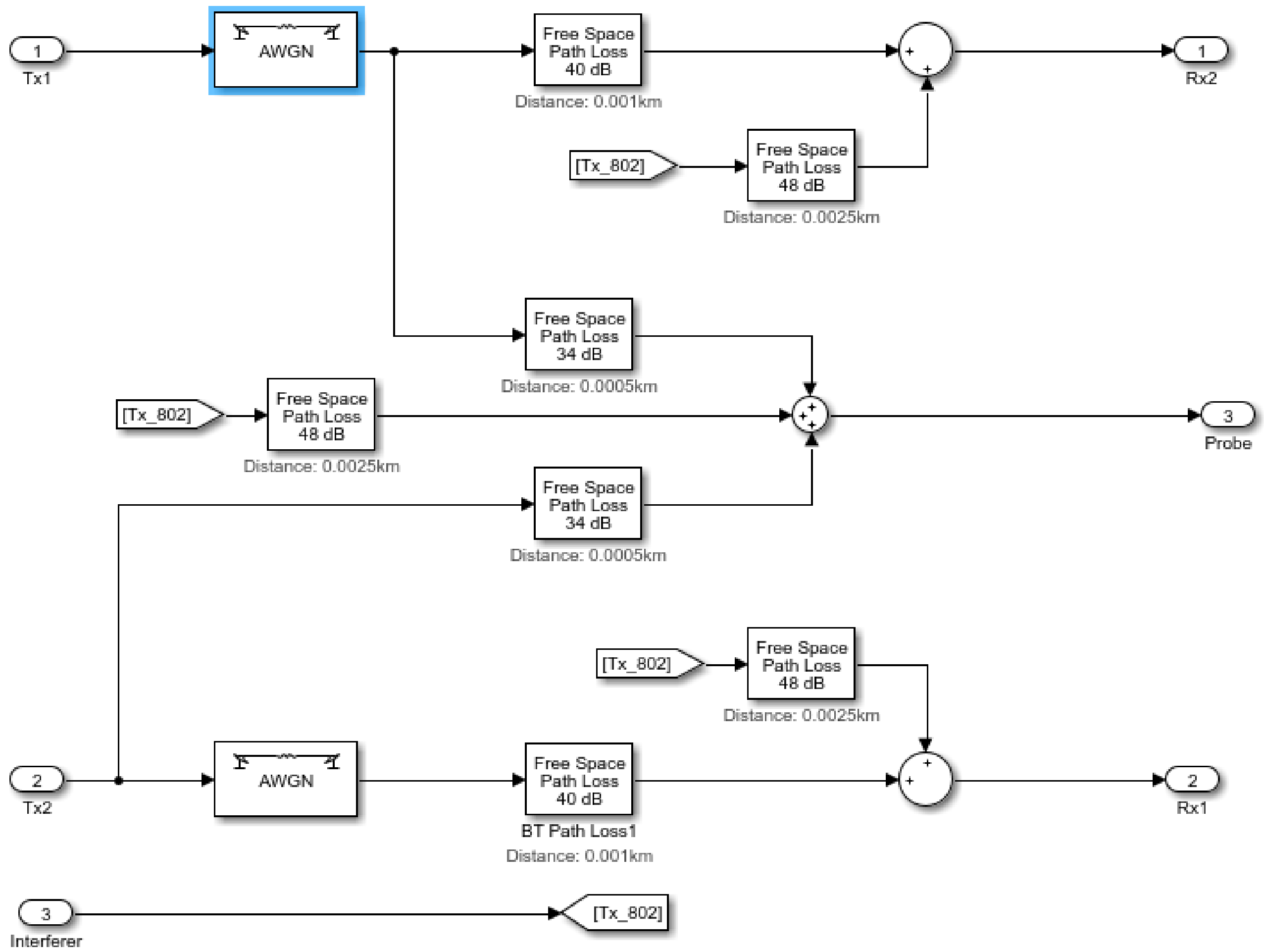


Fig. 2. Model of the transmission channel

The simulation results allow us to estimate the signal levels from Bluetooth transmitters and the interference levels, to determine the relative position in time of the transmission and synchronization slots, to estimate the signal spectrum width.

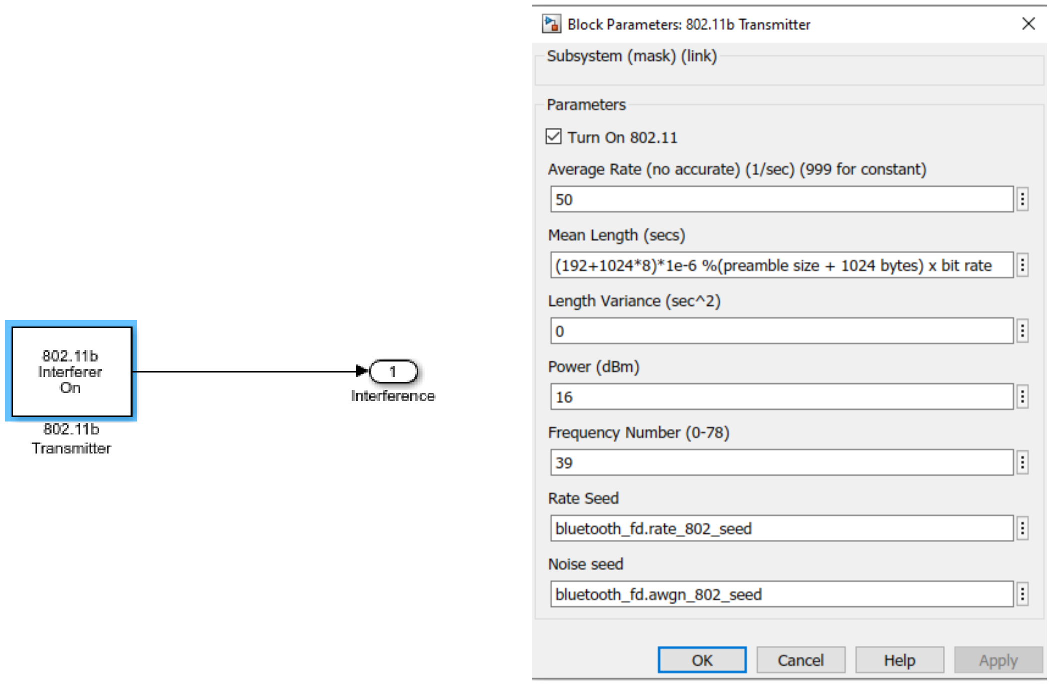
The main criterion for the operability of the transmission channel, the level of its noise immunity and compliance with EMC requirements is the BER value – the ratio of the number of received erroneous bits in the stream to the total number of received bits.

The Automatic Repetition Query (N) display for data transmission unit given possibility of monitoring the correctness of reception in the Bluetooth transmission channel, the input signals of which are self-diagnostic signals of receiving data packets from master and slave Bluetooth devices.

Automatic Repetition Query (N) represents the system with a repeated request to send N data packets. If the packet is received correctly (as evidenced by the checksum), then the value ARQN $= 1$, otherwise – ARQN $= 0$.

The ARQN monitor operation is illustrated by the monitoring results (see Fig. 4).

The Spectrum Analyzer window is composed of two parts (Fig. 5). The first part (Fig. 5, a) presented the operation in the frequency range from 0 to 78 channels, centered on the 39th transmission channel (2441 MHz). The main channel signal of the Bluetooth system given in the specified range as a narrow-band frequency peak. Interference is introduced into the channel in the form of a wideband 802.11b transmitter signal centered at the frequency specified in the Interference block. This is shown in the spectrogram by the domed portion of the spectrum. The intensity of the interference can be adjusted.



(a) (b)

Fig. 3. Block of formation of channel interference (a) and its setup menu (b)

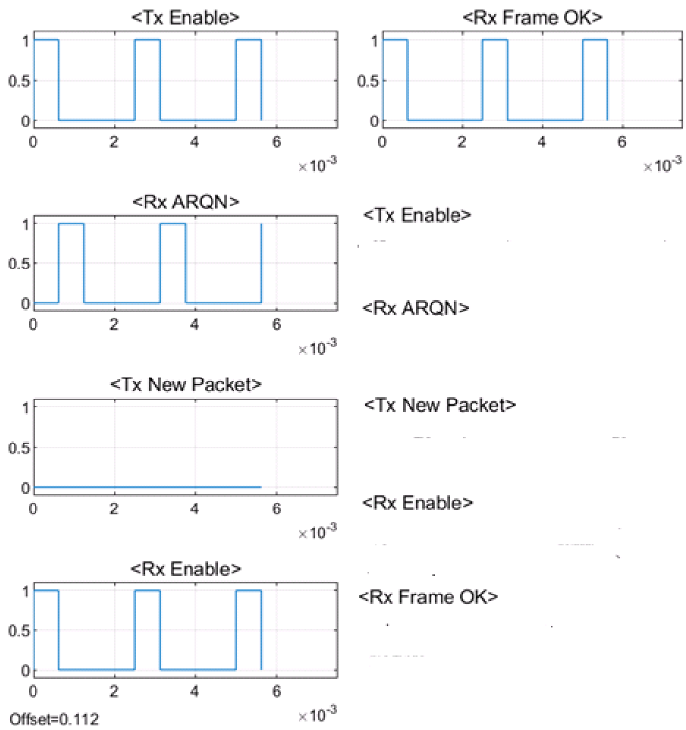


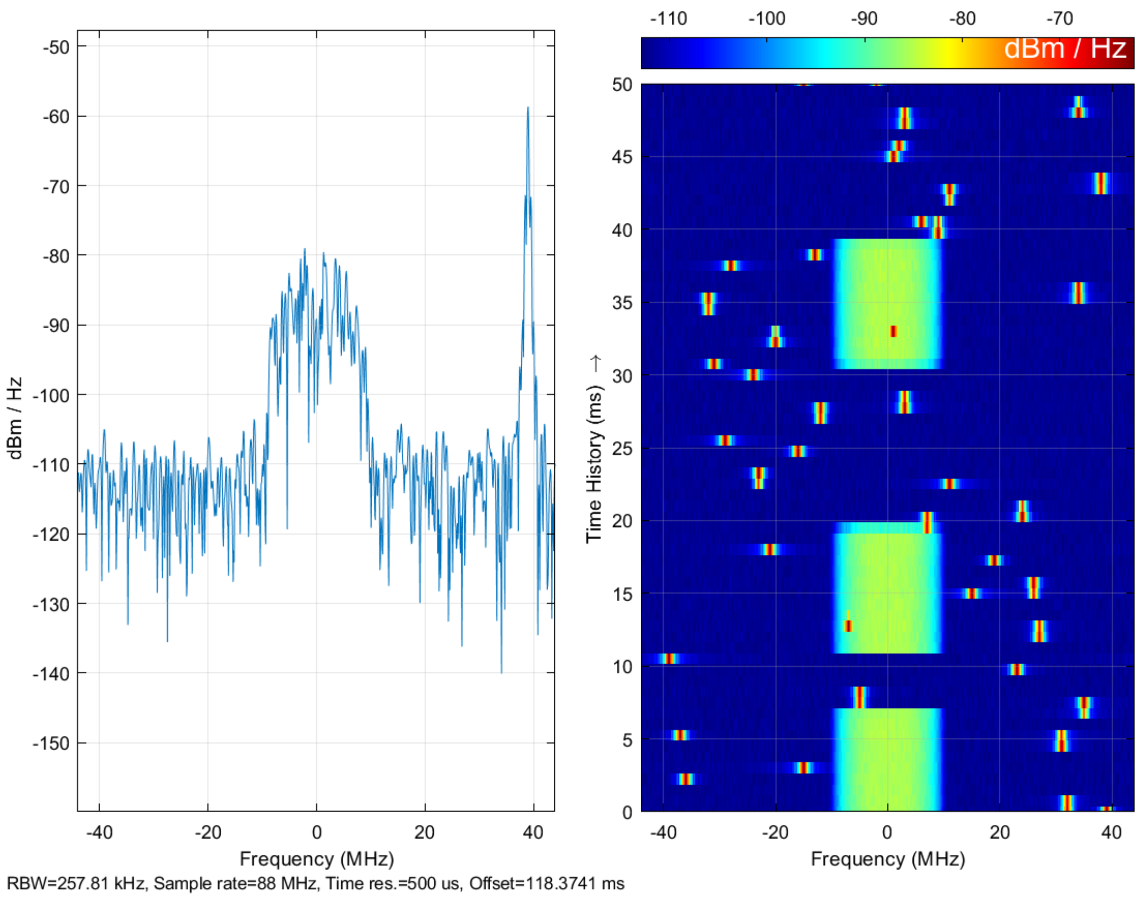
Fig. 4. ARQN transmission quality monitoring window

The second part of the Spectrum Analyzer window (see Fig. 5, b) is a cumulative reflection of spectrograms. Signals with maximum amplitude are distinguished by a warmer color, all manifestations of signal activity displayed on this graph coincide with those recorded on the Timing Diagram.

The Timing Diagram window (see Fig. 6) shows the presence of three signals:

Bluetooth Tx - transmission of a Bluetooth channel and 802.11 Tx - interference from an 802.11b standard transmitter (interference for Bluetooth transmitters);

Slots - time slots of transmission / reception in a duplex channel.



(a) (b)

Fig. 5. Spectrum Analyzer window during operation

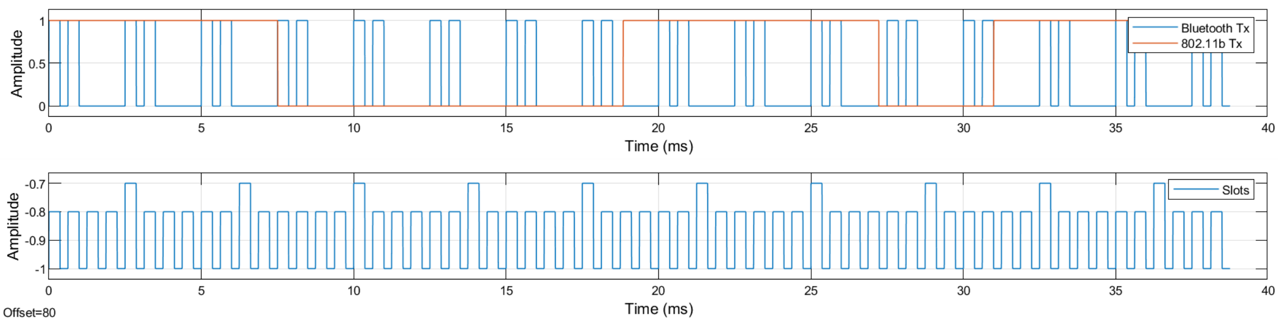


Fig. 6. Window of timing diagrams of activity indication

2 Procedure of simulation

As a result of simulation, the BER indicator of master and slave Bluetooth receiving devices was estimated when transmitting audio data packets of the HV2 type (in the synchronous operation mode SCO) in the event of a change in the distance d, the location of the interference source, which is Wi-Fi 802.11b transmitter. The power of the Bluetooth transmitters Tx1, Tx2 is set at 1 mW (0 dBm), and the interference power (Interferer) is set at 16 dBm. The results of modeling the BER value are shown in Fig. 7.

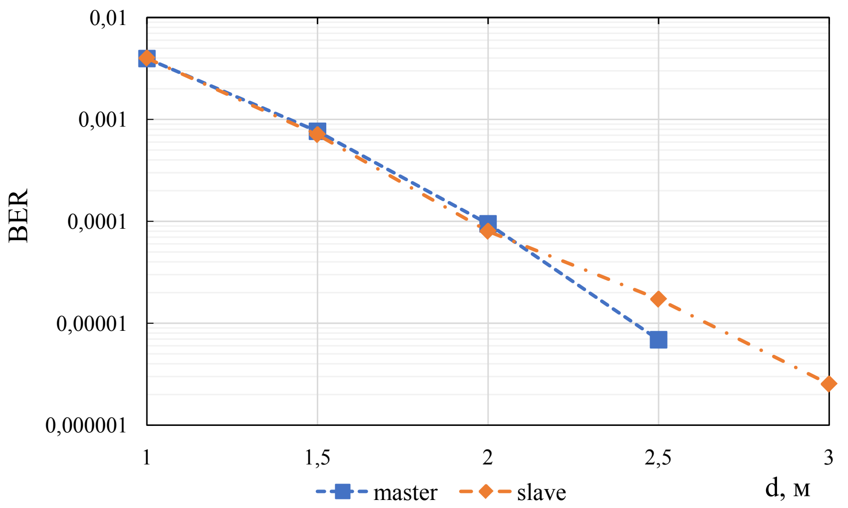


Fig. 7. Results of modeling the dependence of the BER of the master and slave Bluetooth devices on the distance d of the Wi-Fi 802.11b interference source

Fig. 8 shows the view of the Spectrum Analyzer window in the case of a distance to the source of interference d=1 m and d=2.5 m, respectively. In the first case, the level of the useful signal exceeds the interference level by only 6 dB, while the BER error level is at the level of 10^{-3}, which is acceptable, and in the second case, the useful signal exceeds the interference by 14 dB with the obtained BER value at the level of $10^{-5} \dots 10^{-6}$ depending on the type of device (master or slave).

3 Discussion

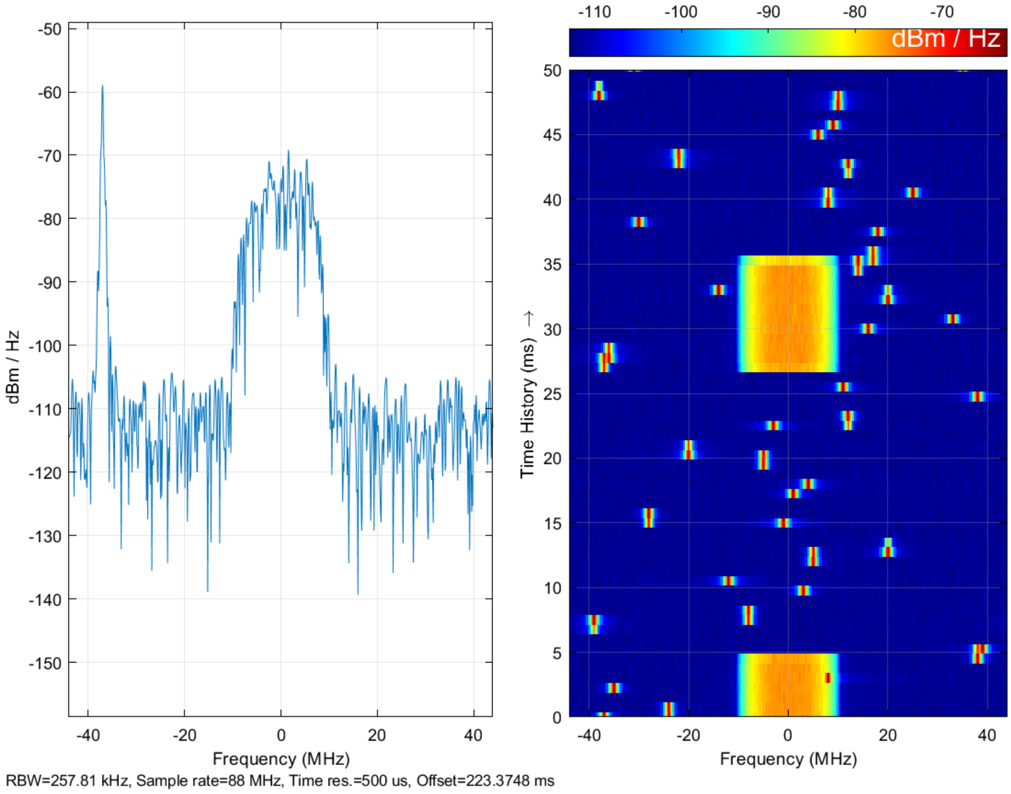
Thus, as shown in Fig. 7 and Fig. 8, the Bluetooth system does a good job of dealing with a single broadband interference due to its using of hopping spread spectrum. However, the problem arises of determining the effectiveness of this mechanism in the case of an increase in the number of transmitting Wi-Fi devices on different channels, which corresponds to a real interference situation during the joint operation of Wi-Fi and Bluetooth devices within the same area.

Modern electronic systems with a wireless interface, in particular, mobile communications, implement operating algorithms that allow changing the signal power and the type of modulation depending on the state of the EME [19]. However, this approach is implemented only within one technology for audio traffic, while data is transmitted using a wireless interface technology, which is supported by base stations at a given distance. Another situation arises when it is necessary to use both wired and wireless channels.

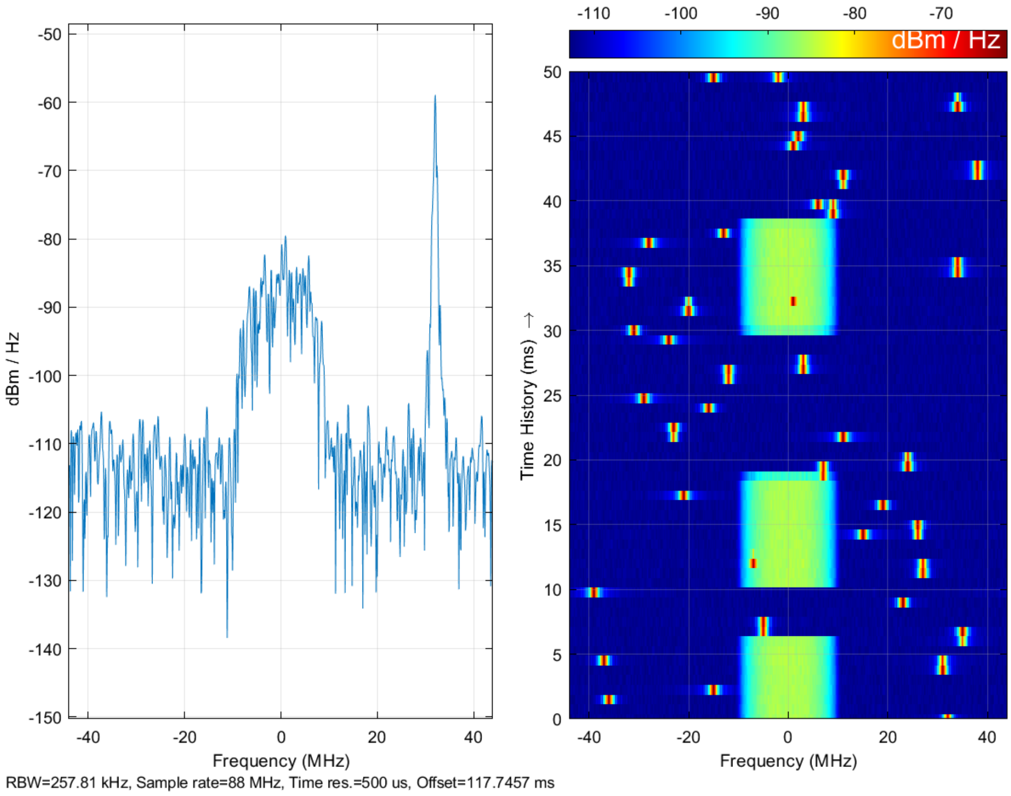
At the same time, in addition to the problem of ensuring intersystem EMC, the internal system EME is complicated. It is possible to solve problems in this situation only in a complex, constructive way - by improving the RFI filter [11], entrusting it with performing an additional function - monitoring the internal resistance at critical frequencies, correcting parameter changes, and limiting the effect of radiation by switching to the type of digital modulation required by the EME criterion and the interface.

It is necessary to monitor the electromagnetic environment and to determine the statistical parameters of interference that operate in the transmission channels of such systems with a wireless interface to form the choice of transmission technology, in particular Long-Term Evolution (LTE). It should be performed according to the BER criterion to ensure electromagnetic compatibility that requires the coordination of hardware and software in order to minimization of costs for the improvement of technical means of ensuring EMC.

It should be noted that even with the permitted level of emission of interference by conductive paths in the conductors of such devices, radiation interference can occur in the near field, and the standard methods of testing devices for electromagnetic compatibility requirements are carried out at 3 m or 10 m from the measuring antenna [20], and in real conditions the circuit with printed conductors as an antenna can be located on the same board at a distance of up to 0.5 m, where the system elements operating at high frequencies in the switch mode or power supplies with intelligent control on the noise levels are located.



(a)



(b)

Fig. 8. View of the Spestrum Analyzer window for the distance from the source of interference d: (a) 1 m; (b) 2.5 m

Conclusion

In the case of a normal distribution of interference in the channel, an electronic device operating in the Bluetooth standard can operate at negative values of the signal-to-noise ratio, which fully correlates with the principles of spectrum spreading. This technology is implemented by high intensity frequency hopping (1600 hops/s). This is a significant advantage over systems such as GSM and Wi-Fi 802.11 b / g, which use spread spectrum technology or orthogonal frequency multiplexing OFDM (WiMAX and LTE).

The Bluetooth system has shown to cope well with a single broadband interference due to the use of hopping spread spectrum. However, the problem of determining the effectiveness of this mechanism in the case of an increase in the number of transmitting Wi-Fi devices on different channels raises respectively to the real interference situation during the joint operation of Wi-Fi and Bluetooth devices within the same area.

Thus, the expediency of monitoring the electromagnetic environment and the transition to the technology of transmission of sound fragments, optimal according to the criterion of ensuring electromagnetic compatibility, has been proved. An advantageous option is to apply a machine learning-based prediction method adapted to this criterion for the adaptive frequency hopping (AFH) map [10], by collecting packet statistics and determining the spectrum.

References

[1] Golmie N., Van Dyck R. E., and Soltanian A. (2001). Interference of Bluetooth and IEEE 802.11: Simulation modeling and performance evaluation. *MSWIM'01: Proceedings of the Fourth ACM International Workshop on Modeling, Analysis, and Simulation of Wireless and Mobile Systems*, pp. 11–18. doi:10.1145/381591.381598.

[2] Lansford J., Stephens A. and Nevo R. (2001). Wi-Fi (802.11b) and Bluetooth: enabling coexistence. *IEEE Network*, Vol. 15, No. 5, pp. 20-27. doi: 10.1109/65.953230.

[3] Golmie N., Chevrollier N. and Rebala O. (2003). Bluetooth and WLAN coexistence: challenges and solutions. *IEEE Wireless Communications*, Vol. 10, No. 6, pp. 22-29. doi: 10.1109/MWC.2003.1265849.

[4] Mathew A., Chandrababu N., Elleithy K. and Rizvi S. (2009). IEEE 802.11 & Bluetooth Interference: Simulation and Coexistence. *2009 Seventh Annual Communication Networks and Services Research Conference*, pp. 217-223. doi: 10.1109/CNSR.2009.41.

[5] Abusubaih M. and Ayyash M. (2012). Mutual interference between bluetooth and 802.11n MIMO devices. *2012 19th International Conference on Telecommunications (ICT)*, pp. 1-5. doi: 10.1109/ICTEL.2012.6221264.

[6] Zhang Q., Chen G., Shang C. and Chang C. (2014). An interference-aware and energy-saving connection protocol for Bluetooth radio networks. *2014 IEEE International Conference on Consumer Electronics - Taiwan*, pp. 11-12. doi: 10.1109/ICCE-TW.2014.6904009.

[7] Al Kalaa O. M., Balid W., Bitar N. and Refai H. H. (2016). Evaluating Bluetooth Low Energy in realistic wireless environments. *2016 IEEE Wireless Communications and Networking Conference*, pp. 1-6. doi: 10.1109/WCNC.2016.7564809.

[8] Bakiko V. M., Popovych P. V., Shvaichenko V. B. (2018). Determination of noise immunity of a communication channel in case of accidental interference [Vyznachennya zavadostijkosti kanalu zv'yazku za vypadkovogo vplyvu zavad]. *Bulletin of the National Technical University "KhPI": coll. sci. papers. Ser.: Technique and Electrophysics of High Voltage*, No. 14(1290), pp. 7-10. [In Ukrainian].

[9] Bakiko V. M., Popovych P. V., Shvaichenko V. B. (2019). Features of electromagnetic compatibility of semiconductor converters instructures with wireless channels [Osoblivosti elektromagnitnoi sumisnosti napivprovidnykovyx peretvoryuvachiv u strukturax izbezprovodovymy kanalamy]. *TEKHNICHNA ELEKTRODYNAMIKA*, No. 3, pp. 55–59. DOI: 10.15407/techned2019.03.055.

[10] Lee J., Park C. and Roh H. (2021). Revisiting Bluetooth Adaptive Frequency Hopping Prediction with a Ubertooth. *2021 International Conference on Information Networking (ICOIN)*, pp. 715-717. doi: 10.1109/ICOIN50884.2021.9333996.

[11] Veksler G. S., Nedochetov V. S., Pilinskijidr V. V.; pod red. G. S. Vekslera. (1990). *Suppression of electromagnetic interference in power supply circuits [Podavlenie elektromagnitnyx pomex v cetyax elektropitaniya]* / 90. Kyiv, Texnika, 167 p. [In Russian].

[12] Dovzhenko A. A., Pilinskyi V. V., Chupakhin A. S., Shvaichenko V. B. (2015). Analysis of permissible regulated levels of emission and sensitivity of the equipment of the cinema and concert complex [Analiz dopustimykh reglamentirovannykh urovney emissii i chuvstvitel'nosti oborudovaniya kinokontsertnogo kompleksa]. *Technologies of electromagnetic compatibility*, No. 3 (54), pp. 18-24. [In Russian].

[13] Chen D., Brown J. and Khan J. Y. (2015). An interference mitigation approach for a dense heterogeneous wireless sensor network. *2015 9th International Conference on Signal Processing and Communication Systems (ICSPCS)*, pp. 1-7. doi: 10.1109/ICSPCS.2015.7391773.

[14] Tshiluna N. B. et al. (2016). Analysis of bluetooth and Wi-Fi interference in smart home. *2016 International Conference on Advances in Computing and Communication Engineering (ICACCE)*, pp. 13-18. doi: 10.1109/ICACCE.2016.8073716.

[15] Sumthane M. Y. and Vatti R. A. (2017). Wi-Fi interference detection and control mechanism in IEEE 802.15.4 wireless sensor networks. *2017 Fourth International Conference on Image Information Processing (ICIIP)*, pp. 1-6. doi: 10.1109/ICIIP.2017.8313767.

[16] Olmedo G., Avilés D. and Paredes N. (2020). Performance Analysis of Non-Uniform Modulations over AWGN and Rayleigh Fading Channels. *2020 15th Iberian Conference on Information Systems and Technologies (CISTI)*, pp. 1-6. doi: 10.23919/CISTI49556.2020.9141053.

[17] Al-Shuraifi Mushtaq, Al-Anssari Ali Ihsan, Mikhail Reznikov. (2014). FRAT-OFDM vs. FFT-OFDM Systems in Fading AWGN Channels. *Electronics and Communications*, Vol. 19, No. 2(79), pp. 53–58.

[18] Denbnoveczkyj S. V., Mel'nyk I. V., Pysarenko L. D. (2016). *Coding of signals in electronic systems. Part 1. Parameters of signals and communication channels and methods of their estimation [Koduvannya sygnaliv v*

elektronnyx systemax. Ch.1. Parametry sygnaliv i kanaliv zv'yazku ta metody ix oczinyuvannya]. Kiyv, Kafedra, 524 p. [In Ukrainian].

[19] Bernard Sklar, Fredric J. Harris. (2020). Digital Communications: Fundaqmentals & Applications 3rd Edition. *Pearson*.

[20] CISPR 22 Edition 6.0 2008-09 IEC STANDARDS. Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement. *CISPR*.

Дослідження впливу на електромагнітну обстановку закону розподілу завад різними видами модуляції для сучасних безпроводових технологій

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Процеси в електронних системах, з живленням від мережі змінного струму промислової частоти з безпроводовими інтерфейсами, зокрема, з можливістю передачі аудіосигналів, які за наявності радіочастотних завад з ймовірними характеристиками, відповідними типовим законам розподілу, впливають на параметри електромагнітної сумісності. Досліджено вплив електромагнітної обстановки, створюваної електронними системами з безпроводовим інтерфейсом, в залежності від законів розподілу радіочастотних завад і застосовуваної технології безпроводового доступу. Проведено моделювання процесів передачі звукової інформації в каналах технологій WiFi і Bluetooth під впливом завад виду адитивного білого гаусівського шуму. Представлені імітаційні моделі програми Matlab, що враховують особливості каналів зв'язку і модуляції, використовувані в цих технологіях, а також особливості завад. Модель містить приймально-передавальні блоки пристроїв Bluetooth, які працюють в дуплексному режимі, блок властивостей каналу передавання, блок формування канальних завад. Модель забезпечує можливість вибору потужності, каналу передавання, інтенсивності появи завади. Проведено оцінку електромагнітної обстановки для ситуації спільної роботи електронних пристроїв для одночасної роботи безпроводових каналів технологій WiFi і Bluetooth. Аудіофрагмент для оцінки якості передавання був вибраний зі звукової композиції Hard As A Rock. Результати моделювання представлені в частотній і часовій областях. Визначено відношення кількості прийнятих помилкових біт в потоці до загальної кількості прийнятих біт для ведучого і веденого пристроїв в залежності від відстані між ними. Показано, що якість переданого аудіоконтенту істотно залежить від відстані. Розроблено рекомендації щодо вдосконалення структур електронних систем з декількома безпроводовими інтерфейсами, що передбачають вибір технології передачі аудіоконтенту за результатами моніторингу електромагінтної обстановки.

Ключові слова: електромагнітна сумісність; багатостандартні інтерфейси; напівпровідникові перетворювачі; моделювання; безпроводове передавання

Исследование влияния на электромагнитную обстановку закона распределения помех разными видами модуляции для современных беспроводных технологий

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Целью исследования являются процессы в электронных системах с питанием от сети переменного тока с беспроводными интерфейсами и возможностью передачи аудиосигналов. При воздействии радиочастотных помех с вероятностными характеристиками, соответствующими типичным законам распределения, возможны существенные изменения параметров электромагнитной совместимости. Исследовано влияние электромагнитной обстановки, создаваемой электронными системами с беспроводным интерфейсом, в зависимости от законов распределения радиочастотных помех и применяемой технологии беспроводного доступа. Проведено моделирование процессов передачи звуковой информации в каналах технологий WiFi и Bluetooth при воздействии помех в виде аддитивного белого гауссовского шума. Представлены имитационные модели приложения Matlab, учитывающие особенности каналов связи и модуляции, используемые в этих технологиях, а также особенности помех. Модель содержит приемо-передающие блоки устройств Bluetooth, работающих в дуплексном режиме, блок свойств канала передачи и блок формирования канальных помех. Модель предусматривает возможность выбора мощности, канала передачи и интенсивности появления помехи. Проведена оценка помеховой обстановки для ситуации совместной работы электронных устройств при одновременной работе беспроводных каналов технологий WiFi и Bluetooth. Аудиофрагмент для оценки качества передачи был выбран из звуковой композиции Hard As A Rock. Результаты моделирования представлены в частотной и временной областях. Определено отношение количества принятых ошибочных бит в потоке к общему числу принятых бит для ведущего и ведомого устройств в зависимости от расстояния между ними. Показано, что качество передаваемого аудиоконтента существенно зависит от особенностей закона распределения помех и расстояния. Разработаны рекомендации по совершенствованию структур электронных систем с несколькими беспроводными интерфейсами, предусматривающие выбор технологии передачи аудиоконтента по результатам мониторинга электромагнитной обстановки.

Ключевые слова: электромагнитная совместимость; многостандартные интерфейсы; полупроводниковые преобразователи; моделирование; беспроводная передача