# EXPERIMENTAL TECHNIQUE AND DEVICES

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## Noises in bioelectronic devices: a case study of electromagnetic interference in biolaboratory facilities

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**Abstract.** Since bioelectrical signals typically have amplitudes below μA and lower than mV, their measurement is significantly susceptible to environmental electromagnetic interference (EMI). In this study, we measured and analyzed the levels of electromagnetic interference in biolaboratory rooms — the birthplace and preliminary test center for any bioelectronic device. We have shown that in an ordinary biolaboratory, which is equipped with typical modern instruments, like digital microscopes, EMI in the sub-250 kHz range can include both periodic and wide-band signals, which can influence the working of impedance sensors and neuroprosthetic implants. The results of our study can be used for the development and testing of noise-suppression systems for bioelectronics applications.

**Keywords:** electromagnetic interference, noise, impedance devices, spectra analysis, neuroprosthetic care, multielectrode arrays

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## Шумы в биоэлектронных приборах: исследование электромагнитных помех в биолабораторных помещениях

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**Аннотация.** Поскольку биоэлектрические сигналы как правило характеризуются низкими значениями своих амплитуд (<мкА и <мВ), на их измерение значительно влияют электромагнитные помехи окружающей среды (ЭМП). В настоящем исследовании мы измерили и проанализировали уровни электромагнитных помех, которые могут возникать в биолабораторных помещениях — в месте создания и первом испытательном центре любого биоэлектронного устройства. Мы показали, что в обычной биолаборатории, которая оснащена типичными современными приборами, такими как цифровые

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микроскопы, ЭМП в диапазоне до 250 кГц могут включать как периодические, так и широкополосные составляющие, которые способны влиять на работу импедансных цитосенсоров и нейро-имплантатов. Результаты нашего исследования могут быть использованы для разработки и тестирования систем подавления шума в биоэлектронных приборах.

**Ключевые слова:** электромагнитные помехи, шумы, спектральный анализ, импеданс, нейропротезы

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## Introduction

Bioelectronic technologies are rapidly entering our lives today [1–3]. Moreover, the devices most commonly used in this field, such as impedance living cell-based biosensors and living neurons/computer interfaces, show great potential for solving important medical problems, such as lost vision restoration and artificial organ development. At the same time, since any cell-based bioelectronic system requires the usage of low voltage and current levels to prevent cell destruction, one of the central challenges in this field is device protection from external electromagnetic interference (EMI) [4–6]. In addition, in-lab testing of bioelectronic devices also requires the use of EMI mitigation methods.

For the development and application of both in-door and out-door EMI-canceling techniques, it is very useful to have real-life noise profiles, which can be used as an example for modeling and testing of the EMI-combat approaches. For this purpose, we have developed the noise measurement unit and MatLab/GNU Octave data processing scripts for capturing the examples of the EMI signals, which can be found in the ordinary biolaboratory, where bioelectronic devices are tested. The obtained data indicates that in such facilities the EMI signal contains not only 50-Hz powerline interference, but also periodic and wideband parts from other electronic devices, in particular from modern digital microscopes. The results of our study can be used as a methodology for EMI analyzing as well as examples of real noise data samples for noise-suppression digital algorithms approbation. Samples can be found on our GitHub page https://github.com/BioElectronicsLab/Noise-samples or available upon request.

## Materials and Methods

EMI signals were measured using the setup, the main scheme of which is presented in Fig.1. It consists of a transimpedance amplifier (TIA) [8], which is commonly used for current measurements in electrophysiological studies [1]. As an operational amplifier, AD8606 (Analog Devices, USA) was used. As input for TIA the 10-cm antenna made of wire was used, which imitates the living-cell interface cable. The TIA output signal was recorded using the L-Card E20-10 ADC (L-Card, Russia). The sampling rate was 500 kHz and the data collection time for one EMI sample was 500 ms (*i.e.* 2 Hz resolution is achieved). The resistance to TIA feedback was 1 MΩ. The EMI spectra were obtained from the analog-to-digital converter time-domain input signal using the fft routine in MatLab and presented in the amplitude spectral density format.

We have measured the EMI noise levels in the five rooms at Saint-Petersburg Academic University: in the special room for cell diagnostics, which contains a lot of switched on devices, including confocal microscope Zeiss Observer.Z1 (Zeiss, Germany); the room for microscopic studies only, which is equipped with Leica DM 4000 B microscope (Leica, Germany); office room, with no switched on devices, which is located near switchgear room; break-room, with

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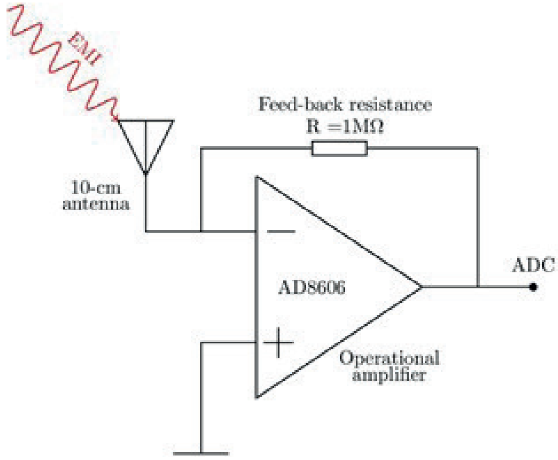


Fig. 1. Experimental setup, used for measuring EMI signals

several switch on PCs; and hall. In addition, since microscopes are widely used in bioelectronics to observe cells, we measured the EMI signals with the microscopes turned on and off to extract the EMI generated by them. For better visual detection of periodic components, the FFT spectra were averaged over 10 EMI samples (i.e. the level of random noise presented in one sample is $\sqrt{10}$ times higher than that shown in the figures).

## Results and Discussion

The results obtained are presented in Fig. 2. One can see from Fig. 2, *a* the EMI in the cell diagnostic room contains a wide band spectrum with significant intensity, which increased with frequency. This observation clearly indicates that the noise influence problem can be relevant for bioelectronics devices even in the testing rooms (Table). Moreover, the wide band nature of this noise sample makes the usage of static filtering noise-cancellation methods inapplicable for EMI suppression if the wide band impedance sensors are tested. To overcome this problem, the progressive tools, like artificial intelligence adaptive filtering approach [8], can be used. Contrary to the cell diagnostic room, in the microscopy room we observed only two wide-band noise parts (57–72.5 kHz and 120–135 kHz), and periodic signal at 78 kHz. The presented 78-kHz signal and its overtones are also presented in all other rooms except the cell diagnostic room, where it possibly is lost in the other interferences. The break room also contains band noises in the ranges of 4–10 kHz, 187–194 kHz, and 204–210 kHz. Surprisingly, the clear 50-Hz powerline EMI with odd overtones (Fig. 2, *b*) is observed only in the office room, which is located near the switchgear room. The most noise-free room was a hall, where only 78 kHz interference was observed.

From the panels Fig. 2, *c* and Fig. 2, *d* one can see that microscopes introduce into the EMI new signatures (78–82~kHz for Leica; 24 kHz, 73 kHz ≈ 24×3 kHz, and 122 kHz ≈ 24×5 kHz for Zeiss); however, their impact is not so high with respect to environment EMI signals. Thus, since the observed EMI spectra demonstrate the variety of noise types, which can be both wide and narrow band, for protecting bioelectronic devices from EMI the common noise canceling techniques are preferable, which may be classified as technological, electronic, and software methods. From a technological point of view, the noise canceling can be achieved not by noise level decreasing, but by increasing the amplitude of the useful signal, which can be done by decreasing the impedance value (increasing current value) of the bioelectrodes via increasing their surface. The last one can be done without affecting the size of bioelectrodes using porous surfaces [1]. The electronic methods for noise canceling include the shielding, which can be utilized in the at-lab conditions; however implementation of such method is complicated in the bioelectronic implantation technologies and with portable biosensor design. The software methods are a more promising tool with respect to shielding for EMI suppression, since these approaches only require the utilization of the computing unit in the bioelectronic device components. For example, the already mentioned above adaptive filtering approach allows to suppress environment noises in the impedance-based biosensors and can be implemented in the real-time regime (see the package NELM for MatLab [9]).

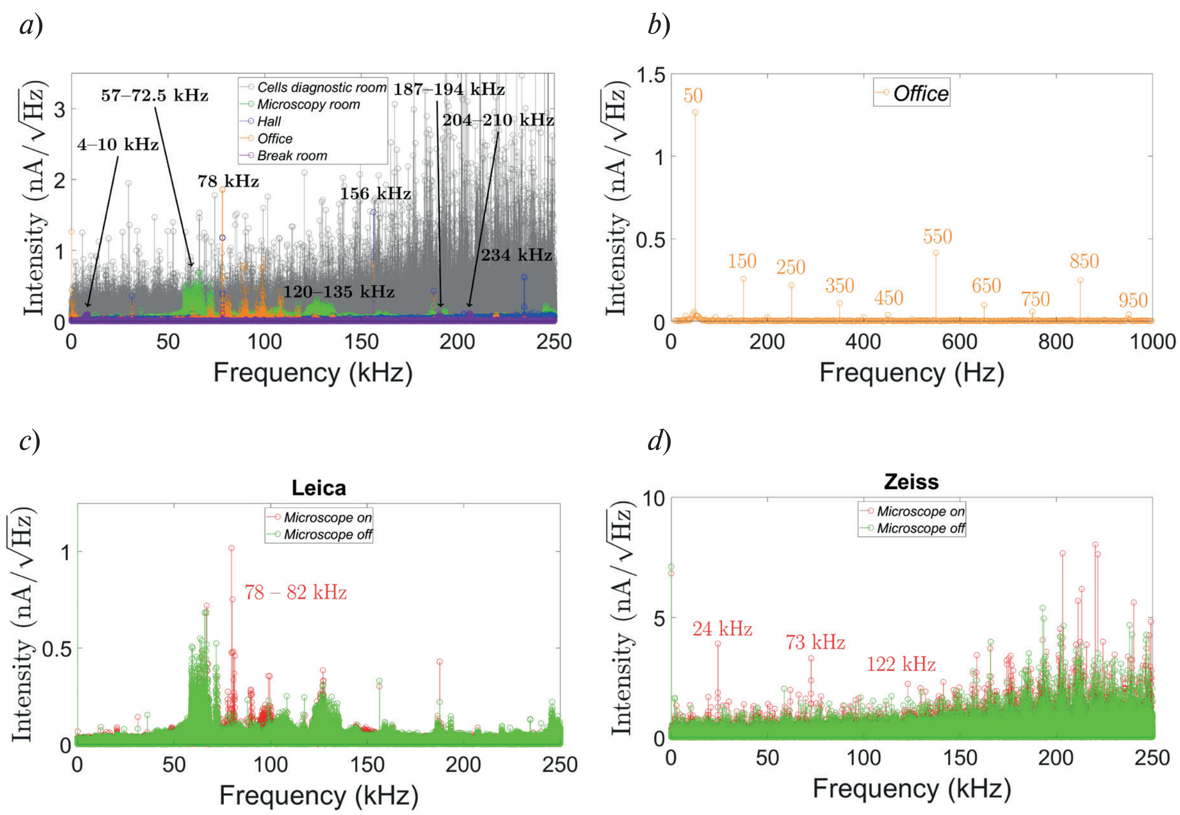


Fig. 2. Comparison of different EMI spectra. For clarity data presented in the amplitude spectral density format. Background (without any microscopes on) noise in a set of rooms (*a*); office room background noise from 1 Hz to 1 kHz that shows 50-Hz powerline and its harmonics (*b*); EMI signals detected while microscopes Leica (*c*) and Zeiss (*d*) were switched on (red) and switched off (green). As one can see, there are clear peaks (78–82 kHz for Leica, and 24 kHz, 73 kHz, and 122 kHz for Zeiss) that correspond with the work of microscopes

Table

**Modeled signal-to-noise ratios for multielectrode array (MEA) 60MEA200/30iR-Ti (MultiChannel Systems, Germany)**

| | Cells diagnostic room | Microscopy room | Hall | Office | Breakroom |
|---|---|---|---|---|---|
| Signal-to-noise ratio (dB) | −3.5 | 14.2 | 15.0 | 8.0 | 16 |

Notation: The signal-to-noise ratios are calculated in the practically used range 10 Hz – 40 kHz as MEA current power to noise power relation in decibels. The power is calculated using rms MatLab routine. The MEA current excitation was performed by sweep-shaped 15-mV excitation voltage in the 240 kHz range. Both noise and MEA signals were preliminary filtered by 10th-order Butterworth filter with cutting frequency 40 kHz. This is simulation of data processing for wideband MEA experiments. Noises are assumed to be additive.

## Conclusion

In this study, we have shown that, in the common case, the influence of EMI on the bioelectronic device functioning cannot be overlooked. Our data shows that even in biolaboratories, where bioelectronic devices are fabricated and tested, the EMI spectra can contain both periodic and wideband noises, which are results of the large number of electronic devices used in the modern world. For fighting with EMI, it is desirable to use low-impedance cell/electronic interfaces like porous electrodes and short-length cables, as well as software noise suppression techniques. In addition, during our work on this study, we have observed that it is very hard to identify the EMI sources using only standalone EMI spectra because there is a significant lack of information on characteristic EMI peaks for various devices. To our best knowledge, only in a few handbooks [10, 11] about ten EMI sources signatures are presented, including electromotor, cell phones, and marginal EMI from nuclear explosion. The creation of a more informative EMI signature database will be very useful for the development of future EMI combat algorithms and electronic devices design. We believe that the results of our study will help bio-electronic engineers to create robust EMI biosensors and implants, which will solve actual healthcare problems.

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