PREMIER Publishing
ppublishing.org

Section 7. Technical sciences in general

DOI:10.29013/AJT-26-3.4-174-178

METHODOLOGY FOR SELECTING THE OPERATING FREQUENCIES OF SENSORS (Search for the optimal operating frequency of a sensor for designing a monitoring system of a single mixture component. Search for the optimal operating frequencies of sensors for designing a monitoring system of two mixture components)

Aliaksandr Achapouski [1]

[1] Architect of AI-Based Security Systems, Specializing in Digital Identity Infrastructure and Real-Time Authentication Phoenix, Arizona

Cite: *Achapouski A. (2026). Methodology For Selecting the Operating Frequencies of Sensors. (Search for the optimal operating frequency of a sensor for designing a monitoring system of a single mixture component. Search for the optimal operating frequencies of sensors for designing a monitoring system of two mixture components). Austrian Journal of Technical and Natural Sciences 2026, No 3–4.* https://doi.org/10.29013/AJT-26-3.4-174-178

Abstract

This study presents the methodological foundations for designing a system intended for monitoring the concentration of components within complex mixtures. A mixture is defined as a multicomponent system in which one predominant component functions as a conditional solvent, while the remaining components are treated as conditionally dissolved elements that may exist in dissolved, suspended, gaseous, aerosol, or composite forms.

The methodology includes experimental validation of resonant sensor prototypes across an extended concentration range, emphasizing the determination of optimal operating frequencies for single- and multi-frequency sensing systems. Particular attention is devoted to equipment preparation, structural material selection, protective and functional coatings, sensor design configurations, and testing procedures, including the evaluation of acidity levels under varying temperature, temporal, and compositional conditions.

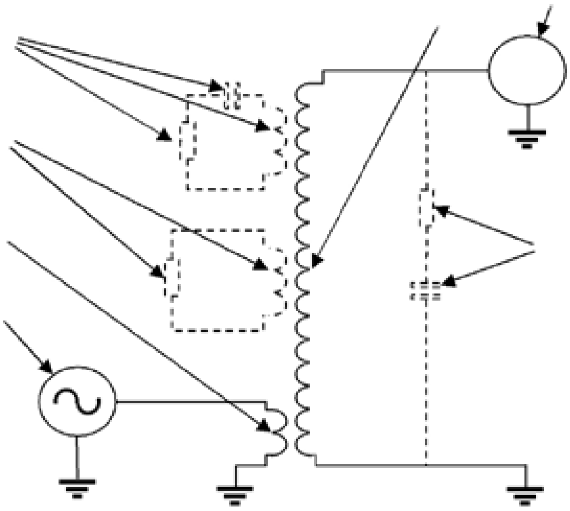
The proposed approach demonstrates that integrating multiple sensor elements operating at different electromagnetic resonant frequencies within a single sensing module significantly enhances analytical capability, enabling rapid and comprehensive material characterization. Further technical specifications and implementation details will be addressed in subsequent publications and related patent documentation.

Keywords: *Non-contact monitoring system; Sensor operating frequency; Optimal sensor operating frequency; Methodology for operating frequency selection; Dissolved components;*

Conditionally dissolved components; Conditional solvent; Liquid single-component substance; Design of a monitoring system; Frequency scanning process; Amplitude variation; Probing voltage; Stabilized constant amplitude; Single-component monitoring system; Optimal operating frequency of a single-component monitoring system; Frequency scanning of a sample; Results analysis; Frequency sample analysis; The selected frequencies constitute the initial data for the design and fabrication of prototype resonant sensors

Principle of measurement (electromagnetic coupling with object under test)

Figure 1. *Equivalent circuitry of RIST-sensor illustrates an electromagnetic coupling with analyte*



Schematic of RIST-sensor (depicted with solid line)

1 – source of an alternating electric field with frequency sweep (sweep generator)

2 – excitation coil

3 – sensing coil

4 – data acquisition system

Electromagnetic response of object under test (depicted with dash line)

5 – vertical displacement currents (dielectric polarization)

6 – vertical ionic currents and eddy currents

7 – linear conductance, displacement and ionic currents caused by difference in electrical potential spread along the sensing coil.

Search for the Optimal Operating Frequency of a Sensor for Designing a Single-Component Mixture Monitoring System

Such a monitoring system may be applied in technological processes in which the concentration of one component may vary, while the concentrations of the remaining components remain constant.

Preparation of Samples for Measurement

Two samples shall be prepared with concentrations of the target component corresponding to the lower and upper limits of the expected concentration variation range.

Frequency Scanning Procedure

Using a potentiostat, the prepared samples shall be subjected to frequency scanning across the entire operating bandwidth of the potentiostat (in our case, from 0.100 MHz to 170 MHz).

During the scanning process, the potentiostat readings are recorded in the form of:

- amplitude variations, and
- phase shift of the current flowing through the sample relative to a harmonically varying probing voltage with a stabilized constant amplitude.

Analysis of Results

Based on the scanning results, several frequencies shall be selected:

- frequencies at which the difference in amplitude between the investigated samples reaches its maximum values;
- frequencies at which the difference in phase shift reaches its maximum values.

The selected frequencies will serve as initial design data for the development and fabrication of prototype resonant sensors.

Selection of the Optimal Sensor

The selection of a set of frequencies based on potentiostat scanning results is preliminary in nature.

To determine the optimal operating frequency of a single-component concentration monitoring system, it is necessary to test each prototype resonant sensor using not two, but at least ten samples with different concentrations of the target component within the anticipated range of its variation.

After testing all prototype sensor samples, the best-performing sensor can be selected. Preference should be given to sensors that, in addition to high sensitivity, demonstrate a **monotonic** change in readings as the concentration of the monitored component changes (to facilitate subsequent calibration).

Lower operating frequencies are generally preferable from the standpoint of electromagnetic interference immunity. In selecting a sensor, design and construction constraints must also be taken into account.

Search for Optimal Operating Frequencies of Sensors for Designing a Two-Component Mixture Monitoring System

Such a monitoring system may be applied in technological processes in which the concentrations of two components may vary, while the concentrations of the remaining components remain constant.

Preparation of Samples for Measurement

Two samples shall be prepared for each target component with concentrations corresponding to the lower and upper limits of the expected range of variation of these concentrations, as well as a sample in which these components are completely absent.

Frequency Scanning Procedure

Using a potentiostat, the prepared samples shall be subjected to frequency scanning across the entire operating bandwidth of the potentiostat (in our case, from 0.100 MHz to 170 MHz). During the scanning process, the potentiostat readings are recorded in the form of amplitude variations and the phase shift of the current flowing through the sample relative to a harmonically varying probing voltage with a stabilized constant amplitude.

Analysis of Results

For each target component, based on the scanning results, several frequencies shall be selected:

- frequencies at which the difference in amplitude between the investigated samples reaches its maximum values;
- frequencies at which the difference in phase shift reaches its maximum values; and
- frequencies (or frequency bands) at which sensitivity to one component is absent while sensitivity to the other component is present.

The resulting sets of selected frequencies shall then be analyzed.

Case 1: Frequencies exist at which sensitivity is present only to one component

This case is the most preferable for designing a monitoring system for the concentrations of the target components.

If such frequencies exist for both components, the choice of operating frequencies is straightforward:

For the fabrication of prototype resonant sensors, operating frequencies should be selected at which, while sensitivity to one component is absent, sensitivity to the other component is maximal. At least one such frequency should be selected for each component. If such frequencies exist only for one of the components, then for the fabrication of prototype resonant sensors for this component, operating frequencies should be selected at which, in the absence of sensitivity to the other component, sensitivity to the target component is maximal. For the other component, operating frequencies should be selected from its frequency set at which the difference in sensitivity to the investigated components is the greatest.

Case 2: No frequencies exist with sensitivity only to one component, but the obtained frequency sets do not coincide

In this case, for the fabrication of prototype resonant sensors, operating frequencies should be selected from each frequency set at which the difference in sensitivity to the investigated components is the greatest.

Case 3: The obtained frequency sets coincide

This case is the most challenging for designing a monitoring system for the concentrations of the target components.

If the frequency set for one component fully coincides with the set for the other component, it is necessary to verify whether the proportional relationship between the amplitude changes and phase shift changes for one component and the amplitude and/or phase shift changes for the other component is preserved at all frequencies.

If the proportionality is preserved throughout, a repeated scan should be attempted using different probing voltage levels.

If it is not possible to achieve any differences, the investigated components are most likely indistinguishable from the perspective of electrochemical impedance spectroscopy.

Nevertheless, even in this case it is possible to fabricate several prototype sensors with different operating frequencies corresponding to the highest sensitivity to changes in the concentrations of the target components, since a resonant sensor produces a more complex воздействие on the test sample (an additional effect of a magnetic field is introduced) than that produced by a pulse generator. If testing of these sensors demonstrates – at least at one frequency – a change in the proportional relationship of sensitivity to concentration variations, then there is, in principle, a possibility to build a monitoring system for the concentrations of the investigated components. The selectivity of such a system will be higher when the difference in the proportional relationship is greater.

Selection of Optimal Sensors

The selection of a set of frequencies based on the results of sample scanning using a pulse generator is preliminary in nature.

To determine the optimal operating frequencies of a two-component concentration monitoring system, it is necessary to test each prototype resonant sensor using not two, but at least ten samples with different concentrations of the investigated components, within the anticipated range of their variation.

After testing all prototype sensor samples, the best sensor pair can be selected. Preference should be given to sensors that, in addition to high sensitivity, demonstrate a monotonic change in readings as the concentrations of the monitored components change (to facilitate subsequent calibration).

Lower operating frequencies are the most preferable from the standpoint of electromagnetic interference immunity.

In selecting sensors, design and construction constraints must also be taken into account.

Figure 1.

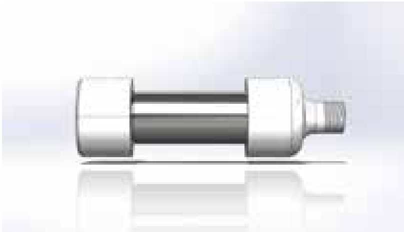


Figure 2.

Figure 3.

Figure 4.

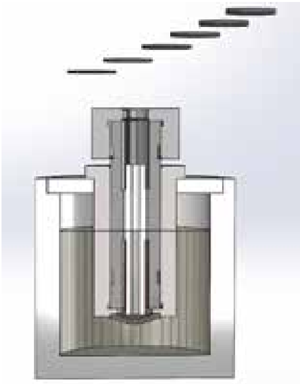


Figure 5.

References

Slobozhanyuk, A., et al. (2020). *Magnetic resonance imaging machine*. U.S. Patent – No. 10. 732, 237. Issued August 4, 2020.

Godoy, J., et al. (2020). *Electron paramagnetic resonance (EPR) techniques and apparatus for performing EPR spectroscopy on a flowing fluid*. U.S. Patent – No. 10,564,308. Issued February 18, 2020.

Wang, H. (2018). *Parallel plate transmission line for broadband nuclear magnetic resonance imaging*. U.S. Patent No. 9,952,297. Issued April 24, 2018.

Hetherington, H. P., et al. (2016). *Transceiver apparatus, system and methodology for superior in-vivo imaging of human anatomy*. U.S. Patent No. 9,316,709. Issued April 19, 2016.

Yonamoto, T., et al. (2015). *Sample holder for electricity-detection electron spin resonance device*. U.S. Patent – No. 9,018,954. Issued April 28, 2015.

Neu, E., et al. (2014). *AFM-coupled microscale radiofrequency probe for magnetic resonance imaging and spectroscopy*. U.S. Patent No. 8,884,608. Issued November 11, 2014.

Tang, L., et al. (2014). *Waveguides configured with arrays of features for performing Raman spectroscopy*. U.S. Patent – No. 8,780,344. Issued July 15, 2014.

Trakic, A., et al. (2014). *MRI apparatus and method with moving field component*. U.S. Patent – No. 8,754,644. Issued June 17, 2014.

Wu, Y., et al. (2012). *Guided mode resonator based Raman enhancement apparatus*. U.S. Patent No. 8,330,952. Issued December 11, 2012.

Poponin, V. (2006). *Method and apparatus for enhanced nano-spectroscopic scanning*. U.S. Patent No. 7,151,598. Issued December 19, 2006.

Chandrakumar, N. (1998). *Device for excitation and detection of magnetic resonance using orthogonal transmitter probe coils*. U.S. Patent No. 5,719,499. Issued February 17, 1998.

Chapman, B., et al. (1997). *Gradient coils having increased performance and decreased power consumption for use in MR systems*. U.S. Patent – No. 5,663,648. Issued September 2, 1997.

Gentsch, M., et al. (1994). *Resonator for electron spin resonance spectroscopy*. U.S. Patent – No. 5, 293, 120. Issued March 8, 1994.

submitted 29.02.2026;
accepted for publication 13.03.2026;
published 30.04.2026

Contact: alexachapouski@gmail.com