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MULTIFUNCTIONAL SENSOR TECHNOLOGY. (Potential application areas of methods, approaches, and technologies of electromagnetic resonance spectroscopy)

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Abstract

The classical and standardized methodology for measuring acidity levels requires mandatory calibration of the measuring instrument using reference solutions with acidity values of pH 4 and pH 7 prior to any measurement. Accordingly, the proposed experimental measurement system also necessitates calibration mechanisms before performing control measurements, which significantly increases the overall measurement time.

During the study, various types and designs of sensors (solenoids) were tested, including a planar sensor configuration used at the final stage of the experiments. A comprehensive global patent search confirmed that this type of sensor, its application for acidity measurement and monitoring, as well as its structural implementation, were employed for the first time. The term *biosensor* traditionally refers to a device in which biological materials – such as enzymes, tissues, bacteria, yeasts, antigens/antibodies, liposomes, organelles, receptors, DNA, and viruses (including coronaviruses)—directly respond to signals generated by the proposed sensor, producing a resonant output functionally linked to the presence and concentration of the target component.

Keywords: *Electromagnetic resonance spectroscopy; electromagnetic resonance measurement; measurement of electromagnetic resonance in biological tissues; influence of membrane presence on the electromagnetic properties of a planar inductive coil*

Potential Application Areas of Electromagnetic Spectroscopy in Multifunctional Sensor Technology in Medicine and Biology Measurement of the concentration and composition of components in liquids

This category includes mixtures such as solutions and dispersed systems: emulsions, suspensions, and biological fluids (blood, milk, lymph, urine, etc.). Owing to the high sensitivity of the proposed sensor design variants, the technology can be widely applied in:

- the pharmaceutical industry within technological processes for the production of medicinal products;
- laboratory and point-of-care analysis of biological fluids such as blood, milk, urine, etc.;

- medical, technical, and food microbiology for monitoring the concentration of microorganisms and the presence of viruses, including coronaviruses.

Measurement of the electromagnetic impedance of biological tissues

At present, impedance measurement of biological tissues at various alternating-current frequencies is widely used in diagnostics as well as in biological and medical research.

For example, a significant increase in tissue impedance at low frequencies allows detection of inflammation at its earliest stages. Certain thyroid disorders are diagnosed by changes in the phase shift angle between current and voltage.

Electromagnetic resonance mammography is an effective method for early detection of breast cancer. Measurement of skin impedance assists in diagnosing dermatological conditions, for example, in identifying non-pigmented malignant melanoma, as well as locating areas of skin contamination with coronaviruses.

Endoscopic impedance measurements may be used to detect pathologies of internal organs. This also includes non-invasive blood analysis – for example, to determine elevated glucose levels- and assessment of lymphatic fluid condition.

In all the above application areas of resonance measurements, electromagnetic spectroscopy technology can make a significant contribution by substantially increasing measurement sensitivity.

In addition, the use of the proposed sensors may enable detection of coronavirus presence in the human throat at early stages of infection.

Application of electromagnetic spectroscopy methods and technologies in biosensors

The term “biosensor” typically refers to a device in which biological materials (enzymes, tissues, bacteria, yeasts, antigens/antibodies, liposomes, organelles, receptors, DNA, viruses – including coronaviruses) directly respond to the signal from the proposed sensor and generate a resonant signal functionally associated with the presence and concentration of the target component.

In this case, the proposed device implements a fundamentally new method of obtaining information about the chemical composition of a solution.

The presence of biological material with unique properties in the solution enables highly selective identification of required compounds in a complex mixture without the need for additional operations involving other reagents, concentration procedures, etc. (hence the term “methods of analysis without the use of chemical and biological reagents”).

Influence of a membrane on the electromagnetic properties of a planar inductive coil

To evaluate the influence of the membrane on the ability of a planar inductive coil to generate a probing electromagnetic field, a dedicated software tool was used, developed on the basis of artificial intelligence and artificial neural networks. This program is capable of calculating and visualizing the electromagnetic field emitted by various inductive coils when electric current flows through their turns.

Three scenarios were simulated:

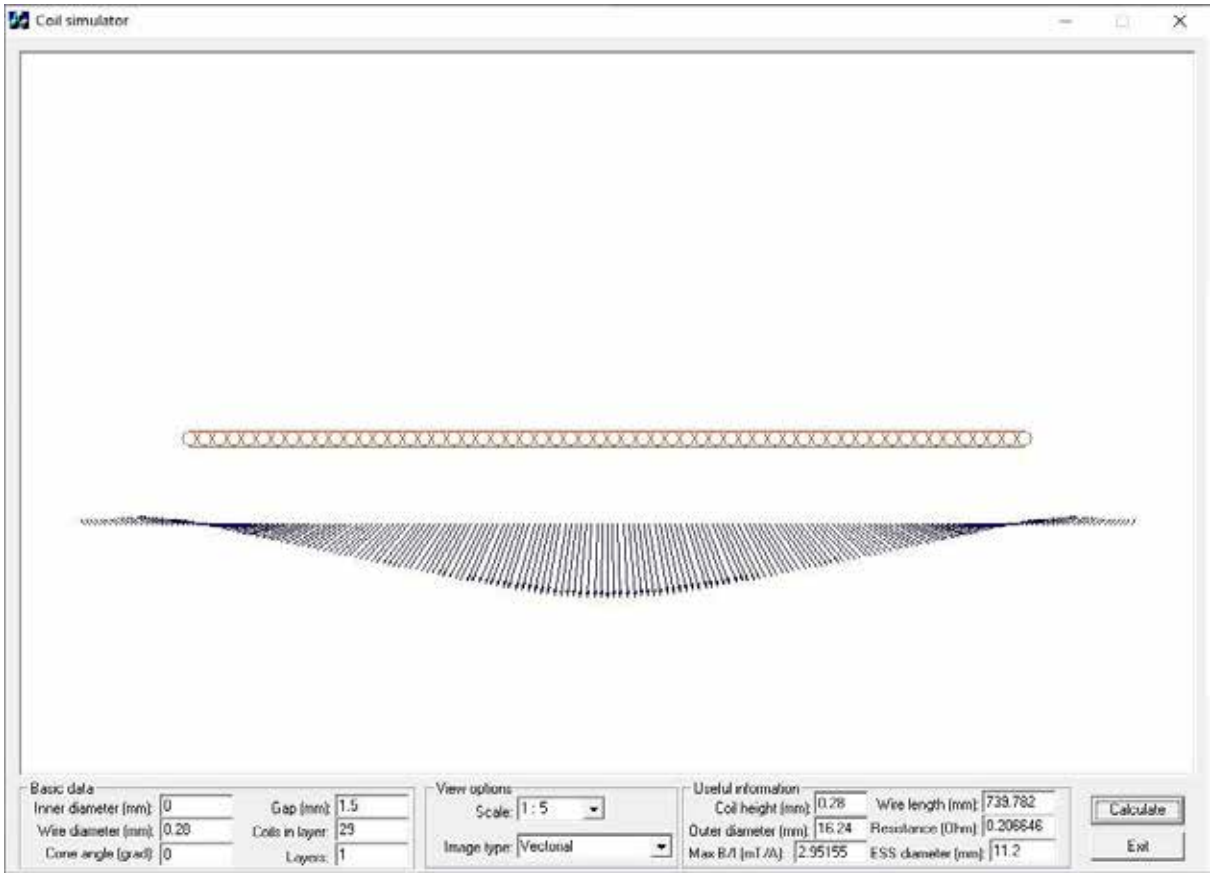
- absence of a membrane, Gap = 0;
- presence of a membrane, Gap = 1 mm;
- presence of a membrane and an additional gap between the membrane and the coil, Gap = 1.5 mm.

The simulations were performed for a planar single-layer coil with a diameter of 16.24 mm and 29 turns of wire, corresponding to the planar inductive coil currently used for evaluating the possibility of pH measurement in liquids.

The images presented above clearly illustrate the attenuation of the probing electromagnetic field as the distance from the inductive coil increases. The key characteristic of this field – Max (relative maximum induction)—decreases from 8.70 (Gap = 0 mm) to 2.95 (Gap = 1.5 mm).

In the classical and standardized methodology for measuring acidity levels, prior to the direct measurement of the acidity of the test sample, calibration of the measuring instrument is mandatory. This calibration is performed using standard buffer solutions with acidity levels of pH 4 and pH 7.

Figure 1.



In accordance with this standard methodology, the proposed experimental measurement system also requires calibration mechanisms prior to performing control acidity measurements. This significantly increases the total time required to carry out the measurement process.

For testing and comparative analysis of measurement results, two basic types of liquids were used: distilled water and regular tap water. To adjust the acidity levels of the test samples, concentrated hydrochloric acid prepared specifically by a chemical laboratory was added.

Various types and designs of sensors (solenoids) were used during the experiments, including a planar sensor (solenoid), which was employed at the final stage of testing.

Based on the results of an extensive global patent search, this type of sensor, its application for such measurements and monitoring, as well as its structural implementation, were used for the first time.

Below is the electrical connection diagram for the planar sensor integrated with the instruments of the test equipment set.

During preparation of this publication, the author conducted a patent search covering a period of 50 years, using as a reference point the systems operating online in real time for contactless monitoring of parameters of industrial processes interacting with the technology and equipment complex for electromagnetic resonance spectroscopy.

Search results:

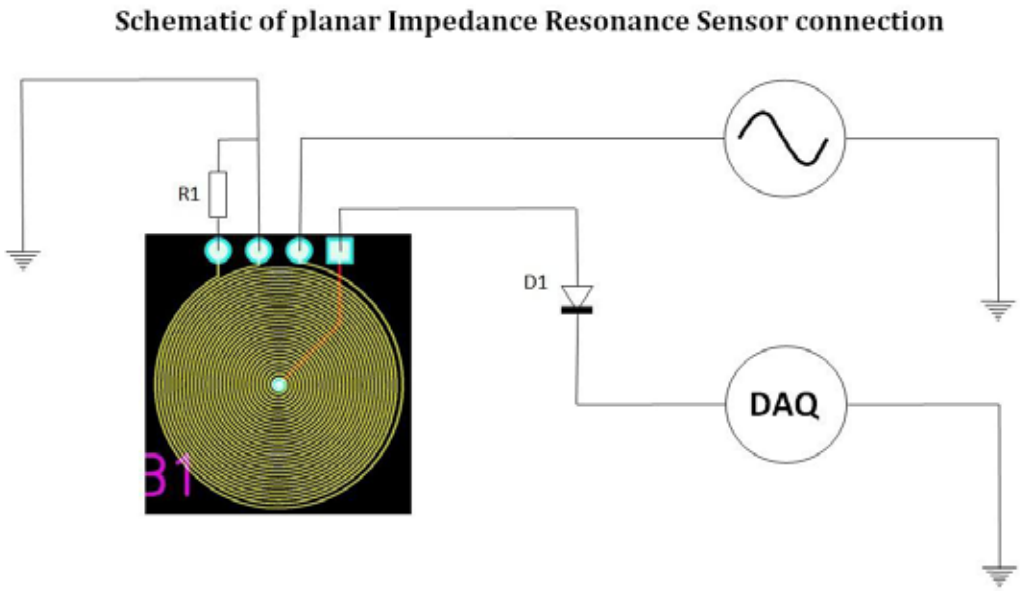
The well-known inventor **Aliaksandr Vitun**, author of comprehensive integrative inventions developed according to the scheme “device – system (consisting of a control and supervisory super-system with functionally embedded subsystems) – software – associated method”, created three advanced interconnected integrative technical solutions. Using active artificial intelligence components and artificial neural networks, these solutions have the potential to complete the full measurement cycle in strict accordance with metrological standards in just 10 milliseconds.

This is a unique performance indicator and may be considered one of **Aliaksandr Vitun’s** significant achievements.

According to metrology experts, the comprehensive methodology invented by Alexander Vitun can not only ensure exceptional measurement speed but will also reliably introduce into technical and technological measurement processes the operational parameters required for the more active use of artificial intelligence and artificial neural networks in industrial workflows.

Furthermore, his (**Aliaksandr Vitun's**) creative multifunctional design developments and original inventions in real-time monitoring and control systems, based on the principles of electromagnetic resonance spectroscopy, make it possible to incorporate into classical innovative technologies elements of quantum superiority, quantum neural networks, advanced quantum neural architectures exhibiting the properties of ultra-precise neural networks with enhanced sensitivity of machine-learning algorithms and new types of artificial synapses for transmitting information between neurons.

Figure 2.



Excitation coil is connected to generator with frequency sweep. Resistance of R1 depends on output resistance of the generator and length of line between the sensor and the generator. If the length of line is less then ¼ of wavelength, the resistor can be omitted. Sensing coil is connected to Data Acquisition (DAQ). If operating frequency of the sensor is more than frequency capability of the DAQ, then the diode can solve that problem.
Both the generator and the DAQ are connected to personal computer and work under control of computer program. The program calculates resonant frequency and amplitude of the sensor and measure their changes caused by presence of analyte under test.

The following diagram presents the measurement results of the resonance levels in samples of distilled water and regular tap water obtained using the planar sensor.

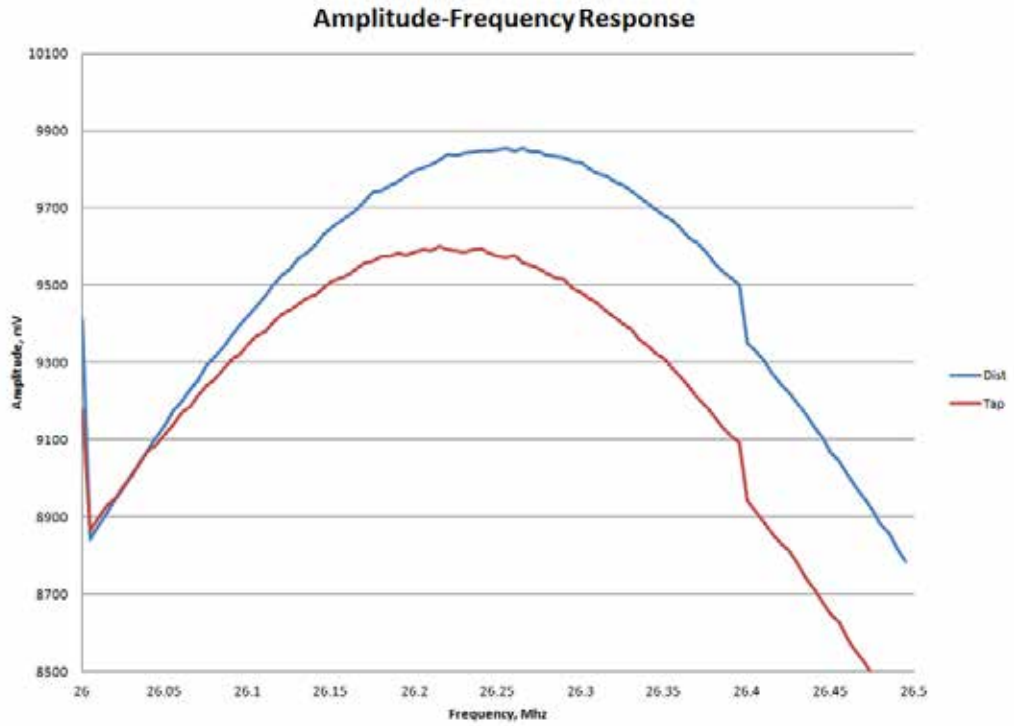
All versions of the tests and measurements demonstrated that the planar sensor has the highest potential for further use, including in the final product – a capsule for autonomous monitoring of gastric acidity in a cow.

Moreover, the planar sensor provides the best conditions for all adjacent components of the capsule. This is largely due to the fact that, while offering higher sensitivity and measurement accuracy, the sensor has significantly smaller overall dimensions.

Therefore, the goal and objectives of this stage of the project are defined as a comparative preliminary verification of all acidity-measurement results using synthetic gastric juice with detailed analytical evaluation of the following parameters:

- sensitivity of the test system to changes in the electrical conductivity of gastric juice samples;
- sensitivity of the test system to changes in the temperature of gastric juice samples;

Figure 3.



- sensitivity of the test system to changes in the chemical composition of gastric juice samples;
- sensitivity of the test system to changes in the acidity of gastric juice samples when additional hydrochloric acid is introduced into their chemical composition;
- sensitivity of the test system to the introduction of organic particles into gastric juice samples;
- repeatability of measurement results across all test variants;
- comparison of measurement results for each case with calibration of the control instrument and with subsequent measurements obtained from this control instrument, which simultaneously monitors:
  - the acidity level of the sample,
  - electrical conductivity of the sample,
  - temperature of the sample,
  - presence and calorimetric content of the sample;
- determination of maximum and minimum permissible deviations when measuring the parameters of gastric juice;
- determination of permissible maximum and minimum limits of acidity deviation when measuring the acidity of gastric juice.

This stage, by its nature, may be executed in at least two versions:

First version:

Carrying out all required measurements using the planar-solenoid sensor on gastric juice samples with different fillers and impurities, in accordance with the table of 22 variants that form the structure of the final report (this version is implemented if no additional funding is provided).

Second version:

Carrying out all required measurements using the planar-solenoid sensor on gastric juice samples for the purpose of calibrating measurement indicators and entering these results into the measurement program and model according to points 3 and 4 (this version is implemented if additional funding is obtained).

Given the superiority of the planar sensor (solenoid) over all other tested variants, a design proposal was made for two types of planar sensors:

– as a single-layer printed circuit board, and

– as a multilayer printed circuit board (with fully identical external dimensions, overall size, and the same number of connection points to the other instruments of the testing module).

The project developer proposed to create these PCB variants using a specialized computer program developed within the company.

According to the conditions set by the PCB manufacturer, the board contour must be square, and before final assembly, the contour may be transformed into a circular shape – or a rectangular pocket must be created in the body of the testing module.

This stage includes an extended cycle of all required calibration measurements and all necessary control measurements using at least two variants of the planar-solenoid sensor: a two-layer working design and a three-layer working design, tested on gastric juice samples with different chemical compositions and with various added particles of organic cow feed, for the purpose of calibrating measurement indicators and entering these results into the measurement program and model according to points 3 and 4.

One of the innovative objectives of the stage is to provide program-level functionality enabling the use of artificial intelligence and artificial neural networks during the processing and evaluation of sensor-based measurement data.

Products manufactured by leading companies specializing in artificial intelligence technologies are already functioning successfully: their inference processors, produced as interface cards, are capable of transmitting approximately one and a half thousand statements per second when solving linguistic tasks, with nearly zero probability of information loss. These companies have recently introduced an even more advanced processor.

Such technologies are in high demand – many individuals and organizations worldwide are attempting to teach computers to solve tasks not easily formalized by conventional methods, meaning tasks that are accessible to humans yet practically impossible to reduce to algorithms. Creating and training neural networks capable of collecting and processing numerous features – on the basis of which a computer can make decisions about the outcome of such non-formalizable tasks – requires sophisticated machine-level solutions.

Therefore, the development of such networks, which in some ways imitate the functioning of the human brain, became possible only with the advent of powerful graphics processors, although the underlying ideas date back to the cybernetics theories of the 1970 s. According to their developers, processors produced by the Israeli company surpass graphics processors in power, efficiency, and suitability for neural-network training.

Repeated Sensitivity Analysis Parameters

(The following repeated list is translated consistently and preserved exactly as in the original.)

- sensitivity of the test system to changes in the temperature of gastric juice samples;
- sensitivity of the test system to changes in the chemical composition of gastric juice samples;
- sensitivity of the test system to changes in the acidity of gastric juice samples when additional hydrochloric acid is introduced;
- sensitivity of the test system to the introduction of organic particles into gastric juice samples;
- repeatability of measurement results across all test variants;
- comparison of measurement results for each case with calibration of the control instrument and with subsequent measurements obtained from the instrument monitoring simultaneously:
- acidity level of the sample,
- electrical conductivity of the sample,
- temperature of the sample,
- presence and calorimetric content of the sample;
- determination of maximum and minimum permissible deviations when measuring gastric juice parameters;
- determination of maximum and minimum permissible deviations of acidity when measuring the acidity of gastric juice.

Use of Resonance Sensor Technology (RIST) in Investigating the Causes of Industrial Accidents

There is no need to prove the necessity of rapid on-site analysis of industrial accident causes. Such express-analysis can be conducted using a RIST sensor or a system of such sensors.

These sensors may be applied, for example, to investigate fractured structures for signs of material fatigue or violations of manufacturing technology or composition.

To enable such express-analysis, certain organizational measures must be undertaken – specifically, establishing a bank of "electronic signatures" (resonance responses of standard reference materials when measured using a RIST sensor or sensor system at a set of operating frequencies).

Once such a database is available, express-analysis consists of measuring the damaged material using a RIST sensor or sensor system and comparing the results with data from the electronic-signature database.

Naturally, before measurement, the surface of the investigated material must be smoothed or cleaned to ensure identical measurement conditions to those used for reference samples.

Of course, the availability of such express-analysis does not eliminate the need for further detailed laboratory investigations.

The express-analysis technology described above – applicable to both electrically conductive and non-conductive materials – can currently be implemented only using Resonance Sensor Technology (RIST).

Existing methods of non-destructive testing based on probing the material with an alternating electromagnetic field are limited in application.

These methods include:

Non-destructive testing based on analyzing the interaction of the electromagnetic field of the transducer with the electromagnetic field of eddy currents induced in the test object.

The method is used to inspect objects made of electrically conductive materials.

Eddy currents are induced in the object by a transducer in the form of an inductive coil supplied with alternating or pulsed current.

The receiving transducer (detector) may be the same or another coil. The transmitting and receiving coils can be placed on the same side or on opposite sides of the test object.

The intensity and distribution of eddy currents in the object depend on its dimensions, electrical and magnetic properties of the material, the presence of discontinuities or structural defects, the relative positioning of the transducer and the test object, and many other parameters.

List of References, Patent and Licensing Information:

1. United States Patent Application
US 2009/0245066 A1
October 1, 2009
Optical Data Carrier, and Method for Reading/Recording Data Therein
Abstract:
An optical data carrier is presented. The carrier includes at least one recording layer composed of a material whose fluorescent properties vary upon multi-photon absorption induced by an optical beam. The recording layer has a thickness that enables the formation of multiple recording planes. At least one non-recording layer is positioned on either the upper or lower surface of the recording layer and differs from it in fluorescent properties. The carrier also includes at least one reference layer with a reflective surface formed at the interface between the recording and non-recording layers.

2. United States Patent Application
US 2008/0285396 A1
November 20, 2008
Method and Apparatus of Formatting a Three-Dimensional Optical Information Carrier

Abstract:
A method is provided for formatting an optical information carrier by creating a sequence of formatting marks for subsequent addressing during data reading/recording. The method records these marks in an interleaved order within the carrier volume, reducing delays associated with writing adjacent marks and significantly decreasing overall formatting time.

3. United States Patent Application
US 2008/0182060 A1
July 31, 2008
Manufacturing of Multi-Plate for Improved Optical Storage
Abstract:
A new optical data carrier and production methods are disclosed. The carrier is characterized by plates with differing material concentrations, providing improved optical storage performance.

4. United States Patent Application
US 2006/0250934 A1
November 9, 2006
Three-Dimensional Optical Information Carrier and a Method of Manufacturing Thereof
Abstract:
A three-dimensional optical information carrier is described, comprising formatting marks located at the nodes of a three-dimensional lattice formed by intersections of equally angled radial planes, equidistant cylindrical spiral tracks, and virtual recording planes.

5. United States Patent Application
US 2007/0288947 A1
December 13, 2007
Swing Arm Optical Disc Drive
Abstract:
A swing-type optical disc drive is disclosed. The drive includes a rotating disc and a swing arm pivoted at one end, with its distal end connected to an encoder. The pivot point and distal point define the swing axis. An optical system is mounted on the arm such that its optical axis is parallel to the swing axis and lies within the same plane. A cam actuator induces swinging motion, positioning the plane so that it remains tangent to the disc's reading/recording track.

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